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DEPARTMENT OF ENERGY, MINES AND RESOURCES

BULLETIN 146

THE DEVONIAN CEDARED AND HARROGATE FORMATIONS IN THE BEAVERFOOT, BRISCO, AND STANFORD RANGES, SOUTHEAST BRITISH COLUMBIA

H. R. Belyea and B. S. Norford

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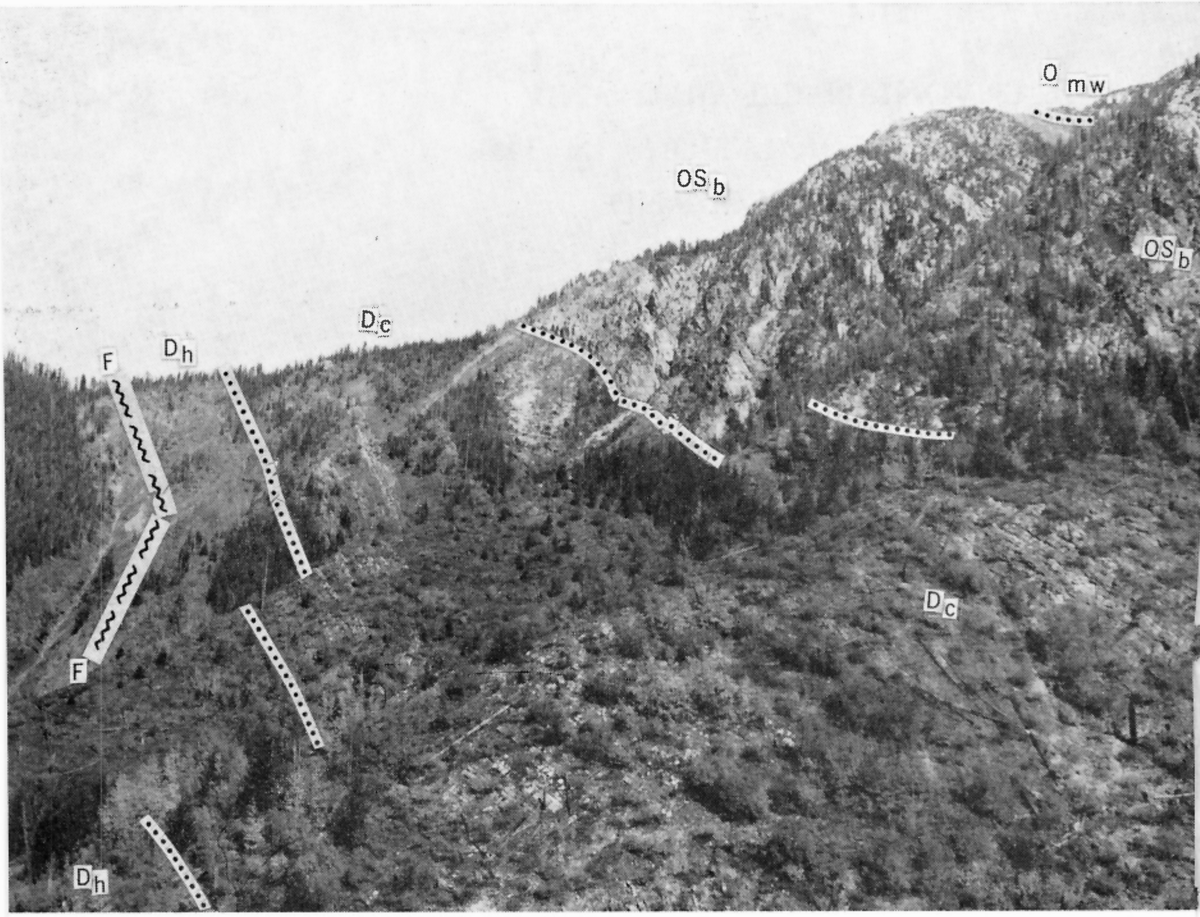

B.S.N., 10-5-1962

PLATE I. Hatch Creek section, Brisco Range, southeast British Columbia; looking northwest from near Hatch Creek. The section is in the overturned northeast limb of a tight syncline and includes the type sections of the Cedared and Harrogate Formations. These two formations were measured in the concealed creek gully in the middle distance.

Legend: D_h—Harrogate Formation; D_c—Cedared Formation; OS_b—Beaverfoot-Brisco Formation; O_{mw}—Mount Wilson Quartzite; F—Fault.

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PREFACE

This report describes Middle Devonian carbonate rocks that are laterally equivalent to gypsum beds at present being actively quarried at Windermere Creek, British Columbia. Detailed sedimentary petrography of these distinctive rocks will assist in recognition of similar sediments elsewhere that may also be marginal to deposits of gypsum and possibly more soluble salts.

J. M. HARRISON,
Director, Geological Survey of Canada

OTTAWA, June 2, 1964

BULLETIN 146 — Die devonischen Cedared- und Harrogate-Formationen in den Beaverfoot-, Brisco- und Stanford-Gebirgszügen im südöstlichen Teil Britisch-Kolumbiens.

Von H. R. Belyea und B. S. Norford

Eine Beschreibung der Stratigraphie und Petrographie der Cedared- und Harrogate-Formationen, eine Folge von mitteldevonischen Karbonatgesteinen im Südosten Britisch-Kolumbiens.

БЮЛЛЕТЕНЬ 146 — Девонские свиты Сидарэд и Гаррогейт в хребтах Биверфут, Бриско и Станфорд, юго-восточной Британской Колумбии.

Е. Р. Белье и Б. С. Норфорд

Дается описание стратиграфии и петрографии средне-девонских свит Сидарэд и Гаррогейт юго-восточной Британской Колумбии представленных серией известковых пород.

CONTENTS

Illustrations

THE DEVONIAN CEDARED AND HARROGATE FORMATIONS IN THE BEAVERFOOT, BRISCO, AND STANFORD RANGES, SOUTHEAST BRITISH COLUMBIA

Abstract

The Harrogate Formation is redescribed and includes less strata than assigned to the formation by Evans (1933). The fauna indicates Givetian (Middle Devonian) age.

The Cedared Formation is proposed for beds placed in the lower part of the Harrogate Formation and in the upper part of the Beaverfoot-Brisco Formation by Evans (1933). Charophytes suggest Middle Devonian age. The Cedared paraconformably overlies Lower Silurian rocks in most outcrops, but an erosion surface and a basal conglomerate are developed at Horse Creek. The Cedared Formation is laterally equivalent to the evaporitic Burnais Formation.

The sedimentary petrography and diagenetic changes of rocks of the Cedared Formation are described in detail. The formation is thought to have accumulated in a gently subsiding basin whose upper surface was lime mudflats covered by shallow water. Dry periods allowed deposition of gypsum in parts of the basin with restricted circulation, and caused local subaerial exposure.

The Cedared, Burnais, and Harrogate Formations correlate with parts of the Elk Point Group of Alberta.

Résumé

Les auteurs décrivent de nouveau la formation d'Harrogate qui comprend moins de strates que ne l'avait signalé Evans (1933). La faune remonte au Givétien (Dévonien moyen).

Le nom de formation de Cedared est recommandé par les auteurs pour certaines couches attribuées par Evans (1933) à la partie inférieure de la formation d'Harrogate et à la partie supérieure de la formation de Beaverfoot-Brisco. Les charophytes portent à croire que les couches remontent au Dévonien moyen. La formation de Cedared recouvre en paraconformité les roches du Silurien inférieur dans la majorité des affleurements, mais on trouve à Horse Creek une surface d'érosion et un conglomérat de base. La formation de Cedared est latéralement équivalente à la formation évaporatique de Burnais.

Les auteurs décrivent en détail la pétrographie sédimentaire et les changements diagénétiques des roches de la formation de Cedared. La formation se serait accumulée dans un bassin s'effondrant peu à peu et dont la surface supérieure comportait des champs de boues calcareuses couverts d'eau peu profonde. Les périodes de sécheresse ont permis au gypse de se déposer dans certaines parties du bassin, à circulation restreinte, et ont aussi causé des affleurements subaériens locaux.

Les formations de Cedared, Burnais et Harrogate correspondent à certaines parties du groupe d'Elk Point en Alberta.

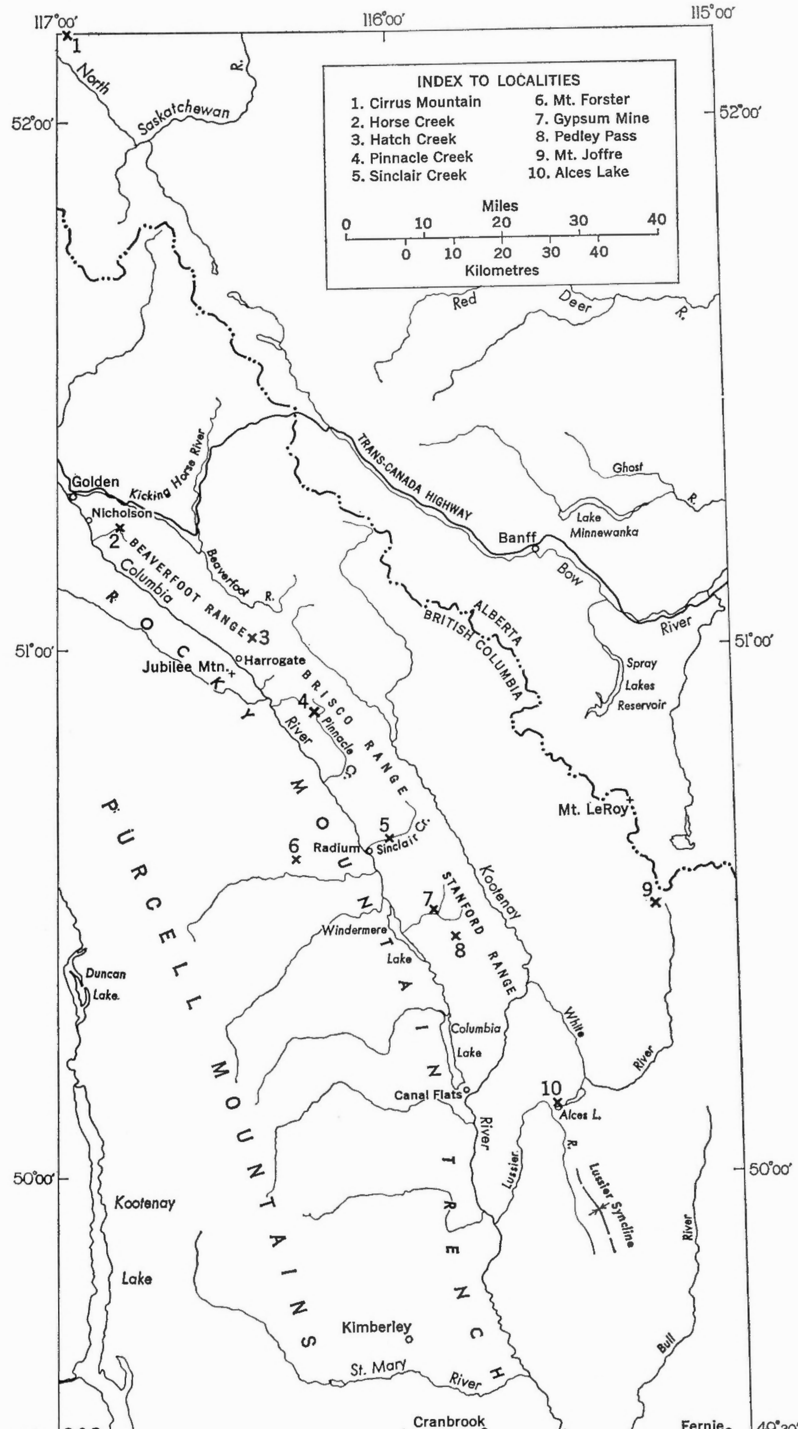

FIGURE 1. Locality Map.

INTRODUCTION

Early geological investigations of the western part of the southern Rocky Mountains were concentrated in the long range of peaks that forms the northeast margin of the Rocky Mountain Trench. The range is split longitudinally by minor saddles into three components: the Beaverfoot, Brisco, and Stanford Ranges. To the southwest, the Columbia River flows along the Rocky Mountain Trench, and to the northeast lies the valley of the Kootenay, Beaverfoot, and Kicking Horse Rivers.

The geology of the range is complex. Tight folds, major longitudinal faults, and minor faults and thrust faults are all well developed. The major structures trend northwest, and obliquely into the Rocky Mountain Trench where they seem to be truncated (Henderson, 1954, p. 29). Precambrian to Devonian rocks outcrop within the Beaverfoot, Brisco, and Stanford Ranges, but Cambrian and Ordovician strata predominate.

Exposures of Devonian rocks are very sparse, and most outcrops are within faulted cores of tight synclines or are associated with steep longitudinal faults. Following the discovery of rich Devonian faunas about forty years ago, the name Harrogate Limestone came into use, to become entrenched in subsequent literature on the Devonian System in Western Canada. The rock unit was not adequately described according to modern stratigraphic standards. The present study redefines the Harrogate Formation and segregates the Devonian rocks of the Beaverfoot, Brisco, and Stanford Ranges into usable lithostratigraphic units.

Acknowledgments

The ideas presented in this paper have greatly benefitted from discussion with many geologists working in the southern Rocky Mountains, in particular P. L. Gordy of Shell Oil Company of Canada, G. G. L. Henderson of the California Standard Company, and J. D. Aitken and G. B. Leech of the Geological Survey. Petrographic studies benefitted greatly from discussions with L. V. Illing, consultant geologist; June Rapson, University of Alberta, Calgary; G. Pouliot, R. M. Proctor, and D. F. Stott of the Geological Survey. G. Pouliot also checked diagnoses of cryptocrystalline dolomite and identified minute crystals and rare minerals. T. P. Chamney, D. J. McLaren, and A. W. Norris, all of the Survey, identified the Devonian fossils and supplied correlations. D. C. Pugh of the Survey studied insoluble residues and heavy minerals from the Cedared Formation. A. E. Portman of Western Gypsum Products Limited kindly allowed study of the quarries at Windermere Creek.

Manuscript received June 2, 1964.

One of the authors (H. R. B.) was responsible for the sedimentary petrography and resulting interpretations of depositional environments and diagenetic changes; field observations and stratigraphic conclusions are the responsibility of the other author (B. S. N.).

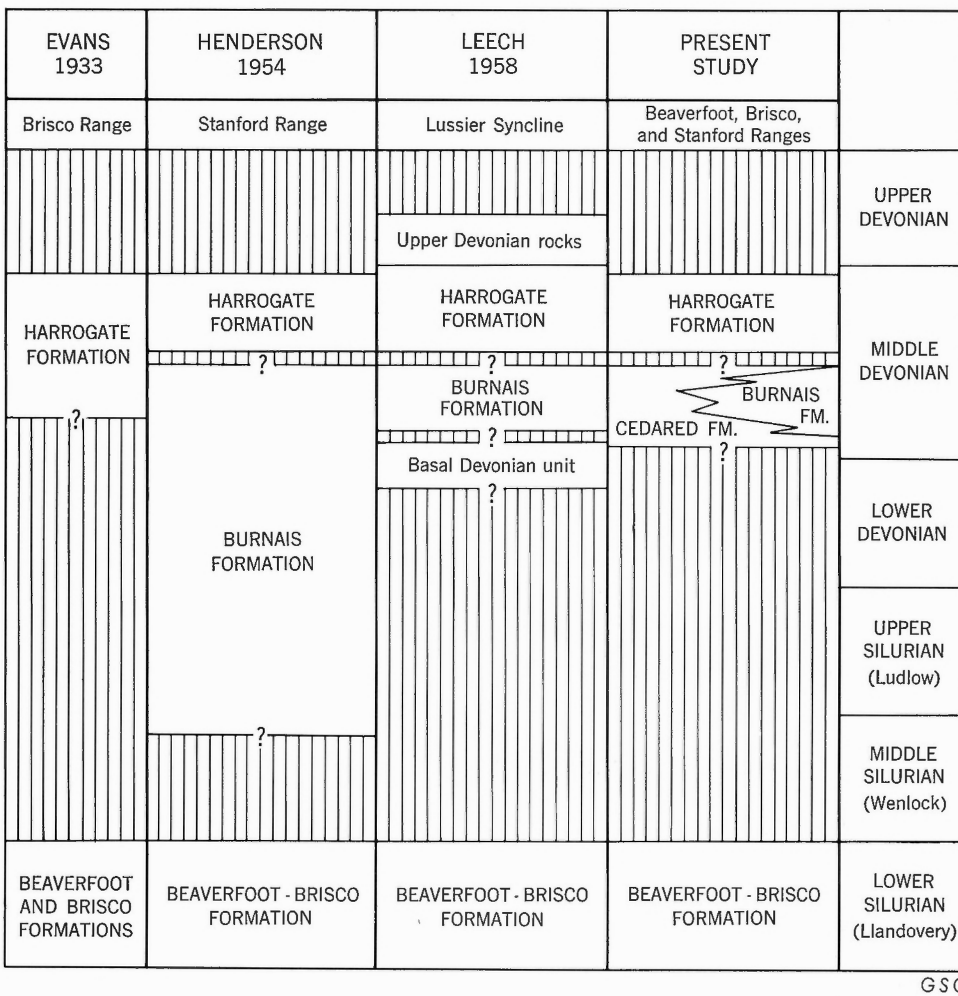

FIGURE 2. Evolution of Devonian terminology in western part of southern Rocky Mountains.

PREVIOUS STUDIES

In 1922 Shepard published a generalized Palaeozoic stratigraphic column for the Rocky Mountain Trench region and gave a list of Devonian fossils from a locality cited only as a mile east of Harrogate. No stratigraphic position or rock description was given. In 1926 he proposed the name Harrogate Limestone within a table of formations. The age was listed as Upper Devonian and the thickness as 600 feet, but no further details were given — no type section, no type locality, no faunal list, and no lithologic description other than that inherent in the name Harrogate Limestone.

Comparison of Shepard's two papers suggests that the 600 feet of Harrogate Limestone is the same unit as one listed in his 1922 generalized column as thin-bedded limestone and shale, Upper Devonian, thickness 500 feet plus. The next step assumes that his fossils, cited as late Middle or early Upper Devonian in 1922, actually came from this same unit and not from any of the other units called Upper Devonian in the same stratigraphic column. Species comparable to those cited by Shepard have been collected from the Hatch Creek section from limestones and shales that seem to correspond to the rocks listed by Shepard in 1922.

The only satisfactory outcrops of Devonian rocks near Harrogate are those of the Hatch Creek valley, about 2 miles northeast of the hamlet, and close to the Hatch Creek Trail that links Harrogate to the Beaverfoot River. Shepard's locality must be near Hatch Creek (Evans, 1933, p. 144)[1].

Measurement of the Hatch Creek section gives a total of 293 feet for rocks thought to correspond to Shepard's unit (thickness 500 feet plus, or 600 feet). The section ends in the faulted axial region of a tight, overturned syncline, and Shepard may have continued his measurement across poorly exposed rocks of problematic structural position that most probably include repeated strata from the other limb of the syncline. Evans gave 389 feet for the same set of rocks (Fig. 3; and Evans, 1933, pp. 143-144). Shepard's figures were probably reconnaissance estimates, not measured thicknesses.

In 1933, Evans published a regional geological study that included the type area of the Harrogate Limestone. A section was measured near Hatch Creek from the base of the Wonah Quartzite, through the Beaverfoot, Brisco, and Harrogate Formations, into the axial region of the syncline. Evans had difficulty in drawing a boundary between the Brisco and the Harrogate, but he may have been unduly influenced by Shepard's figure of 600 feet for the thickness of the Harrogate Limestone. Evans produced a Harrogate unit 698 feet thick (Fig. 3; and 1933, p.

[1]Names and/or dates in parentheses refer to *References* at end of report.

<table>
<tr><th colspan="2">SHEPARD 1922 and 1926
(Interpreted by present authors)</th><th colspan="2">EVANS 1933</th><th colspan="2">PRESENT STUDY</th></tr>
<tr><td rowspan="2">HARROGATE LIMESTONE</td><td rowspan="2">Thin-bedded limestones and shales
(500 + feet, 1922)
(600 feet, 1926)</td><td rowspan="3">HARROGATE FORMATION</td><td>Limestones, weather salmon-brown; partly covered
(295 feet)</td><td rowspan="2">HARROGATE FORMATION</td><td>Dolomites, weather brownish grey, grey, and yellowish brown
(161 feet)</td></tr>
<tr><td>Dark blue limestones with limy shale layers
(84 feet)</td><td>Limestones and shales
(132 feet)</td></tr>
<tr><td>UPPER DEVONIAN</td><td>Quartzites
(500 + feet)</td><td>Sandy limestones, quartzites, dark limestones
(319 feet)</td><td rowspan="2">CEDARED FORMATION</td><td rowspan="2">Dolomites with quartz sand and silt content, quartz sandstones, quartzites, argillaceous limestones, and mudstones
(698 feet)</td></tr>
<tr><td rowspan="2">UPPER DEVONIAN
(in part)</td><td rowspan="2">Massive limestones
(2500 feet)</td><td rowspan="2">BRISCO AND BEAVERFOOT FORMATIONS</td><td>Limestones with scattered sand grains
(389 feet)</td></tr>
<tr><td>Magnesian limestones
(1493 feet)</td><td>BEAVERFOOT - BRISCO FORMATION</td><td>Dolomites, mostly with minor siliceous content
(1607 feet)</td></tr>
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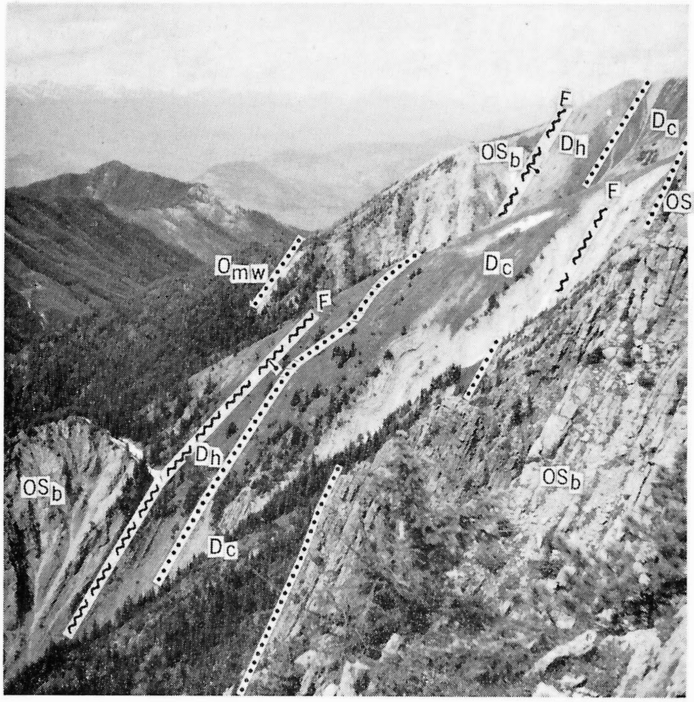
FIGURE 3. Interpretations of the Hatch Creek section.



B.S.N., 10-9-1963

PLATE II.
Typical outcrop of the Cedared and Harrogate Formations in a faulted syncline with overturned southwest limb. The photograph looks into Fraling Creek from a ridge immediately northwest of Pinnacle Creek. Jubilee Mountain and the Rocky Mountain Trench are visible in the background, and the Purcell Mountains in the far distance.

Legend:
D_h—Harrogate Formation;
D_c—Cedared Formation;
OS_b—Beaverfoot-Brisco Formation;
O_{mw}—Mount Wilson Quartzite;
F—Fault.

142), but included beds lower than any indicated by Shepard. The base of the Harrogate was arbitrarily picked at the base of the lowest sandstone bed, 319 feet below the very fossiliferous Devonian rocks. This sandstone bed lies within a sequence of virtually barren carbonates, rare sandstones, and quartzites. The carbonates commonly contain scattered quartz sand and silt. Kindle gave a Middle Devonian age to the fossils collected by Evans from the very fossiliferous beds.

The present study recognizes two diverse sedimentary units within the Harrogate Formation as used by Evans (Fig. 3). The upper unit is thought equivalent to Shepard's Harrogate Limestone, and the lower unit probably corresponds to most of, or all of, the unit of quartzites listed below the Harrogate in Shepard's stratigraphic column. This lower unit continues below the lowest sandstone bed and includes the upper part of the strata referred to the Brisco Formation by Evans.

Later workers have considered the section measured by Evans to be the type section of the Harrogate, and have followed the interpretation of two units within the formation. For example, Andrichuk informally referred to lower and upper Harrogate (1960, p. 167).

The upper unit can be traced 100 miles southeast from Hatch Creek, and Henderson had little difficulty mapping it in the Stanford Range, but found great thicknesses of evaporitic deposits beneath the fossiliferous nodular limestones and shales. Henderson (1954) proposed the name Burnais Formation for the evaporites and thought them equivalent to some part of the lower Harrogate of Evans.

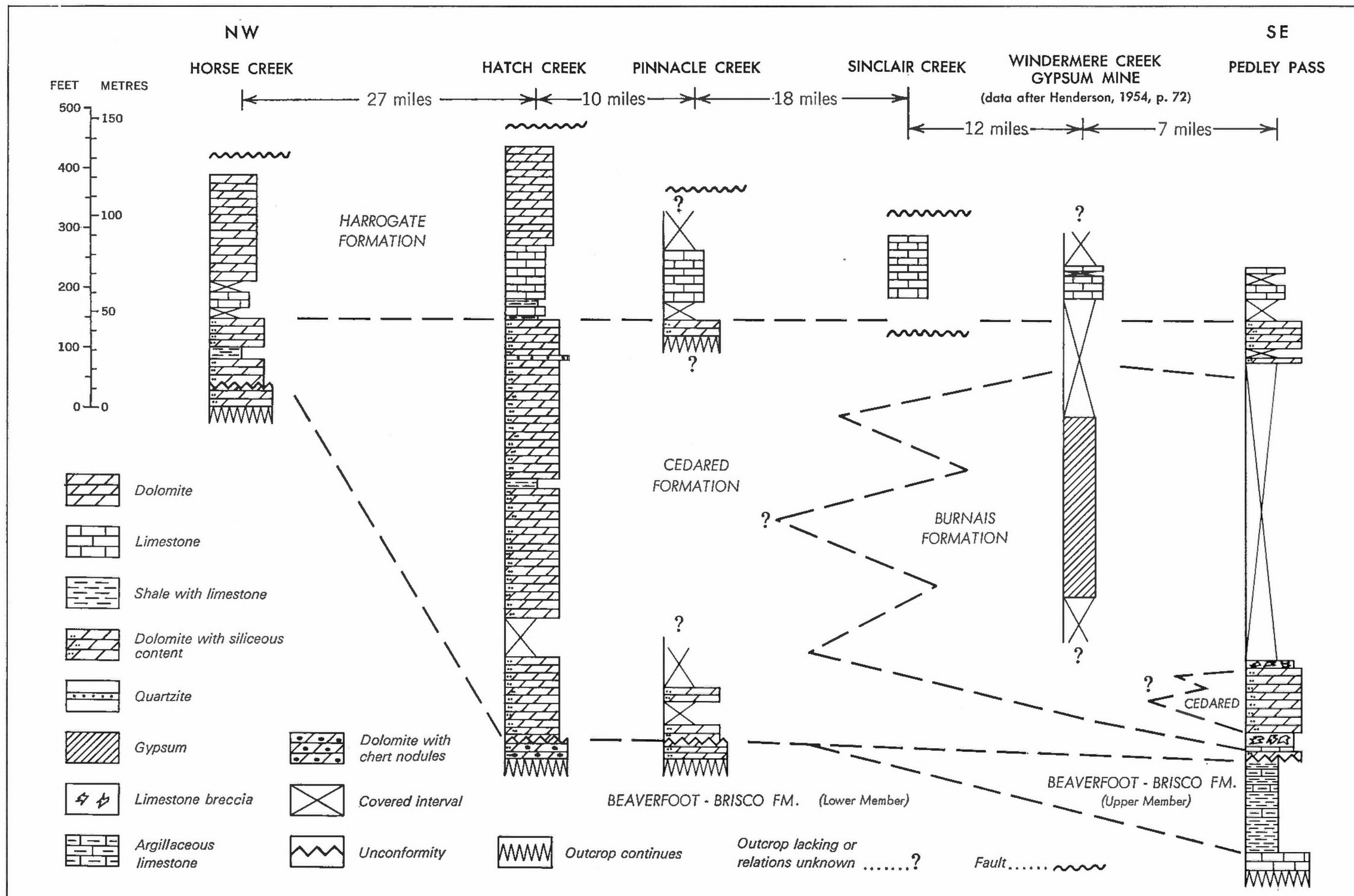


FIGURE 4. Devonian correlation in the Beaverfoot, Brisco, and Stanford Ranges.

B.S.N., 11-1-1962

PLATE III. Disconformable contact between the Cedared and Beaverfoot-Brisco Formations, Horse Creek section, Beaverfoot Range, southeast British Columbia. The outcrop is in the overturned northeast limb of a syncline and the photograph is mounted upside-down. The black dotted line marks an erosion surface cut in the Beaverfoot-Brisco Formation. The basal conglomerate of the Cedared Formation contains pebbles and boulders of Beaverfoot-Brisco dolomites. Legend: Dc—Cedared Formation; OS_b—Beaverfoot-Brisco Formation.

Recent work by Leech south and east of Canal Flats has greatly expanded regional knowledge of Devonian stratigraphy, showing that typical western Rockies and eastern Rockies sequences outcrop within the Fernie map-area (1958). Fossiliferous limestones, shaly limestones, and shales of the Harrogate underlie a distinct Upper Devonian limestone unit, and overlie Burnais evaporites. Local interfingering may possibly occur between the lower part of the Harrogate limestones and the upper beds of the Burnais Formation. A basal Devonian unit of sandy and silty dolomites, dolomites, quartzites, sandstones, and dolomitic shales intervenes between the Burnais and a regional sub-Devonian unconformity. Leech, like Henderson, was very conscious of the barren lower part of the Harrogate Formation of Evans, and considered that the Burnais Formation might be in part its equivalent.

The present paper discards the two-member interpretation of the Harrogate Formation and restricts the formation to the upper beds at Hatch Creek. This course is thought to approximate Shepard's original proposal. A new unit, the Cedared Formation, is introduced for the virtually barren beds beneath the Harrogate and above a regional unconformity that rests on different horizons within the Lower Silurian in the Beaverfoot, Brisco, and Stanford Ranges. This unconformity is almost certainly the continuation of the sub-Devonian unconformity of the Fernie map-area.

CEDARED FORMATION
(new)

Name: From Cedared Creek, on the southwest flank of the Brisco Range, joining Columbia River about 4 miles southeast of Harrogate.

Type section: Hatch Creek section, measured in a steep creek gully at 51°00'N, 116°23'W, about half a mile northwest of Hatch Creek (*see* Pl. I; section given in detail, Appendix A).

Lithology: Dolomites with floating quartz sand and silt, dark aphanitic dolomites, dolomitic quartz sandstones; rare quartzites, mudstones, argillaceous limestones, and breccias; all well bedded and with diverse light weathering colours.

Thickness: 698 feet at the type section, measured by staff.

Base: Paraconformable on Lower Silurian beds of the Beaverfoot-Brisco Formation.

Top: Covered concordant contact with the Middle Devonian Harrogate Formation.

Fossils: Charophytes, very rare ostracods, gastropods, and brachiopods.

Horizon: Assumed Middle Devonian.

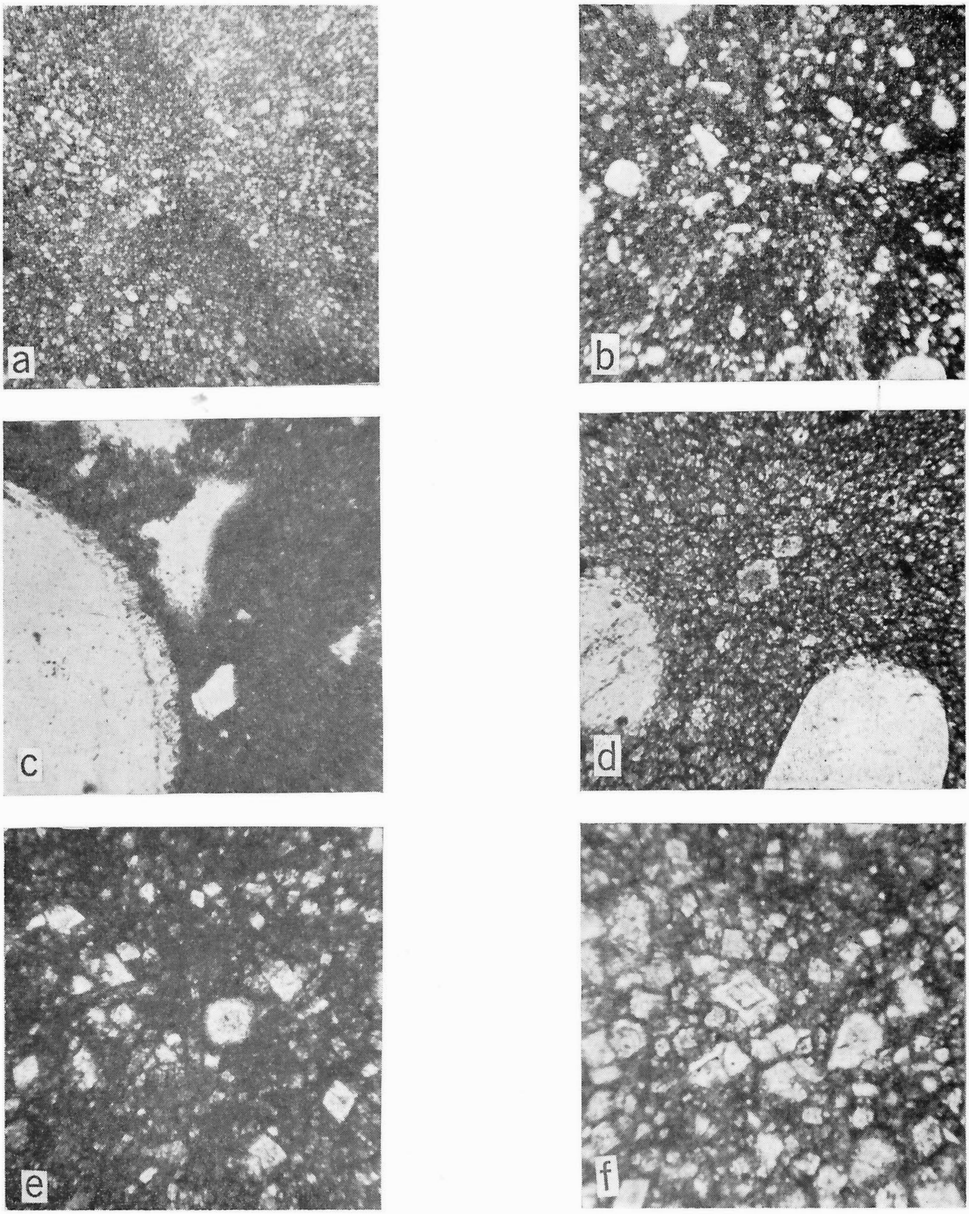
Stratigraphy

The Cedared Formation is best exposed at Hatch Creek, and the following description of the rocks is based primarily on samples from this section. Supplementary sections were studied at Horse Creek to the northwest and at Pedley Pass to the southeast. Additional exposures are present near Pinnacle Creek and in the Stanford Range.

The concordant Cedared-Harrogate contact is a strong break within the Beaverfoot, Brisco, and Stanford Ranges, with abrupt changes in lithology, bedding, and weathering character. Unfortunately, the actual contact is covered in every known outcrop.

The lower boundary of the Cedared Formation is less obvious, for the weathering colours of the basal Cedared beds may be similar to the light greys and light yellowish greys of the top beds of the Beaverfoot-Brisco Formation. Both units are predominantly dolomites, but the uppermost Beaverfoot-Brisco is more resistant, more thickly bedded, commonly contains sparse fossils and chert nodules, and although having minor siliceous content, lacks the floating quartz sand so typical of the Cedared dolomites. The actual contact is exposed in most outcrops and is paraconformable, but an erosion surface and associated basal conglomerate are present at Horse Creek (Pl. III).

PLATE IV. Thin sections of rocks of the Cedared Formation.



a. Laminated cryptocrystalline and microcrystalline silty dolomite; lamina off-set and dragged; fracture healed as dolomite formed. Cedared Formation, 547 feet above base at Hatch Creek. X30.

b. Typical texture of Cedared dolomite: groundmass of grain and crystal size less than 0.008 mm, floating dolomite rhombs, angular quartz silt and sand grains. Cedared Formation, 25 feet above base at Hatch Creek. X30.

c. Dolomite groundmass with crystals less than 0.005 mm. Corroded quartz grains. Intergrowth of dolomite and quartz on rim of quartz grain. Cedared Formation, 345 feet above base at Hatch Creek. X90.

d. Dolomite groundmass with crystals averaging about 0.01 mm outlined by interstitial material. Scattered rhombs up to 0.05 mm with dusty centres. Quartz grains corroded by dolomite. Cedared Formation, 45 feet above base at Hatch Creek. X90.

e. Dolomite groundmass less than 0.005 mm, with vague dolomite rhombs, large rhombs up to 0.06 mm; hematite stained argillaceous material in groundmass. Cedared Formation, 422 feet above base at Hatch Creek. X90.

f. Dolomite with floating rhombs up to 0.04 mm. Zoned dolomite rhomb. Note digitation of margin with groundmass. Cedared Formation, 421 feet above base at Hatch Creek. X90.

Table I

Mechanical Analysis of Cedared Formation[1]

(Percentage Composition by Weight)

	Locality	Hatch Creek							Horse Creek		Pedley Pass
	Height above base in feet	602	490	418	325	210	112	50	60	20	38 – 39
"Coarse Fraction"	Grain Size > 2.00 mm	—	0.04	—	—	—	—	0.1	—	—	—
	2.00 – 1.00	—	0.13	tr	—	tr	—	0.1	3.1	—	—
	1.00 – .500	4.1	0.04	0.16	3.3	5.0	0.11	5.8	4.8	1.2	0.05
	.500 – .250	49.6	0.76	1.59	34.0	28.9	0.49	27.1	26.9	6.4	0.43
	.250 – .125	15.9	2.52	3.34	22.3	17.6	0.21	8.6	21.3	6.4	0.36
	.125 – .062	2.0	1.38	11.85	4.2	3.2	0.61	1.8	4.5	13.7	9.91
	< .062 mm	0.2	0.05	1.35	0.2	0.3	0.01	0.4	1.3	2.3	1.15
"Fine Fraction" [2]		9.7	17.68	16.30	4.2	5.6	2.02	9.2	3.3	7.4	34.0
Total Residue		81.5	22.6	34.6	68.2	60.6	3.45	53.1	65.2	37.4	45.9
Carbonate		18.5	77.4	65.4	31.8	39.4	97.0	46.9	34.8	62.6	54.1

[1] By D. C. Pugh.

[2] Obtained by decantation. Consists mostly of silt, plus a little clay and sand grains.

The Cedared Formation consists chiefly of dolomites, sandy and argillaceous dolomites, sandstones, and less abundant limestones, argillaceous limestones, mudstones, and breccias. The rocks are predominantly grey and yellowish brown, but weather light grey, light yellowish grey, light brownish grey, light brown, and almost white, except for a unit that includes variably weathering reddish grey, reddish brown, and yellowish green recessive, argillaceous beds (Hatch Creek section, unit 6, 17 feet thick; Horse Creek section, unit 2, 21 feet thick). Breccias containing grey and brown rocks in a light grey matrix weather to shades of brown and orange. The uppermost beds in both the Hatch Creek and Horse Creek sections are more argillaceous and are dark grey and dark brownish grey on fresh surfaces, but otherwise are lithologically similar to the beds below. Most of the bedding in the Cedared Formation is a few inches to 2 feet thick, with a few beds reaching 4 feet. Bedding planes are distinct, many being irregular, fluted, and undulatory. Minor erosion surfaces and small channels are not uncommon.

Fresh surfaces of the carbonates show macroscopically aphanitic to finely crystalline, tightly cemented rocks with shiny quartz grains. Weathered surfaces are porous, rough, and irregular, with quartz grains standing out in contrast to the leached carbonate matrix. Weathered surfaces of many beds are distinctly laminated, in places reflecting rhythmic repetition of aphanitic and finely crystalline dolomite laminae (Pl. IVa), less commonly as a result of alternating laminae of dolomite, siltstone, and sandstone, or of sandy dolomite and sandstone (Pl. V). Slump structures formed penecontemporaneously with deposition and burrowing, and pseudobreccias are present at several horizons (Pls. VI, VII, VIII, and IX).

Thin section examination of rocks from the Hatch Creek, Horse Creek, and Pedley Pass sections shows that similiar rock types have developed in all areas and recur throughout each sequence. However, local variations occur in different sections and within any one section. In the following discussion, rock types common to all localities are described first, and variations present at any one section are discussed separately.

Carbonates

The most common rock types are silty and sandy carbonates, chiefly dolomne, although beds of limestone and dolomitic limestone occur. The amount of insoluble material ranges upwards from 2.6 per cent of total weight of sampled rock to dolomitic sandstones and pure quartz sandstones, although most carbonates contain less than 40 per cent (Table I). Material other than carbonate consists largely of quartz silt and sand scattered through the groundmass or collected in laminae and patches. Microcline is present at many horizons. Pyrite, limonite, magnetite, and hematite are widely scattered as small crystals. Clay is finely disseminated through the groundmass of many beds and is locally concentrated as wisps, lenticles, and calcareous mudstone grains. The clay minerals present in a selected suite of samples are listed in Table II.

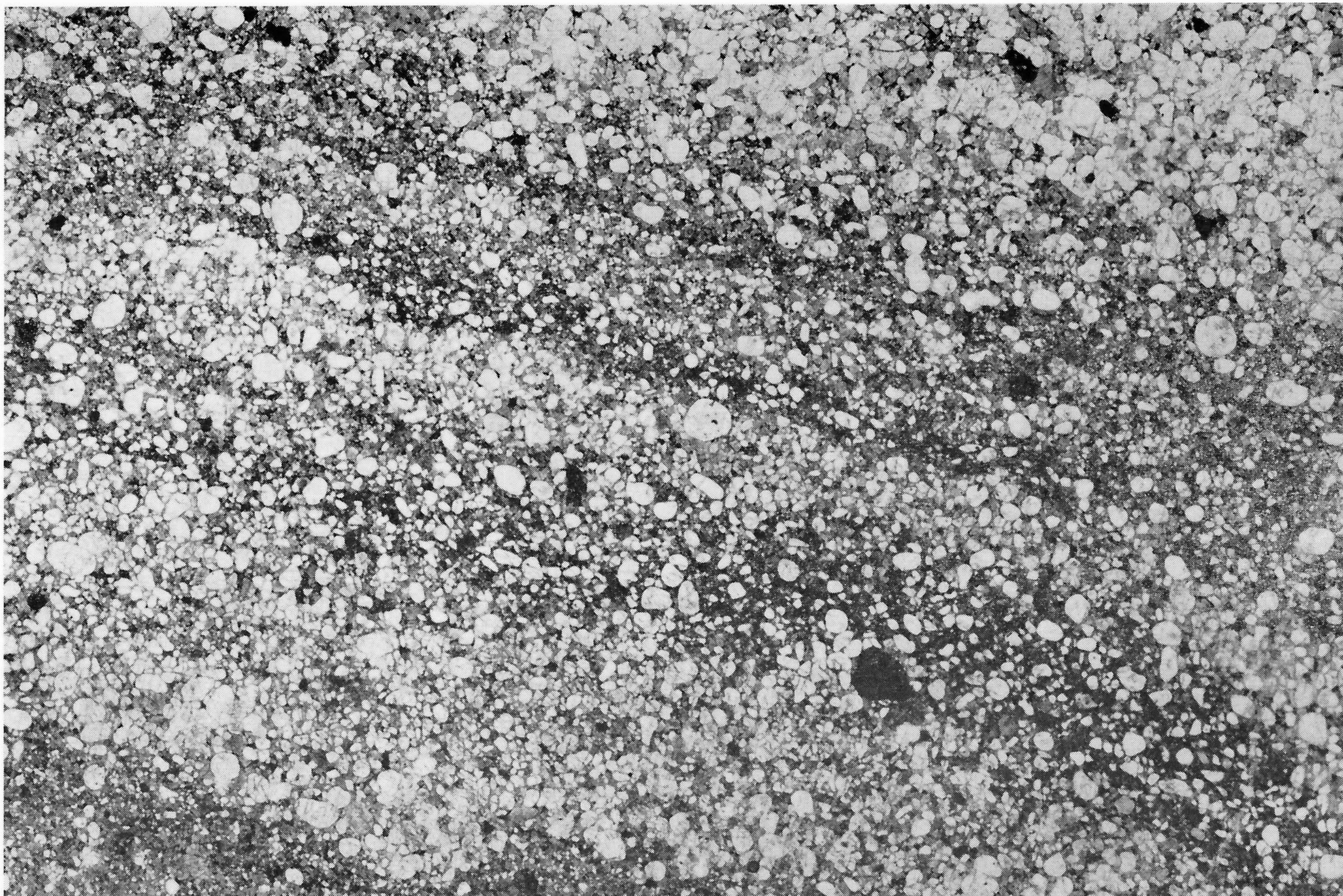


PLATE V. Thin section of rock of the Cedared Formation. Laminated sandstone, siltstone, silty, sandy dolomite. Sandstone is mostly quartz with a few mudstone and chert grains. Note gradation from slightly silty, sandy dolomite to sandstone with dolomite cement. Cedared Formation, 440 feet above base at Hatch Creek. X10.

Table II

Clay Minerals in Cedared Formation, Hatch Creek Section[1]

Height above base in feet	Major rock constituent	Clay minerals (⟶ decreasing quantity)
95	Dolomite	Illite, montmorillonite, chlorite
112	Dolomite	Illite, chlorite
208	Dolomite	Chlorite, illite, montmorillonite
265	Sandstone	Chlorite, illite (trace)
453	Dolomite	Montmorillonite, chlorite
565	Sandstone	Chlorite, illite (trace)

[1]By G. Pouliot.

Considerable variation exists in the texture and grain size of the carbonates. A brief description follows; more detailed considerations of the fabric and its development are reserved for discussion as post-depositional changes. Crystalline dolomite mosaic textures are rare. Most of the dolomite in the lower part of the Hatch Creek and Horse Creek sections is composed of a dolomitic matrix in which crystal sizes are less than 0.01 mm[1], and in which "float" dolomite rhombs, quartz silt, and quartz sand (Pl. IVb). Dark carbonate grains are present in some beds. Some are detrital (Pl. V), others incompletely crystallized relict grains (Pl. IX). The dololutite matrix itself shows some variation in crystal size and development. In places, grains or crystals are about 0.005 mm and crystal faces are indistinguishable at X90 (Pl. IVc); elsewhere, crystal faces average about 0.01 mm and are outlined by interstitial material (Pl. IVd). Larger, floating dolomite rhombs are mostly euhedral or may have two well-developed faces, with sides commonly less than 0.04 mm long. They are scattered through the matrix or concentrated in patches. Smaller rhombs are dusty or cloudy; some larger rhombs have dusty interiors and clear rims (Pl. IVe); others consist of alternating dusty and clear layers (Pl. IVf). Rarely, the core of a rhomb may be a spore case, organic fragment, limonite, magnetite, pyrite, or hematite (Pl. Xa).

Intercalated with these dolomites at both the Hatch Creek and the Horse Creek sections are beds that consist almost entirely of clay-sized carbonate, commonly dolomite (Pl. IVc). Such rocks appear almost, or absolutely, aphanitic at magnifications of 125. In parts of some beds an irregular network of coarser dolomite crystals gives the rock a mottled appearance (Pl. IX). Quartz silt and sand, and a few large dolomite rhombs (up to 0.08 mm in diameter) are scattered sporadically throughout the rocks.

[1]Measurements are recorded for convenience in tenths of millimetres, as measured by micrometer scale, and referred for comparison to the closest Wentworth grade. The term cryptograined refers to limestone grains less than 0.01 mm in diameter; cryptocrystalline refers to dolomite crystals of that size range; micrograined and microcrystalline refer to grains and crystals from 0.01 – 0.06 mm in diameter.

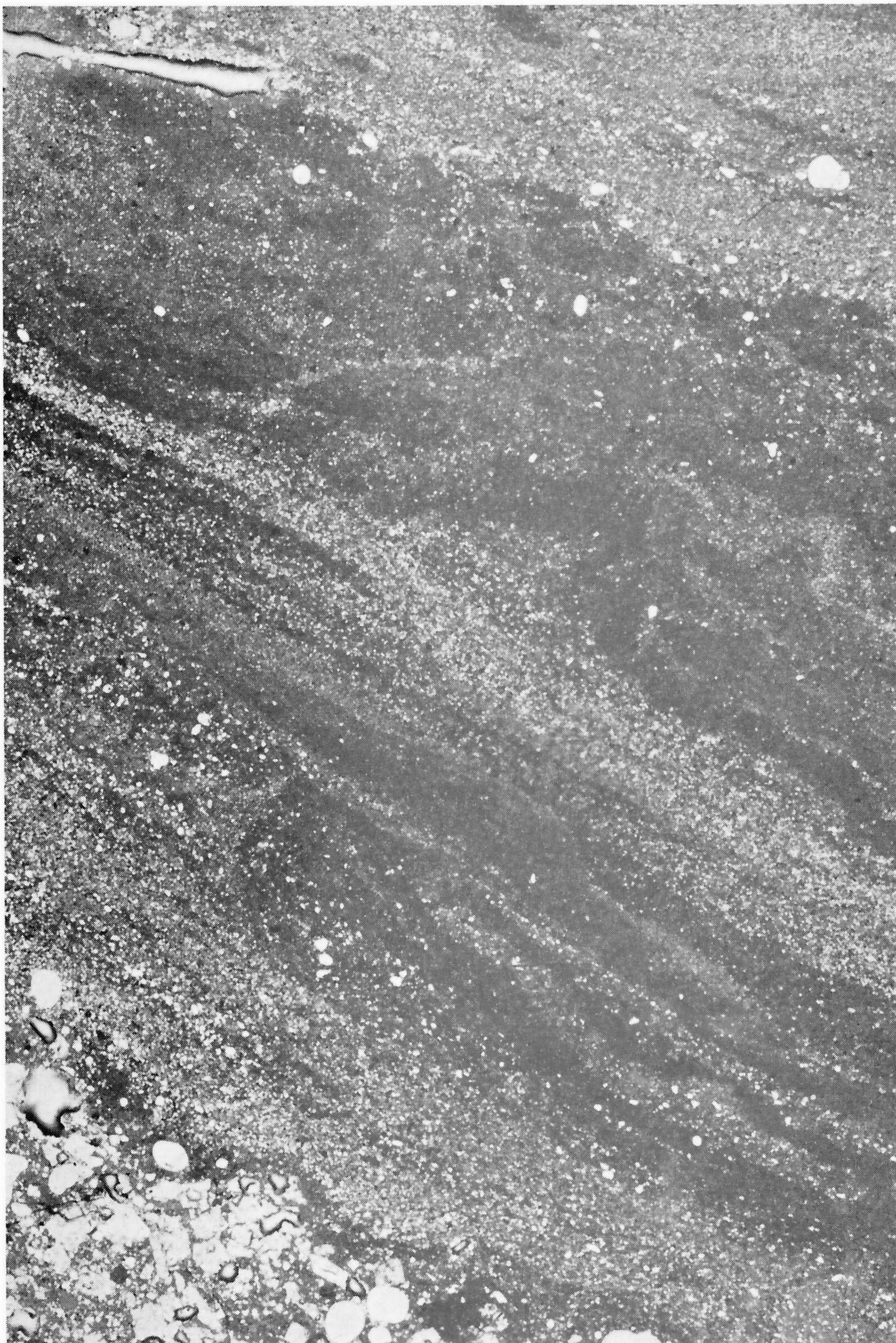


PLATE VI. Thin section of rock of the Cedared Formation. Laminated argillaceous dolomite with crystals less than 0.008 mm, and silty dolomite with rhombs up to 0.06 mm; slump, cut-and-fill structure seem to have occurred after dolomitization began. Irregular patches in upper part of picture are interpreted as relicts of original groundmass. Large white crystals (lower left) are authigenic feldspar intergrown with chert and carbonate. Scattered black crystals are hematite. Cedared Formation, 138 feet above base at Pedley Pass. X10.

Classic dolomites occur in some beds of the Cedared. In places—e.g., 428 (Pl. Xb), 442 and 453 feet above the base of the Hatch Creek section—silt-sized dolomite grains are enclosed within dolomite rhombs, and numerous rounded dolomite grains rest in a slightly argillaceous dolomite matrix. Development of crystal faces tangential to the grains suggests that many more grains have been completely obscured by crystallization of the dolomite. Elsewhere in the Cedared, round and subround grains of both limestone and dolomite, up to 0.1 mm in diameter and occasionally larger, are scattered through both carbonates and sandstones (Pls. V and IX).

Limestones

Limestones are rare, except in the uppermost beds of the Cedared Formation. They are grey, smooth, and even-textured, with most grains less than 0.01 mm in diameter (Pl. Xc, d). Most are partly dolomitized. One laminated rock (at 323 feet above the base at Hatch Creek) consists of alternate layers of aphanitic limestone and fine, crystalline, mosaic-textured dolomite with crystals 0.02 to 0.04 mm in diameter.

Quartz grains

Quartz, as sand, silt, and clay-sized grains, makes up most of the insoluble fraction in Cedared rocks. Minor chert, feldspar, and a few heavy minerals are present in some samples. Quartz silt, as angular and subangular grains and as minute chips and slivers, is commonly present but is relatively abundant in only a few beds (Table I). On the other hand, quartz sand grains are almost ubiquitous. In most rocks the sand grains are distributed at random through the carbonate matrix, but locally they are concentrated to form pods or irregular lenticles (Pl. Xe). The total quartz sand present in different samples ranges from 13 to 65 per cent (Table I). The character and distribution of the quartz sand is similar throughout the Cedared. The sand grains are mostly round, subround, or elliptical, but a few rocks—namely those aphanitic at magnifications of 125—contain a large proportion of angular grains. In the lower part of the Hatch Creek section, many sand grains, otherwise rounded, have one jagged edge, and many small grains have extremely sharp acute-angled edges, suggestive of chips broken from larger fragments and not worn before final deposition (Pls. IVb and Xe). The size range distribution is shown by Table I. Grains between 0.125 and 0.5 mm in diameter (fine to medium sand on the Wentworth Scale) are most abundant, but a few grains exceed 0.8 mm. The longest diameter of the quartz sand is 0.4 to 0.8 mm in most rocks, but reaches 2 mm in a few rocks (e.g., at 25 feet above the base of the formation in the Hatch Creek section). Most quartz grains are clear, with characteristic wavy extinction. Strain shadows are present in some grains, and a few grains contain small inclusions. Orientation of the sand grains seems to be random.

Quartz overgrowths in optical continuity with the original quartz grains are only rarely present, and in many of the examples they are partly or almost entirely corroded by the enclosing dolomite matrix (Pl. XIa). Quartz grains in contact

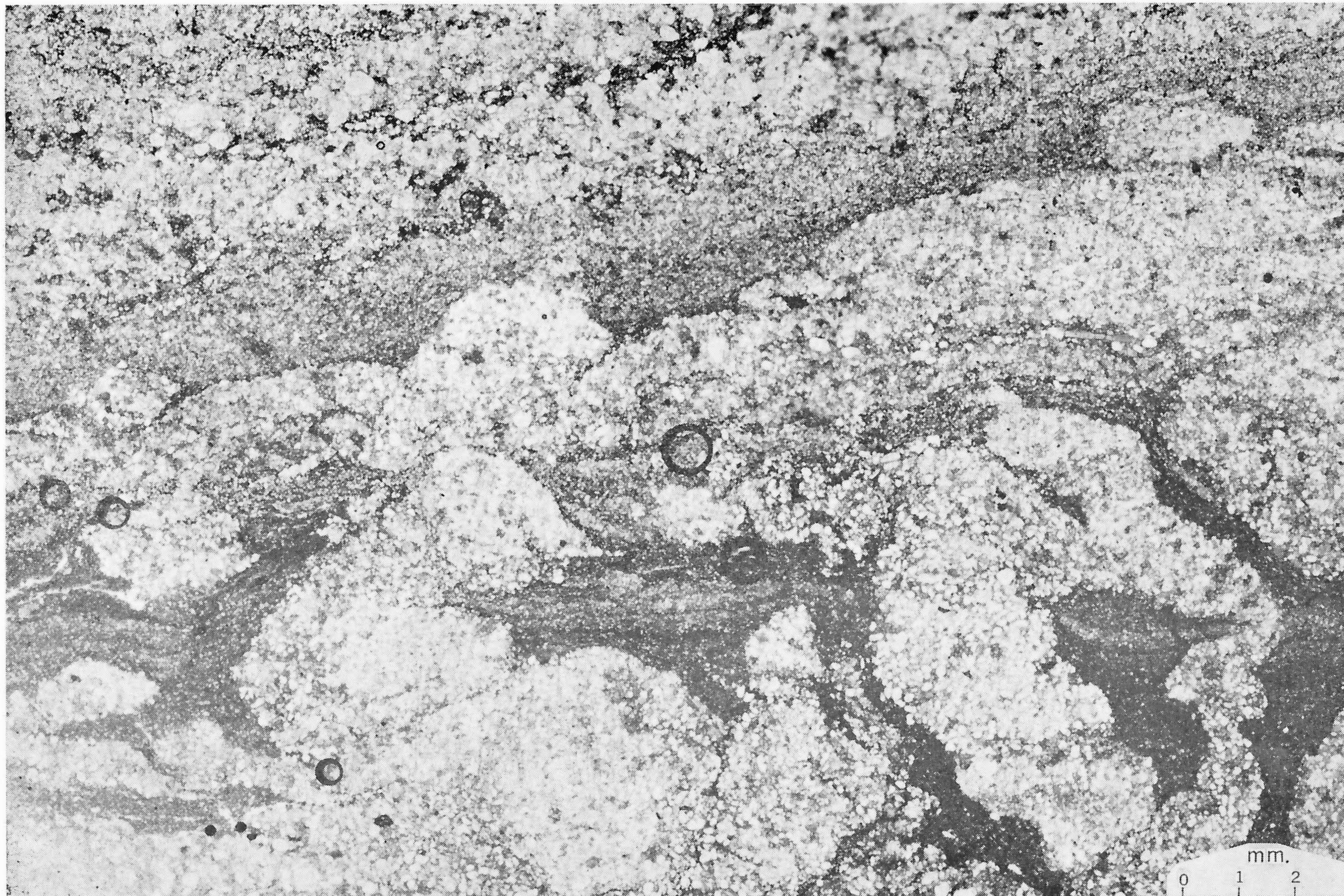


PLATE VII. Thin section of rock of the Cedared Formation. Laminated dolomite, argillaceous, silty; laminae interrupted by sandstone, presumably slumped into cavities caused by burrowing organism or gas bubbles. Laminae containing dolomite rhombs and silt show drag into cavity. Cedared Formation, 415 feet above base at Hatch Creek. X10.

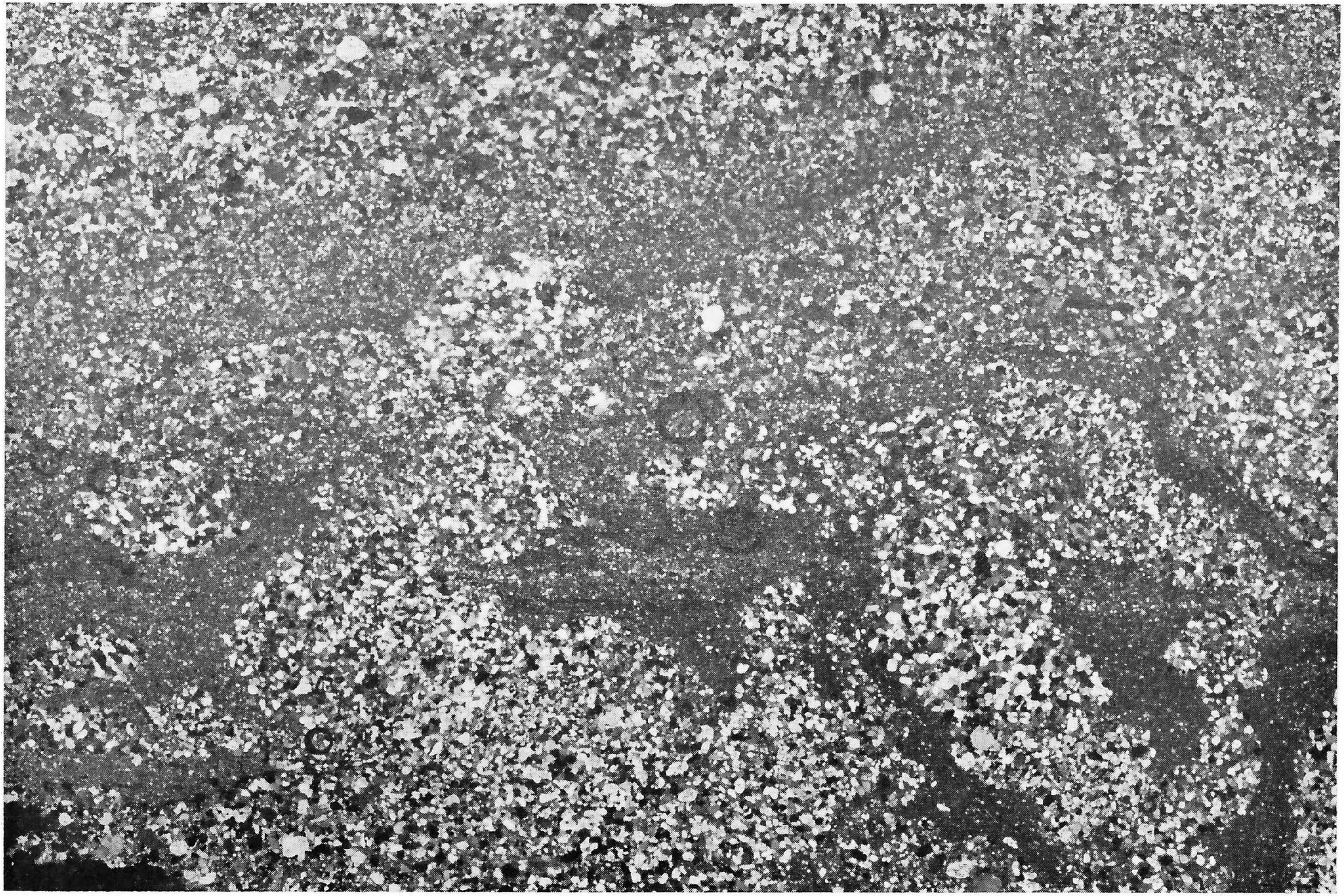


PLATE VIII. Thin section of rock of the Cedared Formation. Same as Plate VII; crossed nicols.

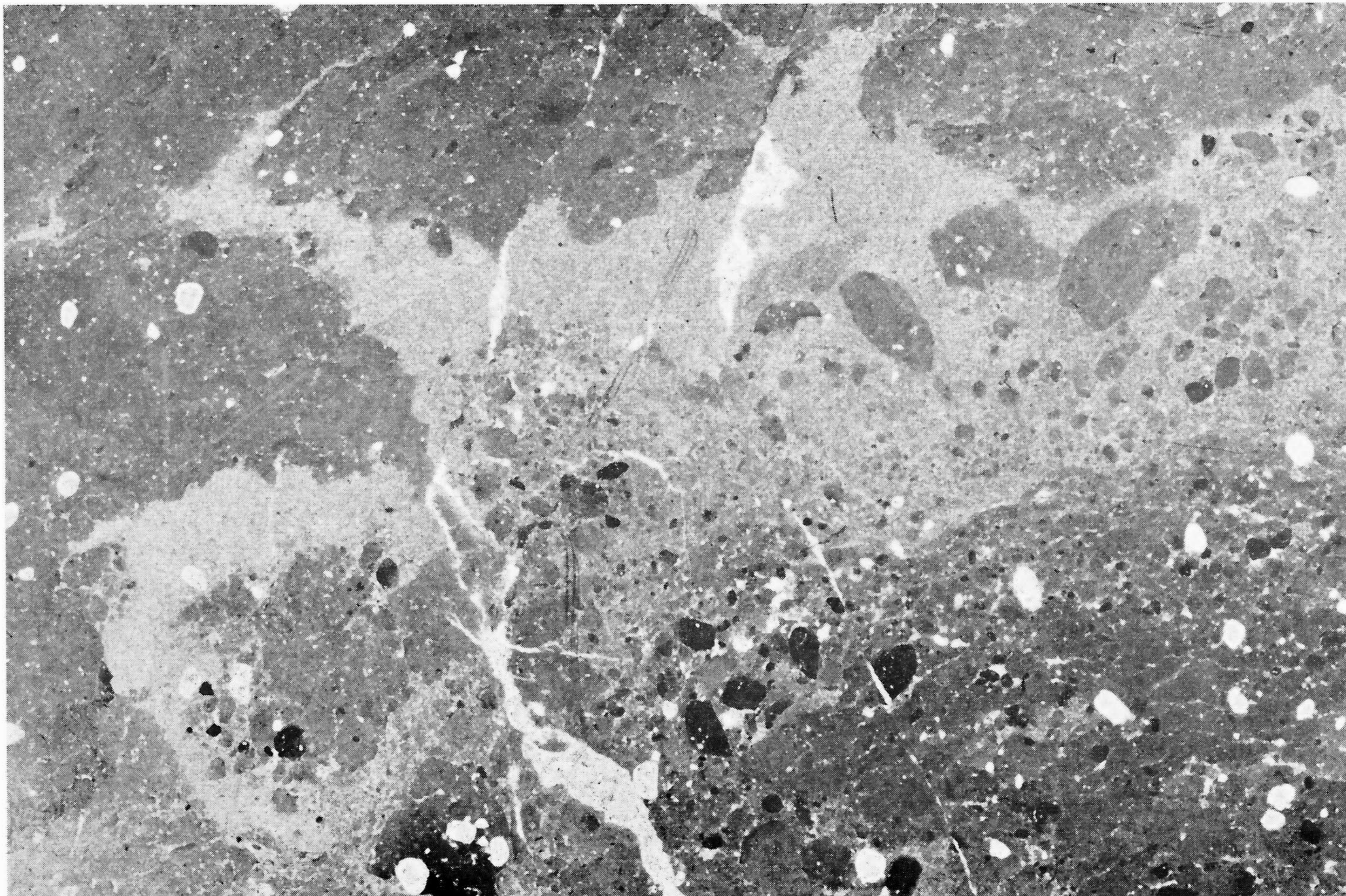
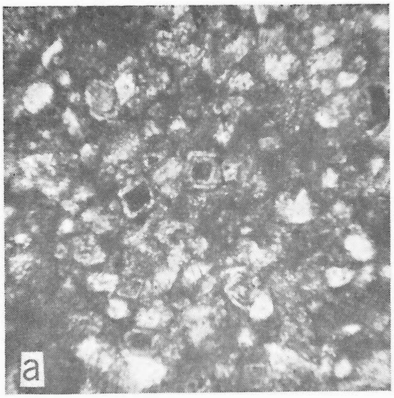
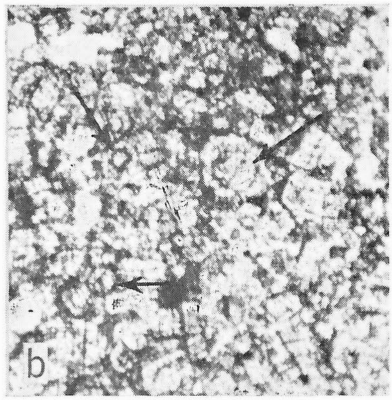
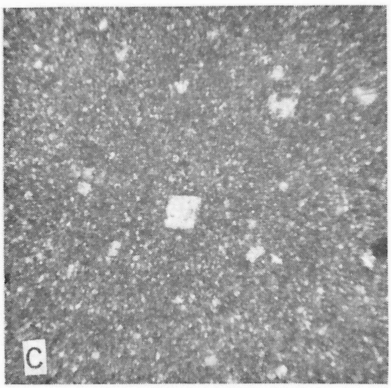


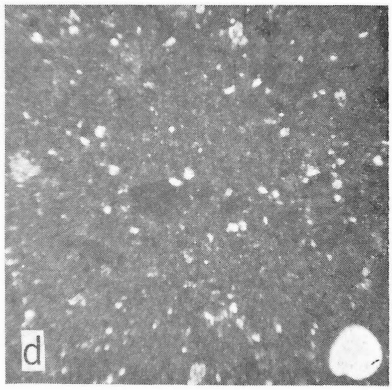
PLATE IX. Thin section of rock of the Cedared Formation. Pseudobreccia: relict grains and probable intraclasts in at least two generations of grain growth mosaic. Main body of groundmass (medium grey) is sandy dolomite with crystals less than 0.008 mm; large "grains" and ghosts of medium grey dolomite in light dolomite are interpreted as relicts; darkest grains seem to be calcareous sandy mudstone intraclasts lithologically similar to mudstones found in Cedared, but may also be relict grains. Coarsest (light grey) mosaic texture is nibbling into finer and spreading as reticulate network through it. Large white grains are quartz. Fractures are calcite-filled and probably related to tectonic events. Cedared Formation, 630 feet above base at Hatch Creek. X10.

PLATE X. Thin sections of rocks of the Cedared Formation.









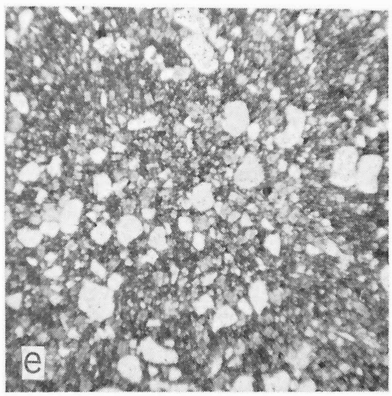
a. Hematite, organic fragments, spore case forming nuclei of dolomite rhombs. Note zoned crystals. Cedared Formation, 138 feet above base at Pedley Pass. X90.

b. Dolomite silt grains enclosed in dolomite rhombs. Cedared Formation, 428 feet above base at Hatch Creek. X90.

c. Limestone, grain size less than 0.01 mm; scattered dolomite rhombs and pyrite. Cedared Formation, 697 feet above base at Hatch Creek. X90.

d. Limestone with darker calcareous intraclasts partly destroyed by grain growth of matrix; scattered quartz silt and sand grains. Cedared Formation, 650 feet above base at Hatch Creek. X30.

e. Quartz grains in dolomite matrix. Note variety of shapes and patchy distribution. Cedared Formation, 10 feet above base at Hatch Creek. X30.



with carbonate have narrow reaction rims of slightly more coarsely crystalline dolomite than the matrix (Pl. XIb). Large parts of quartz grains have been replaced by dolomite (Pl. XIc), and even complete grains, leaving only ghosts to delineate the original extent of the grains (Pl. XId).

Large grains other than quartz are rare. A few rocks contain chert grains (Pl. XIe). Rare orthoclase grains are euhedral and dusty with inclusions (Pl. XIf). The orthoclase is associated with quartz, chert, coarsely crystalline calcite, and argillaceous material, and is believed to be authigenic.

Sandstones

Sandstones are sporadically interbedded with the dolomites. They consist almost entirely of quartz grains in a carbonate or, rarely, siliceous cement (Pl. XIIa-f). A small suite of heavy minerals from a sandstone in the Hatch Creek section was identified by D. C. Pugh. Brown, green, and blue tourmalines occur as well-rounded grains; brown and green hornblendes and subround zircons are common; rutile and possibly andalusite are also present. The sandstones are poorly sorted: grains in some beds range from 0.04 to 0.7 mm in diameter, in others from 0.08 to 0.8 mm; but a few grains in some beds are larger. Large quartz grains are round or subround; smaller ones vary from subangular to angular. The quartz grains are clear or slightly dusty with inclusions, and many show strain shadows. Quartz overgrowths on quartz grains are not common. In the dolomitic sandstones, such overgrowths occur only as badly corroded remnants, mostly at the narrow ends of some ovoid grains (Pl. XIa). Quartz grains in contact with carbonate cement are almost universally corroded. The cement forms a significant proportion of the rock in most sandstones, and in some examples the quartz grains seem to float in the matrix when seen in thin section (Pl. XIIa, b). The cement is commonly dolomite with crystals less than 0.04 mm in diameter, but calcilutite and coarsely-crystalline sparry calcite also occur.

Only a few true quartzites are present (Pl. XIIf). The quartz grains are similar to those of the sandstones and, like them, are poorly sorted. Small grains fill the interstices between large grains; contacts are straight, tangential, or rarely sutured. Silica overgrowths are common on large quartz grains and the cement is silica except for small patches of carbonate.

A few coarsely clastic carbonates occur in the Hatch Creek, Horse Creek, and Pedley Pass sections. They consist of angular, subangular, and even rounded fragments of greyish orange and brown, aphanitic carbonates in lighter coloured, more coarsely crystalline, carbonate matrix. Pellets, coated grains, lumps, charophytes and various unidentified grains are present in some beds. Quartz grains occur both in matrix and within fragments. The source of other fragments is not known, but most of them resemble carbonates found elsewhere in the Cedared Formation and were presumably derived from nearby or subjacent deposits.

Breccias

Breccias occur at several horizons in the Hatch Creek and Pedley Pass sections. They consist of angular fragments of grey, argillaceous limestone and greyish brown, argillaceous, silty, and sandy dolomites, in a yellow-weathering, dolomitic, sandy mudstone matrix. The dolomite and limestone fragments are similar to dolomites and limestones found elsewhere in the Cedared Formation. The breccias are commonly associated with covered intervals. The Cedared is the lateral equivalent of the gypsums and anhydrites of the Burnais Formation (Fig. 4) and the breccias and the covered intervals may be the result of solution of evaporites at any time between their deposition and the present.

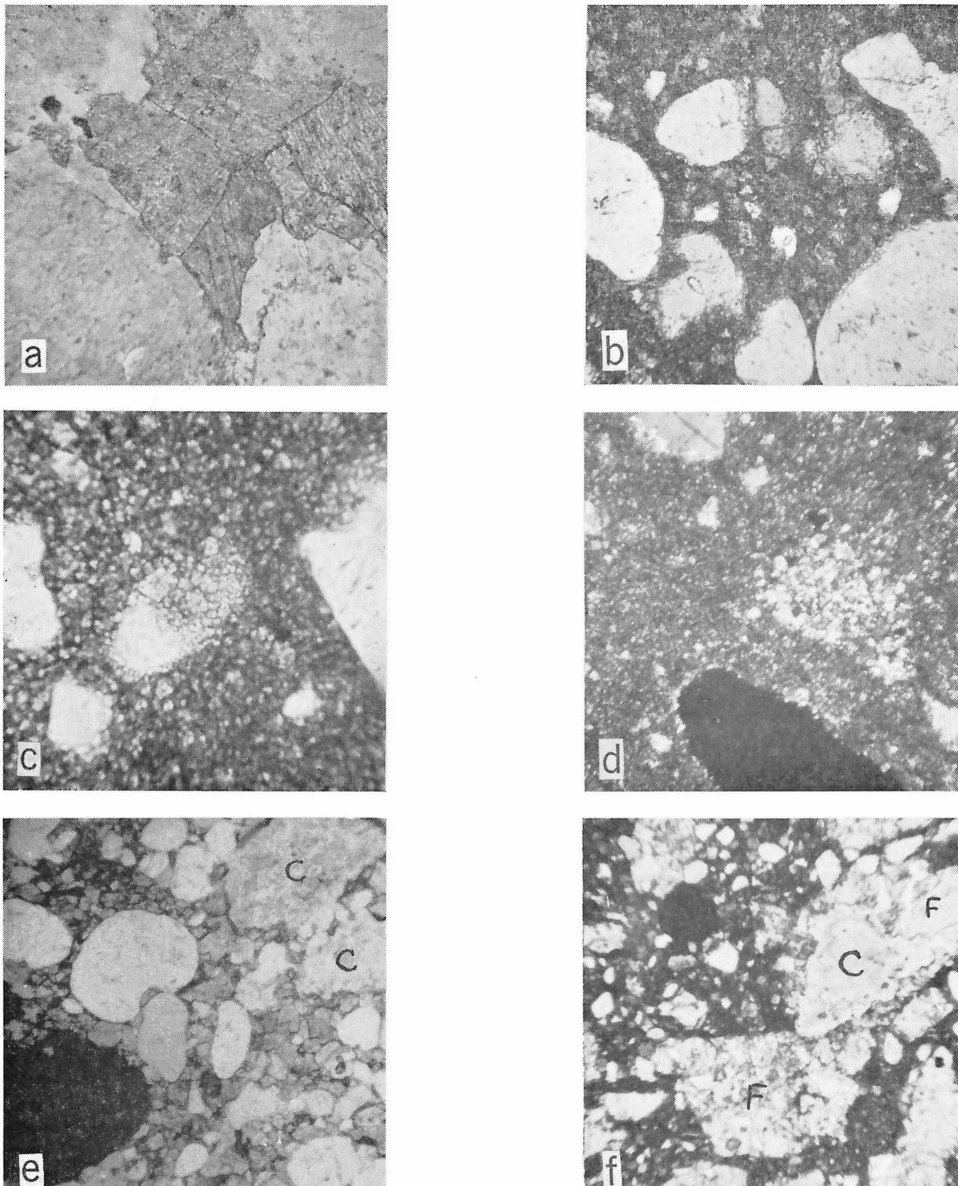
Shaly dolomite (Hatch Creek, unit 6)

The Cedared dolomites and sandstones of the Hatch Creek section are interrupted by a recessive unit at 419 to 436 feet above the base of the formation (*see* Appendix A, unit 6). This unit consists of shaly-weathering, yellowish green, reddish grey, and red mudstones in beds 4 to 8 inches thick, and flaggy, rubbly, argillaceous limestones, dolomitic limestones, and dolomites in beds 2 to 4 feet thick. The mudstones are mixtures of carbonate and clay minerals less than 0.01 mm in diameter (analysis of a sample at 422 feet gave 42 per cent clay and silt residue and 57.4 per cent soluble carbonate). Dolomite rhombs are scattered through the matrix of some carbonate beds, and form more than half of some rocks (Pl. XIII). Mudstone occurs within carbonate beds as pebbles and grains, and as large patches that grade into dolomite through an intermediate mixture of dolomite rhombs and calcareous mudstone. These patches may represent original gradations between mud and carbonate sediment, but more probably are relicts of the original groundmass, or pebbles partly replaced by dolomite rhombs during diagenesis (Pl. XIII). Disseminated angular quartz silt comprises 1 to 8 per cent of the carbonate samples from the unit. The only fossils from the Cedared Formation that are of significant use for correlation are charophytes from this recessive unit. The shaly "red-beds" of this unit divide the Cedared Formation at the type section into upper and lower parts that are similar in lithology, bedding, and weathering characters. The "red-beds" seem to be only a minor facies variation of the otherwise uniform sequence. Light grey, greenish, and pink shaly rocks have been described from the Mount Forster Formation near Horsethief Creek, west of the Rocky Mountain Trench (Walker, 1926, p. 34).

Uppermost beds of Hatch Creek section (unit 9)

The uppermost beds of the Cedared Formation measure 58 feet at Hatch Creek (*see* Appendix A, unit 9). The lower 30 feet is predominantly argillaceous dolomites, the upper 28 feet argillaceous limestones (Pl. Xc). Both dolomites and limestones consist of calcite and dolomite crystals up to 0.05 mm in diameter, set in a matrix of grains preponderantly less than 0.005 mm in diameter. Floating quartz sand and beds and lenses of quartzite and sandstone are common in the

PLATE XI. Thin sections of rocks of the Cedared Formation.



a. Quartz overgrowths on quartz grains corroded by cement of crystalline calcite. Note minute rhombs at and near margin of original quartz grain, suggesting that grain was enclosed in carbonate before quartz rims developed. Cedared Formation, 225 feet above base at Hatch Creek. X90.

b. Quartz grains with dolomite reaction rims encircling one grain, present on sectors of other grains. Cedared Formation, 25 feet above base at Hatch Creek. X90.

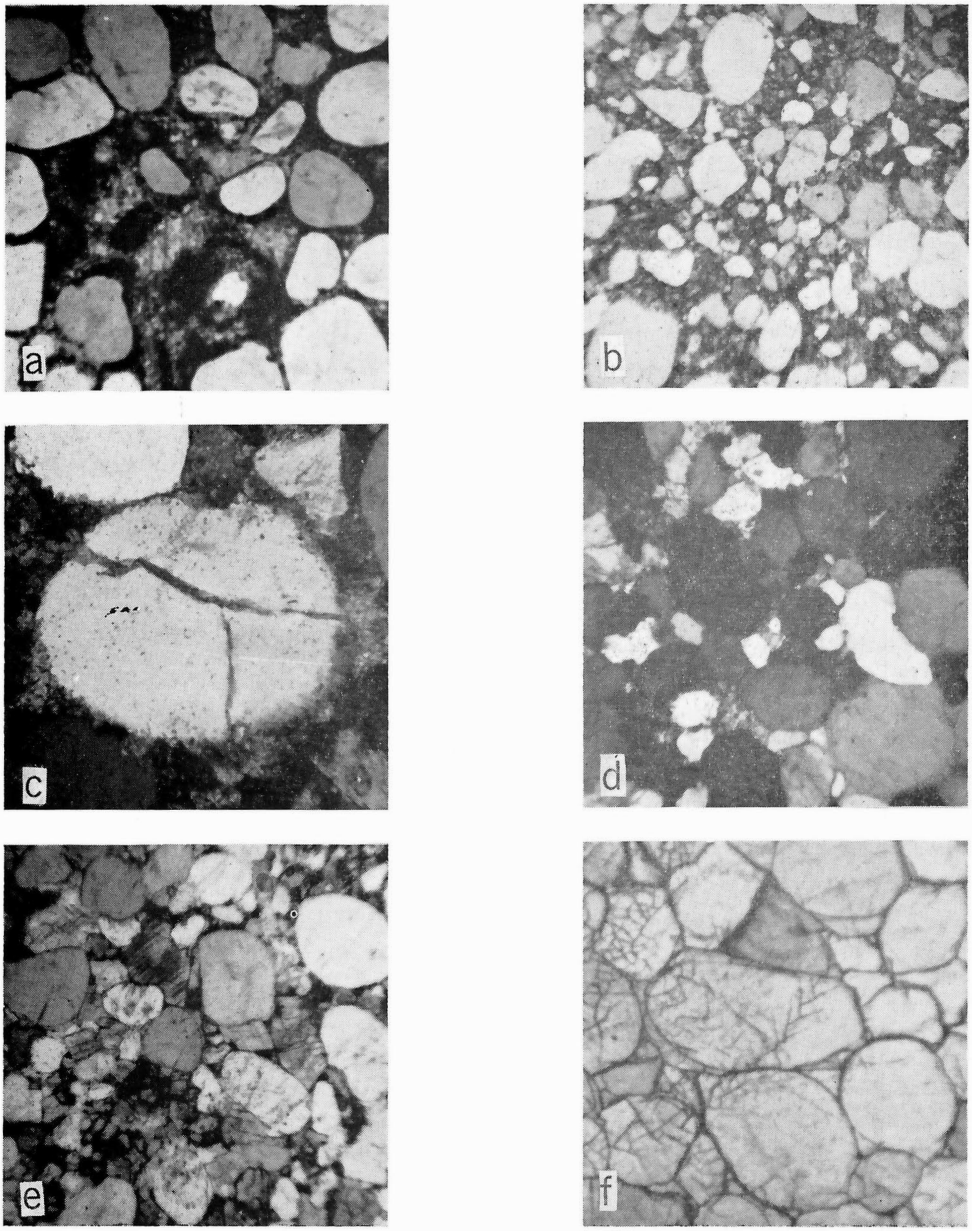
c. Quartz grain partly replaced by dolomite which is more coarsely crystalline than that of the matrix. Cedared Formation, 45 feet above base at Hatch Creek. X90.

d. Ghost grain, probably quartz replaced by dolomite. Cedared Formation, 378 feet above base at Hatch Creek. Crossed nicols. X90.

e. Chert (C) and dark argillaceous dolomite grains in quartz sandstone with dolomite cement. Chert is partly replaced by cement. Cedared Formation, 440 feet above base at Hatch Creek. X30.

f. Authigenic feldspar (F) associated with chert (C) in argillaceous dolomite. In plane of thin section feldspar encloses patches of matrix and almost encloses chert.

PLATE XII. Thin sections of rocks of the Cedared Formation.



a. Quartz sandstone, pore space partly filled by lime mud, remainder by crystalline calcite. Cedared Formation, 602 feet above base at Hatch Creek. X30.
b. Dolomitic sandstone, poorly sorted, grains angular to round; dolomite cement. Cedared Formation, 58 feet above base at Hatch Creek. X30.
c. Sandstone with dolomite grain growth mosaic matrix. Quartz grain cracked and split apart by dolomite. Cedared Formation, 225 feet above base at Hatch Creek. X90.
d. Quartz sandstone: grains subangular to subround, poorly sorted, tightly packed; minor silica and calcite cement. Cedared Formation, 350 feet above base at Hatch Creek. X30.
e. Quartz sandstone, poorly sorted, grains subround to round; dolomite cement. Cedared Formation, 440 feet above base at Hatch Creek. X30.
f. Quartzite. Silica overgrowths in optical continuity with grains. Fracture pattern caused by tectonic movements. Cedared Formation, 635 feet above base at Hatch Creek. X30.

lower part of the unit but rare in the uppermost 15 feet. Quartz silt is common, and some beds contain limestone and claystone grains 0.28 to 0.5 mm in diameter. A 3-inch band within a bed contains about 10 per cent smooth chert nodules at 27 feet below the top of the formation. Bedding surfaces in this uppermost unit are wavy. Small scale cut-and-fill structures are present and channels are cut to depths of 2 inches in an underlying bed 10 feet from the top of the Cedared Formation.

Pedley Pass

The section at Pedley Pass differs from the Hatch Creek and Horse Creek sections in having more breccias, less sandstones, and fewer floating quartz sand grains in the carbonates. A large part of the section is covered. The carbonate rocks, both dolomite and limestone, are similar to those of the other two sections, but generally contain little or no argillaceous material, and are more coarsely crystalline. Some consist predominantly of rhombs in a cryptocrystalline matrix; others have a mosaic texture with interlocking crystal contacts. Some carbonates are equicrystalline: crystals in one rock average 0.1 mm in diameter, in another 0.2 mm, whereas others have a size range of 0.05 to 0.1 mm.

The Cedared Formation thickens abruptly from 159 feet at Horse Creek to 698 feet at Hatch Creek and is probably of a similar order of thickness at Pinnacle Creek, where poor exposure and structural contortion prevent useful measurement (Fig. 4). Farther southeast the evaporites of the Burnais Formation are thought to be tongues and wedges within the Cedared. Thus the section at Pedley Pass is interpreted as follows (Fig. 4).

Unit	*Thickness in feet*
Harrogate Formation	92 (approx.)
Cedared Formation	85
Burnais Formation	488 (approx.)
Cedared Formation	111
Burnais Formation	34
Cedared Formation	6
Beaverfoot-Brisco Formation	1,759

Henderson (1954) erected the Burnais Formation for gypsum beds and very subordinate carbonates and shales. The unit forms extremely poor natural outcrops. The best exposures are at a gypsum mine near Windermere Creek, but only part of the section is represented. There, the gypsum consists of alternating grey, finely crystalline and light grey, coarsely crystalline layers with periodic black carbonaceous laminae. Brecciation of the gypsum is common. Very finely crystalline limestones and dolomites are interbedded with the gypsum, and also occur as fragments within some of the breccias. Henderson described the Burnais carbonates as black fetid limestones and dolomites, bluish grey nodular limestones, limestone-gypsum breccias, and dolomite breccias (1954, p. 26). The present study suggests that limestone breccias that outcrop at Pedley Pass may indicate evaporitic deposition, and assigns them to the Burnais. The Burnais Formation appears to be a mass of evaporitic rocks that merge laterally and vertically with the Cedared Formation.

Post-Depositional Changes

The present textures of Cedared rocks are the result of post-depositional changes during compaction and lithification and also, later, after consolidation. The changes followed an orderly progression from original lime muds to coarse dolomite mosaics, and were accompanied by incomplete destruction of aggregate grains, clastic carbonate, and quartz. The most important changes are those affecting the original lime mud, but the filling of voids and fractures and the development of calcite and dolomite cement can also be recognized. Many of these changes and the textures developed thereby are comparable to those described by Bathurst (1958, 1959), and his terminology has been adopted.

The same series of changes can be recognized throughout the Cedared Formation. The stage to which diagenetic alteration has proceeded differs from rock to rock, and probably depends on the original composition and texture of the sediment, subsequent temperatures and pressures to which the rock has been subjected, the pH and Eh of the diagenetic environment, and the salinity of the connate water.

The finest groundmass found in Cedared rocks consists of dark, non-porous, pasty limestone and dolomite, and cryptocrystalline dolomite. Most grains and crystals are less than 0.005 mm in diameter, but a few, particularly dolomite, are as large as 0.01 mm. In most beds the groundmass is slightly argillaceous, and in places much of the clay-sized fraction is finely ground quartz (Table I). Probably the original grain size and texture of the carbonate muds did not greatly differ from that now preserved. Indeed, Bathurst (1959), in discussing Mississippian lime muds, suggested that the "... factor which has determined this grain size must be the fabric of the original mud." In this sequence, derivation of the cryptograined and cryptocrystalline textures from recrystallized skeletal debris—a common process in some places—is considered unlikely, as recognizable skeletal material is very uncommon, is fairly well preserved, and consists only of charophytes and ostracod fragments. However, some destruction of dark intraclasts of argillaceous carbonate has occurred. These are partly corroded in places by slightly coarser, but still cryptograined, carbonate (Pls. IX, Xd). Most commonly, dark cryptograined limestone and dolomite is replaced by only slightly coarser, and therefore lighter coloured, limestone and dolomite, probably by solution of the original calcilutite and redeposition as slightly larger crystals.

The cryptograined carbonates were probably deposited as ooze or mud in the form of aragonite, calcite, and/or dolomite. The fine material may have precipitated chemically on the depositional interface, or have settled from suspension in the lime-rich waters of a warm sea. The following criteria suggest that the clay-size grains accumulated largely from suspension rather than by precipitation: presence of clay, clastic quartz, and carbonate grains with the cryptograined carbonate; interlamination of carbonate and silty and sandy layers; and, in some laminae, linear fabric of the lime and mud parallel to the depositional surface (Pls. V, VI, VII, and VIII).

Most of the dolomite is probably secondary, after calcite or aragonite, although some of the extremely fine dolomite may be primary. Where secondary, the change

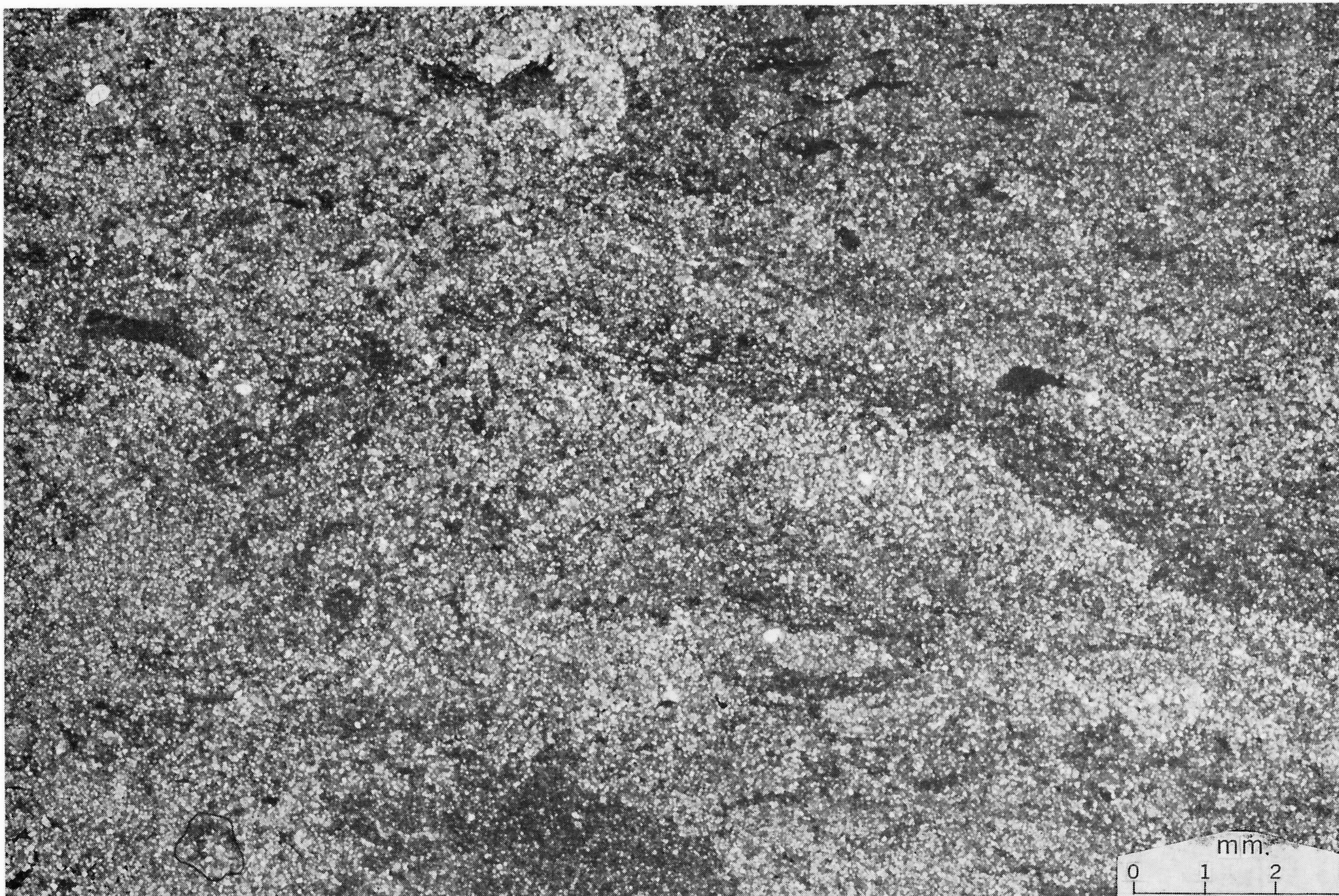


PLATE XIII. Thin section of rock of the Cedared Formation. Dolomite mudstone pseudobreccia. Dark patches and laminae are argillaceous dolomite, probably the original groundmass, but possibly intraclasts replaced by dolomite rhombs, or both. Cedared Formation, 421 feet above base at Hatch Creek. X10.

B.S.N., 9-1-1963

PLATE XIV. Freshly quarried blocks of laminated gypsum and gypsum breccia of the Burnais Formation; Western Gypsum Products Limited mine at Windermere Creek, Stanford Range, southeast British Columbia.

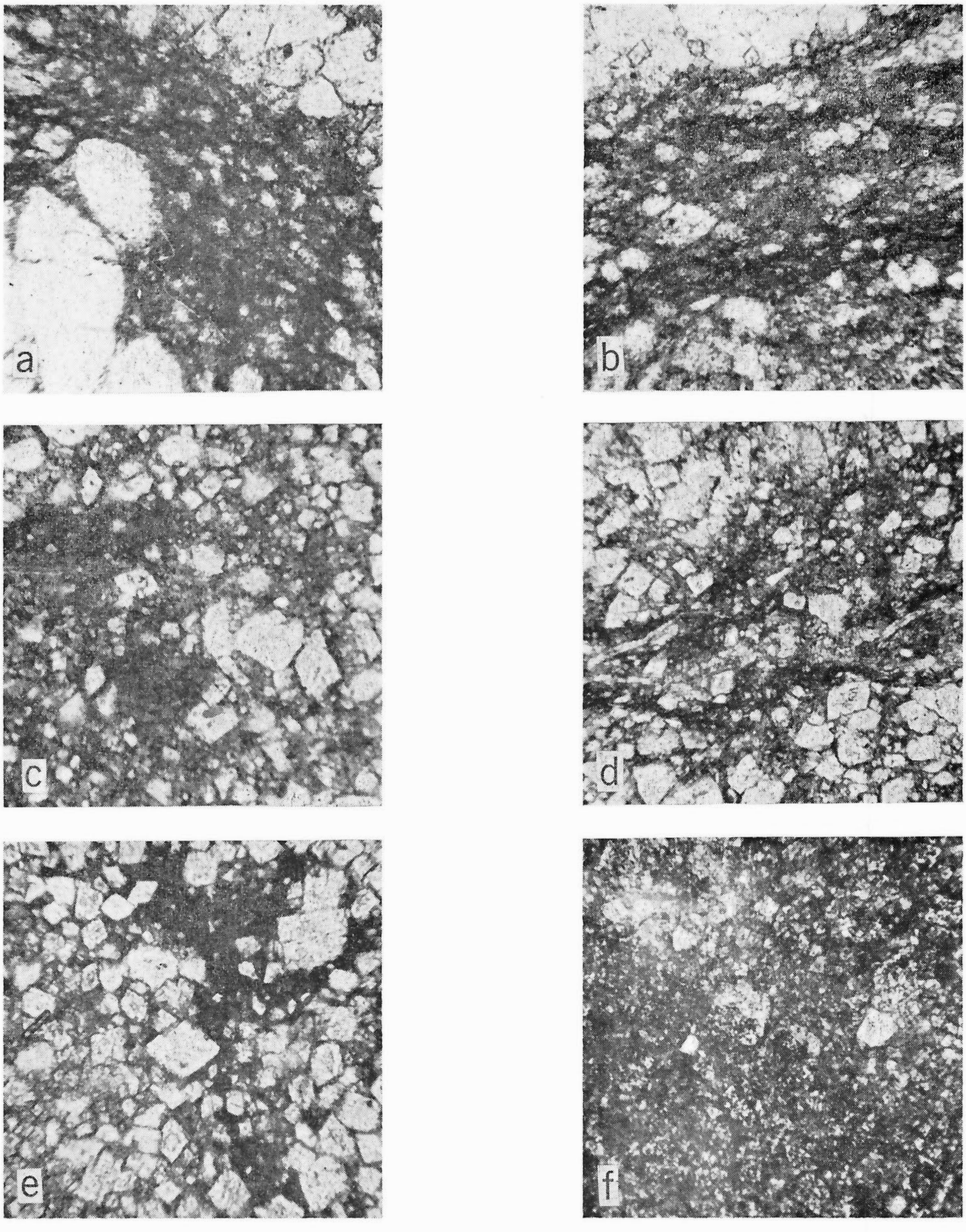
to dolomite seems to have begun very soon after deposition, shortly after burial, or possibly at the depositional interface. Various structures preserved in cryptocrystalline and finely crystalline dolomite suggest that dolomite development began early, although it may have continued over a long period. Plate VI shows laminae of cryptocrystalline dolomite and microcrystalline dolomite, silt and sand. Some laminae are truncated by small channels or cut-and-fill structures; slump and contortion of the laminae are apparent, and one layer seems to have intruded other layers. The structures can be assumed to have formed while the mud was still plastic. Dolomite rhombs and silt grains show a preferred orientation parallel to the movement of the presumably plastic carbonate mud. This suggests, although it does not prove, that the dolomite had formed before plastic deformation occurred. Similarly, in

Pls. VII and VIII, laminae of cryptocrystalline, slightly argillaceous dolomite, and finely crystalline dolomite have been disturbed, presumably while still soft and plastic, by a burrowing organism or a gas bubble. Quartz sand grains from an overlying layer collapsed into the cavity and were cemented later. Note dolomite crystals protruding into sandstone from the argillaceous, laminated layer (Pl. XVb), suggesting that the latter was firm before cementation began in the sandstone. The argillaceous dolomite laminae, quartz silt, and poorly defined, incipient dolomite crystals are draped over quartz grains (Pl. XVa), and show alignment parallel to the direction of movement of the plastic mud (Pl. XVa, b). Later, strong growth of dolomite rhombs cut across the laminae in places, but the early dolomite formed before the carbonate mud was disturbed. In contrast (Pl. XVc, d), laminae in dolomite at 421 feet above the base containing calcite-filled tubules, possibly algae, are cut and even terminated by the growth of dolomite rhombs. Hence, preservation of the slump structures, laminae, and cut-and-fill structures may be significant in suggesting an early beginning to dolomite formation. Another indication of early dolomitization is preserved in off-set dolomite laminae (Pl. IVa) in which the dolomite fabric was established before drag and off-setting occurred. Yet the off-setting must have occurred before complete consolidation, as the minute fault is completely sealed in adjacent layers by later dolomite rhombs. The Cedared may have been deposited under restricted, possibly highly saline conditions, as it is contemporaneous with the Burnais gypsum at Windermere. Ample evidence has already been presented to show that the water was extremely shallow while the Cedared was being deposited. These conditions favour the formation of primary dolomite (Illing, pers. com.) or early diagenetic change from limestone to dolomite.

Minute tension cracks seem to have developed in some beds before diagenesis was complete, in some cases before complete consolidation (Pl. IVa). The cracks are now filled with calcite, dolomite, and hematite and are locally cut by dolomite rhombs (Pl. XVe). They are interpreted as desiccation cracks or slump fractures formed during temporary exposure of freshly deposited beds.

The course of diagenetic changes from lime or dolomite mud to crystalline dolomite mosaic can be followed in various parts of the Cedared Formation. The earliest change is best explained as a reorganization of carbonate, either calcium or calcium-magnesium, to form incipient, optically continuous dolomite rhombs with poorly developed crystal faces (Pls. XVf, XVIa). These dolomite rhombs have a dusty, sometimes sponge-like appearance where optically continuous dolomite surrounds minute (1-2 microns) carbonate and dark grains (probably limonite). A completely clear dolomite rhomb may result, or the centre may remain dusty and be surrounded by a clear rim. The size and abundance of the incipient rhombs probably determine the groundmass fabric (Pl. IVd, e). But what factors determine the size and abundance of rhombs are not certain. The size of the incipient rhombs in places reflects the original grain size (Pls. IVe and Xb); more often, the two bear no apparent relation (Pl. XVf). Different-sized incipient rhombs developed, as if

PLATE XV. Thin sections of rocks of the Cedared Formation.



a. Argillaceous laminae with poorly defined dolomite crystals aligned parallel to laminae probably formed before draping over sand grain occurred (detail of Pl. VIII). Cedared Formation, 415 feet above base at Hatch Creek. X90.

b. Same as XVa but with some well-formed dolomite crystals cutting laminae. Note small dolomite crystals growing from argillaceous layer into sandstone, suggesting that argillaceous layer was a firm mass at the time they formed. Cedared Formation, 415 feet above base at Hatch Creek. X90.

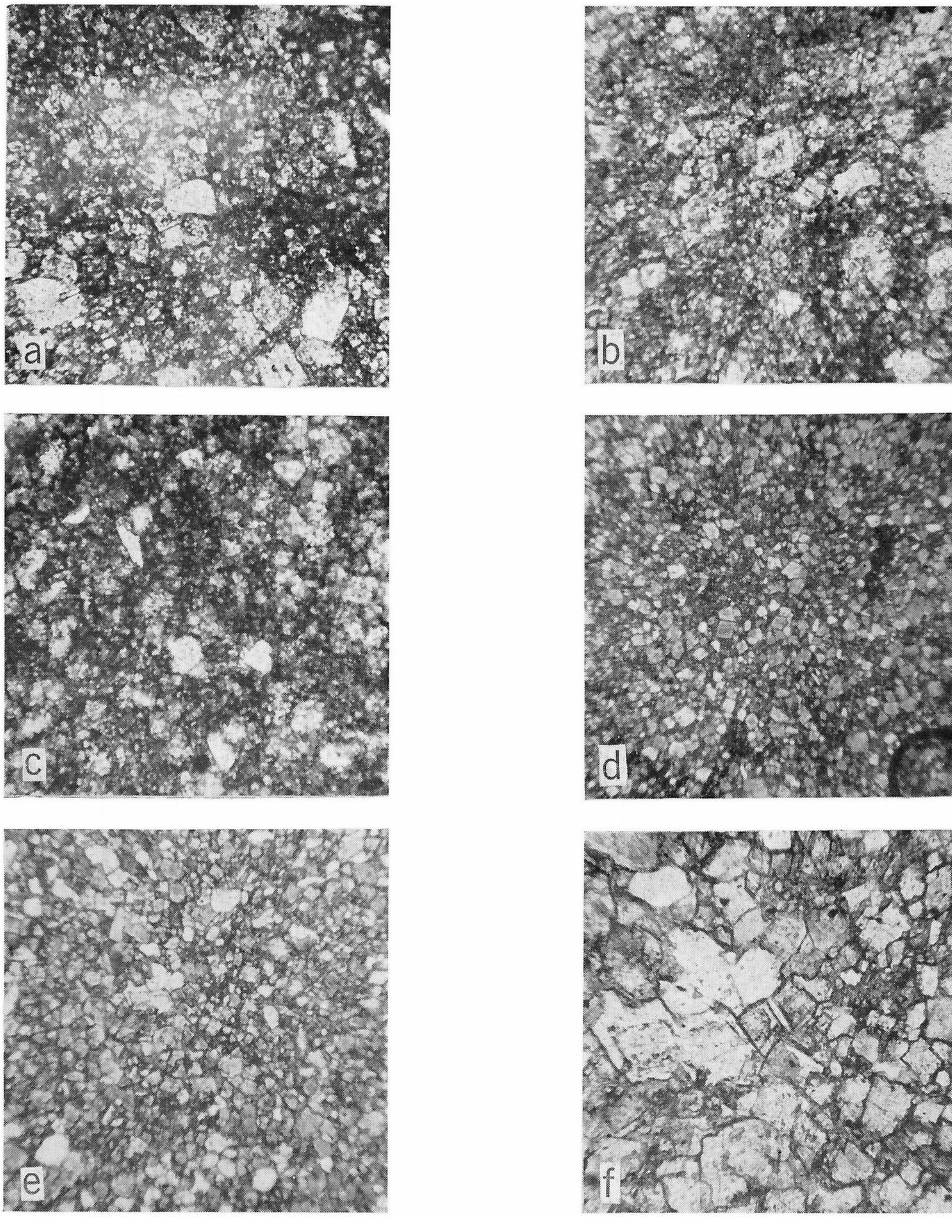
c. Argillaceous dolomite laminae cut by later-formed dolomite rhombs. Tubules filled with calcite may be algal filaments. Cedared Formation, 421 feet above base at Hatch Creek. X90.

d. Same as XVc but with argillaceous layer terminated by dolomite grain growth mosaic. Cedared Formation, 421 feet above base at Hatch Creek. X90.

e. Fracture filled with hematite enclosing small dolomite rhombs but cut by large ones. Cedared Formation, 428 feet above base at Hatch Creek. X90.

f. Incipient dolomite rhombs forming in carbonate. Large rhombs in centre of photograph envelop minute grains of carbonate and limonite. White dolomite forms optically continuous crystal. Cedared Formation, 512 feet above base at Hatch Creek. X90.

PLATE XVI. Thin sections of rocks of the Cedared Formation.



a. Dolomite-limestone contact: limestone, dark (stained), cryptograined; incipient dolomite rhombs near boundary envelop limonite and calcite(?) grains; clear or dusty dolomite rhombs make up most of dolomite. It is suggested that the rhombs crystallized close to their present size within an area of influence of a nucleus. White grains are quartz (see also Pl. XVf). Cedared Formation, 512 feet above base at Hatch Creek. X90.

b. Dolomite fabric, possibly formed as incipient rhombs from a limestone. Clear rims around dusty nucleus suggest crystal growth. Cedared Formation, 25 feet above base at Hatch Creek. X90.

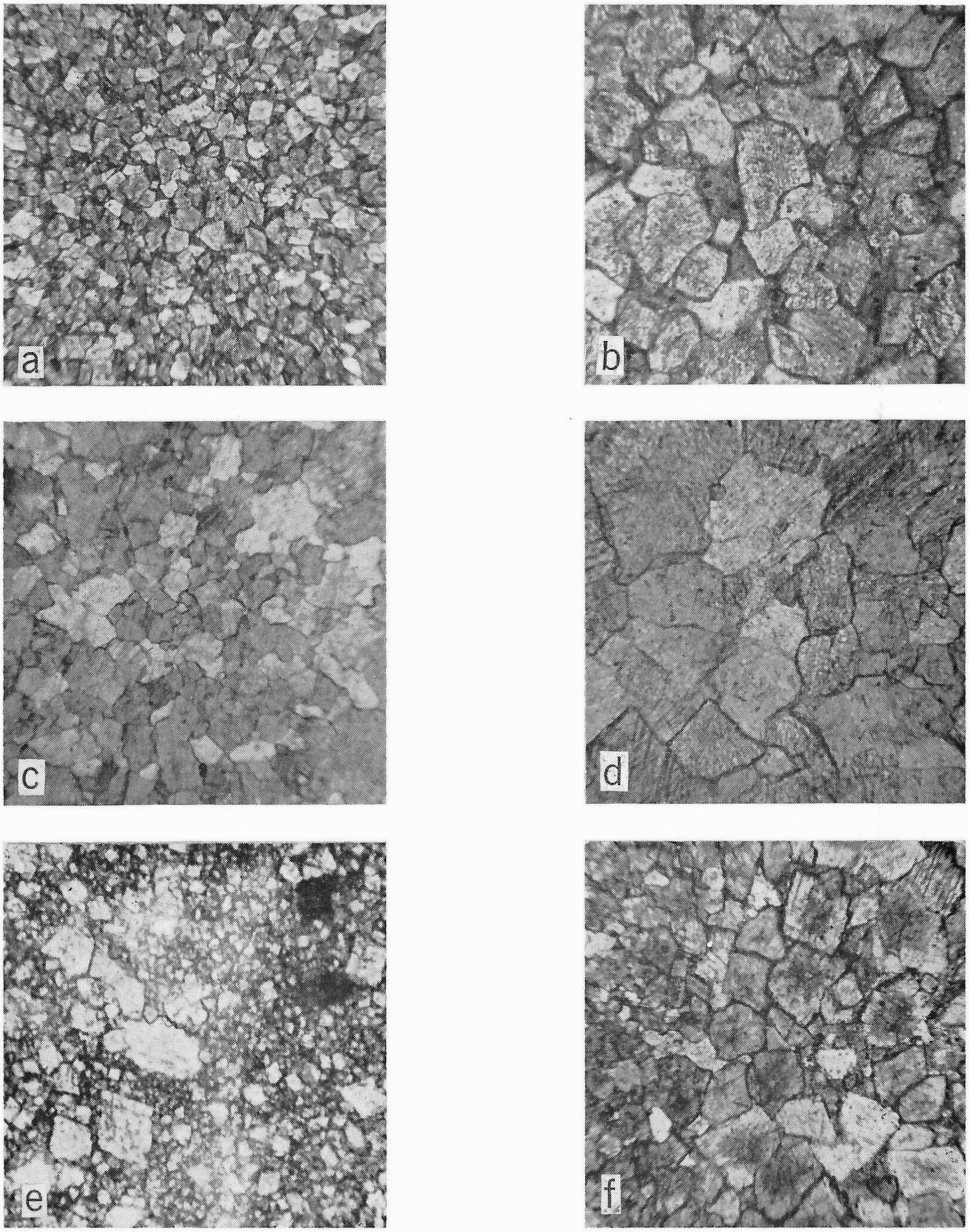
c. Vague dolomite rhombs developing in cryptocrystalline dolomite fabric. Cedared Formation, 25 feet above base at Hatch Creek. X90.

d. Dolomite porphyroblasts in cryptocrystalline dolomite fabric. Compare with Plates Xa, c and IVe which show an increasing abundance of rhombs in matrix. Cedared Formation, 428 feet above base at Hatch Creek. X30.

e. Abundant anhedral and euhedral dolomite rhombs and only small remnants of dolomite mudstone fabric. Cedared Formation, 418 feet above base at Hatch Creek. X30.

f. Same as XVIe. X90. Detail shows interference of rhombs and beginnings of dolomite mosaic fabric where large crystals show growth about dusty centres.

PLATE XVII. Thin sections of rocks of the Cedared Formation.



a. Rhombic dolomite fabric with little matrix. Rhombs may be separated by a film of interstitial material that prevents mutual interference and development of mosaic texture. Cedared Formation, 97 feet above base at Pedley Pass. X30.

b. Same as XVIIa. X90.

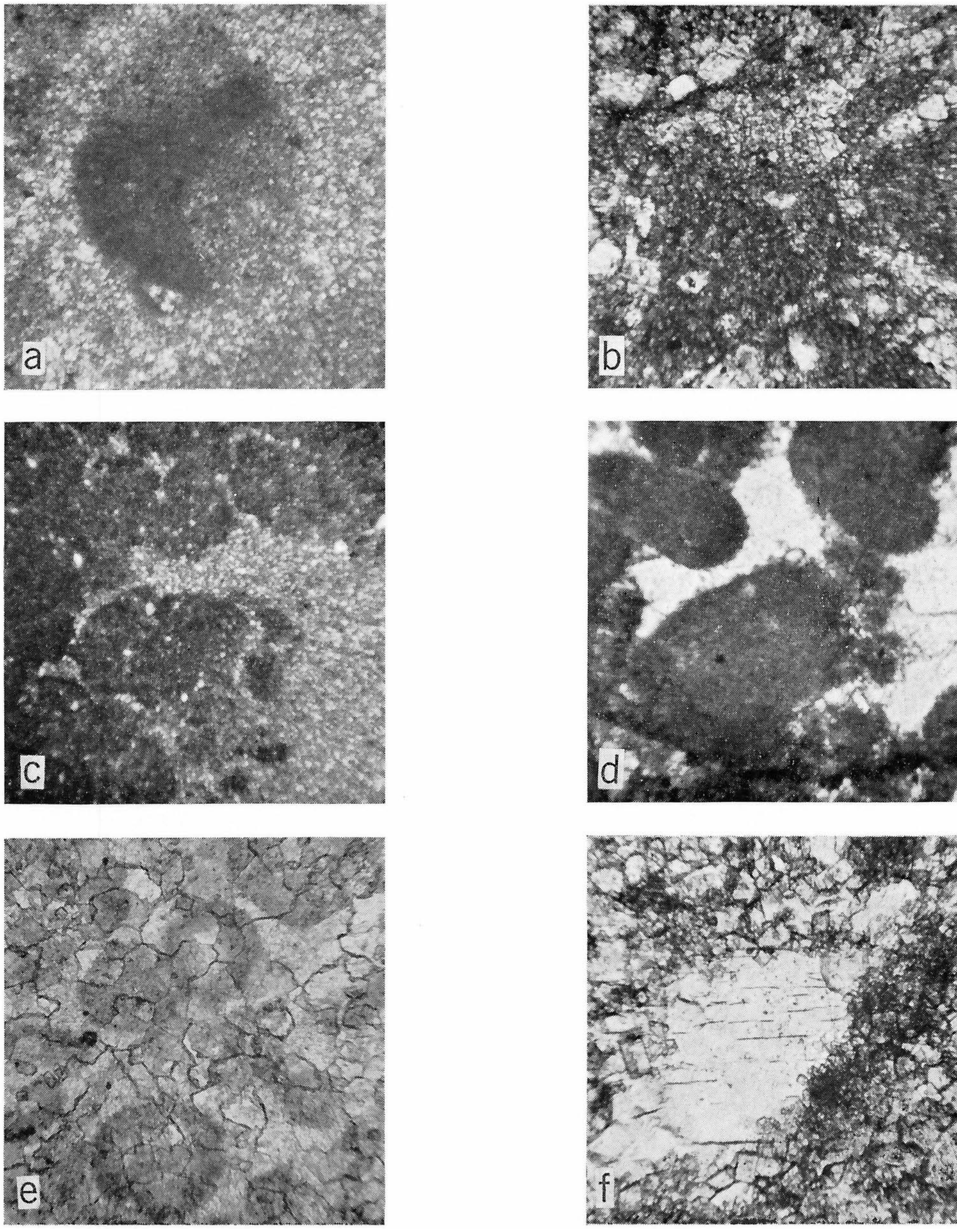
c. Dolomite grain growth with mosaic texture. Some grains show sutured contacts but some rhombic forms are preserved. Cedared Formation, 129 feet above base at Pedley Pass. X30.

d. Same as XVIIc. X90.

e. Dolomite rhombs show denticulate contacts with cryptocrystalline matrix and small rhombs. Large crystals about 0.04 mm. Cedared Formation, 547 feet above base at Hatch Creek. X90.

f. Dolomite coarse (0.2-0.4 mm) grain growth mosaic in contact with fine mosaic. Dusty centres (probably clay particles) of dolomite rhombs surrounded by clear rims are probably remnants of the original matrix preserved by crystal growth and not pellets in a dolomite cement. Cedared Formation, 81 feet above base at Pedley Pass. X90.

PLATE XVIII. Thin sections of rocks of the Cedared Formation.



a. Fragment of sandy limestone in dolomite grain growth mosaic in a pseudobreccia. Increase in crystal size and gradual destruction of fragment is in process. Detail of Plate IX. Cedared Formation, 630 feet above base at Hatch Creek. X90.

b. Pseudobreccia or mottled rock formed by reticulate network of dolomite grain growth mosaic isolating cryptograined dolomite matrix. Cedared Formation, 12 feet above base at Hatch Creek. X90.

c. Fragments of dark cryptocrystalline dolomite isolated by grain growth leading to pseudobreccia. Detail of Plate IX. Cedared Formation, 630 feet above base at Hatch Creek. X90.

d. Pellets or bahamiths cemented by crystalline calcite. Cedared Formation, 90 feet above base at Hatch Creek. X90.

e. Ghosts of bahamiths or of a dark cryptograined rock completely replaced by grain growth mosaic. Note that present crystal bears no relation to original grain boundary. Cedared Formation, 350 feet above base at Hatch Creek. X90.

f. Drusy cavity filled with crystalline calcite in cryptocrystalline dolomite and grain growth mosaic. Note small calcite crystals along rim of cavity. Cedared Formation, 12 feet above base at Hatch Creek. X90.

facility of growth differed from place to place, perhaps reflecting type of material available, original grain size, porosity, amount and composition of connate water as well as its salinity, and temperature.

Coarse dolomite textures in the Cedared developed in three different ways from the fine groundmass. A common development in the Cedared is characterized by an increasing abundance of dolomite porphyroblasts. Plates Xc, IVe, f, XVId, e, f and XVIIa, b, illustrate progressive stages in this type of development.

In the first stage, anhedral and euhedral dolomite rhombs or porphyroblasts are widely scattered through the groundmass of clay-sized and very fine silt-sized carbonate. In the following stages the rhombs increased in size. During this process, clear rims must have formed by solution or leaching of the groundmass and precipitation of clear calcium magnesium carbonate in the space thus created. Several stages of growth with minor interruptions are suggested by zoned crystals (Pls. IVf and Xa). Growth of porphyroblasts into the aphanitic groundmass seems to have been uneven: boundaries are commonly denticulate, and small rhombs have not always been incorporated into larger ones (Pl. XVIIe). As well as increasing in size, the rhombs increased in number, and patches of coarser-grained dolomite formed throughout the fine groundmass. The patches and individual rhombs within patches are separated by a cryptograined or cryptocrystalline matrix, and have the appearance of floating rhombs. This fabric (Pls. IVe and XVIIa) is probably the fabric most commonly developed in Cedared rocks and represents the stage of crystal growth most commonly reached. This stage of crystal growth, which may be called rhombic dolomite, has potential porosity that might be developed if the carbonate of the matrix were removed by circulating connate or ground water. In some rocks, crystal growth has proceeded to the point of elimination of the groundmass and the development of an interlocking, mosaic texture. An example that suggests the beginning of interlocking in a predominantly rhombic texture is illustrated in Pl. XVIf.

A relationship may exist between the presence of non-calcareous material and the type of texture. Interstitial material may prevent interlocking of rhombs and leave a rhombic fabric as the final result. Where no interstitial material is present, reorganization and grain growth may proceed to the mosaic stage (Pl. XVIIc, d). This theory is supported by an occurrence of finely crystalline, rhombic dolomite and abundant quartz silt that grade to more coarsely crystalline, interlocking dolomite with only scattered grains of silt. In summary, Cedared dolomites show a progression of crystallization from an early porphyroblastic stage to a mosaic of almost equigranular rhombs separated by minute quantities of cryptograined groundmass, and finally, where few impurities are present, to a mosaic of crystals of various sizes with mutually interfering boundaries. These textures are typical of the grain growth mosaic described by Bathurst (1958), and the stages described seem to correspond to the history of its development within a dolomite fabric.

The process outlined above suggests an explanation for the dolomite mosaic texture in which clear dolomite crystals contain dusty centres, probably clay particles (G. Pouliot, pers. com.) (Pl. XVIIf). As described above, early-formed dolomite porphyroblasts are commonly dusty throughout. Later, the centre is surrounded by a rim of clear dolomite. If the "dust" consists of minute dolomite or calcite crystals, the clear rims may be caused simply by reorganization of the dolomite. If material other than dolomite is present (e.g., clay), such material may have been leached, and clean dolomite precipitated in its place. This texture of dusty centres enclosed by clear rims persists through all stages of dolomitization to the presumably stable mosaic. The final texture, a mosaic with dusty centres and clear rims, is sometimes interpreted as pellets cemented by clean dolomite (rim cementation of Bathurst, 1958). This example from the Cedared Formation indicates that similar textures may develop as a result of grain or crystal growth in a cryptograined carbonate groundmass.

The proliferation of dolomite rhombs at the expense of the groundmass or of clastic grains sometimes results in the formation of a pseudobreccia (Pl. XIII). Destruction of fine-grained fabric may be incomplete. Ragged fragments and relict grains are left as remnants of the old fabric, and produce a rock that resembles a microbreccia. The fragments are similar to dolomite of adjacent laminae, and their arrangement suggests that they are part of a once continuous layer. Rhombs commonly protrude from the coarser dolomite into the finer.

A less common pattern of crystal growth in the Cedared shows an overall growth of dolomite or calcite mosaic, and occurs in both limestones and dolomites (Pls. IX, Xd, XVIIIa, b, c). In the first stage of growth, dark grains, probably clastic, but possibly relicts of the original rock, become coarser and lighter-coloured and fade into the adjacent matrix, their former presence being indicated by only vague outlines or ghosts (Pl. XVIIIa). A further increase in growth of the mosaic texture has resulted in a corroded irregular boundary where the coarse mosaic encroaches on the finer. Large dark patches, similar to the main body of the rock, seem to be incompletely-altered relict patches, rather than intraclasts. Plate XVIIIc shows in detail the separation of some of the "grains" from the parent rock. Moreover, extension of the coarser fabric through the finer has isolated patches that might be mistaken for grains of bahamith type (Pl. XVIIIb, c). However, the incomplete isolation of some grains, the mosaic texture of the coarser fabric, and the irregular pattern of the pseudograins indicate that this is merely a net-like extension of the grain growth mosaic fabric. Some dark grains in Plate IX seem to have been limestone intraclasts. These, too, have been corroded and partly destroyed. Porphyroblastic dolomite rhombs are sparse or lacking where this type of growth occurs, suggesting a variation in the process of recrystallization from that resulting in porphyroblasts. It is suggested that renewed percolation of connate water may have corroded and dissolved the compacted rock. Coarse dolomite crystals were precipitated in zones of greatest porosity.

Pseudobreccias and mottled rocks are also formed in the Cedared where dolomite grain growth mosaic replaces calcite and leaves unaltered patches of limestone in the dolomite.

Carbonate grains other than detrital and relict grains are rare in the Cedared. One clear example of pellets or bahamiths is illustrated in Plate XVIIId, but other cases are rare. The grains are cemented by clear crystalline calcite. Small crystals coat the grains, suggesting precipitation on the grain surface and radial growth into cavities. This probably occurs in the same manner as the precipitation of aragonite crystals during the formation of grapestones in the Bahamas, as described by Illing (1954). Coarse crystals with plane, rather than curved or sutured, common boundaries have completely filled the original pore spaces between the grains.

In a few rocks, brownish ghosts of smooth, rounded, elongate, and diverse shaped forms may indicate a pelletoid structure (Pl. XVIIIe). The dolomite fabric is a mosaic of dolomite crystals of various shapes and sizes, with curved and interlocking boundaries, and resembles Bathurst's grain growth mosaic. The final mosaic bears no relation to the original grain boundaries, as interpreted from the brown patches. Late Pleistocene oölites, partly replaced by calcite, are illustrated by Ginsburg (1957), and dolomitized oölites are illustrated by Hatch, Rastall, and Black (1950, p. 190) and by Zadnik and Carozzi (1963, p. 11).

The origin of the ghosts is uncertain. Derivation by either of two processes described here is possible. They may originally have been pellets, replaced and/or cemented by crystalline calcite, later replaced by dolomite. A comparison may be made with a charophyte oögonium observed in the Cedared, in which the wall is penetrated and partly replaced by calcite crystals that line the interior and radiate outwards. Pellets, as in Plate XVIIId, tend to act as masses from which the cementing material grew into surrounding voids; or the ghosts may be relicts of an originally continuous cryptograined rock, subjected to grain growth and the eventual development of mosaic texture. Analogy with Plate XVIIIa, c is suggested, the grain growth process having extended to cover the whole area.

The carbonate siltstones (Pl. Xb) have undergone a slightly different diagenetic process. The silt-sized, rounded grains are dolomite and are enclosed in dolomite rhombs. In Plates Xb and XIXe many dolomite grains, still showing part of their original rounded surfaces, have developed crystal boundaries on other surfaces. Others are enclosed by narrow dolomite rims that must have precipitated on the grain from the enveloping connate water (cf. the rim cementation process of Bathurst). Later, the whole was cemented by calcite. This suggests that the dolomite silt grains were deposited in a saline environment rich in calcium and magnesium ions. The grains were not destroyed, although some solution may have occurred, giving extra magnesium ions to the solution. Dolomite rims deposited on the grains seem to have used up all of the magnesium ions available, and the voids between the grains were later filled by calcite.

A few small irregularly shaped patches of coarsely crystalline mosaic occur within the carbonate muds (Pl. XVIIIf). The coarse mosaic typically has plane boundaries, and grades from fine crystals at the margins to coarse at the centres, and suggests growth into cavities (drusy mosaic of Bathurst). How such cavities were formed is not known. Possible modes of origin include evolution of gas, decomposition of organic matter, and internal erosion by migrating pore water (as in

Sander, 1951). Similar mosaics fill centres of some charophyte oögonia. A few patches of coarse calcite mosaic in contact with dolomite mudstone seem to replace mudstone, contrary to Bathurst's (1959) observations. These patches may be a late diagenetic effect due to renewed percolation of calcite-bearing water.

Quartz grains in cryptograined carbonates and in sandstones with carbonate cement are commonly corroded or even completely replaced by carbonate (Pl. XIa, b, c, d). Such corrosion is particularly common in the lowest 420 feet of the Cedared Formation in the Hatch Creek section, but is also present at higher horizons in this section as well as in other sections. Several patterns of corrosion can be distinguished. In some rocks the quartz grains are devoid of silica overgrowths, and the grains have a corroded appearance where attacked by the carbonate. Corrosion may surround grains or may be present only in some sectors (Pl. XIb). Some quartz grains have been completely replaced (Pl. XIe), and the ghosts are visible only because the replacing mosaic is clearer and slightly coarser than the enclosing groundmass. No relation has been determined between presence of corrosion and orientation of the optic axes of grains. Where quartz overgrowths are present, they have been largely corroded by the carbonate matrix (Pl. XIa). The overgrowths may have been present on the quartz grains before transport to their present resting place in the Cedared Formation, and part of their destruction could have taken place in pre-Cedared time. However, the partly or completely corroded overgrowths have the same nibbled appearance as corroded quartz grains that lack overgrowths. A line of minute carbonate rhombs between the rim and the grain (Pl. XIa) suggests that quartz overgrowths formed in situ, and were subsequently attacked by carbonate. Similar replacement of quartz overgrowths by carbonate has been described in the Knox Dolomite (Dietrich, Hobbs, and Lowry, 1963).

In one set of beds in the Cedared Formation of the Hatch Creek section (345 to 380 feet above the base of the formation), both corrosion and the quartz overgrowths have a distinct orientation that seems to be related to tension cracks (Pl. XIXa). Quartz and carbonate intergrowths form rims on diametrically opposite edges of the quartz grains, and the remainder of the borders are in denticulate contact with the enclosing dark pasty matrix, and presumably are in process of being corroded by carbonate. Tension fractures that extend from the boundaries of the quartz grains into the matrix are orientated parallel to the quartz-carbonate rims and normal to the denticulate borders. Quartz, or alternating quartz and carbonate, crystals grow across the tension cracks, so that the directions of crystal growth of quartz and carbonate are parallel within the fractures and on the quartz grains. Evidently, fracturing created a relief of pressure; quartz and carbonate resolved from the denticulate sides of some grains were precipitated on the ends of the grains and in the open fractures. Small fractures that wedge into the matrix from quartz grains contain quartz in optical continuity with the grains. Fractures cut quartz grains in some rocks. Such grains have been partly dissolved and silica has been redeposited with carbonate in the fractures. These features, related to tension fractures, seem to be tectonically controlled, and possibly unrelated to quartz corrosion elsewhere in the Cedared rocks.

Chert, like quartz, may be replaced by carbonate. In one locality (at 138 feet above the base at Pedley Pass) feldspar encloses chert and seems to replace it as well as the cryptograined, slightly argillaceous dolomite groundmass (Pl. XIf).

The cause of replacement of quartz grains by carbonate is not completely understood, although a number of examples have been described in recent years. Walker (1962) and Siever (1962) review much of the published literature. The solubility of silica increases with temperature and pressure, and increases rapidly with pH values above 9. The temperatures and pressures to which the Cedared has been subjected are difficult to evaluate. Its present position in a mountain-built area presumably would have involved higher than normal pressure and temperature.

High pH values may have existed in the connate water. Garrels (1960) has shown that pure deaerated water in equilibrium with $CaCO_3$ has a pH value between 9.9 and 10, and that similar values can be obtained experimentally. Walker (ibid.) believes such high natural pH values may be more common than once thought, as accurate measurements are difficult to obtain. The Cedared is laterally equivalent to gypsum deposits which, as shown by Krumbein and Garrels (1952), are commonly precipitated where pH values are 8 or higher. Hematite and limonite, both common in the Cedared, also form under high pH conditions. Hence, high pH may be considered as a factor in corrosion of quartz grains in the Cedared. The process leading to cementation and corrosion seems to be similar to that proposed by Siever (1959). Silica in solution was deposited as overgrowths on quartz grains at an early stage of diagenesis and shallow burial. Deep burial or medium burial accompanied by high pH caused solution of the silica and precipitation of calcium carbonate.

The sandstones of the Cedared are most commonly cemented by carbonate, less commonly by silica. Interstitial carbonate occurs as argillaceous lime mud, lime silt and sand, and as crystalline calcite. Where lime mud fills the interstices, it seems simply to have been compacted and consolidated.

In Plate XIIa the calcilutite has been either partly reorganized or dissolved and replaced by coarsely crystalline calcite. In part (left of centre, Pl. XIIa), the compacted calcilutite is rimmed by small calcite crystals. Large calcite crystals fill what must have been pore spaces. In other sandstones the original calcilutite matrix has gone through the same diagenetic changes to porphyroblastic dolomite as have the carbonate rocks (Pl. XIIb). Elsewhere, crystalline sparry calcite is the predominant cement. In some sandstones it is associated with pore-fillings of calcisiltite and may be a reorganization of this material, and not an original void filling. The presence of minute limonite crystals in the calcite lends support to this theory.

Siliceous cement is rare (Pl. XIIf); where found, silica occurs as overgrowths on the quartz grains, and a few grains show outlines of incipient quartz crystals in optical continuity with the original grains (rim cementation of Bathurst, 1958). Sutured contacts between quartz grains are rare. Siever (1962) and Dietrich, Hobbs, and Lowry (1963) have recently discussed the problems of source of silica cement and the method of its emplacement in sandstones. Silica derived from corrosion of quartz grains in contact with carbonate cement within the sandstones, or in adjacent sandy carbonates, is probably sufficient to account for all of the siliceous cement in Cedared quartzites.

Pyrite, hematite, and limonite are all present in the Cedared, but little can be deduced about their relationships—whether they are primary or formed during diagenesis. Pyrite is less abundant than the others, and is associated with chlorite. In one case a cube is entirely enclosed by chlorite, which may be a source of the iron. Hydrogen sulphide produced by bacterial reduction of sulphates would react with the iron to form sulphides (Emery and Rittenberg, 1952). Hematite and limonite were present before the dolomite porphyroblasts, and at some horizons are the most common centres about which dolomite precipitated (Pl. Xa).

The final process to affect Cedared rocks seems to have been fracturing of the solid rocks and filling of the fractures with calcite. This phenomenon is probably associated with tectonic movements. The fracture-fillings provide excellent examples of calcite growth from surfaces into cavities to form drusy mosaic.

Fauna, Flora, and Correlation

Fossils are rare in the Cedared Formation. Gastropods have been collected from the uppermost Cedared beds at Pedley Pass. T. P. Chamney has identified fragments of ostracods and brachiopods in a sample from an outcrop near Pinnacle Creek, and charophytes and possible ostracods have been collected from the type section at Hatch Creek (at 420 to 425 feet above the base of the Cedared). The beds with charophytes are about 220 feet below Middle Devonian (Givetian) fossils in the Harrogate Formation. Charophytes have been described from European Lower Devonian rocks, and may be present in the Silurian of Turkestan, but in North America are known only from Middle Devonian and younger rocks (Croft, 1952; Peck, 1953; Grambast, 1959). Dr. Peck of the University of Missouri has examined charophytes collected from the Cedared Formation and reports the presence of species of *Eochara* and *Chovanella.* He suggests that the Cedared Formation is Middle Devonian and that it does not differ much in age from the Slave Point and Watt Mountain Formations. However, field relationships in southeast British Columbia suggest that the Cedared is somewhat older than these two formations. The Cedared lies stratigraphically below the Harrogate Formation that can be correlated by macrofossils with the Methy Formation of the Clearwater River, northeastern Alberta and with the Pine Point Formation of the Great Slave Lake region. These formations are older than the Watt Mountain and Slave Point Formations.

Southeast of the Stanford Range, Leech (1958, pp. 19–20) found that a few gypsum beds outcrop structurally above beds of Harrogate lithology and fauna in the Lussier Syncline, and the upper part of the Burnais Formation may intertongue with basal Harrogate beds. Leech's basal Devonian unit is about 200 feet thick; consists of dolomites (mostly sandy or silty), quartzites, and sandstones (1958,

p. 16); underlies the Burnais; and is probably the Cedared Formation. Similar sandstones and quartzites overlie the Beaverfoot-Brisco Formation at Alces Lake.

Walker (1926, p. 34) studied the isolated Devonian section near Mount Forster, west of the Rocky Mountain Trench, and proposed two formations, both of uncertain age. The uppermost beds of the Starbird Formation are dated as Upper Devonian by Kindle (*in* Walker, 1926, p. 35) and by McLaren (1962, p. 3). The Starbird is reported to grade downward into the Mount Forster Formation. The Mount Forster is described as about 600 feet thick, consisting of light grey, greenish, and pink shales with minor thin limestones, and resting abruptly but apparently conformably on rocks assigned to the Beaverfoot-Brisco Formation. The only fossils known from the Mount Forster are placoderm plates collected by Reesor. In the southern part of the Stanford Range, southwest of the Redwall Fault, basal Devonian rocks are predominantly greenish and reddish weathering and shaly. These rocks probably represent an extension of the Mount Forster Formation east of the Rocky Mountain Trench.

Colourful dolomites, sandstones, siltstones, and mudstones are discontinuously developed beneath the Upper Devonian Fairholme Group in the eastern part of the southern Rocky Mountains. Such rocks are up to 120 feet thick near Ghost River, overlie an erosion surface, and have been called "basal Devonian clastics" by Aitken (1963). Fish and plants suggest Lower and Middle Devonian, respectively, for closely adjacent horizons. A thicker unit disconformably overlies the Middle Ordovician Skoki Formation at Mount LeRoy and Upper Ordovician beds of the Beaverfoot-Brisco Formation at Mount Joffre. Fish from this unit at Mount Joffre suggest early Middle Devonian age (Dineley, pers. com., 1964). Leech reports a unit 219 feet thick resting unconformably on the Cambrian Elko Formation in the eastern part of the Fernie map-area (1958, p. 18).

Farther north at Cirrus Mountain, a thin unit of sandstones and dolomites rests disconformably on Upper Ordovician rocks of the Beaverfoot-Brisco, and grades upward into the Fairholme Group (Norford, 1961).

The Cedared Formation may be equivalent to some part of the lower Elk Point Group of Alberta. A Givetian brachiopod fauna occurs in the upper part of the Elk Point Group and has affinities with that of the Harrogate Formation. Charophytes are present in both the Elk Point and the Cedared.

The lower Elk Point Group in western central Alberta consists of red beds with evaporites, sandstones, argillaceous and evaporitic dolomites, and shales. Thick anhydrite and salt deposits occur to the northeast (Belyea, 1958 and 1959; Sherwin 1962). The lower Elk Point rocks are interpreted (Belyea, 1959) as deposits of basins or broad valleys developed in the pre-Devonian surface, and probably were never continuous with the deposits in the Beaverfoot, Brisco, and Stanford Ranges. The two areas of deposition were probably separated by a land area, the pre-Devonian Western Alberta Ridge (Grayston, Sherwin, and Allan, 1965). Aitken (1963) has described channels cut in what may be the margin of this ridge near Ghost River.

Depositional Environment

Interpretation of the environment of deposition of the Cedared Formation is limited by the scarcity of outcrops. The outcrops are roughly aligned northwest-southeast. The Cedared is not present in the mountains to the east of the Beaverfoot, Brisco, and Stanford Ranges. These mountains are composed of older rocks. No drilling has been done in the floor of the Rocky Mountain Trench to the west. Thus the relative position of the line of outcrops with reference to the margins or to the centre of the depositional basin is not known, and the complete spectrum of facies changes cannot be determined. But the comparatively thin stratigraphic section and the lack of breccias at Horse Creek, northwest of the other outcrops, suggest onlap from Hatch Creek towards Horse Creek, and the presence of a margin to the basin farther northwest. In accordance with such a postulated position for the margin, the thick evaporitic sequence of the Burnais Formation at Windermere Creek and the low content of sand and argillaceous material in the dolomites at Pedley Pass suggest that these localities were farther from the shoreline than Hatch Creek and Horse Creek.

The Cedared Formation directly overlies a sub-Devonian unconformity in the Beaverfoot, Brisco, and Stanford Ranges. In the eastern part of the southern Rocky Mountains the Cedared is not developed, and the basal Devonian rocks are the Upper Devonian Fairholme Group, except for local channel-fill deposits. The regional sub-Devonian unconformity is a major feature of the southern Rocky Mountains, with the immediately subjacent rocks ranging in age from Precambrian to Lower Silurian. During deposition of the Cedared Formation, the sub-Devonian terrain was exposed in the eastern part of the southern Rocky Mountains. The terrain consisted of carbonate rocks, quartzites, quartz-sandstones, and minor shales, and seems to be a logical possible source for the Cedared sediments that consist of carbonates with abundant quartz sand and silt and very minor content of clay minerals.

The even bedding and the consistency of gross lithology from bottom to top of the Cedared indicate relatively constant conditions throughout its deposition. The surface of deposition was probably flat, covered with shallow water, and at times even emergent. Lime mud and possibly dolomite mud and silt accumulated, derived from a terrain rich in limestones and dolomites. The distinct bedding planes, fluting, small cut-and-fill structures, and lenses of quartz sand suggest conditions similar to modern broad tidal flats—not that the sediments are necessarily tidal flat deposits, but that they resemble tidal flat deposits in being periodically close to the surface or exposed. Red mud and the patches and fracture-fillings of hematite and limonite in the Hatch Creek section are indications of the presence of mildly oxidizing conditions during deposition or in the early stages of diagenesis. Slump structures and breccias are common. The latter consist of angular fragments of mudstone and argillaceous carbonate similar to that of the enclosing rock. In some rocks, sharpstones have merely been dragged, bent, or broken from immediately adjacent rocks, possibly by rills that wound across the flat and, changing course from time to time, cut away fragments of the quasi-compacted mud.

The coarse sandstone beds and lenses are thought to have accumulated close to the shoreline. The abundant coarse quartz sand within the carbonates may have been carried out by water currents, long shore drift, tides, and wave undertow, or blown out onto the mud flats. Most grains are scattered through the carbonate mud, but patches of sand may have collected in small irregularities in the surface of the flat. Numerous broken, cracked, and chipped grains suggest that forces of some strength banged grain against grain. Such forces may have been wind or water in the zone of breakers.

Contemporaneous deposition of the Burnais Formation indicates restricted influx of marine water, allowing excessive evaporation, deposition of gypsum and possibly more soluble salts. Growth of algae and other organisms may have accompanied gypsum precipitation. A dry or arid climate must be assumed.

The dark colours, high argillaceous content, and relative lack of quartz sand in the uppermost beds of the Cedared Formation presage the change in conditions that led to deposition of the overlying Harrogate Formation, with an assumed increase in depth of water and the onset of more normal marine conditions.

Thus the Cedared and Burnais Formations are thought to have accumulated in a gently subsiding basin, the surface of which was a lime mudflat covered with shallow water. Large amounts of calcium carbonate and magnesium carbonate in solution were carried into the depositional area by streams draining a predominantly carbonate terrain. Sand and mud could have been derived from outcrops of the Mount Wilson Quartzite and other formations with abundant quartz sand and shale. Restricted circulation and a dry climate resulted in deposition of gypsum in parts of the basin, and caused subaerial exposure of the lime mudflats in some other parts. Winds, currents, or waves, or all three, carried quartz grains into the basin from the shore. The palaeogeography and conditions of deposition of the Cedared and Burnais Formations resemble those of rocks of the lower part of the Elk Point Group of Alberta. Both sequences may have accumulated in long, relatively narrow, topographic depressions with restricted circulation.

HARROGATE FORMATION

Erected: Shepard, 1926, p. 626, as Harrogate Limestone, without lithologic description, type section, or type area other than Rocky Mountain Trench region. The name was amended to Harrogate Formation by Evans (1933, p. 142).

Name: From the hamlet of Harrogate, British Columbia; 33 miles southeast of Golden.

Type section: Here designated, Hatch Creek section, measured in a steep creek gully at 51°00′N, 116°23′W, about half a mile northwest of Hatch Creek (*see* Pl. I; section given in detail in Appendix A), with the lowermost 132 feet supplemented by a section beside Hatch Creek (*see* Appendix A).

Lithology: Limestones, shaly limestones, nodular limestones, and shales in the lower part of the formation at the type section; dolomites in the upper part.

Thickness: 293 feet at the type section, measured by staff. Shepard gave a thickness of 600 feet.

Base: Covered concordant contact with the Cedared Formation of probable Middle Devonian age.

Top: Picked at a breccia bed in the type section that is thought to represent a fault breccia. No stratigraphic top seen within the Beaverfoot, Brisco, and Stanford Ranges, but Leech (1958) reports overlying Upper Devonian (Frasnian) limestones in the Fernie map-area.

Fossils: Corals, stromatoporoids, brachiopods, cephalopods, echinoderm fragments, trilobites, gastropods, clams, sponge spicules.

Horizon: Middle Devonian (Givetian).

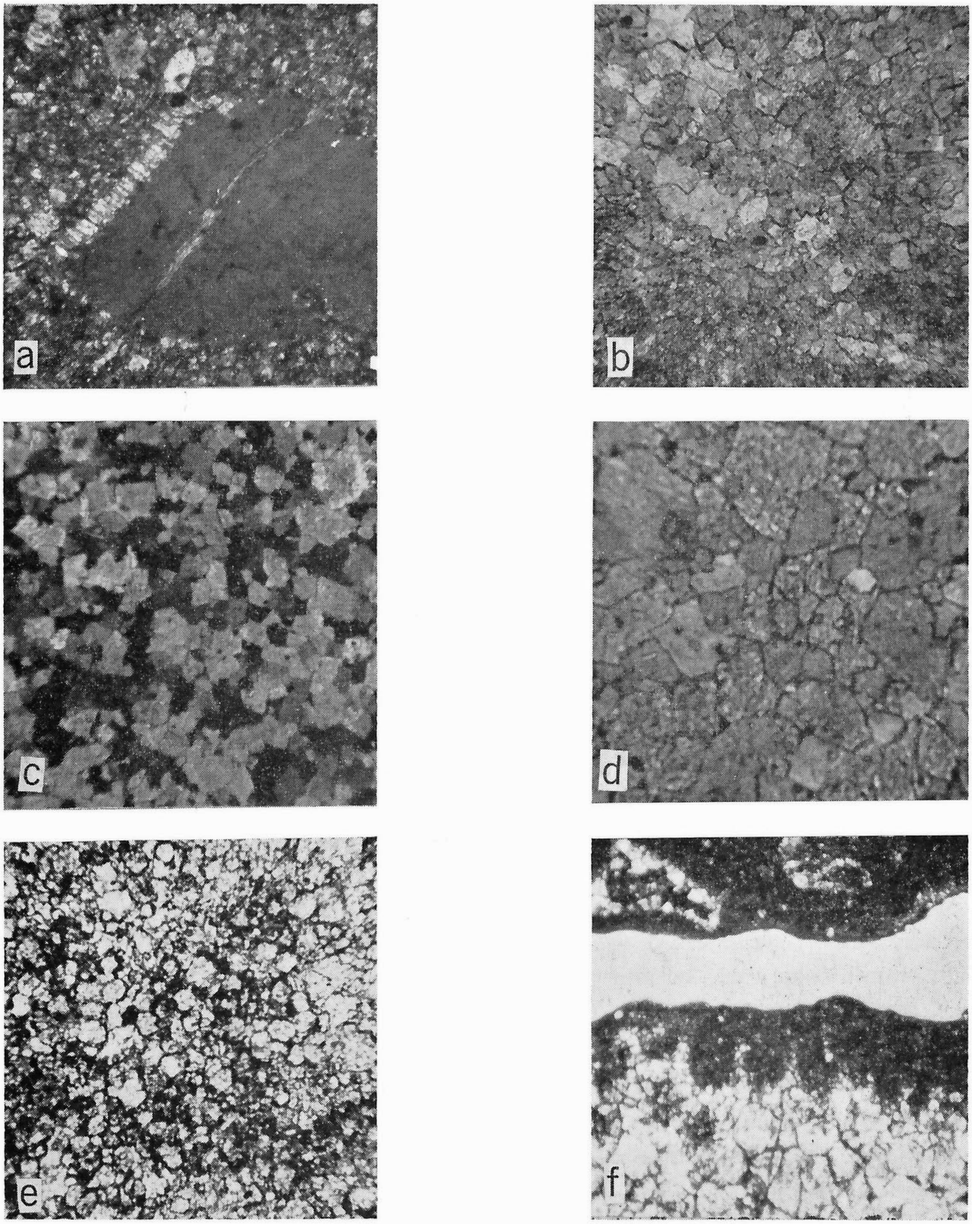
Stratigraphy and Petrology

Two members can be recognized within the formation, but their common boundary is a limestone-dolomite contact and is not thought to be stratigraphically consistent. The lower, limestone, member is more recessive than the upper, dolomite, member and contains interbedded shales in its lower part. Outcrops of the upper member seem to be restricted to Horse Creek and Hatch Creek (Fig. 4). To the southeast, thin sections of the Harrogate Formation are left by faulting and erosion and only the lower member is present. Farther southeast, beyond the Stanford Range, Leech reports that a distinct Upper Devonian limestone unit overlies the Harrogate in the Lussier Syncline where the Harrogate is almost entirely limestone and shale (1958, pp. 21–23).

The lowest beds of the Harrogate Formation at the type section are poorly exposed, grey, non-calcareous, moderately fissile shales that weather grey and brownish grey. The shales are overlain by dark grey and greyish black limestones that weather brownish grey, bluish grey, grey, reddish brown, and light brown. Beds are six inches to two feet thick and have undulatory shaly partings and interbeds.

The limestones of the Harrogate Formation are dark, pasty, highly argillaceous, calcite grains ranging from mud (less than 0.01 mm) to silt (0.01–0.04 mm). The

PLATE XIX. Thin sections of rocks of the Harrogate and Cedared Formations.



a. Quartz grain cut by fracture. Rim of intergrown quartz and dolomite has formed on edge of grain parallel to fracture. Cedared Formation, 482 feet above base at Hatch Creek. X90.

b. Dolomite grain growth mosaic fabric with remnants of finer mosaic. Harrogate Formation, 227 feet above base at Hatch Creek. X90.

c. Dolomite rhombs showing some interference. Harrogate Formation, 127 feet above base at Hatch Creek. Crossed nicols. X30.

d. Detail of XIXc shows incomplete development of grain growth mosaic; some interstitial material apparent. X90.

e. Dolomite siltstone with calcite cement (stained dark). Some silt grains have rhombic faces developed. Harrogate Formation, 252 feet above base at Hatch Creek. X90.

f. Cryptocrystalline dolomite filling corallites in coral replaced by crystalline dolomite. Harrogate Formation, 152 feet above base at Hatch Creek. X30.

latter are rounded and composed of cryptograined limestone, and are probably bahamiths. Argillaceous material is irregularly distributed and gives the appearance of a flocculent mass interspersed with calcite. Grains of dark cryptograined limestone up to 0.5 mm in diameter are widely scattered in some beds and are probably detrital. Irregular black fragments and specks seem to be organic, probably carbonaceous. Thin shell fragments, mostly ostracods, brachiopods, spines, and broken crinoid debris are scattered through many beds, and are common in some.

The predominantly limestone sequence grades upwards to dolomites with some interbedded limestones of similar colour and texture. The dolomites are dark brownish grey, grey, and dark grey, and weather dull brownish grey, yellowish brown, and grey. The beds are mostly from 3 inches to 4 feet thick, but there are a few massive beds reaching as much as 15 feet thick. Most beds have rubbly, irregular surfaces. Corals, brachiopods, crinoids, and ostracods are present in some beds. The dolomites are finely crystalline, but the fabric shows considerable variation in crystal size and shape (Pl. XIXb, c). In most dolomites the crystals are less than 0.04 mm diameter and in many they are less than 0.01 mm. A few beds contain crystals up to 0.3 mm diameter. Many dolomites examined in thin section were free of argillaceous material, and the crystals formed an interlocking or mosaic texture of anhedral, small and large crystals or, less frequently, of equisized crystals. Beds formed of euhedral crystals are not as common as in the Cedared, but are more apt to occur where argillaceous material is present than in pure dolomite. Argillaceous material occurs both as matrix between dolomite rhombs and as wisps and blebs through the dolomite. Dark brown material seen in some thin sections may be organic. A few beds of a clastic dolosiltstone (Pl. XIXe) were encountered and others may be present.

Detailed descriptions of the dolomite fabrics are included with the discussion on diagenesis. The nature of the original rock fabric and the conditions of deposition may in some cases be interpreted from the dolomite fabrics.

The upper part of the Harrogate (i.e., above 900 feet in the Hatch Creek section) contains several zones of laminated dolomite with cross-lamination, slump structures, contorted bedding, and breccias. Lamination seems to be caused by small differences in crystal size, by variation in the amounts of argillaceous material, and possibly by recrystallization. Large blocks of laminated dolomite are incorporated in the overlying beds, some slabs being as much as 5 feet long, although most fragments are under 6 inches in longest diameter. The uppermost bed at Hatch Creek is a coarse breccia containing blocks of dark grey dolomite, similar to that in the immediately underlying beds, and a few blocks of an exotic aphanitic, light brown weathering dolomite. This breccia is interpreted by the authors as a fault breccia because of the presence of rare slickensides, but may conceivably be due to solution of evaporites from a laminated dolomite-evaporite sequence.

Fossils are abundant in some beds of the Harrogate, rare in others, and many are fragmented or comminuted as though worn during transportation.

Post-Depositional Changes

The limestones of the Harrogate are predominantly argillaceous lime muds and have changed little since deposition, except for the effects of compaction. There has probably been a slight increase in grain size as a result of solution and redeposition of fine material. As in the Cedared, the lime mud fabric seems to have been extremely stable and to be close to that originally deposited.

Dolomitization, on the other hand, has effected important changes in the fabric of the Harrogate. Most of the dolomite has a mosaic texture, with interlocking crystals of variable size and shape (Pl. XIXb, c). Size range varies from bed to bed; for example, in one bed crystals range from 0.016 to 0.2 mm in diameter, and in another bed from 0.025 to 0.16 mm. The texture is similar to that suggested by Bathurst (1958) as grain growth mosaic, and also resembles textures in the Cedared that seem to have had a like origin. Elsewhere, rhombic textures similar to those of the Cedared are present (Pl. XIXc, d), and probably developed in a similar manner.

Some microcrystalline dolomite consists of euhedral to anhedral crystals from 0.008 to 0.024 mm in diameter. In one instance dolomite of this type forms the matrix for recrystallized dolomitized shell and coral fragments. The microcrystalline dolomite is present within corallites (Pl. XIXf) and between ostracod valves. By this characteristic it resembles numerous occurrences of lime mud in the Middle Devonian of Alberta, British Columbia, and the District of Mackenzie and is therefore interpreted as a dolomitized lime mud.

A dolomite siltstone in the Harrogate consists of rounded grains between 0.016 and 0.04 mm in diameter in a calcite cement (Pl. XIXe). Most grains are cryptocrystalline dolomite, but a few are limestone. The shape and consistent size of the grains suggest that they are detrital. Many of the grains of both dolomite and limestone are partly or completely enclosed by a narrow dolomite rim with characteristic rhombic faces. Post-depositional changes are the same as those described for similar beds in the Cedared Formation. The environment immediately following deposition was probably rich in calcium and magnesium, possibly as a result of slight solution of the clastic dolomite grains. The matrix of clear crystalline calcite seems to have been precipitated between the grains. In some large patches of cement, calcite crystals increase in size from the silt grain boundaries towards the centre of the patches; crystal boundaries are relatively smooth and lack the interlocking character of grain growth mosaic; and in places crystals developing from opposite sides meet along a straight line. These characteristics Bathurst (1958) has shown to be typical of what he calls granular cementation, that is, precipitation of cement in a void.

Incipient dolomite rhombs similar to those in the Cedared occur at an horizon about 200 feet above the base of the Harrogate at Hatch Creek. Clear dolomite encloses, and has apparently crystallized around, small dolomite crystals and argillaceous material to form incipient rhombs from 0.04 to 0.08 mm in diameter. Most of the large rhombs do not have sharp boundaries and many show interpenetrating relationship. This texture would seem to be an early stage in the formation of a coarsely crystalline dolomite in which all previous textures would be obscured.

Laminated dolomites in the upper part of the Harrogate Formation consist of discontinuous layers of brown, very argillaceous dolomite with scattered calcite grains and lighter grey, less argillaceous dolomite, most grains being less than 0.01 mm in diameter. Adjacent layers are in places gradational, elsewhere have sharp boundaries. In some places, laminae are contorted and slumped. Microbreccias consist of fragments and flat pebbles of the main body of the rock, enclosed in coarser-grained calcite and dolomite. Ostracods occur in some laminae. The original deposit seems to have been a soft spongy calcite or dolomite mudstone. As in most mudstones, the original texture shows but slight alteration. Expulsion of water, compaction, possibly exposure, and drying were followed by slumping and brecciation of the layers at some horizons. Some slumping and offsetting of laminae occurred before complete consolidation; other fractures followed consolidation. Reorganization of the dolomite with increase in grain size (grain growth mosaic) has occurred in the less argillaceous laminae and has replaced parts of large dark grains, leaving only their ghosts. Scattered patches of clear crystalline dolomite, some with circular outline, are common. Dolomite crystals increase in size from the edges towards the centre, which suggests that they fill drusy cavities whose origin cannot be determined. Calcite occurs as cement between grains in the argillaceous layers. Locally, it replaces some of the late clear dolomite and may be related to calcite filling fractures that formed after complete consolidation, possibly during folding.

Fauna and Correlation

Fossils are abundant in some limestones and shaly limestones of the Harrogate Formation. A few poorly preserved corals are present in the lower beds of the upper, dolomitic, part of the formation, but most of the dolomites are unfossiliferous. Table III shows the distribution of megafossils collected from the formation. All these fossils are taken from within 132 feet of the base of the Harrogate and seem to comprise a single fauna. The identifications are by D. J. McLaren and A. W. Norris, who consider the fauna Givetian (Middle Devonian) in age. T. P. Chamney reports probable calcispheres and probable plant fragments from the upper part of the type section (unit 13, at 970 and 950 feet respectively — *see* Appendix A).

Fossils from the Harrogate Formation in the Beaverfoot, Brisco, and Stanford Ranges have been cited in earlier publications and include corals, brachiopods, stromatoporoids, clams, gastropods, trilobites, worms, echinoids, sponges, and echinoderm fragments (Weller *in* Shepard, 1922; Kirk *in* Walcott, 1924; Kindle *in* Evans, 1933; Howell and Bassett *in* Henderson, 1954). Identifications by McLaren of Harrogate fossils from the Fernie map-area are given by Leech (1958, pp. 20–21).

Table III

Distribution of Fossils in the Harrogate Formation

Locality	C	B	D	C	A	C	F	A	B	E
GSC Loc. No.	52147	52145	56096	52148	52142	52149	56092	52143	52144	52146
Footage above base Harrogate	20–46	42–56	42–62 (talus)	63–71	71–72	100	85–125	105–107	83–132	?
Atrypa cf. *A. arctica* Warren		x						x		x
Atrypa cf. *A. asperanta* Crickmay	x		x		x			x	x	
Spinatrypa sp.			x							
Emanuella sp.								?	?	x
Emanuella meristoides (Meek)			x		x					
Schizophoria sp.		x			x			x	x	x
Spinulicosta sp.			x					x		
Plectospirifer (?) sp.		x							x	
Cystiphylloides sp.										x
Hemicystiphyllum sp.	x							x		
Atelophyllum sp.		x						x		
Cyathophyllum (*Peripaedium*) sp.							x			
Dialytophyllum sp.		x								
Xystriphyllum sp.							x			
cerioid rugose coral						x				
Thamnopora sp.	x									
Coenites sp.			x							
Alveolites sp.	x						x		x	
Favosites sp.	x	x		x			x		x	x
Syringopora sp.	x			x					x	
stromatoporoids	x									
Michelinoceras sp.		x								

A Hatch Creek section
B Hatch Creek supplementary section
C Horse Creek section
D Pedley Pass section
E Sinclair Creek outcrop, 50 feet of beds in fault slice
F Pinnacle Creek outcrop

The Harrogate fauna has gross similarities to the faunas of other Givetian formations in Western Canada. Such units include the Methy Formation of the Elk Point Group that outcrops on Clearwater River, and the Pine Point Formation and equivalent rocks of the Great Slave Lake region (Belyea and Norris, 1962; Norris, 1963; McLaren, 1962, Fig. 1). Muller (1961) reports early Givetian limestones from the Rocky Mountains just south of Peace River. McLaren (*in* Belyea, 1959, p. 3) has identified a Middle Devonian fauna from the upper part of the Elk Point Group in the California Standard Spotted Lake 4–21 well, about seventy miles south of Edmonton. This fauna is probably Givetian also.

The Harrogate Formation is probably equivalent to much of the upper part of the Elk Point Group of central Alberta. Marine Middle Devonian rocks are lacking from most of southwest Alberta. This region was probably land during Middle Devonian time and separated the southern part of the Elk Point basin from the area of Harrogate deposition (Grayston, Sherwin, and Allan, 1965).

Depositional Environment

Harrogate sedimentation reflects a continuation of the marine conditions and deeper water that began late in the Cedared, and contrasts with the extremely shallow water conditions of most of that formation. The lower part of the Harrogate, consisting of shales and argillaceous limestones, with little or no sand, may indicate exposure of rocks from a different source than those which contributed to the Cedared. For example, a black shale terrain may have been uncovered, whereas carbonate and sandstone exposures may have been relatively unimportant. Or, it may be that the present outcrops of the Harrogate are far from the shoreline, indicating a transgression of the sea beyond the limits of the Cedared.

A gradual lessening of argillaceous content and the appearance of purer carbonates takes place higher in the Harrogate. This change may have resulted from a number of factors or from combinations of several: greater exposure of a carbonate terrain in comparison with shale; sweeping away of mud from the carbonate banks by currents; shallowing of this part of the basin and consequent by-passing of mud to an area not now exposed.

Deposition of the Harrogate in relatively shallow water is suggested by the presence of lime siltstone and sandstone, and occurrences of corals, brachiopods, ostracods, and crinoids. These organisms are mostly fragmented, presumably moved to their present position by waves or currents. The dark colour of the Harrogate is not incompatible with shallow water deposition. It suggests a euxinic reducing environment. But such an environment may be caused by the sediments being too rich in organic matter for products of their decay to escape, or by their protection from oxidation by algae, by rapid burial, or by deposition in quiet water. Ginsburg (1957) found reducing conditions in all the sediments of the very shallow but poorly ventilated semi-enclosed Florida Bay. R. Bartlett of the Geological Survey (pers. com.) found black shales being deposited in shallow bays off the coast of Nova Scotia.

The lower and middle parts of the Harrogate seem to represent the deposits of a carbonate bank, with somewhat restricted circulation. Stable conditions existed, and subsidence and sedimentation maintained a fair balance.

For the uppermost Harrogate beds sedimentation seems to have overtaken subsidence, and the latest deposits indicate extremely shallow water. Lamination, cross-lamination, and slump structures are common. Intraclasts in breccias include compacted blocks of Harrogate dolomite, possibly broken off as currents changed direction, or slumped off during temporary exposure and desiccation. Evaporites may have been present and their solution allowed the blocks of dolomites to collapse. These beds were probably deposited in a shallow water lime mudflat environment subject to periodic exposure and flooding.

REFERENCES

Aitken, J. D.
1963: Ghost River type section; *Bull. Can. Petrol. Geol.,* vol. 11, pp. 267–287.

Andrichuk, J. M.
1960: Harrogate Formation; *Alta. Soc. Petrol. Geol.,* Lexicon of geologic names in the Western Canada Sedimentary Basin and Arctic Archipelago, pp. 167–168.

Bathurst, R. G. C.
1958: Diagenetic fabrics in some British Dianantian limestones; *Liverpool and Manchester Geol. J.,* vol. 2, pt. 1, pp. 11–36.
1959: Diagenesis in Mississippian calcilutites and pseudobreccias; *J. Sed. Petrol.,* vol. 29, No. 3, pp. 365–376.

Belyea, H. R.
1958: Devonian formations between Nordegg area and Rimbey-Meadowbrook Reef chain; Guide Book, *Alta. Soc. Petrol. Geol.,* 8th Ann. Field Conf. and *Geol. Surv. Can.,* Reprint 2, 1960.
1959: Devonian Elk Point Group, central and southern Alberta; *Geol. Surv. Can.,* Paper 59–2.

Belyea, H. R., and Norris, A. W.
1962: Middle Devonian and older Palaeozoic formations of southern District of Mackenzie and adjacent areas; *Geol. Surv. Can.,* Paper 62–15.

Choquette, G. B.
1956: A new Devonian charophyte; *J. Palaeontol.,* vol. 30, pp. 1371–1374.

Correns, C. W.
1950: Zur Geochimie der Diagenese; *Geochim. et Cosmochim. Acta,* vol. 1, pp. 49–54.

Croft, W. N.
1952: A new *Trochiliscus* (Charophyta) from the Downtonian of Podolia, eastern Europe; *Brit. Mus. Nat. Hist.,* Bull. (Geology), vol. 1, No. 7.

Dapples, E. C.
1959: The behaviour of silica in diagenesis; *Soc. Econ. Palaeontologists and Mineralogists,* Special Pub. 7, Silica in sediments, pp. 36–54.

Dietrich, R. V., Hobbs, C. R. B. Jr., and Lowry, W. D.
1963: Dolomitization interrupted by silicification; *J. Sed. Petrol.,* vol. 33, No. 3, pp. 646–663.

Emery, K. O., and Rittenberg, S. C.
1952: Early diagenesis of California basin sediments in relation to origin of oil; *Bull. Am. Assoc. Petrol. Geol.,* vol. 36, pp. 735–806.

Evans, C. S.
1933: Brisco-Dogtooth map-area, British Columbia; *Geol. Surv. Can.,* Summ. Rept. 1932, pp. 106A II – 197A II.

Fitzgerald, E. L.
1962: Ghost River type section; *J. Alta. Soc. Petrol. Geol.,* vol. 10, pp. 203–207.

Garrels, R. M.
1960: Mineral equilibria; New York, Harper and Brothers, 254 pp.

Ginsburg, R. N.
1957: Early diagenesis and lithification of shallow-water carbonate sediments in south Florida; *Soc. Econ. Palaeontologists and Mineralogists,* Special Pub. 5, Regional aspects of carbonate deposition, pp. 80–100.

Grambast, Louis
1959: Tendances évolutives dans le phylum des charophytes; *Academic Sciences,* Comptes rendus, T. 249, pp. 557–559.

Grayston, L. D., Sherwin, D. F., and Allan, J. F.
1965: Middle Devonian; *Alta. Soc. Petrol. Geol.,* Geological History of Western Canada, pp. 49–59.

Greggs, R. G., McGregor, D. C., and Rouse, G. E.
1962: Devonian plants from the type section of the Ghost River Formation of western Alberta; *Science,* vol. 135, pp. 930–931.

Grégoire, Ch., and Monty, Cl.
1963: Observations au microscope électronique sur le calcaire à pâte fine entrant dans la Constitution de Structures Stromatolithiques du Viséan Moyen de la Belgique; *Ann. Soc. Géologique de Belgique,* T. 85, 1961–1962, Bull. No. 10, pp. 389–397.

Hatch, F. H., Rastall, R. H., and Black, Maurice
1950: The petrology of the sedimentary rocks; London, Thomas Murby and Co., 383 pp.

Henderson, G. G. L.
1954: Geology of the Stanford Range of the Rocky Mountains, Kootenay district, British Columbia; *B.C. Dept. Mines,* Bull. 35.

Illing, L. V.
1954: Bahaman calcareous sands; *Bull. Am. Assoc. Petrol. Geol.,* vol. 38, pp. 1–95.

Krumbein, N. C., and Garrels, R. M.
1952: Origin and classification of chemical sediments in terms of pH and oxidation-reduction potentials; *J. Geol.,* vol. 60, pp. 1–3.

Krynine, P. D.
1940: Petrology and genesis of the Third Bradford Sand; *Pennsylvania State Coll.,* Bull. 29.

Leech, G. B.
1958: Fernie map-area, west half, British Columbia; *Geol. Surv. Can.,* Paper 58–10.
1962: Structure of the Bull River Valley near latitude 49°35′; *J. Alta. Soc. Petrol. Geol.,* vol. 10, pp. 396–407.

McLaren, D. J.
1962: Middle and early Upper Devonian rhynchonelloid brachiopods from Western Canada; *Geol. Surv. Can.,* Bull. 86.

Muller, J. E.
1961: Pine Pass, British Columbia; *Geol. Surv. Can.,* Map 11–1961.

Norford, B. S.
1961: The Beaverfoot-Brisco Formation at Cirrus Mountain, Alberta; *J. Alta. Soc. Petrol. Geol.,* vol. 9, pp. 248–250.
1962: The Beaverfoot-Brisco Formation in the Stanford Range, British Columbia; *J. Alta. Soc. Petrol. Geol.,* vol. 10, pp. 443–453.

North, F. K., and Henderson, G. G. L.
1954: Summary of the geology of the southern Rocky Mountains of Canada; *Alta. Soc. Petrol. Geol.,* Guidebook Fourth Ann. Field Conf., pp. 15–81.

Norris, A. W.
1963: Devonian stratigraphy of northeastern Alberta and northwestern Saskatchewan; *Geol. Surv. Can.,* Mem. 313.

Osmond, J. C.
1962: Stratigraphy of Devonian Sevy Dolomite in Utah and Nevada; *Bull. Am. Assoc. Petrol. Geol.,* vol. 46, pp. 2033–2056.

Page, N. J., and Carozzi, A. V.
1962: Étude du remplacement diagénétique du quartz détritique par les carbonates dans les dolomies cambriennes; *Archives des Sciences,* Genève, vol. 14, fasc. 3, pp. 461–491.

Patterson, J. R., and Storey, T. P.
1962: Supplementary notes on the type Ghost River Formation; *J. Alta. Soc. Petrol. Geol.,* vol. 10, pp. 486–489.

Peck, R. E.
1953: Fossil charophytes; *Botanical Review,* vol. 19, pp. 209–227.

Reesor, J. E.
1957: Lardeau (east half), Kootenay district, British Columbia; *Geol. Surv. Can.,* Map 12–1957.

Sander, B.
1951: Contributions to the study of depositional fabrics; *Am. Assoc. Petrol. Geol.,* 207 pp. [translation by E. B. Knopf]

Shepard, F. P.
1922: Problems in stratigraphy along the Rocky Mountain Trench; *J. Geol.,* vol. 30, pp. 361–376.
1926: Further investigations of the Rocky Mountain Trench; *J. Geol.,* vol. 34, pp. 623–641.

Sherwin, D. F.
1962: Lower Elk-Point Section in east central Alberta; *J. Alta. Soc. Petrol. Geol.,* vol. 10, pp. 185–191.

Siever, Raymond.
1959: Petrology and geochemistry of silica sedimentation in some Pennsylvanian sandstones; *Soc. Econ. Paleontologists and Mineralogists,* Special Pub. 7, Silica in sediments, pp. 55–79.
1962: Silica solubility, 0–200°C and the diagenesis of siliceous sediments; *J. Geol.,* vol. 70, No. 2, pp. 127–149.

Walcott, C. D.
1923: Nomenclature of some post-Cambrian and Cambrian Cordilleran formations; *Smithsonian Misc. Coll.,* vol. 67, No. 8.
1924: Geological formations of Beaverfoot-Brisco-Stanford Ranges, British Columbia, Canada; *Smithsonian Misc. Coll.,* vol. 75, No. 1.
1928: Pre-Devonian Paleozoic formations of the Cordilleran provinces of Canada; *Smithsonian Misc. Coll.,* vol. 75, No. 5.

Walker, J. F.
1926: Geology and mineral deposits of Windermere map-area, British Columbia; *Geol. Surv. Can.,* Mem. 148.

Walker, T. R.
1957: Frosting of quartz grains by carbonate replacement; *Bull. Geol. Soc. Amer.,* vol. 68, pp. 267–268.
1960: Carbonate replacement of detrital crystalline silicate minerals as a source of authigenic silica in sedimentary rocks; *Bull. Geol. Soc. Amer.,* vol. 71, pp. 145–152.
1962: Reversible nature of chert-carbonate replacement in sedimentary rocks; *Bull. Geol. Soc. Amer.,* vol. 73, pp. 237–242.

Warren, P. S., and Stelck, C. R.
1958: Continental margins of Western Canada in pre-Jurassic time; *J. Alta. Soc. Petrol. Geol.,* vol. 6, pp. 29–42.
1962: Western Canada Givetian; *J. Alta. Soc. Petrol. Geol.,* vol. 10, pp. 273–291.

Zadnik, V. E., and Carozzi, A. V.
1963: Sédimentation cycliques dans les dolomies du Cambrien supérieur de Warren county, New Jersey, U.S.A.; *Bull. l'Instit. National Genevois,* T. 42, 55 pp.

APPENDIX A —

Measured sections

APPENDIX B —

Descriptions of samples of the Burnais Formation at Windermere Creek

APPENDIX A — MEASURED SECTIONS

Hatch Creek Section

About 2 miles northeast of Harrogate, Hatch Creek cuts through a tight syncline that is faulted in its axial region. The section was measured in a steep gully (51°00′N, 116°23′W) tributary to Hatch Creek, about ½ mile northwest of Hatch Creek and of the Hatch Creek Trail that closely follows the creek. Evans' section (1933) was probably measured beside a second steep gully midway between the present section and the trail. Both sections measure the overturned northeast limb of the syncline and end in the axial region of the fold. The top of the present section is at the base of a breccia unit that is possibly sedimentary, but most probably a fault breccia. The bottom of the section is at a paraconformity against the Beaverfoot-Brisco Formation. In the Horse Creek section, a seemingly identical horizon is revealed as a disconformity by an erosion surface and overlying basal conglomerate.

Unit	Thickness (feet) Unit	From Base

HARROGATE FORMATION (293 feet)

13 Dolomites, some slightly limy, some with slight siliceous content, very finely to finely crystalline, brownish grey and grey, weather brownish grey, grey, and yellowish brown, bedding 1 inch to 12 inches; some beds laminated, some weather platy. Rare limestones, very finely crystalline, dark grey and grey, weather light grey and grey, bedding 2 to 12 inches. Barren except for probable calcispheres and plant fragments. Unit is more thinly bedded and slightly more resistant than unit 12, contact conformable. Thin sections show unit has variable lithology:

(a) Dolomite mudstone, crystals less than 0.01 mm in diameter, argillaceous; calcite cement

(b) Dolomite siltstones with some limestone grains, 0.016 to 0.04 mm, rounded, some with dolomite overgrowths; scattered large argillaceous dolomite grains; calcite cement

(c) Crystalline dolomite mosaic, interlocking crystals 0.016–0.2 mm

(d) Laminated dolomite, alternating laminae with dolomite crystals less than 0.02 mm, argillaceous and with crystals 0.02–0.06 mm with calcite network, probably cement, some with patchy replacement of argillaceous

Unit		Thickness (feet) Unit	From Base
	limestone by microcrystalline dolomite; scattered angular quartz grains	83	991
12	Dolomites, some with slight siliceous content, very finely to finely crystalline, dark brownish grey, grey, and dark grey, weather dull brownish grey, yellowish brown, dull grey, and grey, bedding ¼ foot to 15 feet; some beds weather somewhat rubbly, others somewhat shaly. Rare ghost colonial corals, brachiopods, echinoderm fragments. Contact with unit 11 conformable, taken at limestone-dolomite change across a bedding plane. Thin sections show that the upper part contains beds composed of cryptocrystalline argillaceous dolomite (less than 0.01 mm) most of which is contained within poorly outlined but optically continuous dolomite rhombs; the lower part consists of microcrystalline dolomite (0.008 to 0.024 mm) and euhedral dolomite rhombs, in part interlocking (0.02 to 0.16 mm). Corals and brachiopod fragments are replaced by crystalline dolomite	96	908
11	Limestones, very finely crystalline to aphanitic, dark grey, weather brownish grey, grey, light bluish grey, reddish brown, and light brown, somewhat rubbly, bedding ½ foot to 2 feet; some beds argillaceous; some undulatory, shaly partings. Covered interval at 770–788. Colonial corals, brachiopods, solitary corals (GSC locs. 52143 803–805, 52142 769–770). Thin sections show limestone, argillaceous, cryptocrystalline; scattered dolomite rhombs; carbonaceous or bituminous specks	45	812
10	Covered interval	69	767
	CEDARED FORMATION (698 feet)		
9	Dolomites and limestones, very finely crystalline to aphanitic, dark grey, grey, and dark bluish grey, weather light grey and light yellowish grey, bedding ¼ foot to 3 feet, very well developed; most beds with minor content quartz sand and silt; some beds argillaceous. At 684, 18-inch quartzite layer; at 671, 3-inch layer within a bed has 10 per cent content rounded chert nodules that weather bluish grey; at 670, some beds weather laminated and a local conglomeratic layer has pebbles with randomly oriented laminations; at 688, an erosion surface 2 inches deep; at 657, 6-inch layer within a bed has 70 per cent content quartz sand in laminae. No fossils. Contact with unit 8 conformable. Thin sections of argillaceous limestones show calcite grains less than 0.008 mm diameter, floating dolomite rhombs up to 0.06 mm diameter, and widely scattered quartz grains up to 0.5 mm diameter, most of them under 0.3 mm	58	698
8	Quartzites, tightly cemented, off-white, weather off-white and yellowish white, resistant, bedding 2 to 4 feet. Quartz sand medium to coarse, mostly subround, with quartz overgrowths in optical continuity with grains; grains 0.3 and 0.7 mm diameter	6	640
7	Dolomites, some slightly limy, very finely to finely crystalline, light grey, grey, and light brownish grey, weather light		

Unit		Thickness (feet) Unit	From Base
	brownish grey, light yellowish grey, light brown, and light grey, bedding ¼ foot to 3 feet, very well developed; most beds with 2 to 30 per cent content floating quartz sand, fine to coarse, subround to round, and quartz silt. Subordinate dolomitic quartz sandstones in the basal and top parts of the unit, grey and light grey, weather light brownish grey and brownish grey, bedding 1 foot to 6 feet, rarely cross-laminated, with up to 70 per cent content quartz sand, fine to coarse, subround to round; composition of sandstones gradational into that of dolomites. Minor dolomites, aphanitic to very finely crystalline, dark bluish grey and grey, weather light yellowish grey, bedding 6 to 18 inches; with minor content quartz silt and sand. At 620–621, several thin laminae of quartzite within a dolomite; at 565, a 2-inch breccia layer with quartzite sharpstones; at 466–490, thin, shaly, limy mudstone interbeds; at 460 and 443, thin, recessive, argillaceous limestone interbeds, weather dark greenish grey. Covered intervals at 522–543, 518–521, 516–517, 512–515, 490–504, 468–469, 456–459. Barren except for microfossils (GSC loc. 60093 460–461). In thin section, most of the dolomite is seen to consist of a cryptocrystalline matrix, slightly argillaceous in places with floating euhedral dolomite rhombs 0.01–0.02 mm, rarely to 0.016 mm in diameter, forming from 25 to 90 per cent of rock; rhombs dusty, some with clear rims; scattered quartz grains up to 0.5 mm in diameter, rounded, subrounded, rarely angular, corroded by dolomite; scattered hematite. A few limestones, argillaceous, cryptocrystalline; at 512 feet partly replaced by incipient dolomite rhombs and grading to dolomite; some microcrystalline dolomite replacing dark argillaceous limestone, forming pseudobreccia at 630 feet; microbreccia of laminated and dark argillaceous dolomite intraclasts, pellets, quartz grains at 575 feet. Sandstones, quartz grains 0.5 to 0.8 mm in diameter, a few grains of chert and argillaceous limestone, some partly cemented by lime mud, partly by sparry calcite; some laminated with siltstone and silty dolomite; pseudobreccia at 630 feet caused by replacement of limestone by dolomite and increase in dolomite crystal size.	198	634
6	Argillaceous limestones, very finely crystalline, greenish grey and greyish red, weather light greenish grey and light reddish brown, recessive, bedding 2 to 4 feet, flaggy and rubbly. Shaly mudstones, slightly limy, greyish yellowish green, weather greyish yellowish green, greyish red, and red, commonly mottled in these colours, very recessive, bedding 4 to 8 inches, ¼ to 1 inch when well weathered. At 433–434½, dolomites with siliceous content, greenish grey, weather pale reddish brown, bedding 6 to 12 inches. Covered interval at 434½–436. Charophytes and ostracods (GSC locs. 72500 425, 72501 422, 60092 420–421). Thin sections show cryptocrystalline, argillaceous dolomite and dolomitic mudstone; rhombs mostly under 0.02 mm, but up to 0.1 mm diameter, scattered to abundant, most cloudy with clear rims. Quartz grains subangular to subround, up to 0.12 mm diameter, are abundant. At 421 feet the rock contains angular pebbles or relict grains of mudstone in argillaceous dolomite and patches of mudstone that grade to matrix by increase in		

Unit		Thickness (feet) Unit	From Base
	abundance of dolomite rhombs. Angular silt-sized quartz grains are scattered throughout; hematite in matrix and filling fractures	17	436
5	Dolomites, very finely crystalline, light grey and grey, weather light brownish grey, pale yellowish brown, and light brown, bedding ½ foot to 5 feet, well developed; with 5 to 49 per cent content floating quartz sand, fine to coarse, subangular to subround. Dolomitic sandstones, light brownish grey, weather light brownish grey, bedding 2 to 12 inches, some surfaces somewhat irregular; with 50 to 60 per cent content quartz sand, fine to coarse, subangular to subround; with laminae of quartzite within sandstone beds; composition of sandstones gradational into that of dolomites that commonly have local sandstone laminae within beds. At 365–419, minor dolomites with minor siliceous content, aphanitic to very finely crystalline, dark grey, weather light yellowish grey. At 416–418, impure quartzites; at 401, subangular pebbles of off-white chert; at 379, recessive 8-inch bed of shaly dolomite; at 322–324, limestones, very finely crystalline, dark grey, weather light grey and light brownish grey. Barren except for microfossils (GSC loc. 60091 379–380). In thin section two types of dolomite can be recognized: (a) Dolomite, cryptocrystalline, slightly argillaceous, matrix with abundant euhedral dolomite rhombs up to 0.04 mm diameter, and (b) between 345 and 378 feet, dolomite, cryptocrystalline, calcareous, argillaceous, in part with ghosts of introclasts or relict grains; quartz grains ubiquitous, rounded, subrounded, most less than 0.4 mm, a few to 0.8 mm, corroded by dolomite; sandstones, quartzose, grains rounded, subrounded, 0.04 to 0.8 mm in diameter, rare silica overgrowths; corroded by dolomite; cryptocrystalline to finely crystalline dolomite cement. Laminated dolomite, siltstone, sandstone. Limestone at 323 feet consists of laminae, 1 to 2 mm thick, of cryptocrystalline and microcrystalline limestone	214	419
4	Covered interval	63	205
3	Dolomites, with minor siliceous content, very finely crystalline, light grey, weather light grey, slightly recessive, bedding 2 to 12 inches; some beds have up to 5 per cent quartz sand; some beds are breccias with up to 25 per cent pebbles and cobbles of dolomite and limestone that weather yellowish grey. Covered interval at 131–137. No fossils. Unit weathers light grey in contrast to unit 2, and has breccias; contact conformable	41	142
2	Dolomites, rarely argillaceous, very finely crystalline, light grey, light brownish grey, and light yellowish grey, weather light grey, yellowish grey, light brownish grey, and greyish orange, bedding 2 to 12 inches; with up to 30 per cent floating quartz sand, very fine to very coarse. Very rare dolomitic quartz sandstones. No fossils. Quartz sand is more common in unit 2 than in unit 1, contact conformable. In thin section, the dolomites are seen to consist of a matrix		

Unit		Thickness (feet) Unit	From Base
	of grain-size less than 0.01 mm, with scattered dolomite rhombs; quartz grains from 0.25 to 0.5 mm diameter are corroded. Laminated bed at 95 feet consists of layers of mottled dolomite, aphanitic and with crystals up to 0.2 mm diameter, with interstitial hematite and limonite; aphanitic dolomite containing subangular to subrounded quartz grains up to 0.4 mm diameter; and siltstone. Sandstones are quartzose with grains 0.04 to 0.7 mm diameter, poorly sorted, rounded to subrounded, corroded; cement is aphanitic, argillaceous dolomite with scattered dolomite rhombs.	46	101
1	Dolomites, very finely crystalline, light grey and light brownish grey, weather light grey, light yellowish grey, and light brownish grey, bedding 1 inch to 24 inches; some beds with up to 45 per cent content floating quartz sand, fine to very coarse, subround to round, some sandstone laminae within such beds. At 10, shaly, flaggy dolomite; at 2, ripple-marks. No fossils. Contact with Beaverfoot-Brisco Formation paraconformable, picked at top of resistant dolomites with chert nodules and echinoderm fragments, and below less resistant dolomites with floating quartz sand in some beds. In thin section, the dolomite matrix is seen to consist of crystals under 0.04 mm diameter with scattered rhombs up to 0.06 mm; argillaceous wisps and laminae occur in some beds; quartz grains up to 0.5 mm diameter are angular to subangular in lower part, becoming subround to round in upper part, corroded. Many grains in lower part have one or more jagged edges. Fractures cut both dolomite and quartz grains, quartz grains partly replaced by dolomite	55	55

BEAVERFOOT-BRISCO FORMATION
LOWER MEMBER (1,607 feet)

Uppermost beds dolomites with minor siliceous content, very finely to medium crystalline, grey, light grey, and brownish grey, weather light grey, resistant, bedding 2 to 18 inches; with layers of chert nodules at 8, 14, 22 and 24 feet below top of formation. Echinoderm fragments at 3 and 6 feet below top; corals and brachiopods at 218–221 feet below top (GSC loc. 52163).

Hatch Creek Supplementary Section

Better outcrop of units 10 and 11 of the Hatch Creek section occurs one hundred yards northwest of Hatch Creek (at 51°00′N, 116°23′W), about half a mile southeast of the main section. This outcrop was probably examined by Shepard and by Evans (GSC loc. 7979, 1933, p. 144). The top of the section is at the base of a breccia unit, 12 feet thick, which may be either a sedimentary breccia or a fault breccia. Dolomites similar to those of unit 7 outcrop beyond this breccia, but the section ends at the last trusted outcrop. Good outcrop of the Cedared Formation is present beneath the Harrogate Formation, but the section only covers the uppermost beds, starting at the base of a quartzite unit that corresponds to unit 8 of the main section, and to the interval 2,107–2,113 of Evans' section (1933, p. 143).

Unit		Thickness (feet) Unit	From Base
	HARROGATE FORMATION (244 feet)		
7	Dolomites, some slightly limy, many with minor siliceous content, very finely to finely crystalline, dark grey and brownish grey, weather brownish grey, yellowish brown, yellowish grey, and olive-grey, bedding 2 to 24 inches, indistinct in some beds, some lamination present, some beds weather rubbly; with dolomite, calcite, and quartz stringers. At 294–296, limestone breccia, weathers light bluish grey, with 30 per cent angular sharpstones of brownish grey weathering dolomites, lamination of different blocks randomly oriented. Unit poorly exposed, covered intervals at 319–323, 306–308, 281–283, 278–280, 257–272, 252–256, 236–249, 225–234. Rare ghost *Coenites* in lower part of unit. Contact with unit 6 conformable, taken at limestone-dolomite change across a bedding plane	112	335
6	Limestones, some with slight siliceous content, very finely crystalline, dark grey and grey, weather bluish grey and light grey, with yellowish brown stains, bedding ½ foot to 4 feet, somewhat rubbly; with brown weathering shaly partings. Brachiopods, corals, cephalopods, sponge spicules (GSC locs. 52144 174–223, 52145 133–147). Contact with unit 5 conformable	92	223
5	Shales, limy, brownish olive-grey, weather light yellowish brown, very recessive, poorly fissile. Limestones, bedding 2 to 3 inches and lithologically similar to those of unit 6, amount to 40 per cent of unit. Barren except for microfossils (GSC loc. 60094 122–131). Contact with unit 4 conformable	9	131
4	Limestones, some with slight siliceous content, very finely crystalline, dark grey, weather bluish grey, bedding 2 to 15 inches. Shales, limy, brown, weather brownish grey and greyish red, poorly fissile, as partings and thin beds; amounting to about 5 per cent of unit. Brachiopods (GSC loc. 60095 117½–118). Contact with unit 3 conformable.	19	122
3	Shales, non-limy, grey, weather grey and brownish grey, very recessive, moderately fissile. Unit very poorly exposed, covered interval at 91–102. Barren except for microfossils (GSC loc. 60096 102–103). Contact with Cedared Formation covered	12	103
	CEDARED FORMATION, UPPER BEDS		
2	Dolomites and limestones, some argillaceous, very finely crystalline to aphanitic, dark grey, grey, and dark bluish grey, weather light yellowish grey, light grey, and brownish grey, bedding 2 to 18 inches, very well developed, some beds laminated; some beds with floating quartz sand, most with siliceous content. At 23–24, quartzite layer 12 inches thick, within a dolomite bed; at 16, 4 inches of shaly dolomite; at 11½–12½, 11-inch layer of quartz sandstone within a dolomite bed. No fossils. Contact with unit 1 conformable	84	91
1	Quartzites, off-white, weather off-white, resistant, bedding 1 foot to 2 feet; with very subordinate sandstones and dolomites. No fossils. Outcrop of rocks similar to those of unit 2 continues beneath unit 1	7	7

Horse Creek Section

A tight syncline, faulted in its axial region, crosses Horse Creek about 3 miles southeast of Nicholson. The Devonian core is preserved in the mountain immediately southeast of Horse Creek, near the headwaters of Pagliaro Creek. A steep gully is cut along the weak axial region of the fold and drains into Horse Creek. The section was measured at the head of this gully and in the adjacent cliffs in the overturned northeast limb of the syncline (at 51°13′N, 116°49′W). The top of the section is at a fault beyond which about 180 feet of dolomites, similar to those of unit 7, intervene before the complexly faulted and contorted axis of the syncline. The base of the section is at an erosion surface cut in dolomites of the Beaverfoot-Brisco Formation and mantled by a thin basal conglomerate (Pl. I).

Unit		Thickness (feet) Unit	From Base
	HARROGATE FORMATION (257 feet)		
7	Dolomites, very finely to finely crystalline, dark grey and brownish grey, weather brownish grey, grey, bluish grey, dark brownish grey, greyish red, and olive-grey, bedding ¼ foot to 2 feet; with some vugs and stringers of coarse dolomite. At 382–382½, 10 per cent dolomite sharpstones within a bed. Very minor shales in basal beds of unit. Colonial corals below 265, poorly preserved (GSC locs. 52149 259, 52148 222–230)	194	416
6	Covered interval	14	222
5	Limestones, finely crystalline, dark grey, weather dark grey, recessive, bedding 2 to 24 inches, somewhat nodular; with up to 30 per cent content limy shales, greyish black, weather greyish black and brownish grey, as beds and as irregular partings within nodular limestones. Colonial corals, stromatoporoids, brachiopods, solitary corals (GSC loc. 52147 179–205)	30	208
4	Covered interval	19	178
	CEDARED FORMATION (159 feet)		
3	Dolomites, aphanitic, dark grey, grey, and brownish grey, weather light yellowish grey, light grey, and light bluish grey, bedding ¼ foot to 2 feet, well developed, with rare laminated beds; most beds with siliceous content. At 155, bed with jostled dolomite blocks with fractured lamination; at 150, rare shaly dolomite interbeds; at 108, 5 per cent content calcite vugs. No fossils. Contact with unit 2 covered	52	159
2	Dolomites, aphanitic, dark grey, weather light grey, light yellowish grey, light bluish grey, light brownish grey, and pale red, bedding 6 to 12 inches; most beds with siliceous content. Earthy mudstones, greyish brown, weather greyish brown and greyish red, recessive, bedding 1 inch to 2 inches, and as interbeds between dolomites. Covered interval at 98–107. Barren except for microfossils (GSC loc. 60097 88–90). Contact with unit 1 conformable, picked at top of last dolomite bed with floating quartz sand content	21	107

Unit		Thickness (feet) Unit	From Base
1	Dolomites, very finely crystalline to aphanitic, light grey and light brownish grey, weather light yellowish grey, light brownish grey, and light yellowish brown, bedding 1 inch to 18 inches, well developed but some surfaces undulatory; most beds with 5 to 30 per cent content floating quartz sand and minor quartz silt, very fine to coarse, subangular to round. Rare layers of quartz sandstone and quartzite within dolomites. At 60–63, 52, and 31–44, fine to coarse pebbles of black chert in some beds, subangular to angular, amounting to ½ to 3 per cent of rocks, concentrated in basal layers of some beds, rarely scattered throughout. At 85, brown shaly partings; at 61, 6-inch quartzite band within a dolomite bed; at 45, 12-inch cross-laminated quartz sandstone bed; at 12, 3-inch layer with 10 per cent content elongate, subround dolomite pebbles. At 0–1, dolomite conglomerate; matrix dolomite with abundant quartz sand; roundstones about 20 per cent of rock, pebbles to cobbles of light grey weathering dolomites similar to those of the subjacent Beaverfoot-Brisco Formation; the conglomerate rests on an irregular erosion surface 6 inches deep. No fossils. Contact with Beaverfoot-Brisco Formation disconformable	86	86
	BEAVERFOOT-BRISCO FORMATION, LOWER MEMBER (uppermost 93 feet measured)		
	Dolomites, very finely to medium crystalline. light grey and very light grey, weather light grey with light brown staining, resistant, bedding 2 to 10 feet; without floating quartz sand but with minor siliceous content; without chert nodules. No fossils	73	
	Dolomites, finely to medium crystalline, light grey, weather light grey, resistant, bedding 2 to 10 feet; without floating quartz sand but with minor siliceous content; with 5 to 30 per cent content dark grey chert nodules, weather greyish white, in layers paralleling bedding. Colonial and solitary corals (GSC loc. 52182). Similar outcrop continues beneath these rocks but lacks chert nodules	20	

Pedley Pass Section

Devonian rocks are present in the southwest limb of a syncline at Pedley Pass (50°27′N, 115°46′W). The Mary-Anne Fault cuts off the Devonian section within the Harrogate Formation just northeast of the synclinal axis. The lower part of the section was measured on the north face of an east-trending ridge. The upper part, units 6 to 13, is almost entirely covered and was measured along the top of the ridge. Thicknesses of these units are not accurate. Swallow holes are present within unit 6, both on the ridge and along the strike in the valley to the northwest. The section lies six miles southeast of the Western Gypsum Products Limited quarries at Windermere Creek and unit 6 is probably mostly Burnais Formation.

Henderson (1954, p. 68) drew the top of the Beaverfoot-Brisco Formation at the top of unit 5. Norford (1962, pp. 445–448) later split off an unnamed unit thought to be lithologically distinct from the Beaverfoot-Brisco, placing the boundary at the base of unit 3, influenced by Henderson's indication of Silurian fossils within unit 2. Further field work has been unable to duplicate Henderson's collection, and the present paper picks the base of unit 1 as the most significant lithological break, below barren dolomites, and above fossiliferous argillaceous limestones with rare argillaceous dolomites and shales. The preceding discussion reveals the lack of any discordance between the two formations, and the contact is interpreted as paraconformable.

Unit		Thickness (feet) Unit	From Base
	HARROGATE FORMATION (about 92 feet)		
13	Limestones, aphanitic, dark grey, weather bluish grey and yellowish grey, recessive, bedding 6 to 18 inches; with calcite veins; with argillaceous interbeds. Tentaculitids (GSC loc. 56097)	6	816
12	Covered interval	24	810
11	Limestones, some argillaceous, aphanitic, dark grey, weather bluish grey and greyish orange, recessive, very poorly exposed, bedding ½ inch to 6 inches; some beds nodular; with about 20 per cent of unit dark grey shale, weathers dark grey. Brachiopods, corals (GSC loc. 56096 from outcrop and talus)	20	786
10	Covered interval	42	766
	CEDARED AND BURNAIS FORMATIONS (about 724 feet)		
	Cedared Formation, upper tongue		
9	Dolomites and rare dolomitic limestones, very finely crystalline to aphanitic, dark grey and grey, weather greyish yellow, pale orange, light grey, yellowish grey, and light olive grey, bedding ½ foot to 2 feet; some beds poorly laminated; most beds with content of quartz silt and rounded quartz sand; some beds with minor content sharpstones. Rare gastropods (GSC loc. 56095 712–713)	46	724
8	Covered interval	32	678
7	Dolomites, limy, very finely to finely crystalline, grey, weather yellowish grey and light grey, bedding 2 to 8 inches, well developed; with content of quartz silt and rounded quartz sand. No fossils	7	646
	Burnais Formation, upper tongue		
6	Covered interval, assumed occupied mostly or entirely by Burnais Formation. Swallow holes at 550–588	477	639
5	Limestone breccias, slightly dolomitic, light olive-grey, weather light grey, matrix aphanitic, sharpstones mostly leached, giving pocketed and cavernous appearance, with light yellowish brown silty debris in well weathered surfaces, bedding 1 foot to 2 feet; fine and coarse vuggy porosity about 25 per cent. No fossils. Contact with unit 4 conformable	11	162
	Cedared Formation, middle tongue		
4	Dolomites, aphanitic to finely crystalline, mostly very finely crystalline, off-white, very pale orange, light orange-grey,		

Unit		Thickness (feet) Unit	From Base
	weather whitish grey, light grey, very light pinkish grey, yellowish grey, and greyish orange, bedding 2 to 24 inches, well developed; most beds with minor siliceous content. Minor dolomites, very finely to coarsely crystalline, light brown and light orange-brown, weather yellowish orange, light orange-brown, light brownish grey, and reddish brown, bedding 2 to 12 inches, somewhat undulatory, rare beds laminated; with minor siliceous content; such dolomites predominate at 100–120. Rare quartz sand and silt in poorly exposed uppermost beds of unit. Covered interval at 138–150. No fossils. Contact with unit 3 disconformable with an erosion surface 2 feet deep	111	151
	Burnais Formation, lower tongue		
3	Limestone breccias, weather rubbly, bedding thick, indistinct, locally strongly contorted. Matrix amounts to about 50 per cent of rock: limestone, very finely to finely crystalline, grey, weathers light bluish grey and bluish grey. Sharpstones irregularly shaped, pebbles, cobbles, boulders, with rare patches of bedded rock with their stratifications at any angle to that of the unit (an aspect of one such block measures 1 foot by 8 feet); about 40 per cent of sharpstones are limestones, weather light bluish grey and bluish grey; about 60 per cent are dolomites, many with siliceous content, weather pale yellowish orange, orange-pink, pale pinkish orange, and pinkish brown; rare sharpstones are silty mudstones, weather greyish yellowish green and pale reddish brown. No fossils. Contact gradational with unit 2	24	40
2	Limestones, aphanitic to very finely crystalline, dark grey, weather light bluish grey and yellowish grey, rubbly, bedding 1 foot to 4 feet; calcite veins present. No fossils. Contact with unit 1 conformable	10	16
	Cedared Formation, lower tongue		
1	Dolomites, very finely crystalline to aphanitic, brownish grey and brown, weather light grey and greyish orange, bedding ½ foot to 3 feet, well developed; some beds with minor siliceous content; with very recessive dolomite at 0–1, bedding 1 inch to 3 inches. No fossile. Contact with Beaverfoot-Brisco Formation poorly exposed, paraconformable	6	6

BEAVERFOOT-BRISCO FORMATION
UPPER MEMBER (166 feet)

Argillaceous limestones and limy shales, weather light brownish grey, light grey, brown, and light brown, recessive, thinly bedded. Graptolites, trilobites, brachiopods (GSC locs. 42021–42023, 47397, 52174, 52175). Contact with lower member covered but probably conformable.

BEAVERFOOT-BRISCO FORMATION
LOWER MEMBER (1661 feet)

Uppermost beds limestones, aphanitic, weather light grey, resistant, bedding 1 foot to massive, commonly weathering into layers 1 inch to 6 inches thick; with calcite stringers and vugs in some beds. Cephalopods, brachiopods, trilobites (GSC locs. 42019 and 52173 within 20 feet of top of member).

APPENDIX B — DESCRIPTIONS OF SAMPLES OF THE BURNAIS FORMATION AT WINDERMERE CREEK.

Western Gypsum Products Limited have three quarries at Windermere Creek These are here designated according to their elevations as Upper Mine, Middle Mine, and Lower Mine.

Upper Mine:

Gypsum is laminated and banded, layers 1 to 3 mm thick, black laminae separate gypsum layers; bedding irregular and contorted with minute faults; gypsum laminae are white, grey, light brownish grey, coarsely crystalline, and finely crystalline; some gypsum is mottled and interbedded with light yellow-brown, gypsiferous dolomitic limestone with pinpoint, lath-shaped, and rhombic pores on weathered surface. Breccia of angular, light grey and light brownish grey gypsum fragments in calcareous dark grey shale.

Middle Mine:

Limestone, grey to dark grey, finely crystalline, argillaceous, silty, scattered large, rounded, frosted quartz grains; in part laminated; varies to grey calcareous shale. Gypsum is banded grey to light grey, coarsely crystalline and grey, finely crystalline; black laminae

Lower Mine:

Limestone, dark grey, aphanitic, tight, compact, argillaceous. Gypsum, clear, very coarsely crystalline, and light grey to white, coarsely crystalline. Breccia near shallow hole by the road about half a mile west of the lower mine: round and angular fragments of limestone, dark grey, aphanitic; limestone, grey, argillaceous, laminated, soft; limestone, buff, finely crystalline; buff, dolomitic limy claystone, yellow weathering, limestone matrix. Quartz grains large, subangular to subrounded.

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121 Surficial geology of the Cornwall and St. Lawrence Seaway project areas, Ontario, *by* J. Terasmae, 1965, $2.50 (M42-121)

122 Glacial Lake McConnell and the surficial geology of parts of Slave River and Redstone River map-areas, District of Mackenzie, *by* B. G. Craig, 1965, $1.00 (M42-122)

123 Latest Lower Triassic ammonoids from Ellesmere Island and northeastern British Columbia, *by* E. T. Tozer, 1965, $2.00 (M42-123)

124 The structure and metamorphism of Mesa Lake map-area, Northwest Territories, *by* J. V. Ross, 1966, $1.00 (M42-124)

125 Stratigraphy of the Rocky Mountain Group in the southeastern Cordillera of Canada, *by* D. K. Norris, 1965, $2.75 (M42-125)

126 Feldspar and quartz phenocrysts in the Shingle Creek porphyry, British Columbia, *by* H. H. Bostock, 1966, $2.00 (M42-126)

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130 The copper content of Canadian Shield rocks, Red Lake-Lansdowne House area, northwestern Ontario, *by* R. F. Emslie and R. H. C. Holman, 1966, 90 cents (M42-130)

131 The Permian ammonoids of Arctic Canada, *by* W. W. Nassichuk, W. M. Furnish, and B. F. Glenister, 1965, $2.00 (M42-131)

132 The Cretaceous Smoky Group, Rocky Mountain Foothills, Alberta and British Columbia, *by* D. F. Stott, 196–, $3.75 (M42-132)

133 Upper Devonian stromatoporoids from the Redwater Reef Complex, Alberta, *by* J. E. Klovan; Upper Devonian stromatoporoids from southern Northwest Territories and northern Alberta, *by* C. W. Stearn, 1966, $4.50 (M42-133)

134 Contributions to Canadian palaeontology: Part I, Trilobites from Upper Silurian rocks of the Canadian Arctic Archipelago, *Encrinurus* (*Frammia*) and *Hemiarges;* Part II, Ordovician and Silurian tabulate corals *Labyrinthites, Arcturia, Troedssonites, Multisolenia,* and *Boreastor;* Part III, A new species of *Hemicystites, by* T. E. Bolton and G. Winston Sinclair, 1965, $2.50 (M42-134)

135 Type lithostrotionid corals from the Mississippian of Western Canada, *by* E. W. Bamber, 1966, $1.50 (M42-135)

136 Surficial geology of Dawson, Larsen Creek, and Nash Creek map-areas, Yukon Territory, *by* P. Vernon and O. L. Hughes, 1966, $1.00 (M42-136)

137 A geochemical method of correlation for the Lower Cretaceous strata of Alberta, *by* E. M. Cameron, 1966, $1.35 (M42-137)

138 Reconnaissance of the surficial geology of northeastern Ellesmere Island, Arctic Archipelago, *by* R. L. Christie, 196–, $1.65 (M42-138)

139 Groundwater studies in the Assiniboine River drainage basin, *by* Peter Meyboom: Part I, The evaluation of a flow system in south-central Saskatchewan, 1966, $2.00; Part II, Hydrologic characteristics of phreatophytic vegetation in south-central Saskatchewan, 196–, $1.65 (M42-139)

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