BRITISH COLUMBIA DEPARTMENT OF MINES
HON. R. E. SOMMERS, *Minister* JOHN F. WALKER, *Deputy Minister*

BULLETIN NO. 35

Geology of the

STANFORD RANGE

of the Rocky Mountains

Kootenay District, British Columbia

By G. G. L. Henderson

VICTORIA, B.C.
Printed by DON MCDIARMID, Printer to the Queen's Most Excellent Majesty
1954

TABLE OF CONTENTS

ILLUSTRATIONS

PHOTOGRAPHS

Geology of the Stanford Range of the Rocky Mountains, Kootenay District, British Columbia

SUMMARY

1. The Stanford Range is one of the western ranges of the Rocky Mountains lying between the Rocky Mountain trench and the Kootenay River, about midway between Cranbrook and Golden.

2. The range has a maximum relief of over 6,000 feet and an average local relief of about 3,000 feet. Although it contains no glacial erosion features, the presence of erratics at high elevations indicates that at one time at least it was covered with ice.

3. All the rocks in the Stanford Range are sedimentary. They range in age from Late Precambrian to Middle Devonian and consist mostly of limestones, dolomites, argillaceous limestones, and limy shales. The remainder of the section, about 30 per cent, is made up of black shales, quartzites, argillites, slates, conglomerates, and rock gypsum.

4. The gypsum occurs in a thick section interbedded with occasional calcareous members, and the whole comprises a new formation for which the name Burnais is proposed. The age of the Burnais formation is between Middle Silurian and Middle Devonian.

5. A unique metamorphic rock, resembling a phyllite, is developed within a mile-wide zone of shearing that follows the Kootenay and White Rivers on the northeastern side of the map-area. This shearing is associated with a regional longitudinal fault named the White River break, and remains within the limits of McKay group strata throughout its exposed length.

6. The Stanford Range is divided into three fault blocks by two longitudinal faults, the Redwall and Stanford, that extend throughout the length of the range. The fault blocks are named the Eastern, Central, and Western, and each contains distinct types of structures.

7. The Eastern fault block, between the Kootenay River (White River break) and the Stanford fault, contains the lower limb of a southwesterly overturned, almost recumbent fold which is locally contorted into large nappe-like dragfolds.

8. The Central fault block, between the Stanford and Redwall faults, is characterized by upright, inclined, and overturned anticlines which are separated from each other by faulted synclines.

9. The Western fault block, between the Redwall fault and the Rocky Mountain trench, contains complex, longitudinal trending folds which are intricately dissected by a network of faults. In addition, a large area is underlain by obliquely trending, imbricate thrust structures. These are indicative of shortening of the range along an axis almost parallel with its trend.

10. The Redwall and Stanford faults, as well as many of the other faults in the range, are characterized by wide red- or brown-coloured breccia zones. The movement on the Redwall fault is large and is mostly strike-slip. Strike-slip movement may also have occurred on the Stanford fault, but, unlike the Redwall fault, this cannot be proved.

11. Metamorphism in the Stanford Range is generally restricted to areas of tight folding and the border zones of major faults. With the exception of the intense altera-

tion of McKay group rocks along the White River break, the effects of metamorphism are limited to those usually attributed to low-grade dynamic metamorphism.

12. The Rocky Mountains at this latitude are composed of four separate structural sub-provinces for which the following names are proposed: Foothills sub-province, Front Ranges sub-province, Main Ranges sub-province, and Western Ranges sub-province. Each of these contains distinct structure, stratigraphy, and topography.

13. The Stanford Range forms part of the Western Ranges sub-province, which is distinct from the other sub-provinces inasmuch as the folds are overturned toward the southwest instead of the northeast, the structures are a great deal more complex, and the structural trend is about 10 to 15 degrees oblique to the trend of the Rocky Mountains and the Rocky Mountain trench.

14. The Western Ranges sub-province is separated from the Main Ranges sub-province by a major longitudinal fault zone that extends from Blaeberry southeastward along the Beaverfoot, Kootenay, and White Rivers for at least 120 miles. The name White River break is proposed for this fault. The sub-province is bounded on the southwest by the Rocky Mountain trench.

15. The White River break separates the southwesterly overturned structures of the Western Ranges sub-province from flat to gently folded strata of the Main Ranges sub-province. It also marks a distinct break in the stratigraphic continuity of the western Rocky Mountains.

16. The White River break appears to dip southwest. It is interpreted as a thrust fault of younger age than the southwesterly overturned structures of the Western Ranges sub-province, which are believed to have been formed by a major wedge uplift of the Main Ranges sub-province.

17. Gypsum of commercial grade occurs in enormous quantities within the map-area, particularly along Windermere Creek and the Kootenay River. It is in the form of sedimentary rock gypsum, and the evidence of primary origin is conclusive.

18. A preliminary graph is presented showing the stability relationships of gypsum and anhydrite as functions of temperature and pressure. Under average thermal conditions, gypsum appears to be metastable at depths below 3,500 feet, and in the presence of a water solution should be converted to anhydrite. In the presence of a salt solution, transformation should occur at shallower depths.

19. The thickness of the known strata overlying the primary gypsum suggests that there was no post-Middle Devonian deposition in this part of the Western Rocky Mountains.

CHAPTER I.—INTRODUCTION

LOCATION

The Stanford Range is one of the western ranges of the Canadian Rocky Mountains in southeastern British Columbia (*see* Fig. 1). It is bounded on the west by the Rocky Mountain trench and on the east and south by the Kootenay River. On the north it is separated from the Brisco Range by the low Sinclair-Swede Creek divide.

The map-area flanks Columbia and Windermere Lakes and extends from Canal Flats on the south to about 5 miles north of Athalmer. It includes all the Stanford Range except the northern fifth which lies within Kootenay National Park and was previously mapped by Evans (1933). In addition to the Stanford Range, about 15 square

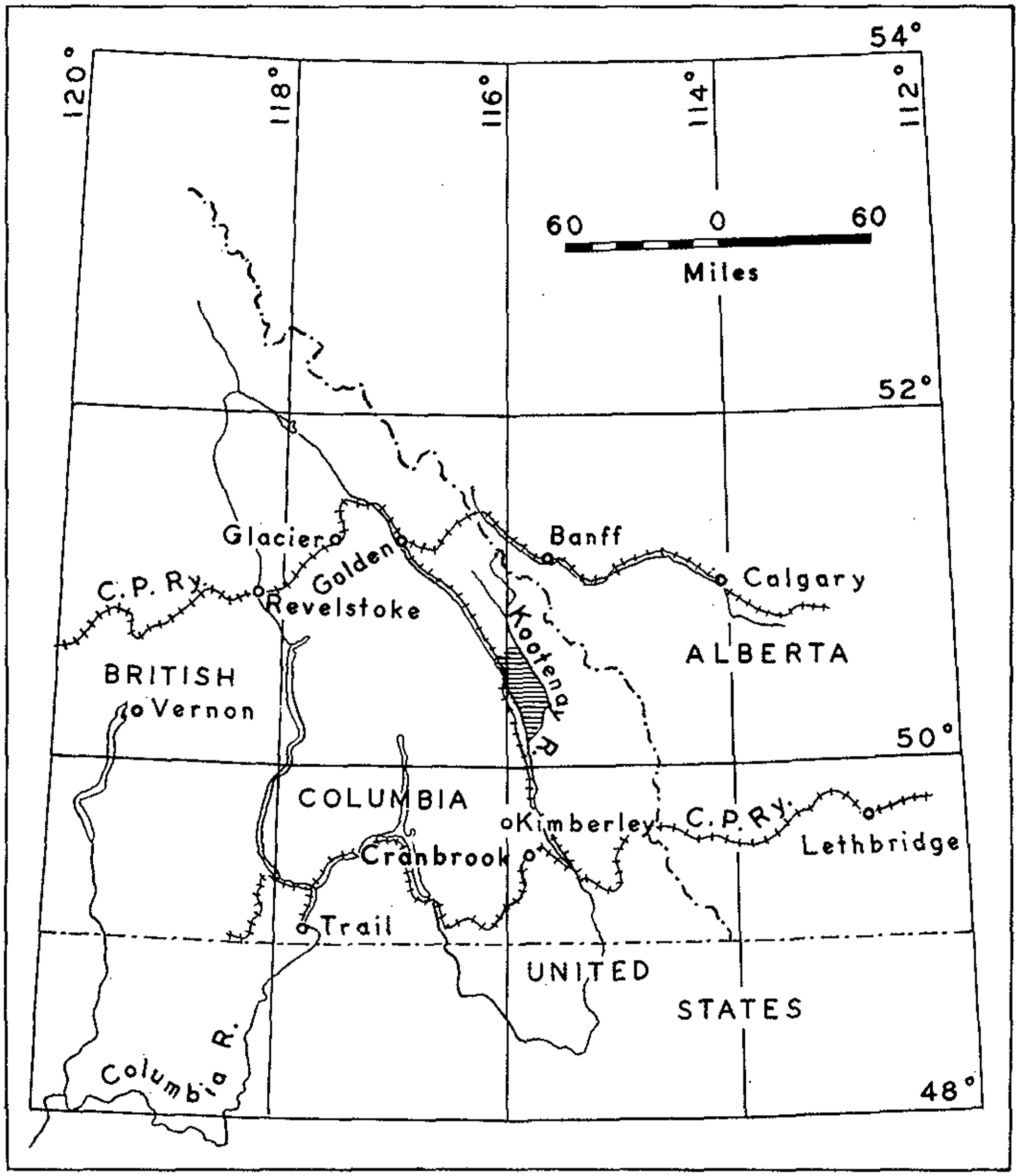

Figure 1. Key map of southeastern British Columbia.

miles south and east of the Kootenay River is included within the map-area. The total area covered is about 400 square miles.

ACCESS

A branch line of the Canadian Pacific Railway runs along the Rocky Mountain trench on the southwest side of the range. This connects with the main line of the Canadian Pacific Railway at Golden in the north and with the southern line at Cranbrook in the south. Railway stations at Canalflat, Lake Windermere, and Radium provide suitable points of access to the southern, central, and northern parts of the area respectively.

Provincial Highway No. 95, following the Rocky Mountain trench, makes the area readily accessible by road. The main Banff–Windermere Highway, branching from Highway No. 95 at Radium Junction, crosses the mountains via Sinclair Pass and provides access to the northern parts of the Stanford Range. The eastern side of the area may be reached by means of a forestry road running up the Kootenay River valley from Canal Flats. This road is in relatively good condition as far as Pedley Creek, about 27 miles north of Canal Flats, and may be travelled readily in all types of cars. Farther north, however, and especially under wet conditions, only vehicles with high clearance can continue with reasonable safety. Another dirt road, known locally as the " Settlers Road," runs southeastward from the Banff–Windermere Highway and makes connection with the end of the forestry road. It is therefore possible under good conditions to drive completely around the Stanford Range.

Only a few roads provide access to the interior parts of the range. The most important follows Windermere Creek and leads to No. 1 quarry of Columbia Gypsum Products, Inc. From the end of this road good horse-trails continue along both forks of Windermere Creek. The one along the main fork of Windermere Creek follows the creek to its head, whence it continues through Tegart Pass and joins the forestry road along the Kootenay River. Other parts of the range are accessible by horse-trails following Stoddart, Burnais, Madias, Tatley, and Warspite Creeks. In addition, an excellent Indian trail follows the east side of Columbia Lake. In general, even where established trails are not present, horse travel within most parts of the area may be easily accomplished by utilizing the numerous game trails.

PREVIOUS WORK

The principal previous mapping in this region was done by J. F. Walker in 1922 to 1925 and by C. S. Evans in 1925 to 1927. Prior to this, reconnaissance work had been done by Dawson (1885), Shepard (1922 and 1926), Schofield (1922), and Walcott (1923).

Walker mapped the Windermere map-area, the eastern part of which is included within the area of this report. The map units established by him, except for minor modification in names, were employed in the later mapping by Evans (1933) and by the present writer. Evans mapped the Brisco-Dogtooth area, which adjoins the Windermere area on the north and includes the northern fifth of the Stanford Range. His interpretation of the structure and additions to the knowledge of the stratigraphy were particularly helpful.

More recently, Cummings (1948) and McCammon (1950) mapped in detail some of the gypsum occurrences on Windermere Creek.

FIELD WORK AND ACKNOWLEDGMENTS

This report is based on twelve months of field work carried out during the summers of 1950, 1951, and 1952. Geological observations were plotted directly on to aerial photographs in the field and later transferred to the base map either by Kail plotter or by " raying."

The base map was prepared from aerial photographs by the Interim Map Section of the Air Division of the Department of Lands and Forests.

The contours for a large part of the area were taken from existing topographic maps and for the remainder were drawn stereoscopically by G. E. P. Eastwood.

The field work was greatly facilitated by the willing help of the residents of the district. In particular, the kind assistance of J. M. Cummings and E. C. Phillips, of Columbia Gypsum Products, Inc., in supplying office space and providing full access to their maps and other data was of great help to the writer.

Capable assistance was rendered in the field by J. A. Lawrence and A. J. Witherspoon in 1950; R. A. Stuart, A. J. Witherspoon, and C. M. Trigg in 1951; and J. S. Phillips in 1952.

All palæontological identifications in this report were made by B. F. Howell, of Princeton University, to whom the writer is much indebted. The writer gladly acknowledges the help of G. C. B. Cave, of the Department of Mines Analytical Laboratory, in connection with the discussion on the origin of gypsum. Many valuable suggestions were received from F. K. North, of the California Standard Company.

TOPOGRAPHY

The topography of the Stanford Range is dominated by a number of northwesterly trending, almost parallel structural ridges. These are deeply incised and partly dissected by transverse valleys which contain trunk streams or tributaries to streams occupying the longitudinal valleys between the ridges. The ridge tops are at elevations between 5,200 and 8,000 feet and range in character from some that are broad and rounded to others that are narrow and almost knife-edged (*see* Plates II and III).

Within the range the local relief is from about 2,500 to 4,000 feet, but, adjacent to the Rocky Mountain trench or Kootenay River valley, the local relief is commonly about 4,500 feet and may be as much as 6,000 feet. The highest summit in the Stanford Range, Indianhead Mountain, has an elevation of about 8,820 feet, and the lowest point in the area, on the Columbia River at the north boundary, has an elevation of 2,618 feet. The maximum relief is thus about 6,200 feet.

The Stanford Range is bounded on the east by the deep, broad valley in which the upper Kootenay River is incised. This valley, together with the valleys of the Beaverfoot and White Rivers, forms a conspicuous topographic lineament over 90 miles long. The part of it that adjoins the map-area has a fairly flat, terraced floor about 2 miles wide lying at an elevation of about 3,250 feet. The Kootenay and White Rivers are entrenched in steep canyons 50 to 300 feet below the level of the main terrace.

The Rocky Mountain trench forms the western border of the map-area and is well described by Walker (1926, p. 3) as follows: "The Rocky Mountains trench in this district is a valley 3 to 6 miles wide. The north-flowing Columbia River, its sloughs and Windermere Lake, occupy a median depression about three-quarters of a mile wide. The level of the lake is 2,566 feet above sea-level and this is about the average elevation of the central depression, which is rimmed by steep, silt banks broken by numerous dry gullies. Dissected terraces flank this depression at elevations of roughly 2,700, 2,800, and 3,000 feet above sea-level. The rainfall in the trench is small and the terraces have a semi-arid appearance, with the trees set well apart, little or no underbrush, and sparse grass."

DRAINAGE

All the creeks within the map-area are tributary to the Kootenay or Columbia Rivers. Many are small and intermittent, sometimes completely drying up during the summer months. Others flow underground for part of their lengths, and many disappear altogether where they emerge on to the terraces of the Kootenay or Columbia valleys.

The drainage pattern of the creeks and rivers to a certain degree reflects the underlying structure. In the Stanford Range many of the oblique or transverse parts of the major creeks are located along oblique or transverse faults. Good examples of this are shown by parts of Shuswap, North Windermere, and Pedley Creeks. In a similar manner, the longitudinal parts of many of the streams tend to be located along longitudinal faults, as is evidenced by parts of Mary-Anne, Pedley, Windermere, and Shuswap Creeks.

The upper part of the Kootenay River is possibly the best example of a structurally controlled river. It rises about 60 miles northwest of the map-area and flows southeastward to a point just below where it is joined by the White River. Throughout this length the river's course is controlled by a narrow band of soft, calcareous chloritic phyllite that is developed along a major fault zone. The southeastern continuation of this same fault controls also the course of the White River from its mouth to a point just east of White Swan Lake.

Below its confluence with the White River, the Kootenay swings abruptly to a course that is almost southwest. In doing so, it cuts for a short distance obliquely across the topographic and structural trend and forms a sharp canyon at Gibraltar Rock. Below Gibraltar Rock the river swings to a southerly course and the valley widens again where the river passes over an area underlain by gypsum. The increased valley width is maintained until another more gentle swing in strike from south to about southwest occurs at a point about 6 miles northeast of Canal Flats. This direction of flow, which coincides with an assumed oblique fault, continues until the Kootenay reaches the Rocky Mountain trench, and follows a southeasterly course.

It is probable that during part of Tertiary time the Kootenay River continued on its southerly course from Gibraltar Rock, and carved the broad valley to the east of Mount Grainger that is now partly occupied by Lussier River. The river was diverted northeast of Mount Grainger, either by damming or by capture, to its present southwesterly course which takes it by way of a much narrower valley into the Rocky Mountain trench.

The Columbia River rises in Columbia Lake in the southern part of the map-area and flows at a very low gradient northwestward through Windermere Lake and along the Rocky Mountain trench. The total drop between Columbia Lake and Golden, a distance of 85 miles, is only 80 feet.

The Kootenay River, where it emerges from the mountains at Canal Flats, is only about 2 miles south of the south end of Columbia Lake. The divide between the two drainage systems is only a few feet high and is occupied by the partly marshy, flat area known as " Canal Flats." A canal was constructed across this flat in the latter part of the last century but was used for the passage of only one boat before being abandoned.

GLACIATION

Glacial erosion features, such as U-shaped valleys, hanging valleys, and cirques, have not been observed in the Stanford Range. However, it is probable that ice at one time completely covered the entire range because erratics are found up to elevations of 7,500 feet. Some positive evidence of ice cover is found farther to the north, near Harrogate, where Walker* reports a large erratic of the Ice River intrusion just west of the summit of the Brisco Range. This indicates that at one time the ice must have been sufficiently thick to have transported the erratic southward across the Brisco Range from the Ice River.

Additional evidence of the existence of an ice-sheet is provided by the thick deposits of stratified silts and gravels that occur along the floor of the Rocky Mountain trench and Kootenay River valley. These deposits are presumably Pleistocene in age and are overlain in some places by deposits of till.

It is evident that the area was covered by a continental ice-sheet that produced a very limited amount of erosion. The ice disappeared probably by stagnation and melting in a fashion similar to that suggested by Rice (1937) in the Cranbrook area. However, unlike the Cranbrook area, the Stanford Range does not appear to have been subject to a late-stage alpine glaciation.

* Personal communication.

The floor of the trench is characterized by three well-defined terraces that occur on either side of the medial depression occupied by Columbia Lake, Windermere Lake, and the Columbia River. The terraces are composed mostly of stratified silts and gravels which on both sides dip at low angles toward the centre of the valley. The writer agrees with Walker (1926), who believes that these deposits at one time filled the valley and that the terraces were developed as the result of post-glacial excavation by the Columbia River. An alternative explanation proposed by Rice (1937) suggests that at least some of the terraces resulted from deposition of silts and gravels in local lakes which were flanked by blocks of stagnant ice.

A number of large depressions resembling kettle holes occur within the stratified deposits in the floor of the trench. These depressions are restricted to two bands, each about one-quarter of a mile wide, which trend approximately at right angles to the trench. One of the bands is about 1 mile north of Fairmont Hot Springs and the other passes through the north end of the village of Invermere.

BIBLIOGRAPHY

Allan, J. A. (1911): Geology of Field District and Vicinity, British Columbia, *Geol. Surv., Canada,* Sum. Rept., 1911, pp. 175–187.

——— (1913): Rocky Mountains, Bankhead to Golden, *Int. Geol. Cong., XII,* Guide Book, No. 8, pp. 167–201.

——— (1914): Geology of Field Map-area, B.C. and Alberta, *Geol. Surv., Canada,* Mem. 55.

Alling, H. L. (1928): Geology and Origin of Silurian Salt of N.Y. State, *N.Y. State,* Mus. Bull. No. 275.

Birch, F., *et al.* (1942): Handbook of Physical Constants, *Geol. Soc. Amer.,* Special Papers No. 36.

Burling, L. D. (1914): Early Cambrian Stratigraphy in the North American Cordillera, *Geol. Surv., Canada,* Mus. Bull. 2.

——— (1916): Notes on the Stratigraphy of the Rocky Mountains, Alta. and B.C., *Geol. Surv., Canada,* Sum. Rept., 1915, Pt. B, pp. 97–100.

——— (1918): Further Light on the Earlier Stratigraphy of the Canadian Cordillera, *Geol. Soc. Amer.,* Vol. 29, pp. 145–146.

——— (1922 (A)): The Relations between the Purcell Range and the Rocky Mountains in B.C., *Amer. Jour. Sci.,* Vol. 3, pp. 254–256.

——— (1922 (B)): A Cambro-Ordovician Section in the Beaverfoot Range, B.C., *Geol. Mag.,* Vol. 59, pp. 452–461.

Clarke, L. M. (1949): Geology of the Rocky Mountain Front Ranges near Bow River, Alberta, *Amer. Assoc. Petrol. Geol.,* Bull., Vol. 33, No. 4, p. 632.

Cummings, J. M. (1948): *Minister of Mines, B.C.,* Ann. Rept., 1948, pp. 185–188.

——— (1953): The Windermere Gypsum Deposit, *Western Miner,* Vol. 26, No. 11, pp. 80–81.

Daly, R. A. (1912): North American Cordillera, 49th Parallel, *Geol. Surv., Canada,* Mem. 38.

——— (1915): Geological Reconnaissance between Golden and Kamloops, B.C., *Geol. Surv., Canada,* Mem. 68.

Dawson, G. M. (1885): Preliminary Report on the Physical and Geological Features of That Portion of the Rocky Mountains between 49° and 51° 30′, *Geol. Surv., Canada,* Ann. Rept., Pt. B, pp. 169 *et seq.*

Deicha, G. (1943): Bi-monthly, Seasonal and Annual Zones in the Parisian Gypsum, *Soc. Geol., France,* (9), pp. 83–85.

Deiss, C. F. (1939): Cambrian Formations of Southwestern Alberta and Southeastern British Columbia, *Geol. Soc. Amer.,* Bull., Vol. 50, pp. 951–1026.

——— (1940): Lower and Middle Cambrian Stratigraphy of Southwestern Alberta and Southeastern British Columbia, *Geol. Soc. Amer.,* Bull., Vol. 51, pp. 731–794.

Evans, C. S. (1933): Brisco-Dogtooth Map-area, British Columbia, *Geol. Surv., Canada,* Sum. Rept., 1932, Pt. A II, pp. 106–187.
Gill, W. D. (1952): The Tectonics of the Sub-Himalayan Fault Zone in the Northern Potwar Region and in the Kangra District of the Punjab, *Quart. Jour. Geol. Soc.,* London, Vol. 107, Pt. 4, pp. 395–413.
Goldman, M. I. (1952): Deformation, Metamorphism, and Mineralization in Gypsum-Anhydrite Cap Rock, Sulphur Salt Dome, Louisiana, *Geol. Soc. Amer.,* Mem. 50.
Hume, G. S. (1944): Petroleum Geology of Canada, *Geol. Surv., Canada,* Econ. Geol. Ser., No. 14.
——— and Link, T. A. (1945): Canol Geological Investigation in the Mackenzie River Area, N.W.T. and Y.T., *Geol. Surv., Canada,* Paper 45-16.
Jones, V. (1935): Origin of Gypsum Deposits near Sandusky, Ohio, *Econ. Geol.,* Vol. 30.
King, R. H. (1947): Sedimentation in Permian Castile Sea, *Amer. Assoc. Petrol. Geol.,* Bull., Vol. 31, pp. 470–477.
Link, T. A. (1949): Interpretation of Foothills Structures, Alberta, Canada, *Amer. Assoc. Petrol. Geol.,* Bull., Vol. 33, pp. 1475–1501.
MacDonald, G. J. F. (1953): Anhydrite-Gypsum Equilibrium Relations, *Amer. Jour. Sci.,* Vol. 251, No. 12, pp. 884–898.
MacKay, B. R. (1952): Geology of the National Parks of Canada in the Rockies and Selkirks, *Can. Geog. Jour.,* Vol. 44, pp. 145–177.
McCammon, J. W. (1950): *Minister of Mines, B.C.,* Ann. Rept., 1950, pp. 221–224.
McConnell, R. G. (1887): Report on the Geological Structure of a Portion of the Rocky Mountains, *Geol. Surv., Canada,* Ann. Rept. 2, Pt. D.
McGehee, J. R. (1940): Pre-waterways Paleozoic Stratigraphy of Alberta Plains, *Amer. Assoc. Petrol. Geol.,* Bull., Vol. 33, pp. 603–613.
Newlands, D. H. (1921): Geology of Gypsum and Anhydrite, *Econ. Geol.,* Vol. 16, pp. 393–404.
North, F. K. (1952): Personal communication.
Posnjak, E. (1938): The System $CaSO_4$-H_2O, *Amer. Jour. Sci.,* Vol. 35-A, pp. 247–272.
——— (1940): Deposition of Calcium Sulphate from Sea Water, *Amer. Jour. Sci.,* Vol. 238, pp. 559–568.
Raymond, P. E. (1922): The Ceratopyge Fauna in Western North America, *Amer. Jour. Sci.,* 5th ser., Vol. 3, pp. 204–210.
Ridell, W. C. (1950): Physical Properties of Calcined Gypsum, *Rock Products.*
Rice, H. M. A. (1937): Cranbrook Map-area, B.C., *Geol. Surv., Canada,* Mem. 207.
Ruedemann, R. (1947): Graptolites of North America, *Geol. Soc. Amer.,* Mem. 19.
Schofield, S. J. (1914): The Pre-Cambrian (Beltian) Rocks of Southeastern British Columbia and Their Correlation, *Geol. Surv., Canada,* Mus. Bull. No. 2.
——— (1915): Geology of Cranbrook Map-area, B.C., *Geol. Surv., Canada,* Mem. 76.
——— (1920): *Roy. Soc., Canada,* Trans., Vol. 14, Sec. 4, p. 135.
——— (1922): Relationship of the Precambrian (Beltian) Terrain to the Lower Cambrian Strata of Southeastern British Columbia, *Geol. Surv., Canada,* Mus. Bull. No. 35.
Shepard, F. P. (1922 (A)): Possible Silurian Tillite in Southeastern B.C., *Jour. Geol.,* Vol. 30, pp. 77–81.
——— (1922 (B)): Problems in Stratigraphy along the Rocky Mountain Trench, *Jour. Geol.,* Vol. 30, p. 361.
——— (1926): Further Investigations of the Rocky Mountain Trench, *Jour. Geol.,* Vol. 34, pp. 632–641.
Stewart, F. H. (1949): The Petrology of the Evaporites of the Eskdale No. 2 Boring, East Yorkshire, Part I., *Min. Mag.,* Vol. 28, pp. 621–675.

——— (1951 (A)): The Petrology of the Evaporites of the Eskdale No. 2 Boring, East Yorkshire, Part II, *Min. Mag.* Vol. 29, pp. 445–475.
——— (1951 (B)): The Petrology of the Evaporites of the Eskdale No. 2 Boring, East Yorkshire, Part III, *Min. Mag.*, Vol. 29, pp. 557–572.
Udden, J. A. (1924): Laminated Anhydrite in Texas, *Geol. Soc. Amer.*, Bull., Vol. 35, pp. 347–354.
Walcott, C. D. (1908): *Smithsonian Misc. Coll.*, Vol. 53, No. 1.
——— (1910): *Smithsonian Misc. Coll.*, Vol. 53, No. 7.
——— (1912 (A)): *U.S. Geol. Surv.*, Monograph 51.
——— (1912 (B)): *Smithsonian Misc. Coll.*, Vol. 57, No. 17.
——— (1917): *Smithsonian Misc. Coll.*, Vol. 67, No. 3.
——— (1920): *Smithsonian Misc. Coll.*, Vol. 67, No. 6.
——— (1923): *Smithsonian Misc. Coll.*, Vol. 75, No. 1.
——— (1927): *Smithsonian Misc. Coll.*, Vol. 75, No. 4.
——— (1928): *Smithsonian Misc. Coll.*, Vol. 75, No. 5.
Walker, J. F. (1926): Geology and Mineral Deposits of Windermere Map-area, B.C., *Geol. Surv., Canada*, Mem. 148.
——— Bancroft, M. F., and Gunning, H. C. (1930): Lardeau Map-area, B.C., *Geol. Surv., Canada*, Mem. 161.
Warren, P. S. (1927): Banff Area, Alberta, *Geol. Surv., Canada*, Mem. 153.
——— and Stelck, C. R. (1949): The Late Middle Devonian Unconformity in Northwestern Canada, *Roy. Soc., Canada*, Trans., 3rd ser., Vol. 43, Sect. 4.
Williams, M. Y. (1923): Reconnaissance across Northeastern B.C. and the Geology of the Northern Extension of Franklin Mountains, N.W.T., *Geol. Surv., Canada*, Sum. Rept., 1922, Pt. B.
Wilson, A. E. (1926): An Upper Ordovician Fauna from the Rocky Mountains, B.C., *Geol. Surv., Canada*, Mus. Bull. No. 44.

CHAPTER II.—STRATIGRAPHY

FOREWORD

The Stanford Range, the Brisco Range, and part of the Van Horne and Hughes Ranges together form a separate structural sub-province of the Rocky Mountains (*see* p. 42). This sub-province is separated from the main ranges of the Rocky Mountains by a major fault zone that extends southeastward from Blaeberry to Leanchoil and then follows the valleys of the Beaverfoot, Kootenay, and White Rivers. On the southwest the sub-province is bounded by the Rocky Mountain trench.

Within the ranges constituting the sub-province both structure and stratigraphy differ vastly from the structure and stratigraphy in the adjacent ranges. The stratigraphy, in general, is characterized by a greatly reduced Cambrian section, the presence of a thick Ordovician, Silurian, and Middle Devonian succession, and the absence of rocks younger than Middle Devonian (Recent conglomerate is not considered). The structure is unique in the Rocky Mountains because of its complexity and because the folds are overturned toward the southwest instead of toward the northeast. Furthermore, the structural trend is at an angle of about 10 degrees to the trend of the Rocky Mountains and of the Rocky Mountain trench.

The geology of the Stanford Range is typical of the sub-province as a whole, but it includes several unique features. The most important of these are (*a*) a large thickness of evaporites within the sequence, (*b*) one and probably two large longitudinal strike-slip faults, and (*c*) a large though localized area of oblique-trending imbricate thrust structures.

GENERAL STATEMENT

In the Stanford Range all the rocks exposed are of sedimentary origin. They make up a concordant sequence that ranges in age from Late Precambrian to Middle Devonian and has a maximum aggregate thickness of about 13,000 feet. Two erosional unconformities may be present, one between the Precambrian and Cambrian rocks, and the other within the Ordovician sequence.

Precambrian rocks consist of slates, quartzites, and pebble-conglomerates of the Horsethief Creek formation and have a total exposed thickness of less than 700 feet. Palæozoic rocks comprise the rest of the section and are dominantly limestones, dolomites, and limy shales. Black shales, quartzites, sandstones, and other clastic rocks make up less than 20 per cent of the Palæozoic section and gypsum about 10 per cent.

The strata are intensely folded and faulted. The folds, as in the rest of the sub-province, are characteristically overturned to the southwest, in direct contrast to northeasterly overturning in the rest of the Rocky Mountains at this latitude and in the Purcell Mountains. Numerous longitudinal and oblique faults, particularly on the western side of the range, cut the folds into segments and considerably complicate the over-all structure.

Dynamic metamorphism has had a profound effect on some formations in areas of tight folding and in areas adjacent to major faults. The effects on the McKay group are sufficiently great to warrant a separate description.

Two major longitudinal faults extend throughout the length of the Stanford Range and divide it into three structural blocks, each of which is characterized by a distinct set of structures. The western fault is named the Redwall and the eastern the Stanford. Tremendous movements along these faults have brought widely separated segments of formations into juxtaposition. In fact, the fault blocks resulting from these dislocations are so important that the stratigraphy can only be discussed with reference to them. The three fault blocks are:—

(*a*) Eastern fault block—the area between the Kootenay River and the Stanford fault:

(*b*) Central fault block—the area between the Stanford fault and the Redwall fault; and

(c) Western fault block—the area between the Redwall fault and the Rocky Mountain trench.

In the following descriptions of the formations, the details of measured sections and of palæontology have been separated from the body of the text and placed in Appendices A and B, pages 66 and 73.

Table of Formations

Period	Formation or Group	Lithology	Thickness in Feet in Major Fault Blocks		
			Western	Central	Eastern
Pleistocene and Recent	....	Till, gravels, silts, travertine, conglomerate	....	....	....
Middle Devonian	Harrogate	Nodular limestones and shales	350+	140+	(1)
	Burnais	Gypsum, limestone and shale	500+	750–1,300+	?
Silurian	Brisco	Dolomites, limestones, some shale	1,500+	2,000	1,800+
Ordovician	Beaverfoot	Dolomite, some limestone			
Ordovician	Wonah	White quartzite, some sandstone	0	0–150	100–400
		Possible Disconformity			
Ordovician	Glenogle	Black shales, some sandy argillites	0	0–1,000	300–2,150
Upper Cambrian and Ordovician	McKay group	Interbedded limestones and shales, argillites	0–2,000	4,000+	3,500
Upper Cambrian	Sabine	Reddish weathering limestones and argillites	0–700	(1)	(1)
Middle and (or) Upper Cambrian	Jubilee Upper	Massive dolomite	500–1,000	1,000	(1)
	,, Lower	Well-bedded laminated dolomite	1,000	(1)	(1)
Middle Cambrian	Burton	Interbedded sandstones, shales, quartzites, and dolomite	0–360	(1)	(1)
Lower Cambrian	Cranbrook	Quartzite	0–250	(1)	(1)
		Probable Disconformity			
Proterozoic	Horsethief Creek	Quartzites, conglomerates, and slates	600+	(1)	(1)

[1] Not exposed.

HORSETHIEF CREEK FORMATION

The Horsethief Creek strata are the oldest exposed within the Stanford Range. The formation was defined by Walker (1926) as part of the Windermere series, which he believed to be Precambrian in age. No fossils have been found in it.

Walker (1926, p. 15) describes the Horsethief Creek formation as consisting chiefly "of grey, green and purplish slate with several lenticular beds of coarse quartzite and pebble conglomerate and numerous thin interbeds of blue-grey, crystalline, and mostly non-magnesian limestone, which occur at different horizons but form a relatively small part of the whole formation." This quotation well describes the occurrences of Horsethief Creek formation between Windermere Creek and Tatley Creek where purplish and red slates are dominant rock types. Southward from Tatley Creek, however, the formation becomes much more arenaceous and conglomeratic and, at the south end of the area, alternating beds of coarse-grained quartzite and pebble conglomerate make up more than 70 per cent of most sections.

The quartzites are invariably composed of coarse, rounded grains of white quartz and quartzite that are cemented by a fine-grained mass of calcite and quartz. The interstices between the fine particles of the cement are filled with amorphous hematite or limonite which gives the cement a characteristic brownish or reddish-brown colour. Occasional particles of feldspar, crystalline limestone, shale, and fine-grained dark limestone are also present. Most of the quartzite beds contain some scattered pebbles of white quartz.

The conglomerates are similar to the quartzites in mineralogical composition. The pebbles range in size from one-quarter inch to as much as 6 inches in diameter but are most commonly between one-half and 1 inch. They are slightly ellipsoidal in shape and are as a rule well rounded. Argillaceous partings and lenses of shale are common within pebble conglomerate beds. Near the headwaters of Warspite Creek one of these argillaceous zones, beneath an overlying quartzite bed, passes gradationally downward into a flat-pebble conglomerate bed. The fragments of this flat-pebble conglomerate are green and red slate as much as 2 inches long by half an inch thick and are set in a silty matrix.

Limestone beds occur at intervals throughout the formation but seem to be more common near the upper contact. The limestone ranges from a white, crystalline, essentially non-magnesian variety to a buff-weathering fine-grained dolomite. Both on Windermere Creek and on the divide between Geary and Warspite Creeks, a 5-foot bed of magnesian limestone conglomerate occurs about 10 feet below the upper contact.

Exposures of the Horsethief Creek formation are restricted to the southern part of the Western fault block. The thickness of the formation is unknown because nowhere is the lower contact exposed. The greatest known thickness of somewhat more than 600 feet is on the southeast slope of Mount DeSmet. Twelve miles south of the map-area, between Ram Creek and Diorite Creek, Walker and Schofield (1922) observed that the Horsethief Creek formation and the underlying Toby formation pinch out. Farther south the Lower Cambrian Burton formation rests directly on the Roosville formation of the Upper Purcell series.

LOWER AND MIDDLE CAMBRIAN

The Lower and Middle Cambrian rocks, shown in one colour on Figure 2, comprise undivided Cranbrook and Burton formations. Both formations were named by Schofield (1915 and 1922) in the Cranbrook and Elko areas. Within the Stanford Range these formations are so poorly exposed and limited in distribution that it was not practical to map them separately.

This unit includes the oldest Palæozoic rocks found within the map-area. The Lower Cambrian part, the equivalent of the Cranbrook formation, is made up of well-bedded white quartzites. These weather to a brownish-white colour and have an over-all blocky appearance caused by bedding joints. Cross-bedding is common in some of the beds, particularly near the base. On the southeast flank of Mount DeSmet the quartzites are 260 feet thick and rest with apparent conformity on the underlying red, blue, and grey slates of the Horsethief Creek formation.

The Middle Cambrian part of the unit, equivalent to the Burton formation, comprises a series of interbedded quartzites, shales, sandstones, and dolomitic limestones. On Mount DeSmet the Burton has a thickness of 346 feet and lies conformably between the Cranbrook formation and the overlying Lower Jubilee dolomite.

Walker measured the section of Lower and Middle Cambrian rocks on Mount Grainger, 2 miles south of Mount DeSmet, and found the Cranbrook formation to be 675 feet thick and the Burton formation to be 730 feet thick. A rapid thinning of these formations toward the north is thus indicated. The northerly thinning is also indicated by the fact that in the section exposed east of Columbia Lake the Cranbrook formation is estimated to be 100 feet thick and the Burton formation 220 feet thick. In the next well-exposed section to the north, on the divide between Warspite and Geary Creeks, neither the Cranbrook nor the Burton formations are present, and the Lower Jubilee dolomite rests directly on the Horsethief Creek formation. The Cranbrook and Burton formations pinch out somewhere between Lansdowne Creek and Geary Creek and are missing in the northern half of the map-area.

A measured section of both formations as exposed on the southeast flank of Mount DeSmet is included in Appendix A. No fossils were found in this section, although they are reported from both formations on Mount Grainger.

JUBILEE FORMATION

This formation was named the Jubilee limestone by Evans (1933, p. 125) and was described by him as consisting of "massive-bedded, cliff-forming magnesian limestone, generally grey in colour, and weathering grey to white." Chemical analyses* show that more than 95 per cent of the rock consists of the mineral dolomite, and thus, to conform with present practice, the unit is called the Jubilee formation instead of the Jubilee limestone. The formation was correlated by Walker with the Ottertail formation of the Field map-area and was mapped as such by him within the Windermere map-area. The present mapping has extended sufficiently far south to show that the formation is also the equivalent of the Elko formation named by Schofield in the vicinity of Crowsnest Pass.

The Jubilee formation occurs almost entirely within the western fault block. It is between 1,500 and 2,000 feet thick, but at most occurrences it is either incompletely exposed or so cut up by faults that reliable measurements of thickness cannot be made.

No fossils were found or have been reported from the Jubilee formation, but an approximate age may be obtained from its position in the stratigraphic sequence. On Sabine Mountain it is conformably overlain by beds of the Sabine formation which contain an abundant medial Upper Cambrian fauna. On Mount Grainger, a few miles to the southeast, the base of the Jubilee is exposed and Middle Cambrian fauna occur within the Burton formation a few feet below this contact. This age of Middle and (or) Upper Cambrian agrees with that determined by Evans farther north.

It was found convenient for structural mapping to subdivide the Jubilee formation into two map units, the Upper and Lower Jubilee dolomite. The Upper Jubilee consists essentially of unbedded, massive dolomite, whereas the Lower Jubilee is composed of bedded, well-laminated dolomite. In most cases the laminated Lower Jubilee passes gradationally into the massive Upper Jubilee, so that the position of the contact cannot be located exactly. However, the gradational zone is rarely more than 40 feet thick, and the error involved does not influence the over-all usefulness of the subdivision. In certain areas in which the exposures were insufficient to define clearly the contact between the upper and lower units the rock has been mapped as undivided Jubilee.

Lower Jubilee Dolomite

The Lower Jubilee dolomite is distinguished from the Upper Jubilee dolomite by its well-bedded and normally laminated character. With the exception of one or two beds of mottled, partly dolomitized limestone, it is composed exclusively of fine-grained light- and dark-grey dolomites that occur in well-defined beds from 6 inches to 4 feet thick. Black, brown, or white chert is found in small quantities throughout many of the beds in the form of irregular blebs, lenses, and thin discontinuous lentils. In one or two beds, chert is present in appreciable amounts, occurring as irregular lace-like intergrowths parallel to the bedding.

Primary lamination, present in nearly all of the beds, is the most distinctive feature of the Lower Jubilee dolomite (*see* Plate IV). The laminæ range in thickness from less than 0.01 inch to more than 0.5 inch and in abundance from one to as many as fifty per inch. The lamination consists of alternations of normal, fine-grained dark-grey dolomite and whitish sandy laminæ composed of dolomite and quartz. In thin section the sandy laminæ are seen to be coarser-grained (0.06 mm.) than the dark-grey dolomite (0.005 mm.) and to contain as much as 30 to 40 per cent quartz. Cross-bedding and slump structures are common.

Wherever a complete section is exposed, the Lower Jubilee dolomite is about 1,000 feet thick. A complete section of the unit was measured on the south flank of Fairmont Mountain (*see* Appendix A, p. 66).

* One analysis made in connection with the present work is given in Appendix C. Other analyses are reported in Limestones of Canada, Part V—Western Canada, *Can. Dept. of Mines and Resources,* Bureau of Mines, No. 811, p. 214.

Upper Jubilee Dolomite

The Upper Jubilee dolomite is characterized by an almost complete absence of recognizable bedding. Where stratification is present, the beds are very thick, commonly as much as 20 feet, and can only be identified with certainty under favourable conditions.

The Upper Jubilee consists almost entirely of fine-grained light-grey crystalline dolomite. Certain beds are fragmental, containing angular dolomite fragments, normally about one-quarter to one-half inch in diameter, that are set in a matrix of fine-grained crystalline dolomite. Most beds contain appreciable amounts of granular chert in the form of intricate honeycomb structures, irregular masses, and thin lenses. Chert also occurs in delicate lace-like outlines that resemble corals. It is normally white, but in places it is pink or reddish-brown.

The weathered surface of the Upper Jubilee is a uniform light grey, but locally the lowest beds may be stained a light-pink colour. At the few places where the full thickness of the Upper Jubilee can be observed, as in exposures east of Fairmont Hot Springs, it is between 500 and 1,000 feet thick.

McKAY GROUP

The McKay group was named by Evans for a succession of alternating shales and limestones that include faunal horizons ranging in age from Late Cambrian to Ordovician (Chazy). For most of the Stanford Range no attempt was made to separate this group into its constituent formations, and hence it is shown in one colour on Figure 2.

Throughout the entire map-area, wherever the base is exposed, McKay strata conformably overlie the Upper Jubilee dolomite. In the Eastern and Central fault blocks the McKay is overlain by the Glenogle shale, and in the Western fault block, where the Glenogle shale and Wonah quartzite are absent, it is overlain with apparent conformity by basal beds of the Beaverfoot-Brisco formation.

To the east of Fairmont Hot Springs and in the southern part of the Western fault block, only the Upper Cambrian portion of the McKay group is present. The lithology of these Upper Cambrian beds differs sufficiently from that of the normal McKay strata for it to be possible to map them as an individual formation. This is the Sabine formation, named by Schofield at its type locality on Sabine Mountain, north of Canal Flats. A separate description of the Sabine formation is given at the end of the description of the McKay group.

McKay Group

The McKay group consists of a thick series of alternating thinly bedded limestones, limy shales, and limy argillites, with occasional massive limestone and cherty dolomite members. Many of the limestone beds, particularly in alternating limestone and shale sections, are intraformational conglomerates. These consist of oval and elliptical-shaped fragments of dense fine-grained limestone in a fine-grained matrix. The matrix is in general calcareous, but in some places it is dolomitic and ferruginous.

In the Central fault block, near the upper contact of the group, selectively dolomitized limestone members are common. Differential weathering of the dolomitic zones produces peculiar honeycombed surfaces.

Chert nodules and lenses are common in the McKay near the upper contact, but are rare lower down. They are commonly black and disk-shaped, range in diameter from 1 inch to 5 feet, and are rarely more than 2 inches thick. Small rounded nodules of limonite are also present near the upper contact, east of Pedley Pass and at the head of Mary-Anne Creek. Ripple-marks and mud cracks are common, particularly in association with beds of intraformational conglomerate.

The rocks normally weather light grey, but in some localities, particularly on Fourpoints Mountain, some parts of the McKay are notably ferruginous and weather to a reddish-brown colour. The McKay erodes more rapidly than the other formations, producing rounded forms and gentle slopes. Parkland timber growths often develop on areas underlain by the McKay.

McKay group strata are widely distributed throughout the Stanford Range, and occur in all three fault blocks. In the Eastern fault block they are the oldest rocks present and have an exposed thickness of 3,500 feet or less. In the Central fault block the group attains its maximum exposed thickness of over 4,000 feet. An incomplete section totalling over 2,400 feet was measured on a ridge at the head of Mary-Anne Creek, 1½ miles southeast of Indianhead Mountain (*see* Appendix A). In the Western fault block the thickness shows rapid and irregular variations. North of Stoddart Creek, more than 2,000 feet is exposed below a fault. On Fourpoints Mountain, south of Windermere Creek, the McKay is less than 1,000 feet thick. Three miles south of Fourpoints Mountain the McKay pinches out, and the Beaverfoot-Brisco formation rests directly upon the Upper Jubilee dolomite. However, 1 mile farther south, on the western flank of Mount Tegart, the McKay is again present in what is thought to be a down-dropped block and is about 2,000 feet thick. Such irregular and rapid variations cannot be accounted for by variations in primary deposition alone, and must have been caused, in part, by considerable horizontal movement along the numerous known faults that brought widely separated segments of the group into juxtaposition.

Evans (1933, p. 129), from his studies of the faunal zones of the McKay group, showed that the beds range in age from Late Cambrian to Chazy (*see* Appendix B). In the western part of the Brisco Range the upper McKay beds are of the same age as part of the Glenogle shale farther to the east, and it is apparent that there must have been contemporaneous deposition of a limestone facies in the west and a black shale facies in the east. It is probable that similar conditions existed in the Stanford Range, but, because of insufficient fossil evidence, this could not be proved.

Sabine Formation

S. J. Schofield (1920) proposed the name Sabine for the "fossiliferous Upper Cambrian formation that conformably overlies the Elko formation" on Mount Sabine at the south end of the Stanford Range. Evans (1933, p. 130), when defining the range of the McKay group, placed the Sabine formation in his table as equivalent to the Upper Cambrian rocks of the McKay. It is in this sense that the name Sabine is used by the present writer.

The Sabine formation consists chiefly of alternate thin beds of bluish-grey crystalline limestone and thicker beds of grey argillite. In the most northerly exposures of the formation, on Fairmont Ridge, the limestone beds are from 1 to 3 feet thick and are separated from each other by 8 to 10 feet of light-grey calcareous argillite. Differential weathering of the more or less uniformly spaced limestone beds produces a crude ribbing effect that is seen in the best exposures of the Sabine. The limestone beds weather to a rust or reddish-brown colour as a result of the appreciable hematite content of the cement. Some of this iron appears to have been carried into the grey argillites by seepage, producing an over-all rusty-brown colour that is characteristic of this formation.

Many of the limestone beds have a sandy feel and contain visible grains of white quartz. Others are intraformational conglomerates, containing well-rounded fragments that range from one-quarter of an inch to 2 inches in diameter. Mud cracks and indistinct ripple-marks, though very common, are not well enough developed to be used for top determinations.

The calcareous argillite beds are characterized by the presence of at least two sets of fracture cleavage. In most cases one cleavage is essentially parallel to the bedding and the other is at right angles to the dip. The intersection of the two cleavages leads to the production of pencil-like fragments. The size of the fragments is variable and largely depends on the spacing between cleavage planes. The most common interval is between one-quarter of an inch and three-quarters of an inch. When more than two sets of fracture cleavage are present, or when the two sets are not at right angles, less regular and usually finer fragments are produced.

In the southern exposures of the Sabine on Mount Sabine and Mount DeSmet, the lower 250 feet of the formation weathers a normal reddish-brown and consists of well-cleaved argillaceous limestones and limestone conglomerates with occasional 1-foot beds of bluish, crystalline limestone. The upper 450 feet of the formation weathers a light grey and is composed of blue-grey limestone, limestone conglomerate, and grey-weathering calcareous argillite.

The Sabine formation occurs only in the southern part of the Western fault block. Elsewhere its stratigraphic equivalent, the Upper Cambrian portion of the McKay, does not differ sufficiently in lithology from the rest of the McKay to permit separate mapping.

Considerable and irregular variations in thickness of the formation were noted. On the south limb of a syncline at the north end of Fairmont Ridge, the formation is 150 feet thick and wedges out to the west in a distance of less than 200 feet. On the north limb of the same syncline there is a mere lens of the Sabine with a maximum thickness of less than 50 feet. Similar variations in thickness were noted in a succession of thrust blocks occurring farther south along Fairmont Ridge. In general, however, the formation thickens southward; the greatest thickness on Fairmont Ridge is about 370 feet, and on Mount Sabine it is just over 700 feet.

The limestone beds on Fairmont Ridge contain an abundant fauna which has been identified by Howell as equivalent in age to the Prosaukia sub-zone of the Franconian stage of the Cambrian; i.e., Medial Upper Cambrian (*see* Appendix B). No fossils were discovered at the type locality on Mount Sabine, but those reported by Walcott (1924) from the lower part of the formation there are almost identical with the species found near Fairmont Hot Springs.

Metamorphosed McKay

On the northeastern side of the map-area, across a width of about 1 mile along the Kootenay and White Rivers, strata of the McKay group are so highly sheared and metamorphosed that they have lost their sedimentary features. For this reason this band was mapped as a separate lithological unit designated as metamorphosed McKay.

The metamorphism was caused by intense shearing along a major longitudinal fault zone which follows the Kootenay and White Rivers and extends far beyond the limits of the present map-area. This fault, for which the name White River break is proposed, is described in Chapter V. Within the map-area the McKay has been sheared in a zone about 2 miles wide, but in only half this width has the shearing been sufficiently intense to produce a complete transformation of the sedimentary character. Within this zone of more intense shearing the limestones, limestone conglomerates, and calcareous shales of the McKay are bleached and transformed into a remarkable, calcareous, chloritic "phyllite"* (*see* Plate V). The phyllite is a non-bedded, greenish-grey foliated rock that can be easily broken or disintegrated by hand. It is so very fine-grained that even under the microscope it appears as a dense mat of tiny particles (0.001 millimetre). Some parts of it have a mottled appearance due to sporadic patches of dark-grey coloration, but on the whole it is remarkably uniform. The rock weathers a greenish-white colour that is very distinctive and readily recognizable in all occurrences. Within the thinly foliated rock there are isolated fragments of less-sheared limestone which appear to be uncomminuted remnants of the more competent parts of the limestones and limestone conglomerates from which the phyllite was formed. These remnants are normally about the size of cobbles, but a few blocks as large as 20 to 30 feet long have been found. Most of the larger ones are highly contorted and consist of bluish-grey, partly altered

* The rock is too fine-grained to be a schist, although its structure can only be described as schistose. Genetically, the rock is probably a calcareous mylonite, but from a descriptive point of view the term "mylonite" is misleading. The term "phyllonite" is not applicable, implying, as it does, a reduction in grain size. In the absence of a more suitable term the rock will be referred to as "phyllite."

limestone. In places, however, these larger remnants are not contorted and appear as discontinuous slabs of bedded limestone completely surrounded by phyllite. Some of the smaller remnants consist of crystalline calcite, but more commonly they are composed of fine-grained chloritized limestone. Stringers and ribs of quartz or calcite as much as 18 inches wide are sparsely scattered throughout the phyllite.

The foliated character of the rock is produced by a pronounced though erratic cleavage which has a northwesterly strike and a steep variable dip. The erratic nature of the cleavage results from non-parallelism of the more prominent cleavage planes, which are spaced from one-eighth to one-half inch apart, and hence no one plane persists very far before it joins with another. Many of the cleavage planes bend around less-sheared remnants or terminate against them, and some die out for no apparent reason. Further irregularity is produced by variations in the dip of the cleavage, which usually ranges between 60 degrees northeast and 60 degrees southwest, but may alternate rapidly between these limits. In some exposures the cleavage is almost horizontal, and in places along the canyon of the White River it is crenulated in a series of discontinuous chevron folds.

A second, poorly developed cleavage is sometimes seen cutting and displacing the more prominent cleavage. It is much more regular than the cleavage constituting the foliation, but as a result of its incipient development, it resembles closely spaced jointing rather than a typical cleavage.

In thin section the phyllite is so fine-grained that very little information about it can be obtained. Using index oils and the powdered rock, however, the mineralogical composition was determined as principally quartz, carbonate, and chlorite, with minor amounts of sericite.

In an attempt to obtain some idea of the chemical composition of the phyllite, representative samples were collected at intervals along its length, and four of these were submitted for partial chemical analyses. The results of the analyses, together with descriptions of the locations, are included in Appendix C. Considering the heterogeneity of the rocks from which the phyllite is apparently derived and the wide interval between the samples, the results show a surprisingly small variation in composition. Three of the four samples are remarkably uniform, but the fourth differs in the content of most of the constituents because of a much lower percentage of calcium carbonate. Further consideration of the chemical composition, together with a detailed description of the development of the phyllite from the McKay strata, is given in the section on metamorphism in Chapter III.

Although the phyllite band is known to be about 1 mile wide, it is poorly exposed, and outcrops are usually restricted to roadcuts and river canyons. Fresh exposures of it are rare, because when subjected to weathering it crumbles away very quickly and forms a clayey soil. It is very well exposed in the canyon of the White River, and to the north of the map-area excellent exposures may be seen in some new roadcuts to the west of Leanchoil on No. 1 Highway.

GLENOGLE SHALE

Burling (1922 (A), p. 456) proposed the name Glenogle for a thick succession of graptolitic shales near Glenogle that range in age from Beekmantown (Canadian) to Chazy (Lower Ordovician). Walker correlated the graptolitic shales of the Windermere area with the Glenogle, and Evans later confirmed this correlation.

The formation consists of black shales, argillaceous sandstones, and a few beds of blue-grey limestone. The black graptolitic shales, for which the Glenogle is noted, usually occur in the lower part of the formation, but in some places they constitute the entire formation.

The upper part of the formation consists of brown-weathering sandy argillites, and impure calcareous and thinly bedded argillaceous sandstones which tend to become progressively more arenaceous toward the upper contact. In some places in the western side of the Central fault block the upper or sandy part of the formation is missing, and the overlying Wonah rests directly on the lower or black shale portion.

The Glenogle shale is restricted in distribution to the Central and Eastern fault blocks. At the head of Windermere Creek, within the Eastern fault block, the formation is more than 2,150 feet thick, including 1,627 feet of black shales. Toward the north the unit thins to 1,650 feet on Mount Sinclair and toward the south thins to about 300 feet on Nappe Mountain. On the Eastern side of the Central fault block, adjacent to the Stanford fault, the Glenogle ranges in thickness from about 1,000 feet at the northern end of the map-area to less than 300 feet at the southern end. On the western side of the same fault block, adjacent to the Redwall fault, the Glenogle is less than 600 feet thick at the north end of the range and is missing in the southern half of the range. A primary thinning toward the west and south is therefore indicated.

The large collections of fossils made by Walker (1926) from the thick section at the head of Windermere Creek contained fauna of the three Deepkill zones (Beekmantown) only. Normanskill (Chazy) forms are reported from Evans's (1933) collections farther to the north but appear to be absent within the Stanford Range. The fauna of the Glenogle is thoroughly discussed by Ruedemann (1947, pp. 101–105). Fossils were collected by the writer from one of the most westerly exposures of Glenogle shales, south of Pedley Pass (*see* Appendix B). This section was found to contain only forms belonging to the Third Deepkill zone (Lower Ordovician).

WONAH QUARTZITE

This formation was named by Walcott (1924) after Wonah Ridge on Mount Sinclair at the north end of the Stanford Range. No identifiable fossils have yet been found in the formation, but from its stratigraphic position it is known to be Middle and (or) Upper Ordovician in age.

The formation consists of massive beds of white sedimentary quartzite and a few beds of brownish-white sandstone. The quartzite is a compact, medium-grained rock which at most places contains about 98 per cent of well-rounded quartz grains. The sandstones are medium to coarse grained and less pure in composition than the quartzites.

The Wonah has a whitish weathered colour that is very distinctive, making it easily recognizable and very useful as a marker horizon. Here and there, where minor amounts of hematite are present in the cement, the Wonah weathers to a brownish or reddish-brown colour.

The bedding in the Wonah, although inconspicuous, can usually be distinguished by slight differences in grain size between the different beds. The coarser-grained layers weather more readily and so accentuate the bedding. Apart from bedding, primary structures are rare, but normal and torrential cross-bedding were seen at a few places.

The Wonah quartzite is widely distributed in the Central and Eastern fault blocks but is not present in the Western fault block. The formation shows a primary thinning from east to west throughout the map-area. At the headwaters of North Windermere Creek in the Eastern fault block it is more than 350 feet thick, whereas in the canyon of North Windermere Creek in the Central fault block it is only 100 feet thick. Farther to the west the thickness decreases to 12 feet at the western edge of the Central fault block. On Swansea Mountain the Wonah is missing and the overlying Beaverfoot-Brisco formation rests directly on McKay strata. Another example of this westerly thinning of the Wonah is seen on Indianhead Mountain within the Central fault block. There the Wonah is 40 feet thick on the eastern limb of an anticline and pinches out on the western limb.

Apart from the westerly thinning, the Wonah shows a regional thinning toward the south. Evans reported it to be over 1,000 feet thick in the northern part of the Brisco Range, whereas its greatest thickness in the Stanford Range, in the Eastern fault block at the north boundary of the map-area, is about 400 feet. This southerly thinning continues through the present map-area.

No conclusive evidence of an erosional unconformity at the base of the formation was noted. Regionally, however, the Wonah rests at different places on different age zones of the Glenogle shales. This is indicative of either irregular deposition of the Glenogle or post-Glenogle erosion. The actual contact between the Wonah and Glenogle is always concordant; in places it is sharp, particularly in the eastern exposures, but more commonly it is gradational, the Glenogle becoming progressively more arenaceous until it passes into a lower sandstone member of the Wonah quartzite.

BEAVERFOOT-BRISCO FORMATION

The Beaverfoot formation was named by Burling (1922) and was believed by him to be Richmond in age. Walcott subsequently discovered that the upper part of Burling's Beaverfoot formation contained Silurian fossils. Instead of changing the age range of the formation, he created the name Brisco formation for the Silurian portion. However, no lithologic distinction is recognizable, and Walker, Evans, and the present writer have mapped the Ordovician and Silurian rocks as one unit.

The formation consists chiefly of medium- to thin-bedded light-grey dolomites and bluish-grey limestones. At the top the rocks are dominantly limestones and contain several calcareous shale and black shale members, whereas the lower members are all dolomites and tend to be more thickly bedded. (*See* measured section, Appendix A.) Certain members consist of irregular intergrowths of dolomite and limestone and have a nodular or mottled appearance on the weathered surfaces. These members are believed to have resulted from the selective dolomitization of primary limestones. Chert nodules and lenses are present in several beds throughout the section, and are particularly common in the Western fault block in a member occurring about 50 to 150 feet above the base. At a few places, as on the south flank of Nappe Mountain, occasional bands of orthoquartzite and impure calcareous sandstone occur within the unit.

The Beaverfoot-Brisco formation weathers a pinkish grey or light grey. It is like the Jubilee dolomite in forming prominent cliffs but may be distinguished from the Jubilee as a whole by its well-bedded character, its scarcity of laminations, and the presence of fossils.

In the Eastern and most of the Central fault blocks it concordantly overlies the Wonah quartzite, the contact being sharp in some places and gradational in others. In the Western fault block the Beaverfoot-Brisco formation rests directly on beds of variable age within the McKay group, and at one locality north of Mount Tegart, where the McKay is absent, the Beaverfoot-Brisco rests upon the Upper Jubilee dolomite. At all these contacts no direct evidence of a disconformity was noted. The upper contact of the unit has not been observed.

The Beaverfoot-Brisco formation is widely distributed throughout the Stanford Range, occurring in all three fault blocks. The most complete section of the formation is exposed at Pedley Pass in the Central fault block, where it is at least 2,000 feet thick. The upper contact is hidden in an area of drift that is believed to be underlain principally by the Burnais formation. (For complete section, *see* Appendix A.) Elsewhere in the range, either because of topographic or structural limitations, only partial sections of the formation are exposed.

The Beaverfoot-Brisco formation ranges in age from Richmond (Upper Ordovician) to Niagaran (Middle Silurian). Fossils are fairly common in the majority of beds, and most forms, particularly in the lower half of the unit, are completely replaced by silica. For details of the palæontology, *see* Appendix B.

BURNAIS FORMATION

This is a new formational name proposed for a thick succession of bedded gypsum and interbedded limestones that occurs at several localities throughout the map-area. The name is taken from Burnais Creek, near Windermere, on which the gypsum is well exposed. Neither contact of the formation has been observed nor has any complete section been obtained. However, stratigraphic relationships indicate that it occupies a position in the sequence between the Beaverfoot-Brisco formation and the Harrogate formation.

The Burnais formation is composed principally of well-bedded and finely laminated gypsum (*see* Plate XV). The gypsum weathers light grey to purplish grey, but commonly this colour is obscured by the presence of white gypsite. At several places on Windermere Creek and along the Kootenay River a thickness of more than 600 feet of gypsum is exposed. It is sufficiently pure for commercial use and is being mined on Windermere Creek by Columbia Gypsum Products, Inc. For a full description of the gypsum, *see* Chapter V.

Interbedded with the gypsum, but making up only a small percentage of the total formation, are a number of thin members composed of calcareous rocks. Although each of these members exhibits very distinctive lithology, none could be correlated between different outcrops. It is possible that they are not interbeds but are lenses of local areal extent. The calcareous rock commonly is black fetid limestone or dolomite which is either thinly or thickly bedded or occurs as angular fragments in unusual limestone-gypsum breccia beds. In the latter form the limestone fragments are set in unlaminated white gypsum that is more coarse-grained than the normal gypsum. A second type of breccia that is interbedded with the gypsum consists of angular, irregularly sized fragments of dark-grey fetid dolomite set in a fine, dense dolomitic matrix. Another type of calcareous member consists of black carbonaceous shale and thin-bedded bluish-grey nodular limestone. The exposed sections of most of the limy members were measured, and two sections are listed in Appendix A.

The Burnais formation occurs at seven localities within the map-area. At one of these, near Pedley Pass, the formation does not actually outcrop but is believed, because of numerous sink holes, to underlie the covered ground between the Beaverfoot-Brisco formation and the Harrogate formation. At all the other localities the total area of outcrop is small compared with the area underlain by the formation. Outcrops as a rule are restricted to the banks of streams and steep gullies, the bottoms and sides of large sink holes, and the crests of steep divides. At the Kootenay River occurrence large outcrops are present on the higher parts of cigar-shaped transverse ridges that trend toward the Kootenay River from both sides.

Extensive stripping and trenching along Burnais Creek, Windermere Creek, and the Kootenay River have considerably increased the number of exposures and added much to the knowledge of the formation. This work proved the reliability of sink holes, gypsite, and (with certain reservations) Recent conglomerate as guides to the occurrence of gypsum. With the aid of these guides it is possible in most instances to trace the areal extent of the gypsum in spite of the scarcity of outcrops.

At Pedley Pass the Burnais formation appears to be about 700 to 750 feet thick. On Windermere Creek and the Kootenay River a much greater thickness is indicated, possibly as much as 1,300 feet, of which more than 75 per cent is gypsum. These figures are only estimates because nowhere could the gypsum be completely measured.

On the evidence of its position in the stratigraphic sequence, the Burnais formation was deposited at some time between the Middle Silurian (Niagaran) and Middle Devonian. No fossils were found and a more exact age determination is not possible.

In correlating the sequence of the Stanford Range with that of the Brisco Range at Harrogate and that of Starbird Ridge on the west side of the trench, several interesting points arise. At Harrogate, Evans reports a continuous succession from the top of the Wonah quartzite to the uppermost fossiliferous portion of the Harrogate formation. This section is devoid of gypsum. The lithology and fossil content of the upper beds of the Harrogate formation at Harrogate are almost identical with those of the beds overlying the gypsum in the Stanford Range. It is therefore possible that the lower 320 feet of Evans's Harrogate formation, consisting of dark dense limestones, argillaceous limestones, and sandy magnesian limestones with interbeds of quartzite, may be the age equivalent of the Burnais formation.

On Mount Forster and Starbird Ridge north of Horsethief Creek, Walker reports a concordant sequence that includes 200 feet of Beaverfoot-Brisco formation, 600 feet of Mount Forster formation, and about 230 feet of Starbird formation. Fossils from the top 30 feet of the Starbird formation were considered by Kindle to belong to the Upper Devonian. Recent reidentification of Walker's collection by D. J. McLaren* confirms Kindle's identifications but admits that some doubt must remain as to whether the Starbird is Middle or Upper Devonian in age until further collections have been made.

North (1952), who has studied both the Starbird and the Harrogate at their type localities, states that the lithology of the two formations is very similar and believes that the total stratigraphic evidence strongly supports a correlation between them. The writer concurs on the additional grounds that the red and green shales of the Mount Forster formation, which underlies the Starbird, are very similar to those occurring in the upper part of the Burnais formation at Dry Creek in the Stanford Range (*see* Section, Appendix A, p. 71). This suggests a possible correlation between the Mount Forster formation and the Burnais. Such a correlation would not be out of keeping with current concepts of the type of sedimentation often associated with evaporite deposition. However, even if this correlation is correct, it does not yield any further information concerning the age of the Burnais formation because the age of the Mount Forster formation is not known. Walker provisionally classed the Mount Forster formation as Devonian on the strength of its sharp lower contact with the Beaverfoot-Brisco formation and its gradational upper contact with the Starbird formation, but until fossils have been found its age must remain in doubt.

HARROGATE FORMATION

The Harrogate formation was named by Shepard (1926) and includes the youngest bedrock strata found within the Stanford Range. Although it is known to occupy a stratigraphic position above the Burnais, the actual contact between the two formations is not exposed. On Windermere Creek and Dry Creek the stratigraphic gap is less than 150 feet, and all indications point to concordance between the Harrogate and Burnais.

The Harrogate formation consists for the most part of thin-bedded nodular limestones with intercalations and interbeds of calcareous shale. The nodular limestones are dark purplish grey and are commonly fetid. They are everywhere fossiliferous. The intercalations, partings, and interbeds of calcareous shale are light buff, dark brown, or light grey in colour and give an over-all shaly appearance to the formation. A few members of light-grey dolomite and blue-grey limestone occur at two localities.

The Harrogate formation occurs in four small areas within the Stanford Range. Three of these are in the Central fault block where the Harrogate is closely associated with the Burnais formation. In the fourth, on Fairmont Ridge within the Western fault block, the contorted Harrogate is isolated in a small down-dropped block amongst much-faulted Cambrian and Ordovician rocks (*see* Plate VIII). Only partial sections of the formation are exposed at all these localities, and therefore nothing is known about its true thickness. Details of the section at each locality are given in Appendix A, and their respective fossil contents are given in Appendix B.

The nodular limestone members were found to contain an abundant Middle Devonian fauna at all four localities. The fauna of the Stanford Range occurrences appears to be almost identical with but not as complete as that reported by Evans from the Harrogate in the Brisco Range. *Spirifers,* although common in collections from the Brisco Range, have not been found in the Stanford Range.

PLEISTOCENE AND RECENT

Thick deposits of stratified silts and gravels occur on the floor of the Rocky Mountain trench, and similar but less thick deposits occur along the Kootenay River valley.

*Personal communication.

Presumably most of these are Pleistocene in age, but to what extent they have been augmented by Recent alluvium has not been determined. It is even possible that some of the silts may be Tertiary in age because similar-appearing silts in the vicinity of St. Mary River, 80 miles to the southeast, contain Tertiary (Miocene) plant remains.

The silts weather to a greyish white and are invariably calcareous. They are interbedded with the gravels either as uniform beds or as discontinuous lenses. In many beds well-developed slump structures were noted.

The gravels consist largely of well-rounded cobbles which are composed mostly of limestone, quartzite, argillite, and quartz. They tend to be poorly bedded and more lens-like than the silts.

At a few places, beds of sand as much as 10 feet thick are present. The sand is normally silty and highly cross-bedded.

Excellent exposures of these deposits occur along the shores of Windermere Lake and along the higher terraces on either side of the lake. At many places, but particularly in the vicinity of Dutch Creek, very striking " hoodoos " are developed by erosion.

Nothing is known of the absolute thickness of the deposits in the Columbia River valley. A bore-hole on the floor of the valley near the mouth of Dutch Creek was drilled to a depth of 160 feet and did not encounter bedrock. This proves the existence of at least 640 feet of superficial deposits above the bedrock floor of the trench at the mouth of Dutch Creek. A hole drilled to a depth of 200 feet near Edgewater, about 12 miles north of the map-area, also failed to reach bedrock.

Bedrock is visible in the banks of the Kootenay River along most of its length adjacent to the Stanford Range. The river is incised about 300 feet below the level of the main terrace. A bore-hole close to the river at Gibraltar Rock failed to reach bedrock at a depth of 176 feet.

Till overlies the silts and gravels in a few places, but for the most part it appears to have been removed by erosion. Two miles east of Canal Flats and just north of the road an exposure of tillite was seen to be both underlain and overlain by stratified silts and gravels.

Recent hot-spring deposits of travertine occur at several places within the map-area. The largest is on the west bank of the Kootenay River about half a mile north of the mouth of Nine Mile Creek. At this locality, locally known as Red Rock, the travertine covers an area one-quarter mile long and about 100 feet wide and has a maximum thickness of about 60 feet. It overlies glacial gravels and contains numerous silicified Recent plant remains. Other conspicuous accumulations of travertine occur at Fairmont Hot Springs and on the east shore of Columbia Lake about 3½ miles north of Canal Flats.

Deposits of tufa-cemented gravel or Recent conglomerate are common, particularly within areas underlain by gypsum. These conglomerates appear to be formed by cementation of gravels by deposition of calcium carbonate from ground-waters. The majority of the deposits are of Recent age, but some of them must have formed prior to the Pleistocene because boulders of tufa-cemented gravel occur in glacial tills along the floor of the trench.

In the interior of the range the lower slopes of all the stream valleys are mantled by Recent alluvium. At higher elevations large accumulations of talus are common, particularly beneath cliffs of Upper Jubilee dolomite.

CHAPTER III.—STRUCTURAL GEOLOGY

GENERAL STATEMENT

The Stanford Range, the Brisco Range, and part of the Van Horne and Hughes Ranges together form a structural sub-province of the Rocky Mountains. This sub-province is bounded by two prominent linear structures, the Rocky Mountain trench on the southwest and the White River break on the northeast.

The Rocky Mountain trench marks the western edge of the Rocky Mountains proper and also represents a line of demarcation between the northeasterly overturned structures of the Purcell Mountains and the southwesterly overturned structures of the sub-province. The White River break marks the eastern edge of the sub-province and separates it from the main ranges of the Rocky Mountains, in which the folding is dominantly gentle but in which there are local areas of northeasterly overturning. The relatively narrow sub-province, with its southwesterly overturned structures, lies between two much larger areas which have an opposite direction of structural overturning.

Structures within the sub-province have an approximate northwest trend that is slightly oblique to the more northerly trending Rocky Mountain trench. They all enter and are apparently truncated by the Rocky Mountain trench toward the north.

Within the Stanford Range the structural geology is complex. Two principal longitudinal faults, the Redwall and Stanford, divide the range into three major fault blocks, each of which is characterized by distinct types of structures. The Eastern fault block, between the Kootenay River (White River break) and the Stanford fault, contains the lower limb of a southwesterly overturned, almost recumbent fold, the lower limb of which is locally contorted into large nappe-like dragfolds. The Central fault block, between the Stanford and Redwall faults, is characterized by upright, asymmetrical, and southwesterly overturned anticlines which are separated from each other by faulted synclines. The Western fault block, between the Redwall fault and the Rocky Mountain trench, contains longitudinal and obliquely trending folds which are intricately dissected by a network of faults.

The obliquely trending structures of the Western fault block consist of a number of contorted subsidiary fault blocks that have been imbricated by southeasterly directed thrusting. This type of oblique structure has not been recognized elsewhere within the Rocky Mountains. It is of considerable importance in the history of the Stanford Range inasmuch as it proves that localized longitudinal shortening of the range has taken place. Furthermore, the fact that the longitudinal shortening is restricted to part of the Western fault block and does not occur in the Central fault block furnishes proof that there has been some strike-slip movement along the Redwall fault. Stratigraphic and structural evidence indicate that this strike-slip movement was large, probably at least 5 miles.

The two principal faults of the Stanford Range, the Redwall and the Stanford, are both characterized by wide red- or brownish-coloured breccia zones. They both extend throughout the length of the range but converge southeastward and appear to join just southeast of the map-area. Toward the north, Evans mapped the Redwall fault for 3 miles within the Brisco Range and projected it an additional 30 miles along the Rocky Mountain trench. Nothing is known about the northern extension of the Stanford fault.

The movement on the longitudinal Redwall fault was principally one of strike-slip. This type of movement is structurally of the utmost importance and may indicate that similar movement occurred along the fault or faults that are believed to underlie the Rocky Mountain trench at this latitude. Considerable strike-slip movement may also have taken place along the Stanford fault, but the evidence is insufficient for proof.

Numerous other faults both longitudinal and oblique occur within the Stanford Range. Many are marked by breccia zones, whereas others are simply breaks which are rarely detected except by the stratigraphic or structural discrepancy they produce.

At four places within the map-area the Burnais and(or) Harrogate formations are contained in well-defined down-dropped structures.

Only slight metamorphism accompanied the deformation throughout most of the map-area. For the most part it is restricted to the border zones of certain faults and to the axial zones of folds, and consists of minor recrystallization, bleaching, and the development of cleavage. Slate-like cleavage locally is well developed within the less competent units such as the McKay group and the Horsethief Creek formation. Relatively intense metamorphism has occurred along the White River break, and rocks of the McKay group in a band about 1 mile wide have been converted to calcareous chloritic phyllite as a result of intense shearing and bleaching. Some chemical changes, principally the elimination of lime, accompanied this transformation.

THE EASTERN FAULT BLOCK

The dominant structure in the Eastern fault block is the lower limb of an almost recumbent anticline which is overturned to the southwest. This structure is exposed for a length of 25 miles within the Stanford Range and is known to continue southeastward for at least 3 miles within the Hughes Range. Its northern limit is not known. Within the Stanford Range it is cut off to the southwest by the Stanford fault and to the northeast by the White River break.

For most of its exposed length within the Stanford Range the limb is consistently overturned, with a uniform northwest strike and a northeast dip generally ranging between 30 and 80 degrees. For the remainder of its exposed length—i.e., for 6 miles north of Gibraltar Rock and 5 miles north of Bear Creek—the limb is contorted into a number of drag-like major folds (*see* Plates I and VI). Measurements of attitudes of these folds and of associated dragfolds suggest that the axial plane of the major fold strikes about northwest and dips northeastward at angles between 10 and 30 degrees. They further suggest that the plunge in the northern 20 miles of the Stanford Range is 5 to 10 degrees

Plate I.—Aerial view of large nappe-like dragfolds near Gibraltar Rock.

northwest and that in the southern 5 miles it is flat to gently southeast. Because of the northwesterly plunge for the greater part of its length and because of deep incision by the Kootenay River at the south end, progressively deeper parts of the limb tend to be exposed from northwest to southeast.

Large drag-like folds which complicate the lower limb of the major fold are well exposed near Gibraltar Rock along the Kootenay River. Study of these folds affords information on the character of the folding as a whole and provides evidence as to the nature and probable magnitude of movement on a longitudinal fault; this evidence is considered suggestive of the sort of movement that may have occurred along the Stanford fault. In the following description the three folds are considered in upward order from the bed of the Kootenay River (*see* Plate I).

The lowest fold, No. 1 in Plate I, is the best for detailed study because it is the only one of the three that is well exposed on both sides of the Kootenay River. By comparing the natural sections on either side of the river, and thus obtaining a three-dimensional view, the fold is seen to have an essentially horizontal although slightly dome-shaped axial plane, around which the bedding is folded in a tight, almost isoclinal fashion. The arching of the axial plane about the axis parallel to the range is sufficient to give the fold a slightly nappe-like appearance. Fold 2 has the same nappe-like character, as displayed by the trace of the Wonah quartzite on the ridge marked "X" in Plate I and by the nose of McKay strata exposed on the ridge marked "Z."

Fold 2 has a nearly horizontal axial plane that dips northwestward down the major structural plunge at about 5 degrees. This fold has a consistently northwestward plunge throughout its exposed length.

Fold 3 is similar to fold 2 in that its axial plane plunges northward at 5 to 8 degrees and is bowed about an axis parallel to its trend. Only the lower limb of fold 3 is visible in Plate I.

The outcrop pattern of folds 1 and 2 is complicated by irregular topography and by a number of small faults. The most important of the faults cuts through folds 1 and 2 and produces a repetition of them. Comparison of the relative positions of the axial planes on both sides of the fault shows an apparent inconsistency with respect to the vertical movement. The displacement of the axial plane of fold 1 indicates a relative vertical movement of the west side down, whereas the displacement of the axial plane of fold 2 indicates an opposite movement. This apparent inconsistency is explainable by a horizontal or strike-slip component of movement on the fault. The axial plane of fold 1, although slightly domed, is essentially horizontal, and therefore the displacement of the axial plane in vertical section is an accurate measure of the dip-slip component of movement. On the other hand, the axial plane of fold 2 dips northwestward at about 5 degrees, so that a sufficient horizontal displacement on the fault of west side northward would counteract the effect of this dip-slip movement. However, in order not only to counteract the effect of dip-slip but also to produce an opposite vertical separation almost equal in amount, a relatively large horizontal component of movement is required. On the assumption that the plunge of 5 degrees northwest remains constant, this strike-slip component of movement is calculated to be about twenty times that of the dip-slip component, or about 1½ miles. The possibility of such a large strike-slip on an essentially longitudinal fault has considerable significance in the structural history of the range, particularly as a similar type of movement may be inferred along the Stanford fault.

THE CENTRAL FAULT BLOCK

The Central fault block is characterized by upright, inclined, and overturned anticlines which are separated from each other by faulted synclines. South of Windermere Creek two separate anticlines occupy the block, but north of Windermere Creek three are present as a rule (*see* Cross-sections A-A′, B-B′, C-C′, and D-D′, Fig. 3). The overturning is to the southwest.

One of the most persistent anticlines is in the western part of the fault block in the southern half of the map-area (*see* Plate VII). It has been traced continuously from 2 miles north of Mount Tegart to the Kootenay River, a distance of 15 miles. It is cut off toward the south by the convergence of the Redwall and Mary-Anne faults, and toward the north it is lost in covered ground near upper Windermere Creek. The anticlinal structure involving the Harrogate and Burnais formations that appears to underlie Windermere Creek and the upper part of Burnais Creek is believed to represent the northern continuation of this same fold.

The axial plane of this fold is vertical in some places but generally dips northeast at 60 to 85 degrees. There appears to be a culmination in the fold at the oblique fault near Madias Creek. Southward the plunge is from 0 to 10 degrees southeast, whereas northward the plunge appears to be about 5 degrees northwest. The bedding on the western side of the fold steepens to vertical and in places is overturned adjacent to the Redwall fault. In a few places on the eastern side of the fold a steepening occurs adjacent to the Mary-Anne fault (*see* Cross-section D-D′).

The second of the pair of anticlines occupying the southern half of the Central fault block lies between the Mary-Anne and Stanford faults. It is cut off toward the north by convergence of these faults. At its north end the fold is open and slightly asymmetrical, with an axial plane that dips northeastward at 70 to 80 degrees. Toward the southeast the fold becomes more tightly compressed and more overturned. South of the Kootenay River only the lower limb is present, and this is strongly overturned toward the southwest. At four places along its length the fold is cut by northeasterly striking, apparently vertical faults. The displacement on three of these indicates that the south side moved relatively downward and possibly westward. On the fourth fault the movement appears to have been south side up relative to the north side.

North of Windermere Creek the structure of the Central fault block is dominated by a prominent anticline that is continuously exposed from a point about 1½ miles northwest of Pedley Pass to the north boundary of the map-area. South of North Windermere Creek the axial plane strikes north 35 degrees west and dips steeply northeast. The axis plunges southeast at 5 to 10 degrees. In this locality the fold is broad, open, and slightly asymmetrical. It is cut off on the east by the Stanford fault. To the west, in the vicinity of Windermere Creek, it is succeeded by a syncline which is cut out by a fault 1 mile to the northwest. Toward the southeast the anticline and syncline both terminate in a partly faulted transverse roll or basin-like structure 1½ miles northwest of Pedley Pass. On the south side this transverse roll passes into the eastern limb of the western anticline.

Along North Windermere Creek the anticline is cut by an apparently vertical fault which displaces the fold axis and against which the axis swings about 15 degrees in strike from north 35 degrees west to about north 20 degrees west. The plunge is unaffected. The indicated movement on this fault is south side relatively down and westward.

North of North Windermere Creek the western limb of the anticline becomes progressively steeper, and is slightly overturned to the southwest near Shuswap Creek. This may be owing to a change in shape of the fold with depth because, with a continuing southerly plunge, progressively deeper parts of the fold are exposed toward the north.

Along Shuswap Creek the fold is again displaced by an oblique fault with a movement similar to the one along North Windermere Creek. North of Shuswap Creek the fold is a tight, asymmetrical anticline that is overturned to the southwest. The axial plane strikes nearly northwest and dips about 40 degrees northeast. The plunge is about 10 to 15 degrees northwest. In addition to being more overturned and more tightly folded, the fold here has a more complicated form (*see* Cross-section A-A′).

Another anticline occupies most of the area at the headwaters of Shuswap Creek in the northeast corner of the Central fault block, and is separated from the foregoing anticline by an apparently vertical fault. Toward the south it is cut off near the head of North Windermere Creek by the convergence of this fault with the Stanford fault. The axial plane of the fold strikes parallel to the range and dips steeply northeast. The axis plunges gently northwest.

The northwestern segment of the Central fault block, between the Burnais and Redwall faults, contains two areas of contrasting structure. South of Burnais Creek the segment contains an incomplete anticlinal fold which appears to plunge northwestward at about 35 degrees, whereas north of Burnais Creek it is occupied by a panel of sediments dipping uniformly northeast. The transition between these two structures is so abrupt that a fault is believed to lie between them.

Little is known of the structure in the thickly covered part of the Central fault block underlain by the Burnais formation along Windermere and Burnais Creeks. From information obtained near the Windermere Creek quarry the principal structure is believed to be a tight southwesterly overturned anticline and has been indicated as such on Cross-section B-B′. North of Windermere Creek the whole area appears to be a large down-dropped block* that is bounded by steeply dipping to vertical faults. The same block is believed to continue south of Windermere Creek although the longitudinal boundary faults are not exposed. A south boundary fault of the down-dropped block is assumed, although no fault was observed in the field, because of the relationship between the southernmost gypsum exposures on Windermere Creek and the anticline involving Beaverfoot-Brisco strata that lies to the southeast in the vicinity of Mount Tegart. Even if it is assumed that the gypsum in Windermere Creek valley is folded in a northern continuation of the anticline on Mount Tegart, the difference in elevation between the crest of Mount Tegart, where upper beds of the Beaverfoot-Brisco are exposed, and the southern occurrence of gypsum on Windermere Creek is much too great to be overcome by the 5-degree northwesterly plunge of the fold. The geometry of the situation requires that the Windermere Creek portion of the fold be down-faulted about 2,000 feet.

THE WESTERN FAULT BLOCK

The structures of the Western fault block are the most complex in the Stanford Range. This fact was appreciated at the start of the work and, as a result, much of the Western fault block was mapped in greater detail than the rest of the range. In spite of this greater detail the structure is still imperfectly understood, and much more detailed mapping would be required to solve the structure completely.

In view of their complex nature, no attempt is made to give detailed descriptions of all the individual structural elements. Instead, a general description is attempted in which specific examples are used for illustration. For the purpose of such description and because of the areal distribution of structural types, it is convenient to subdivide the Western fault block into five separate geographical units. These areas are designated as north of Tatley Creek, south of Tatley Creek, Mount Sabine and Mount DeSmet, Kootenay River down-dropped block, and southeast of Kootenay River. A description of the structures in each area follows.

NORTH OF TATLEY CREEK

To the north of Tatley Creek, as in the Central and Eastern fault blocks, the structures are essentially parallel with the trend of the range. They consist for the most part of upright and overturned folds which have been sliced into a number of segments by a network of longitudinal and oblique faults. The direction and magnitude of the movement along most of these subsidiary faults are not known, and hence it is, in general, impossible to reconstruct with any degree of accuracy the original fold outlines or to interpret the relationships between the folds in adjacent fault blocks.

An example of these complex relationships is seen in the area to the west and southwest of Mount Tegart. There, as shown in Cross-section C-C′, the greater part of the width of the Western fault block is occupied by a northwesterly trending syncline and

* This could be called a graben block inasmuch as younger rocks appear between older, but because the mechanics of formation of the block are not known, the term is avoided.

a similarly trending faulted anticline. However, on the east side of the block adjacent to the Redwall fault, there is a subsidiary fault block containing a segment of a fold which is overturned to the south, almost recumbent, and trends nearly at right angles to the other folds. The stratigraphic relationships add further complications because north of the subsidiary block the McKay, after progressive thinning from the north, is not present, yet within the subsidiary block it is about 2,000 feet thick. South of this block the McKay is hidden as far as the north end of Fairmont Ridge, where it is represented by a mere 50- to 200-foot thickness of Sabine formation.

Much of the structural complexity of this part of the Western fault block is the result of faulting. The majority of the faults are either parallel or at right angles to the range and are almost invariably steeply dipping or vertical. Most of them appear to join other faults, although some, such as the fault on the northwest flank of Fourpoints Mountain, die out into folds. Others appear to die out into the bedding, and presumably their movements are taken up by interbed slippage. Many of the faults have breccia zones similar to but narrower than those of the major longitudinal faults which are described later. Others are more or less sharp breaks that are detectable only by the stratigraphic or structural displacement produced by them.

Complexity of another sort is introduced by irregularities in the shapes and attitudes of the folds. In a few cases a fold or segment of a fold changes shape so markedly along strike that no one cross-section is sufficient to illustrate it. This relationship is well demonstrated by the anticline adjacent to the Redwall fault on Fourpoints Mountain. On Fourpoints Mountain it appears to be overturned to the west, whereas 1½ miles to the southeast (*see* Cross-section C-C′) it is overturned to the east. Since the fold is continuous between the two points, a twisting or folding of the axial plane is indicated.

South of Tatley Creek

A most significant bend in the structural trend takes place at Tatley Creek. From a trend of north 30 degrees west, north of Tatley Creek, all structures within the Western fault block swing to an oblique trend of north 70 degrees west. This swing is particularly well demonstrated by a northwesterly trending syncline that is continuously exposed between Madias and Tatley Creeks (*see* Cross-section D-D′). At Tatley Creek the syncline swings to a trend of north 70 degrees west where it is well exposed on the north end of Fairmont Ridge. The oblique trend persists for 12 miles south of Tatley Creek, almost to the south end of the Stanford Range.

In addition to the change in trend a unique type of structure is present south of Tatley Creek. In general, this structure consists of a series of imbricate thrust blocks that appear to have been thrust southward one on top of the other. Considered in detail, the relationships are more complex because the rocks within each thrust block are complexly folded and most of the north-dipping thrust faults are themselves contorted.

The northernmost imbricate thrust structure is immediately south of the obliquely trending syncline at the north end of Fairmont Ridge. The formations occurring in the syncline are found also in the successive oblique thrust blocks, and it would appear that there has been a simple repetition of the southern limb of the syncline were it not for an over-all change in structural pattern. To the south, the lowermost imbricate block is thrust over longitudinal folds north of Mount DeSmet, along a fault that appears to extend from Mount Sabine to Dry Creek. The oblique imbrication is not entirely restricted to strata trending obliquely to the range.

The area of imbricate thrust structures is divided into two segments by a longitudinal fault, extending from the head of the south fork of Dry Creek almost to Fairmont Hot Springs, which has the effect of displacing the western segment relatively to the south. As the fault does not appear to extend southward beyond the known limits of oblique imbrication, it is presumed to be a tear fault that is associated with the southernmost oblique thrusts. On the divide between Geary and Warspite Creeks the tear fault dips steeply northeast, but elsewhere its dip is not known. In Cross-section F-F′ it appears very flat because the strike is nearly parallel with the line of section.

If the intricate shape of each thrust block is ignored and only the over-all northerly dips are considered, it is seen that they are flatter toward the south (*see* Cross-section F-F′). Several easterly and southeasterly dips were observed in the most southerly thrust block north of Mount Sabine. These facts suggest that the imbricate thrust blocks may represent segments of the north limb of an obliquely trending anticline.

The individual thrust blocks are folded, and the three northern blocks in particular outcrop in an elongated S-shaped pattern as a result of the folding. In each block the folds are fan-like and show a progressive increase in plunge toward the east. This is well illustrated by the two northern blocks which contain, from west to east, a tight northwesterly trending anticline of less than 10 degrees plunge, an open syncline that plunges north at about 20 degrees, and an open anticline that plunges northeast at about 40 degrees. In the remaining thrust blocks the strata range in dip from 50 degrees northward to horizontal; folding is present, but because of the flatter dip the folding is more difficult to interpret.

The thrust faults between the blocks cut obliquely across the bedding, but have shapes similar to the bedding. This is particularly true of the three northernmost faults which have S-shaped outcrop patterns. In general, the faults dip more steeply than the bedding. Changes in their attitude are closely related to changes in attitude of the bedding. For example, the southern boundary fault of the northernmost thrust block dips gently north where the bedding is flattest near the synclinal axis, and abruptly steepens to about 60 degrees on the crest of Fairmont Ridge where the dip of the bedding increases to 50 degrees to the north-northeast. Farther east the fault swings a little more easterly in strike and dips steeply northward, whereas the bedding strikes southeast and dips 65 degrees northeast.

Interpretation of the Oblique Structure.—The existence of obliquely trending thrust structures proves that a crowding or shortening took place in a direction almost parallel to the trend of the range. The fact that this shortening occurred within the Western fault block and that there was no similar shortening within the Central fault block indicates a differential strike-slip movement between the two major fault blocks. In other words, some strike-slip movement must have occurred on the Redwall fault to have allowed the observed longitudinal shortening of the Western fault block. This involved a southerly movement of the Western fault block relative to the Central fault block. This direction of movement is in agreement with the movement that appears to have taken place along the longitudinal tear(?) fault south of Fairmont Hot Springs. It is also in agreement with that suggested by the bend in the regional trend at Tatley Creek, assuming that the bend is a large dragfold.

As previously mentioned, the general attitudes of the thrust blocks suggest that they may be segments of the northern limb of an obliquely trending anticlinal structure. The question arises as to whether the folded shape of the thrust blocks may be related to (*a*) previously formed dragfolds on the limb of the anticline that were subsequently thrust-faulted, (*b*) cross-folding of the thrust blocks during and (or) after the thrust faulting, or (*c*) drag along the Redwall fault as a result of the southerly movement of the block as a whole. The last possibility may be eliminated because the folds on the east side are opposite in shape to drags that might result from the apparent strike-slip movement on the Redwall fault. Of the other two possibilities, the writer favours the cross-folding origin because the individual thrust faults are curved in a manner that suggests they were folded with the thrust blocks but to a lesser extent. The presence of the tight northwesterly trending anticlines on the west sides of the two northern thrust blocks, compared to the more open and more obliquely trending folds on the eastern sides of the same blocks, is considered as additional evidence in support of the cross-folding origin.

The ultimate causes of the oblique structures are obscure, as are the reasons for their formation in this particular part of the Western fault block. The fact that they are localized and that no similar structures are known in the Central and Eastern blocks suggests that they are not the product of a second period of deformation but are a localized effect of the regional deformation. Further consideration of this matter is given in Chapter IV.

Mount Sabine and Mount DeSmet

On Mount Sabine and Mount DeSmet at the southern end of the Stanford Range the structure is again parallel with the trend of the range. On Mount Sabine the structure is an open upright syncline which plunges northwest at about 20 degrees. The eastern limb of this syncline was, before faulting, continuous with the anticlinal structure exposed on Mount DeSmet and northward (*see* Plate IX). This anticline appears to plunge between 20 and 30 degrees northwestward.

Kootenay River Down-dropped Block

The Kootenay River down-dropped block has an area of about 5 square miles straddling the Kootenay River and Nine Mile Creek. It contains only outcrops of the Burnais formation, and these are so few and far between that the internal structure of the block is unknown. In general, the structure appears to be anticlinal and may possibly represent a down-dropped portion of the anticline exposed on Mount DeSmet.

The block is bounded on the northwest by a prominent red-coloured vertical breccia zone which trends southwest from where it outcrops on the Kootenay River opposite the mouth of Nine Mile Creek. Throughout its length it truncates formations that range in age from Precambrian to Ordovician. It is probable that this fault joins the southeastern boundary fault of the same block along the Kootenay River valley north of Mount Grainger. The southeastern boundary fault was seen only in outcrops south and southwest of Nine Mile Creek, but from stratigraphic relationships it appears to trend southwest along the southwesterly flowing part of the Kootenay River. The block is bounded on the northeast by the Redwall fault.

Southeast of Kootenay River

All the rocks in this section are involved in a single broad anticlinal structure, from the first exposures just south of the Kootenay River at Canal Flats to the eastern limit of mapping. The crest of the anticline is exposed in scattered outcrops of Horsethief Creek formation (not shown in Fig. 2) in the Rocky Mountain trench south of Canal Flats. From there eastward successively younger formations of the eastern limb are exposed. Because of the discrepancy between this structure and that north of the river a fault is assumed to lie between the two, probably a continuation of the southeastern boundary fault of the Kootenay River down-dropped block.

FAULTS

Redwall Fault

This major fault extends throughout the entire length of the Stanford Range and separates the Western from the Central fault block. It continues northward for 3 miles through the west flank of the Brisco Range, and disappears under drift and alluvium on the floor of the trench. Because of the stratigraphic differences between Steamboat and Jubilee Mountains on the west and the main Brisco Range on the east, Evans (1933) projected the Redwall fault for an additional 30 miles northwestward along the Rocky Mountain trench. To the south the Redwall fault converges with and appears to join the Stanford fault just southeast of the present map-area.

South of Windermere Creek the strike of the fault is approximately northwest and north of that creek is about north 30 degrees west. This swing in strike along Windermere Creek coincides with a similar swing in strike of the adjacent structures in the Central fault block. The fault trace contains many minor bends but is not influenced by the topography, a fact that indicates that the dip is approximately vertical. Where the fault can be seen in section, such as in the steep valleys of Sinclair and Shuswap Creeks, it is vertical.

Within the Stanford Range the fault is characterized by a wide red-coloured breccia zone which outcrops in many places like a gigantic red wall. The breccia zone is particularly well exposed one-quarter of a mile east of Radium Hot Springs on the Banff–Windermere Highway. It ranges in width from 100 feet, just north of Windermere Creek, to more than 1,000 feet on the divide between Tatley and Mary-Anne Creeks, east of the north end of Fairmont Ridge (*see* Plate X). In most places the breccia is about 200 feet wide and passes gradationally into the wallrock on either side.

The breccia consists of angular to sub-rounded fragments which range in diameter from a fraction of an inch to more than 10 feet and are cemented with calcite and hematite; locally, appreciable silica is also present. The majority of the fragments effervesce in acid, even at places where the wallrock on both sides is dolomite, apparently as the result of almost complete replacement of most of the dolomite fragments by calcite. Random fragments of quartzite, presumably of the Wonah, also occur. Nearly all of the fragments, particularly near the centre of the breccia zone, are partly shattered, with thin seams of the cement filling the cracks.

Zones of relatively intense shearing occur throughout the breccia zone, but generally are more common near the centre. They are marked by 4- to 10-foot-thick sheets of highly contorted, partly schistose material composed mostly of granulated and sheared rock. These zones of more intense shearing usually weather a darker red than the surrounding breccia.

Marginal alteration of the wallrock occurs at most places along the Redwall fault. This alteration consists of recrystallization, bleaching, carbonatization, and the addition of minor amounts of iron oxide. At a few places, such as at the headwaters of Tatley Creek, there is also an appreciable amount of silicification. The occurrence of specular hematite in pods within the breccia and as stringer-like masses in the wallrock bordering the breccia is considered proof of the hydrothermal origin of at least some of the solutions. The alteration is commonly buff or yellow coloured and dies out gradationally into the unaltered wallrocks. Zones of alteration 150 feet wide have been noted, but they are commonly less than 50 feet wide.

The Redwall fault breccia is well exposed throughout most of its length and is readily recognized by its bright-red colour. At places where it has been deeply eroded, remnants of the breccia are often left in the form of " hoodoos " or pillars. This feature is characteristic of all the major fault breccia zones.

The movement on the Redwall fault appears to have been an oblique slip in which the horizontal component of movement was very much greater than the vertical component. The existence of strike-slip movement has been deduced from a consideration of the longitudinal shortening of the Western fault block south of Tatley Creek (*see* p. 35).

As previously mentioned, the movement appears to have been left hand in direction; i.e., a southerly movement of the Western fault block relative to the Central fault block. The following evidence supports this direction of movement: (*a*) Marked longitudinal shortening west of the Redwall fault and none east of it; (*b*) left-hand movement appears to have occurred along the longitudinal tear(?) fault south of Fairmont Hot Springs; (*c*) left-hand movement is in agreement with possible dragging that is suggested by the bend in the regional trend at Tatley Creek.

The age relationships across the fault provide an approximate measure of the vertical displacement. In general, they indicate that the west side was upthrown about 1,000 to 3,000 feet relative to the east side.

Some measure of the magnitude of the total movement may be obtained from consideration of the detailed stratigraphic relationships across the fault. For example, at the north end of Fairmont Ridge the McKay group is more than 4,000 feet thick east of the fault, whereas at the same elevation west of the fault, the McKay, represented by the Sabine formation, is not more than 400 feet thick. This tremendous change in thickness of calcareous sediments which represent the same interval of time could only be produced by juxtaposition of different parts of the depositional basin. Even if the McKay thins rapidly westward, the indicated displacement must still be large—probably 5 or 6 miles at least. Because the fault is essentially vertical and the indicated vertical displacement is 3,000 feet or less, it is probable that most of the displacement was accomplished by strike-slip movement.

The amount of longitudinal shortening by oblique thrusting between Tatley Creek and Sabine Mountain is an approximate measure of the magnitude of the strike-slip movement on the Redwall fault. This shortening is estimated to be at least several miles and possibly as much as 10 miles.

It is possible that the Kootenay River down-dropped block may be the displaced segment of the Windermere-Burnais Creeks down-dropped block and, if so, the 18 miles between them is an approximate measure of the horizontal displacement, although not necessarily a measure of the strike-slip component of movement. This suggested relationship can neither be proved nor disproved by existing evidence and is mentioned only as a possibility.

Stanford Fault

This fault extends throughout the length of the map-area and forms the western boundary of the Eastern fault block. At the extreme south end of the Stanford Range it is vertical, but elsewhere it appears to dip steeply to the east. In general, the fault strikes between north 30 degrees west and northwest; a few bends cause local deviations from this strike. One bend near the head of North Windermere Creek is adjacent to a minor fold in the Eastern fault block, suggesting that the attitude of the fault may be influenced to a certain degree by adjacent bedding.

The Stanford fault is very similar in general character to the Redwall, with the exception that its fault breccia weathers brown instead of red owing to an abundance of limonite rather than hematite in the cement. The breccia zone is most commonly between 50 and 150 feet wide, but widths as great as 700 feet have been observed. Only minor marginal alteration occurs along it.

Little is known of the movement on the Stanford fault. The general location suggests that the fault may be a steep easterly dipping thrust that was initiated at the same time as the major overturned fold of the Eastern fault block. Apart from the vertical component, however, some strike-slip movement probably occurred. The principal evidence in support of strike-slip movement is derived from the stratigraphic thicknesses of the Glenogle shale on either side of the fault. At the head of Windermere Creek in the Eastern fault block the Glenogle is more than 2,000 feet thick, but it is only 300 to 500 feet thick in the Central fault block immediately across the Stanford fault. Primary thinning of this magnitude, particularly in black shales, is unlikely to have taken place in a distance shorter than 4 to 5 miles. Consequently, unless the Stanford fault has obscured by faulting a syncline of very large amplitude, the rapid change in thickness must be attributed to horizintal displacement that brought different parts of the basin into juxtaposition. Inasmuch as the Glenogle shows a regional thinning from north to south, a right-hand movement is indicated; i.e., east side south.

Possible supporting evidence of strike-slip movement on the Stanford fault is furnished by the small fault near Gibraltar Rock, described on page 31. The right-hand strike-slip movement on the small fault is in the same direction as the movement indicated for the Stanford fault.

Mary-Anne Fault

The Mary-Anne fault lies within the Central fault block and outcrops at intervals over a total length of 14 miles. Toward the north it joins or is truncated by the Stanford fault. Toward the south it merges with the Redwall fault.

The fault is represented by a wide, brown-weathering, vertically dipping breccia zone which separates two anticlinal structures in the southern part of the Central fault block. The breccia is very similar in composition to that of the Stanford fault and, like both the Redwall and Stanford fault breccias, in many places outcrops in the form of " hoodoos." " Hoodoos " of the Mary-Anne fault breccia are well exposed just southeast of the low divide between Pedley and Mary-Anne Creeks. The movement along this fault is not known.

Burnais Fault

The Burnais fault is within the Central fault block between Windermere Creek and the north boundary of the map-area. In the southern part of its length it forms the western boundary of the down-dropped block containing the Windermere Creek gypsum deposits. Where it outcrops it is characterized by a reddish and brown breccia zone similar to that of the Redwall fault. The breccia is more than 200 feet wide just north of Burnais Creek, but in most outcrops it is less than 50 feet wide. Minor alteration of the wallrocks, including some bleaching and recrystallization, occurs on the divide between Windermere and Burnais Creeks.

The fault appears to be vertical, but no definite information regarding the dip is available.

Other Faults

Many other faults have breccia zones similar to the ones already described. The most notable of these are: (*a*) The fault that branches from the Burnais fault and extends southward along the east side of Windermere Creek, forming the east boundary of the Windermere-Burnais Creeks down-dropped block; it is very poorly exposed, but the few outcrops show a red and brown breccia zone about 10 to 50 feet wide. (*b*) The southern boundary fault of the down-dropped block of Harrogate formation on Fairmont Ridge. This has a bright red-weathering breccia. Alteration includes some bleaching, recrystallization, and silicification in a border zone as much as 20 feet wide. (*c*) The northwest and southeast boundary faults of the Kootenay River down-dropped block. Both faults have red-weathering breccias.

The remainder of the faults have either no breccia developed along them or only minor amounts of it. Among those without breccia zones are the majority of the oblique faults of the Central and Eastern fault blocks. Many oblique faults are very poorly exposed, and their presence may be indicated only by the displacements along them. Others that are well exposed, such as several of the north-dipping oblique thrust faults south of Tatley Creek in the Western fault block, have narrow slickensided fault zones along which stratigraphic separations of as much as 2,000 feet have taken place.

The movements on the oblique faults in the Central and Eastern fault blocks are almost invariably the same; i.e., south side down and possibly westward relative to the north side. In the Western fault block no regularity exists.

METAMORPHISM

In general, metamorphism in the Stanford Range is restricted to areas of tight folding and to the border zones of major faults. In some instances, as in the case of the McKay strata along the Kootenay River, metamorphism has been sufficiently intense to change completely the character and composition of the original sediments. More commonly, however, the effects are less severe and are limited to those usually attributed to low-grade dynamic metamorphism.

The medium- to thick-bedded dolomite, limestone, and quartzite units, such as the Jubilee dolomite, Wonah quartzite, Beaverfoot-Brisco formation, and most of the Cranbrook and Burton formations, show the least effects of metamorphism. Joints are common, but cleavage and recrystallization textures are rare except at axial zones of very tight folds or along the border zones of several of the major longitudinal faults. Extensive recrystallization and some rock-flowage can be seen in outcrops of the Beaverfoot-Brisco dolomite along the Kootenay River between 1 and 2 miles southeast of Gibraltar Rock. At this locality the Beaverfoot-Brisco possesses a strong cleavage and is so recrystallized that bedding is difficult to detect. Where the bedding can be detected, it is seen to pinch and swell in an irregular manner. The rock itself has a striped appearance caused by alternate narrow bands of white crystalline dolomite and dark-grey crystalline dolomite. This banding is commonly, but not always, parallel to the cleavage.

In the border zone of the Redwall fault the normally grey dolomite and limestone beds are in many places bleached and are stained a light-brownish colour owing to the addition of small amounts of iron oxide. Locally there has been addition of calcite, in some places sufficient to produce an apparent dedolomitization of dolomite beds. In other words, in the border zone of certain faults a dolomite member appears to pass gradationally into an altered rock which effervesces in acid. The effervescence is of introduced, secondary calcite and not calcite formed by the removal of magnesium from the dolomite.

In thin-bedded limestone and shale units, such as the Horsethief Creek formation, McKay group, Glenogle shale, and Harrogate formation, the effects of metamorphism are more pronounced. Many of the shales are locally converted to argillites which may be highly cleaved. Similarly, some of the thin argillaceous limestone beds are so intensely cleaved that they now resemble slates. In this category are included certain beds of the McKay group that are reduced to pencil-like fragments by two or more intersecting cleavages.

Dynamic metamorphism has affected the shape of the pebbles in the intraformational limestone conglomerates of the McKay group. These are commonly ellipsoidal even in areas of slight deformation and, where highly deformed, they are elongated to the point of resembling cigars, with lengths about ten times their diameters. Rock-flowage on a formational scale is shown by the marked thinning in the Glenogle shale and McKay group on the lower limbs of the recumbent folds in the Eastern fault block, just northwest of Gibraltar Rock. Just east of Gibraltar Rock a similar thinning of the Glenogle shale and Wonah quartzite takes place down dip toward the nose of another recumbent fold that is believed to lie just below river level. At river level the Wonah has pinched out altogether, and the Glenogle has thinned from 300 to 20 feet. Bedding in the Glenogle is almost obliterated by the formation of prominent cleavage, extreme dragfolding, some brecciation, and dyke-like intrusions of the underlying McKay limestone. Small fragments of recrystallized limestone are irregularly distributed throughout the Glenogle, which here consists of a highly carbonaceous, pitch-black slate. Some of the local residents have mistaken these outcrops for impure coal seams.

Metamorphosed McKay Group

The following description is supplementary to that already given in Chapter II and is concerned with the physical and chemical changes that took place during extreme metamorphism of rocks of the McKay group to calcareous chloritic phyllite.

Study of the relations between the phyllite and the McKay group rocks of the Eastern fault block proves that the phyllite is the product of dynamic metamorphism of McKay strata. In the field a gradational transformation of the McKay can be traced from normal well-bedded limestones, limestone conglomerates, and calcareous shales to a phyllitic end product. The transformation that takes place across variable widths up to a maximum of about 1 mile commonly is first recognized by the development of minor folds in previously undeformed beds of the McKay. With increasing metamorphism the folds become progressively more numerous and complex until they themselves are folded and crumpled, and are partly disrupted by movements along the cleavage which is well developed in all beds. Nearer the phyllite band the cleavage is very prominent, and the intricate folds are so disrupted and sheared that bedding can be recognized only as occasional massive beds that are less highly deformed. At this stage, chlorite appears for the first time on some of the slip surfaces and the whole rock acquires a bleached appearance similar to the phyllite. With slight increase in metamorphism, chlorite is more abundant and the rock loses the remainder of its sedimentary features, becoming a phyllitic mylonite or phyllite.

In an attempt to determine the chemical changes that occurred during the formation of the phyllite, partial chemical analyses were made of samples of the McKay group rocks, and of the rocks representing different stages in the development of the phyllite. The results* of these analyses show that with increasing intensity of metamorphism there is indicated a progressive increase in the percentage of silica, iron oxide, alumina and phosphorus, soda and potash, and a corresponding decrease in lime and carbon dioxide. The percentage of magnesia remains more or less unchanged. In view of the small number of samples there appears to be only one conclusion that may be drawn from the analyses; namely, that with increasing metamorphism there is a decrease in the amount of lime and carbon dioxide in the rock. Recalculation on the assumption that carbonate has been removed indicates that other changes have taken place. However, investigation of this matter will have to await adequate sampling of the McKay and its equivalent phyllite.

The present sampling indicates, if its does not prove, a lowering in the lime content of the rock.

* The results of these analyses, together with descriptions of the sample locations, are given in Appendix C.

CHAPTER IV.—REGIONAL GEOLOGY AND INTERPRETATIONS

The subject-matter of this chapter involves such a large area and has such far-reaching implications that only an outline can be attempted. The material is included in this bulletin because it is believed essential to a consideration of the origin of Stanford Range structures.

The regional setting of the Stanford Range is discussed, and it is pointed out that at this latitude the Rocky Mountains are divisible into four structural sub-provinces. The sub-provinces are separated from each other by major faults. In the case of the westernmost sub-province, which includes the Stanford Range, the eastern-bounding fault is marked by a mile-wide zone of shearing and mylonitization along the Beaverfoot, Kootenay, and White Rivers—the name White River break is proposed for this fault.

The White River break not only separates the complex southwesterly overturned folds of the western sub-province from open to northeasterly overturned folds of the adjoining sub-province, but also marks a distinct breach in the stratigraphic continuity of the western Rocky Mountains. In view of its significance and regional extent, this fault is described as fully as the known facts allow.

To emphasize the conflict in geological relationships existing across the White River break, an outline is given of the outstanding features of the geology of the sub-province to the east of it.

Finally, the more important regional problems are listed and possible solutions for some of them are suggested. In particular, it is believed that a wedge mechanism may account for the presence of conflicting geological features on opposite sides of the White River break.

REGIONAL SETTING OF THE STANFORD RANGE

Between latitudes of approximately 50 degrees and 51 degrees 30 minutes the Rocky Mountains are composed of four separate structural units in which the structure, stratigraphy, and physiography are so distinct that they may be regarded as structural sub-provinces. The following names are proposed for the four sub-provinces, from east to west: The Foothills sub-province, the Front Ranges sub-province, the Main Ranges sub-province, and the Western Ranges sub-province. A brief description of each sub-province is given, in order to outline the regional setting of the Stanford Range.

The Foothills sub-province lies along the eastern flank of the Rocky Mountains and is marked by a belt of northwesterly trending valleys and ridges. Within this belt the structure is characterized by numerous imbricate thrust slices that are accompanied by remarkably little folding. The stratigraphy consists mostly of Mesozoic rocks with a few inliers of Palæozoic rocks.

The Foothills structures die out eastward at most places along a marked frontal fault, usually referred to as a sole fault. Westward, they terminate abruptly against the first Front Range of the Rocky Mountains.

The Front Ranges sub-province lies to the west of the Foothills sub-province and is separated from it by a large southwesterly dipping thrust fault. At the latitude of Banff this frontal fault is named the McConnell fault, which is well exposed on Yamnuska Mountain, north of the Banff–Calgary Highway.

Structurally, the Front Ranges consist of three or four large thrust blocks which, like the much smaller thrust slices of the Foothills, are imbricated toward the northeast. Each thrust block forms a northwesterly trending mountain range and is separated from the adjacent thrust blocks by longitudinal valleys. The ranges have steep, rugged cliffs on their eastern sides and less steep dip slopes on the west. The formations of the Front Ranges consist principally of Upper Devonian and Mississippian and relatively minor amounts of Cambrian, Ordovician, and Cretaceous rocks.

The next and most extensive sub-province is called the Main Ranges sub-province because it contains what are known to many as the Main Ranges of the Rocky Mountains.

The topography of this area is characterized by high castellated peaks ranging in elevation from about 8,500 to more than 11,000 feet.

The Main Ranges sub-province is bounded on the east by a major southwest-dipping thrust fault. This fault, called the Castle Mountain thrust* by some geologists, is known to extend from just south of Mount Assiniboine northwestward for more than 200 miles. It has a strike of about north 30 degrees west and is parallel to the main trend of the Rocky Mountains and to the Rocky Mountain trench. The western limit of the Main Ranges sub-province is marked by the White River break, the name proposed for the major fault zone that extends northwestward from near White Swan Lake along the White, Kootenay, and Beaverfoot Rivers to Leanchoil and thence into the Rocky Mountain trench at Blaeberry.

Within the Main Ranges sub-province are found the remarkably flat and gently folded beds that are so commonly referred to as typical of the Rocky Mountains. At places, particularly in the southern and western parts of the sub-province, there are areas in which tight folds are present. These tighter folds are inclined† and overturned toward the northeast. For the most part, the Main Ranges are composed of competent Cambrian and Precambrian rocks. These rocks form a thick stratigraphic section and typically underlie areas characterized by flat-lying beds and gentle folds. South of latitude 51 degrees considerable areas of the sub-province are underlain by less competent rocks, probably of Ordovician(?) age, and it is within these areas that the more complex folding occurs.

The Western Ranges sub-province lies between the White River break and the Rocky Mountain trench. It includes part of the Van Horne Range, the Brisco Range, the Stanford Range, and at least part of the Hughes Range. Toward the north the sub-province is truncated at the trench, but toward the south—i.e., south of the Stanford Range—its limits are unknown.

The Western Ranges sub-province is characterized by southwesterly overturned folds, numerous steeply dipping faults with both longitudinal and oblique trends, and a regional structural trend that is about 10 to 15 degrees oblique to the trend of the Rocky Mountains and to the Rocky Mountain trench. The rocks in the sub-province are principally Cambrian, Ordovician, and Silurian in age. Some Precambrian and Middle Devonian rocks are also present.

Topographically, the sub-province consists of a number of northwesterly trending ridges ranging in elevation between 5,500 and 9,000 feet.

THE WHITE RIVER BREAK

The White River break is the name proposed for the major longitudinal fault zone that limits the Western Ranges sub-province on the northeast. The fault zone has been traced continuously from just east of White Swan Lake northwestward to Kootenay Crossing. From there northwestward to Blaeberry it has been observed on the big bend of the Kicking Horse River and on the terraces east of Blaeberry, where it disappears beneath covered ground in the Rocky Mountain trench. It is assumed to extend continuously between Blaeberry and White Swan Lake, a distance of 120 miles. In all probability it extends farther to the southeast, but no reconnaissance work has been done in that region.

Throughout its length the fault zone is a line of demarcation between the southwesterly overturned, highly faulted structures of the Brisco-Stanford Ranges and the flat-lying or northeasterly overturned structures of the Main Ranges of the Rocky Mountains. It also marks a pronounced change in lithology of rocks of approximately the same age on either side of it. The fault zone is characterized by a prominent topographic lineament in the form of a trench which extends along most of its known length.

* It has also been called the Johnston Creek fault by Deiss (1939).

† Used in the sense of " leaning toward "; i.e., the axial planes of northeasterly inclined folds dip southwest.

The fault approximately parallels the structures of the Stanford and Brisco Ranges and, like them, is truncated to the north by the Rocky Mountain trench. No definite information is available concerning the dip of the fault. However, a southwest dip is indicated on the Palliser River, where a sheared zone, occurring along the fault, has a sharp eastern contact that dips toward the southwest at 60 degrees. Another southwest dip is indicated on Elk Creek, a northeast tributary of the White River 4 miles north of White Swan Lake. A southwest dip is again suggested southeast of Blaeberry by the topographic trace of the fault on the mountains between Blaeberry and Leanchoil.

The fault is marked by a 1- to 2-mile-wide zone of shearing, across half of which a remarkable calcareous chloritic phyllite* is developed (*see* Plates V and XI). The phyllite has a characteristic greenish-white weathered colour which, together with a complete absence of bedding, makes the rock easily recognizable in all occurrences. The very light-grey to white colour is the result of intense bleaching of the pre-existing rocks, and the greenish hue is due to the presence of finely divided chlorite. The phyllite is particularly well exposed along the White River and is responsible for the white banks after which the river was named.

The phyllite is characterized by a pronounced foliation that is produced by a well-developed though irregular cleavage. The irregularity results from non-parallel orientation, discontinuity, and rapid variation in dip of the principal cleavage planes. This prominent cleavage may be cut and displaced by a second, poorly developed cleavage resembling closely spaced joints. The second cleavage is well exposed in some new roadcuts on No. 1 Highway to the west of Leanchoil.

Throughout the phyllite there are sporadic limestone fragments that apparently represent unsheared remnants of the rocks from which the phyllite was formed. These range in dimension from 1 inch to about 30 feet but are most commonly of cobble size. The larger remnants are commonly contorted, but in places they are undeformed slabs of bedded limestone surrounded by phyllite. Most of the remnants consist of partly chloritized limestone, but a few of the smaller ones are composed of crystalline calcite.

The phyllite forms a band about 1 to 1½ miles wide and characterizes the fault zone throughout its entire length. Toward the southwest, at least within the Stanford Range, it passes gradationally into less-sheared rocks of the McKay group. This contact relationship has already been discussed (*see* p. 40). Toward the northeast, along the Palliser River, the contact is sharp between the phyllite and essentially unsheared limestone of the Goodsir(?) formation, but on Elk Creek, a tributary of the White River, a narrow zone of less-sheared limestone lies between the two. Along the Kicking Horse River the shearing extends well to the east of the phyllite proper, and the phyllite bears an obscure relationship to a second sheared zone lying to the east of the White River break.

Conclusion.—The White River break is of fundamental importance in the structural framework of the Rocky Mountains because it separates areas of greatly different structure and stratigraphy. Available evidence indicates that the break dips southwest and, therefore, cannot have formed at the same time as the southwesterly overturned structures of the Western Ranges sub-province. No matter what the mechanics of thrusting were that produced these folds, any faults related to the folding must dip to the northeast. The White River break does not dip northeast, but it does mark the northeastern limit of the southwesterly overturned structures. From these relationships it is concluded that the White River break must post-date the formation of the southwesterly overturned structures. The fault is believed to represent a major southwest-dipping thrust on which the southwesterly overturned structures of the Stanford Range were moved northeastward on to the essentially flat-lying structures of the Main Ranges. These interpretations are further expanded in the section on regional interpretations (*see* p. 49).

A most remarkable feature of the White River break is the mile-wide zone of shearing and mylonitization. It is not known why this shearing developed nor why it remains within the limits of the McKay group throughout a length of more than 115 miles. Nor

* For a full description of the phyllite *see* Chapter II, p. 22, and Chapter III, p. 40.

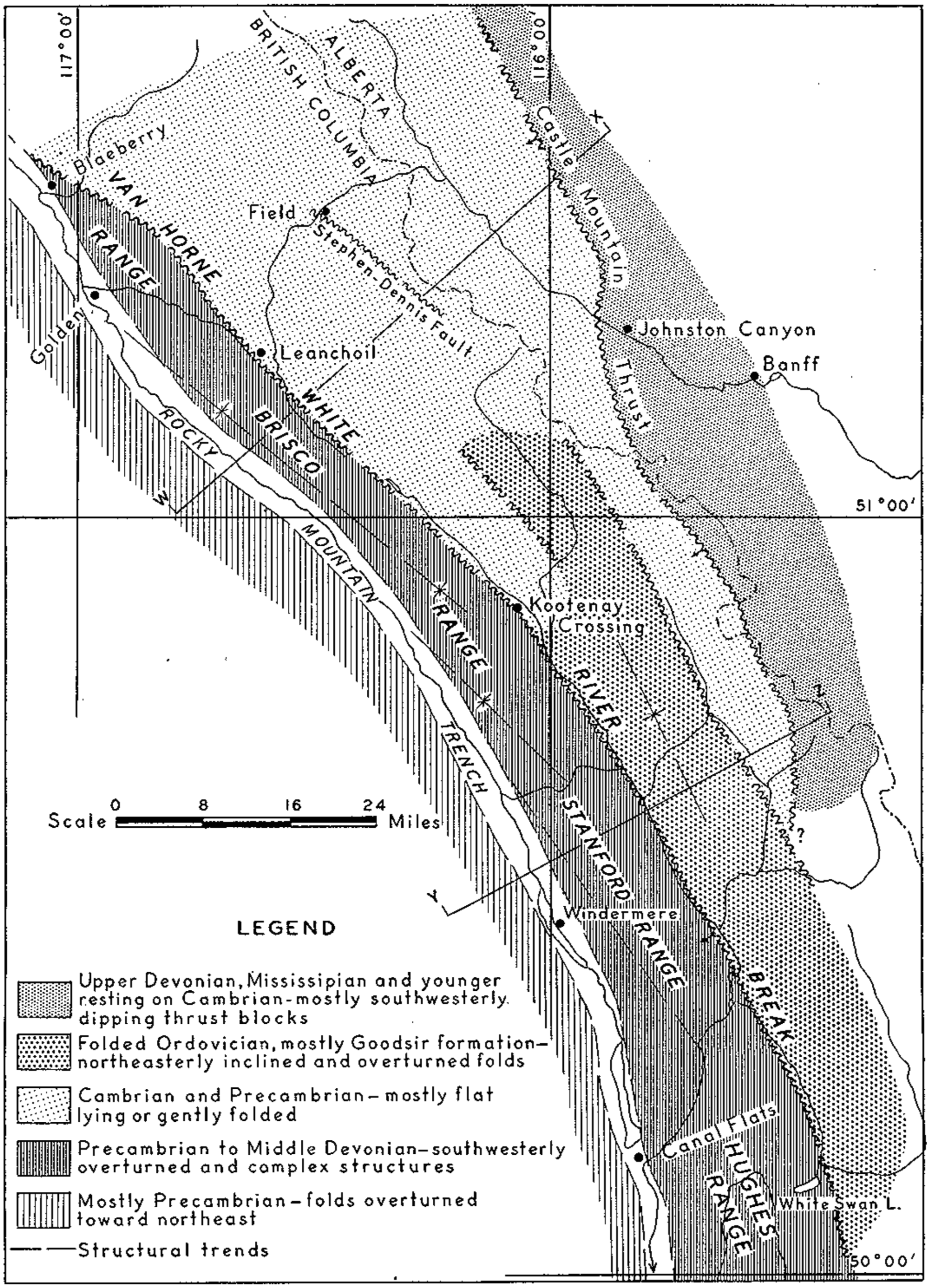

Figure 4. Regional geology of part of the Rocky Mountains.

is it known whether the phyllite is entirely a product of the movement on the White River break or whether it may in part represent a zone of prior deformation along which the thrust fault was localized.

GENERAL GEOLOGY OF THE MAIN RANGES SUB-PROVINCE

Before the regional significance of the White River break could be determined, it was found that much more information would have to be obtained on the geology of the Main Ranges sub-province, specifically in that part of the Rocky Mountains lying between the main line of the Canadian Pacific Railway and the 50th parallel and extending eastward to about the British Columbia-Alberta boundary. With this in mind, the writer carried out some broad reconnaissance work during the summer of 1952. Observations were made principally during several low-level flights over the entire area. These observations were supplemented and in part checked by photographs and by a number of widely spaced ground traverses along the western fringe. The results of this work are shown in generalized form in Figure 4 and in cross-sections W-X and Y-Z in Figure 5.

From this reconnaissance, supplemented by the data of previous workers, principally Dawson (1885), Allan (1914), and Evans (1933), the most outstanding features of the geology of the sub-province appear to be as follows:—

(*a*) The area is bounded on both the west and east sides by major faults. On the west it is bounded by the White River break and on the east by a major west-dipping fault (Castle Mountain thrust), along which Cambrian rocks have been thrust northeastward on to the folded succession of the Front Ranges. The Castle Mountain thrust fault is known to extend northward for 150 miles from a point just west of Johnston Canyon and southward to a point just south of Mount Assiniboine (F. K. North, 1952). Within the area under consideration it marks the western boundary of known outcrops of post-Middle Devonian rocks.

(*b*) Between Leanchoil and Johnston Canyon the entire width of the area is occupied by a panel of essentially flat or gently dipping competent Cambrian and Precambrian rocks. In general, this panel wedges out southward, apparently by convergence of the bounding faults, and is succeeded by less competent and more highly deformed younger rocks, probably the Goodsir formation* of Upper Cambrian or Ordovician age. Between Kootenay Crossing and Leanchoil, on the western side of the panel adjacent to the White River break, the attitude of the massive Cambrian formations changes from horizontal to moderately inclined, with dips up to 60 degrees southwest. This may represent dragging due to southwesterly directed thrusting which will be described later.

(*c*) The thick Goodsir formation, which occurs only on the mountain tops in the Field map-area, becomes more widespread to the south and is the principal formation occurring in the areas marked as "folded Ordovician" in Figure 4. East of the White River near White Swan Lake the Goodsir was observed from the air to be overlain by Glenogle shale, Wonah quartzite, and Beaverfoot-Brisco rocks. This gradational decrease in age of the rocks southeastward on the western side of the sub-province suggests a regional southeasterly plunge that was confirmed by field observations.

(*d*) In areas of "folded Ordovician," most of the folds are either asymmetrical or overturned toward the northeast (*see* Plate XII). Also, most of the thrust faults in these areas dip southwest (*see* Plate XIII). This northeasterly overturning and thrusting, which is characteristic of the remainder of the Rocky Mountains, starts immediately to the east of the White River break.

* Age in dispute—*see* Evans, 1933, pp. 131–134.

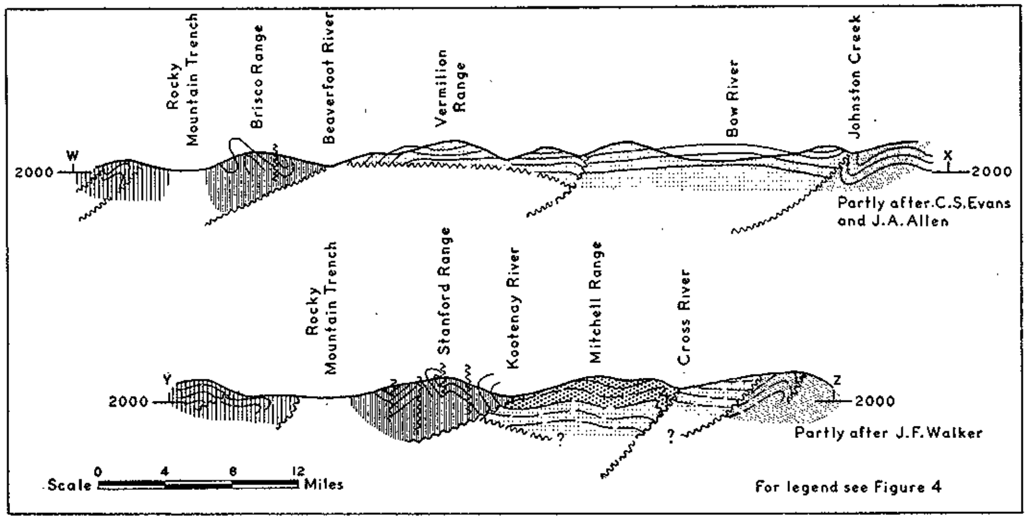

Figure 5. Structural sections W-X and Y-Z across the Rocky Mountains.

(*e*) A major longitudinal fault extends northwestward from the Albert River to and along the Mitchell River for at least 20 miles. This fault dips southwest and separates "folded Ordovician" on the west from flat-lying Cambrian rocks on the east. Although the age relationships across the fault indicate it to be a normal fault, the drag features associated with it are indicative of reverse movement (*see* Plate XIII). This fault may extend farther northwestward than shown on Figure 4 and may possibly join up with the Stephen-Dennis fault of the Field map-area.

(*f*) Within the Field map-area a major sheared zone was mapped by Allan (1914) within the lower part of the Chancellor formation. This sheared zone forms the base of the Ottertail Range and floors a large part of the area drained by the Ottertail River. It is cut off to the northeast by the Stephen-Dennis fault.

(*g*) A zone of shearing along the floor of the Vermilion River appears to be similar to that described by Allan. The shearing there is probably within the Ottertail and Goodsir formations but is considered to be continuous with the zone of shearing within the Field map-area, and it is interpreted as a gently eastward-dipping thrust fault.

(*h*) Although there is considerable similarity in general lithology between the Upper Cambrian-Ordovician formations of the Field map-area and those of the adjacent Brisco Range, no definite correlation has been established between them. In particular, much controversy exists over the correlation of the Goodsir formation (Allan, 1911 and 1914) with the McKay group (Evans, 1933). This arises principally from the fact that fossils have been found only in the lower 300 feet of the Goodsir formation, whereas fossils occur throughout the McKay group.

Evans (1933, pp. 131–134) gives a careful review of the controversy and shows that, as a result of it, two hypotheses have been put forward to explain the observed differences in the sediments and their fossil content. The first, put forward by Walcott, suggests that the deposits of the two areas were laid down in separate basins that were not contemporaneous and that later faulting has brought them into juxtaposition. The second view, held by Walker and favoured by Evans, is that deposition was contemporaneous, or partly so, in both areas and that both areas were part of the same basin. Differences in the sediments and the fossil content are ascribed by Evans to slight differences in the depositional environment.

The writer favours this second view and believes that the contemporaneous deposition of the two formations—i.e., the Goodsir formation and the McKay group—is substantiated by the discovery near White Swan Lake of the same younger formations overlying the Goodsir as overlie the McKay within the Stanford and Brisco Ranges. The differences in lithology and fossil content are believed to represent different facies of the same formation, probably deposited in widely separated parts of the same depositional basin, that have been brought into juxtaposition by a large amount of movement along the White River break.

REGIONAL PROBLEMS

This section deals with the principal regional problems of that part of the Rocky Mountains which includes the Stanford, Brisco, and Van Horne Ranges and the Main Ranges sub-province between latitudes of 50 degrees and 51 degrees 30 minutes. The problems in this section are numerous, but only those features considered of regional significance are included in the following list. In selecting the list, emphasis is given to structural problems because they are the ones most familiar to the writer and the ones which have received the least attention in the past.

(1) The Rocky Mountain trench.
(2) Truncation of the structures of the Stanford, Brisco, and part of the Van Horne Ranges at the Rocky Mountain trench. The structural trend of these ranges is at about 10 degrees to the trench.
(3) Southwesterly overturning of the structures of the Western Ranges sub-province is in direct contrast to the northeasterly overturning immediately to the east of the White River break and to the west of the Rocky Mountain trench.
(4) Longitudinal shortening of part of the Stanford Range and strike-slip movements along at least one of the major longitudinal faults.
(5) The highly elevated panel of almost flat-lying Cambrian and Precambrian rocks occupying the central part of the Rocky Mountains.
(6) The origin of the White River break and its relationship to the structures on either side and to the stratigraphic discontinuity existing across it.
(7) The wide zone of shearing and mylonitization associated with the White River break.
(8) Cambrian palæogeography of the Rocky Mountains.
(9) Source areas of the Upper Cambrian, Ordovician, Silurian, and Middle Devonian sediments.
(10) Post-Middle Devonian history of the area, including the possible reasons for the absence of post-Middle Devonian sediments.
(11) The age and significance of the Windermere series.

Some of the features involved in the foregoing list extend well beyond the limits of the area under consideration and pose problems that are so diverse and complex that they are unlikely to be solved until a great deal more mapping has been done. To a certain extent the same is true of all of the problems, and at this stage only speculative interpretations are possible. However, little progress is made toward the solution of regional problems of this magnitude unless the workers most familiar with them put forward their theories as well as their facts. For this reason, the following interpretations are included.

These interpretations are hypotheses proposed by the writer as reasonable solutions to most of the above problems. They are presented dogmatically in the interest of clarity.

Structural Interpretations

The writer agrees with previous workers (Walker (1926), Evans (1933)) that deformation of the Rocky Mountains was produced by compression from the southwest. The Purcell Mountains appear to have provided a relatively stable mass front that was parallel to the Rocky Mountain trench.

In the early stages of deformation a major wedge uplift was initiated that eventually was responsible for the more or less vertical uplift of the panel of essentially horizontal rocks occupying the Main Ranges of the Southern Rockies. The wedge was bounded on the east by the westerly dipping thrust that passes near Johnston Canyon (Castle Mountain Thrust) and on the west by an easterly dipping thrust believed to be represented by the sheared Chancellor in the Field map-area and by the sheared rock in the floor of the Vermilion River valley. The narrowing of the flat panel toward the south indicates that the strike of the western boundary fault must have been about northwest, oblique to the trend of the Rocky Mountain trench and to the main trend of the Rocky Mountains.

With continuing compression from the southwest, the wedge was uplifted, and at the same time was thrust outward toward the northeast and southwest. On the southwest this thrusting produced in the Stanford Range southwesterly overturned folds with a trend that was approximately parallel with the front of the thrust sheet and, consequently, slightly oblique to the trend of the Rocky Mountain trench. It is probable that these folds were highly compressed by being caught between the relatively stable mass of the Purcell Range and the southwesterly directed thrusting of the wedge, and that the longitudinal breccia faults of the Stanford Range were initiated at this time. Because the longitudinal faults were slightly oblique to the principal northeasterly compression, which is assumed to have been at right angles to the Rocky Mountain trench, a component of the compression would have acted parallel to the strike of the faults. This component would have acted toward the southeast and could have accounted for the observed strike-slip movement of west side to the south on the Redwall fault.

Uplift probably continued until the southwestern boundary thrust of the wedge became flattened to the point that further relief of stress by wedge mechanics became ineffective. At this point a southwest-dipping thrust was formed approximately along the southwest margin of the wedge. This is the White River break, on which most of the subsequent northeasterly thrusting took place and on which the previously formed, southwesterly overturned folds of the present Stanford and Brisco Ranges were thrust on to the relatively flat-lying formations of the wedge. The White River break also had the effect of cutting off the western part of the wedge and bringing into juxtaposition two widely separated parts of the Palæozoic depositional basin. The diagrammatic sketches in Figure 6 illustrate this stage of deformation, and show that another part of the same depositional basin may underlie the White River break. Movements on the two faults need not necessarily have been excessive to have produced a large foreshortening of the basin. Such foreshortening would account for the stratigraphic discontinuity that exists between the Stanford-Brisco Ranges and the adjacent ranges to the east.

The structures within the western part of the wedge are known to plunge southward, and it is assumed that the southwestern boundary thrust of the wedge, which is exposed within the Field area, becomes progressively more deeply buried toward the south. Consequently, the younger and much less competent Goodsir formation is brought in contact with the White River break farther to the south, where it shows the influence of northeasterly movement in the form of inclined and northeasterly overturned folds and related southwesterly dipping minor thrust faults. Similar structures are not found in the Field area, where the more massive Lower and Middle Cambrian formations are in contact with the White River break, suggesting that the fault passed through the relatively competent units without the accompaniment of folding.

Rocky Mountain Trench

The present work, being entirely confined to the area east of the Rocky Mountain trench, has contributed little additional information relating directly to the origin of the trench. The oblique-trending structures along Columbia Lake do not appear to persist across the trench, and extreme shearing is noted in exposures of Toby(?) conglomerate just east of Canal Flats railway station. These two facts supply evidence to indicate that

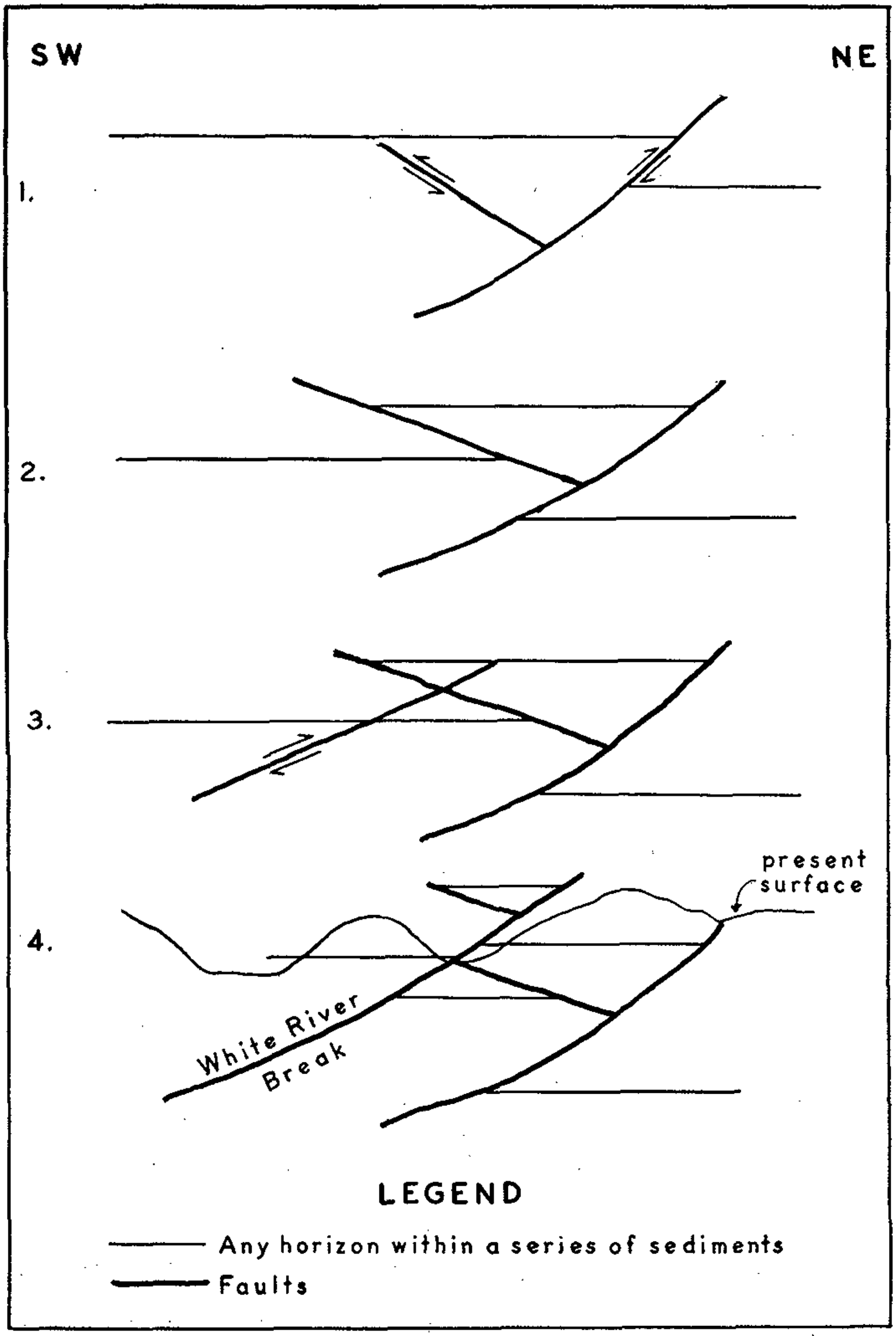

Figure 6. Diagrammatic cross-sections showing theoretical development of wedge and of White River break.

a fault or zone of faulting lies along the trench in this vicinity. It is possible that the large strike-slip movement along the longitudinal Redwall fault may be indicative of similar movement on a fault or faults along this part of the trench. However, it is considered more probable that the fault along this section of the trench is a westerly dipping thrust fault which is younger than the longitudinal strike-slip faults of the Stanford Range.

Stratigraphic Interpretations

The geological history of the Stanford Range can be interpreted only to a limited extent because of the incompleteness of the exposed section. Only a general description of the history will be attempted, and will be confined principally to the Palæozoic era. An adequate description of the Precambrian history of the region has already been given by Walker (1926).

The oldest Palæozoic horizon that can readily be correlated to the north and south of the Stanford Range is the Jubilee formation of Middle and (or) Upper Cambrian age. Within the Stanford Range, pre-Jubilee Palæozoic rocks are represented by quartzites, sandstones, and shales of the Cranbrook and Burton formations. These formations have a maximum combined thickness of 600 feet on Mount DeSmet at the south end of the map-area and to the north pinch out entirely in the vicinity of Lansdowne Creek. North of Lansdowne Creek, wherever the contact is exposed, the Jubilee formation is seen to rest directly on the Precambrian Horsethief Creek formation.

Although pre-Jubilee Palæozoic rocks are missing or are present only in minor amounts within the Stanford Range, they occur in much greater thicknesses to the north, east, and south of the range. Within the Dogtooth Mountains, Evans (1933) reports more than 8,000 feet of quartzites, argillites, slates, and shales between the Horsethief Creek and Jubilee formations. In the Field map-area there is approximately 6,000 feet of Lower and Middle Cambrian rocks below the Ottertail formation.* At Mount Assiniboine, about 20 miles northeast of the Stanford Range, a Lower and Middle Cambrian sequence, similar to that in the Field area, is reported by Deiss (1940) to be at least 4,500 feet thick. South of the Stanford Range the Cranbrook and Burton formations increase rapidly in thickness, and in the vicinity of Ram Creek are reported by Schofield (1922) to have an aggregate thickness of about 1,500 feet. Farther south, in the Cranbrook map-area, the Cranbrook formation is about 600 feet thick and is overlain at most places by the Lower Cambrian Eager formation, which is more than 6,000 feet thick.

From the distribution and thickness of the Lower and Middle Cambrian sediments lying between the Precambrian and the Jubilee formation, it is apparent that the Stanford Range must have been a "high" within the Palæozoic basin during at least part of this interval. Either the sediments were not deposited or they were deposited and later eroded before deposition of the Jubilee formation. Elsewhere the lithology and thickness of the pre-Jubilee sediments, particularly those of the Lower Cambrian, imply rapid geosynclinal sedimentation with a source area to the west, probably within the Purcell region.

The Jubilee and post-Jubilee sequence throughout the entire area is characterized by an abundance of carbonates and by only minor amounts of associated clastic sediments. This type of sedimentation suggests that at some time during the late Middle Cambrian or early Upper Cambrian the former geosynclinal sedimentation was replaced by depositional conditions of shelf type which persisted throughout the remainder of the period represented by the section; i.e., until the Middle Devonian. At two periods during this interval of time there must have been partial isolation of at least part of the basin. During the first period the Glenogle black shales were deposited, and during the second the Burnais gypsum was precipitated.

Some doubt exists as to the source area of Jubilee and post-Jubilee sediments. Walker (1926) has suggested that a land-mass existed in the region of the Purcell Range during this period because of abundant shallow-water features in the McKay group and

* Assumed to be the equivalent of the Jubilee formation.

Wonah formation and the manner in which the Palæozoic formations overlap one another and thin toward the west. However, if the Purcell region were the source area after the Middle Cambrian, it is very difficult to explain the scarcity of clastic sediments, particularly when it is considered that the Precambrian sequence in the Purcells consists chiefly of clastic rocks and that this source area would have been only a few miles west of the edge of the depositional basin. Because of this, the writer does not believe that the Purcell region was an important source area for sediments during Late Cambrian to Middle Devonian time, even though it may periodically have been slightly emergent within the Palæozoic basin.

During the late Middle Devonian or early Upper Devonian a significant change occurred in the Palæozoic basin. In the Foothills and Front Ranges sub-provinces there are no Silurian or Middle Devonian sediments and only sporadic occurrences of Ordovician sediments. This evidence, together with that of an erosional unconformity below the Upper Devonian, indicates that during at least part of the interval between the Cambrian and Upper Devonian the eastern part of the Rocky Mountains at these latitudes must have been a land area. During the late Middle Devonian or early Upper Devonian broad downwarping must have occurred before deposition commenced in the Upper Devonian. This deposition, once started, continued with only minor interruptions until the Laramide Revolution.

In the west, within the Western Ranges sub-province, the history of the basin is less clearly defined. Partial isolation of the basin at some time between the Middle Silurian and Middle Devonian is predicated by the presence of the Burnais gypsum in the Stanford Range. This was followed in the Middle Devonian by more widespread deposition of limestone and shale, represented by 300 to 600 feet of Harrogate formation. The subsequent history of the basin is unknown because no younger formations have been found. Two possibilities present themselves: either (*a*) the sediments were deposited and subsequently eroded, or (*b*) the downwarping in the east was accompanied by upwarping in the west sufficient to raise the area above the zone of deposition throughout the remainder of the Palæozoic, Mesozoic, and Tertiary. Decision between these alternatives will have to await much additional and detailed mapping, but at the present time the balance of evidence is slightly in favour of the second. Some of this evidence is derived from consideration of the probable history of the gypsum deposits and is discussed in the following chapter (*see* p. 60).

CHAPTER V.—ECONOMIC GEOLOGY

Gypsum is the only mineral found in commercial quantity within the map-area. It occurs within the Burnais formation as relatively pure beds that in places total more than 600 feet thick. Where this formation outcrops, principally along Windermere Creek and the Kootenay River, extremely large deposits of a good grade of gypsum have been found. These deposits have been estimated to contain more than 500,000,000 tons of commercial gypsum and hence must be considered among the largest in North America.

A few small deposits of barite as well as several of silver-lead-zinc and of copper mineralization have been discovered. Descriptions of the most important of these are included at the end of this chapter.

GYPSUM

History and Production

Primary gypsum was discovered in 1947, although secondary gypsum, occurring in sink holes on Windermere Creek, was reported by Walker in 1926. The first discoveries were made by E. E. Bryan, of Invermere, who, in partnership with E. C. Phillips and T. Cameron, located five claims on Windermere Creek in the vicinity of the present quarry-site. In the autumn of 1947 Columbia Gypsum Products, Inc. was formed to exploit these deposits, and early in 1948 development work and road construction were started.

After the finding of gypsum on Windermere Creek, discoveries in other parts of the range followed quickly. In 1948 deposits on Burnais Creek were discovered by Henry Cooper and Albert Cooper, of Windermere, and in 1949 large deposits on the Kootenay River were discovered by Gabriel Paul, of the Kootenay Indian Reservation. Gypsum was found in 1949 on the divide between Madias and Tatley Creeks by Joe Jimmy and in the autumn of 1950 between Shuswap and Stoddart Creeks by Henry and Albert Cooper. Three additional occurrences of gypsum were found in the course of the geological mapping, but they are, in general, thickly covered.

A few trial carloads of gypsum were shipped in 1949, but steady production did not commence until 1950. Up to the end of 1953 a total of approximately 90,500 tons of gypsum was shipped. In addition to this production by Columbia Gypsum Products, Inc. a few carloads of gypsum were shipped by Western Gypsum Products Limited in 1951 from a small quarry near the Kootenay River. This quarry has since been abandoned.

Physical Character of the Gypsum

The gypsum deposits occur as thick units of rock gypsum within the Burnais formation. The units range in thickness from 100 to more than 600 feet and are separated by relatively thin calcareous members which consist mostly of black fetid limestone, limestone-gypsum breccia, and carbonaceous shale. Locally, an occasional thin bed or lens of limestone-gypsum breccia occurs within the gypsum.

The gypsum is a fine-grained light-grey rock that superficially resembles limestone. It is generally well bedded and finely laminated (*see* Plates XV and XVI). The laminated character is produced by an alternation of three types of laminæ, each fine-grained and possessing a distinctive composition and colour. For purposes of description, they are named on a colour basis as follows: (*a*) Tan laminæ, (*b*) white or light-grey laminæ, and (*c*) black or very dark grey laminæ.

The tan-coloured laminæ range in thickness from 0.01 to about 0.4 inch and commonly make up about 40 to 50 per cent of the gypsum. They are finer grained, harder, and compositionally less pure than the white or light-grey laminæ.

The white or light-grey laminæ comprise about 50 per cent of all the gypsum. They have a definite sugary or crystalline appearance and are commonly slightly thicker than the tan laminæ. The colour of this type of laminæ shows a complete gradation from white to light grey and appears to be controlled by the quantity of impurities present.

The black or very dark grey laminæ are everywhere very thin, appearing as hair-lines in most cases. Under the microscope they are seen to be composed of carbonaceous material and very tiny grains of carbonates. They commonly occur on one or both sides of the tan laminæ.

Under a hand-lens or, more clearly, under the microscope, a finer lamination is seen to exist in each tan and white or light-grey lamina. The finer lamination is produced by a repetition of the coarser lamination on a much smaller scale. The finer laminæ range in thickness from 0.05 to 1.0 millimetre but average about 0.1 millimetre. As many as thirty may occur within one coarse lamina.

All the laminæ show a lateral variation in thickness. Laminæ less than 0.1 inch thick commonly lens out within a hand specimen and those about one-quarter of an inch thick rarely extend for more than 1 foot. This lenticular form is characteristic of every lamina, and because of it the three types of laminæ show large variations in their individual thicknesses. In a 6-inch thickness of gypsum it is normal to find the tan and light-grey laminæ each to range in thickness from a minimum of almost zero to a maximum of about 0.5 inch. No regularly repeated sequence appears to be present. Two tan laminæ may be separated by a light-grey lamina in one place, whereas in another place they may be separated by a black lamina. Similarly, light-grey laminæ may alternate in the sequence with tan laminæ and some may be separated only by black laminæ.

At one time it was thought that the coarse lamination might have a cyclical arrangement similar to the varving of glacial clays, but the foregoing description clearly indicates that no such regularity or rhythm is present.

Several types of penecontemporaneous or diagenetic structures can be seen everywhere in the gypsum but rarely in appreciable quantity. Typical slump structures are possibly the most common. These may be confined to one coarse lamina or may involve several laminæ; in either case, the area affected is rarely more than 2 inches wide and is commonly less than 1 inch. The structures vary from simple folds to highly complex folds that have been largely broken up by minor fractures. In only a few cases is there evidence that solution took place before deposition of the overlying laminæ, and consequently the slump structures are of little use for determining tops of beds.

Minor faults, that affect only a few laminæ, are common. Many of these are less than 1 inch long and cause displacement of the order of 0.1 to 0.2 inch. They usually die out into minor folds. Penecontemporaneous brecciation of isolated parts of the gypsum is another common primary structure. Pods of brecciated gypsum range in size from half of one lamina to as much as 1 foot wide. The fragments are as a rule irregular in shape, although they commonly are elongated parallel to the bedding. They are set in a matrix of gypsum which may have a slightly different colour or texture from that of the fragments. Another type of interbedded breccia consisting of fragments of limestone set in a white gypsum matrix has already been mentioned. There appears to be little difference between the two types of breccia, and it is probable that both owe their origin to penecontemporaneous deformation.

Cross-bedding and minor erosional unconformities occur in the gypsum, but are rarely well enough developed to be used for determining tops of beds. The minor erosional unconformities appear to have formed by penecontemporaneous solution or erosion that produced irregular surfaces on which overlying gypsum was precipitated. In the two most distinctive examples seen, the erosional plane was immediately overlain by one of the black laminæ. This suggests that the black carbonaceous laminæ formed within the normal sequence under conditions related to periods of non-deposition or slight solution.

Although diagenetic structures are common, localized laminar corrugation typical of that ascribed to expansion folding has not been found. Transformation of anhydrite to gypsum involves an increase in volume of 30 to 50 per cent, and normally produces considerable disruption of any primary lamination, commonly by local crumpling and intense folding. The absence of this type of structure is considered to be important evidence of a primary origin of the gypsum.

Secondary structures, such as joints, minor faults, and dragfolds, are widespread but produce little deformation of the gypsum as a whole. Flowage phenomena and other secondary structures that of necessity involve extensive deformation of the gypsum have not been observed except within the border zones of major faults. This is particularly remarkable in view of the intensity of the regional deformation in the Stanford Range. Gypsum in similar circumstances elsewhere is usually exceedingly deformed.

Of the secondary structures, joints are by far the most widespread. The commonest set is normally at right angles to the bedding. The joints are spaced from 2 inches to 4 feet apart, and are seen in the quarry to extend for more than 100 feet vertically. Between the joints numerous irregular, minor cracks are developed. Both these and the regular joints are as a rule filled with seams of secondary crystalline gypsum that has been deposited by ground-water solutions. Minor displacement of the laminæ occurs along many of the joints (*see* Plate XVI).

Major faults have a marked effect on the gypsum wherever they traverse it. These effects may be summarized as follows:—

(*a*) Disruption and in many cases total destruction of the more or less regular lamination that is so characteristic of the gypsum.

(*b*) Pronounced total brecciation adjacent to the fault, passing outward into less-brecciated but highly contorted zones.

(*c*) Differential bleaching which produces pods, lenses, and irregular zones of white non-laminated crystalline gypsum.

(*d*) Over-all reduction in grade. This is probably due to addition of carbonates and silicates and some iron oxides by hydrothermal solutions introduced along the fault zones.

Dragfolds were noted in gypsum occurrences along Nine Mile Creek but are not common. No recognizable cleavage is developed in the gypsum.

Features Developed as a Result of Weathering

Weathering initially produces a thin non-laminated crust on gypsum exposures. The crust is normally a light blue-grey or purplish grey, but in some instances it is very light blue-grey or creamy in colour. It has a composition slightly more pure than the gypsum on which it develops. In most exposures the crust has an open, sugary texture, but in places where the gypsum is in contact with running water, such as along the banks of the Kootenay River, the crust is fine grained and dense.

With continued weathering and with favourable topography, the gypsum slowly disintegrates to form a fine gypsum earth or gypsite. This is white or creamy in colour and, although apparently very fine grained, it possesses a distinctly gritty or sugary feel. In places along the Kootenay River more than 6 feet of gypsite occurs above the gypsum, but elsewhere in the range thicknesses over 3 feet are not common. The gypsite is always less pure than the gypsum from which it develops, as a result of contamination by other materials.

A characteristic Recent conglomerate commonly forms over the gypsum instead of gypsite. It is predominantly, although not entirely, restricted to areas underlain by gypsum. The conglomerate is made up of well-rounded pebbles, cobbles, and occasional boulders that are cemented by a fine-grained commonly buff-coloured matrix. Most of the fragments can be identified as belonging to the formations occurring within the range, but some of them, particularly along the Kootenay River, are obviously from much farther afield. For example, pebbles from the Ice River complex and from the Cross River diorite are common.

The cementing material of the conglomerate is so strong that fracture will usually take place through the pebbles instead of around them. In thin section, it is seen to be very fine grained and to consist mostly of tiny grains of carbonates, slightly larger grains of quartz, and irregular patches of iron oxides. Dust-size particles consist probably of clay minerals. A chemical analysis of a selected sample of the cement yielded the following results: SiO_2, 21.44 per cent; Al_2O_3, 5.62 per cent; Fe_2O_3, 2.15 per cent; CaO, 36.70 per cent; MgO, 1.67 per cent; CO_2, 28.02 per cent; SO_3, 0.89 per cent; combined H_2O, 2.00 per cent. Spectrochemical analysis of the same sample showed that minor amounts of potassium and titanium were present. The trace constituents included manganese, copper, sodium, strontium, chromium, and barium.

The conglomerate is developed most commonly on gently sloping hillsides and in areas where sink holes are present. In several of the larger sink holes the upper 50 to 75 feet of the walls consists of conglomerate unconformably overlying the gypsum, which in some cases is exposed beneath. Accumulations as thick as this are probably formed by the cementation of gravels that have sloughed off the hillsides into the developing sink holes. In most sink holes, and to a certain extent in all conglomerate occurrences, the conglomerate is most indurated at the base of the exposures and tends to become less and less indurated upward until, at the surface, it passes into uncemented gravels.

At some places a cemented earthy material, locally called " hardpan," is found overlying the gypsum. This hardpan seems to be very similar to the conglomerate, except that it is composed of finer particles. It occurs directly above the gypsum, above conglomerate, or as seams and lenses within the conglomerate.

The cementation of the conglomerate and hardpan is probably caused by deposition of calcite from ground-waters that have become saturated with carbonates as a result of the solution of gypsum. The reactions may be as follows:—

$$H_2CO_3 + CaSO_4.2H_2O \rightarrow CaCO_3 + H_2SO_4 + 2H_2O$$

$$Ca(HCO_3)_2 + CaSO_4.2H_2O \rightarrow 2CaCO_3 + H_2SO_4 + 2H_2O$$

The waters of Windermere Creek and of other creeks that drain areas underlain by gypsum are highly charged with sulphates as well as with carbonates, indicating that some at least of the gypsum is carried off in solution. Lime is also precipitated by these creeks as a white coating on pebbles and boulders at several places along their courses.

Probably the most distinctive feature associated with the weathering of the gypsum is the development of sink holes. These show a complete range in size from a few feet in diameter and a foot deep to those 400 to 500 feet in diameter and 100 to 150 feet deep. Most of the sink holes are round, with diameters about one and one-half times as great as their depths. However, some of the larger ones, particularly those that were formed by the compounding of two or three small sink holes, are very irregular in shape and show a considerable range in depth-diameter ratios.

The size of a sink hole depends chiefly on the depth of overburden. Where the depth is less than 10 feet and the slope is fairly gentle, such as at the head of Burnais Creek, numerous small sink holes are developed. On the other hand, where the overburden is approximately 10 to 30 feet, fewer but much larger sink holes tend to be developed, as along Windermere Creek. Where the overburden is very deep or the ground is almost flat, as in parts of the Kootenay River occurrences, a very characteristic topography often results. This consists of a flat or slightly rolling terrain that is broken occasionally by shallow dish-like depressions. These depressions are interpreted as sink holes which, either because of excessive overburden or because of incipient development, show only slight surface expression.

There seems little doubt that the sink holes originated owing to the collapse of near-surface subterranean caverns. Several such caverns have been uncovered in the opening-up of the quarry on Windermere Creek. The fact that no sink holes are developed in areas underlain by limestone is ample evidence that under existing climatic conditions gypsum is much more soluble than limestone.

Composition

The bulk composition of the gypsum is remarkably uniform throughout all the occurrences. Except where it has been contaminated with impurities adjacent to major faults, the rock gypsum is composed of at least 85 per cent and usually over 90 per cent of the mineral gypsum. In rock of commercial grade—i.e., over 90 per cent gypsum—insoluble impurities comprise less than 1 per cent. These are principally silica, carbon, alumina, and iron oxides. The remainder, about 6 to 8 per cent, is made up of fine grains of carbonates which occur throughout the gypsum. Native sulphur in the form of isolated blebs was noted at several places in the quarry and in outcrops farther up Windermere Creek, but is relatively rare.

Under the microscope the tan-coloured and black laminæ are seen to contain most of the impurities, whereas the white or light-grey laminæ are composed almost entirely of gypsum. The following table shows the results of separate analyses of a tan and of a light-grey lamina. The figures represent percentages.

	SiO_2	R_2O_3	CaO	MgO	CO_2	SO_3	H_2O+	H_2O-	$CaSO_4.2H_2O$
Tan lamina	0.82	0.28	32.72	1.24	2.65	43.23	18.95	0.11	93.0
Light-grey lamina	0.32	0.12	32.88	Trace	0.50	45.75	20.43	0.04	98.5

N.B.—R_2O_3 includes the oxides of iron, aluminium, titanium, zirconium, and phosphorus. CaO reported includes a small fraction of 1 per cent of SrO.

A number of complete chemical analyses of gypsum samples from the Windermere Creek occurrences have been reported previously by Cummings (1948) and McCammon (1950). To supplement these the writer collected a number of samples from some of the other occurrences for analysis. The results of these analyses together with those of Cummings and McCammon are included in Appendix C.

A point of interest becomes evident if the percentage of gypsum in each sample is calculated independently on the basis of each of its constituents; i.e., CaO, SO_3, and H_2O. In all the samples the percentage of gypsum indicated by the content of SO_3 is either equal to or 1.0 per cent less than the gypsum indicated by the content of H_2O. This shows that virtually no anhydrite is present in these samples. Furthermore, during the course of exploration and mining, partial analyses were continually made, and none indicated an appreciable quantity of anhydrite. These tests have extended to a depth of more than 150 feet.

It is also of interest to note that if the percentages of gypsum present in a sample are calculated independently from the SO_3 or H_2O content and from the CaO content, there appears to be a slight excess of CaO in each sample.* This apparent excess may consist of SrO or CaO combined with insoluble impurities to form some mineral that has not been identified. Another possibility is that some of the MgO may be present as brucite, making more CO_2 available to form calcite and consequently reducing the amount of CaO available to form gypsum.

The colour of the powdered gypsum and hemihydrate made from it is greyish white. This property prohibits use of the gypsum in the manufacture of finishing plaster but is not detrimental to its use in other phases of the gypsum industry. The low content of insoluble impurities makes the gypsum particularly desirable to the cement industry.

Origin

The gypsum deposits of the Stanford Range are of sedimentary origin. The complete absence of expansion folding structures so characteristic of secondary gypsum deposits, the very widespread occurrence of a uniform primary lamination, and the absence of anhydrite at depth clearly indicate that the gypsum was not formed by hydration of anhydrite. The gypsum was precipitated from sea water as gypsum and has remained as such since its formation.

* The percentage of CaO in the gypsum was estimated in the following manner: Enough of the CO_2 was used to convert all the MgO to $MgCO_3$, and the remaining CO_2 was used to form $CaCO_3$, using part of the CaO, for this pur pose. The remainder of the CaO is the quantity assumed to be present in the gypsum mineral.

This fact may appear to conflict with observations made at many other gypsum deposits. The following discussion is intended to show that no conflict exists, and that gypsum is the primary calcium-sulphate mineral normally to be expected when sea water is evaporated.

It has been noted in many places in North America and elsewhere that bedded calcium sulphate deposits encountered by drilling at depths below 2,200 feet are without exception* in the form of anhydrite. Also, many deposits of calcium sulphate that are gypsum at the surface pass downward into anhydrite. Two interpretations of these facts have been suggested: (*a*) That all calcium sulphate is deposited as anhydrite and that gypsum only results from secondary hydration of anhydrite at or near the surface, or (*b*) that most of the calcium sulphate is deposited as gypsum which undergoes a pressure-temperature conversion to anhydrite at depth.

The first interpretation appears to be well substantiated by field evidence that shows that in most gypsum beds the pre-existing material was anhydrite. However, although this evidence proves in many instances that gypsum developed from anhydrite, it does not necessarily prove that the anhydrite itself was primary, and, furthermore, the first interpretation does not account for primary gypsum deposits such as those of the Stanford Range. On the other hand, Posnjak (1938 and 1940) has shown that on evaporation of sea water at temperatures below 42 degrees centigrade it is not possible to precipitate anhydrite without previously precipitating much of the calcium sulphate as gypsum.

The second interpretation is in accord with the chemistry of sea water and is substantiated in part by occurrences of primary gypsum. Most, if not all, of the facts of field distribution of calcium sulphate deposits would be explained by it if a depth transformation of gypsum to anhydrite could be proved.

In the course of investigating the literature for possible evidence in support of a depth transformation, it was discovered that, although Posnjak (1938) had determined the transition temperature of gypsum to anhydrite in the presence of a water solution to be 42 degrees centigrade at a pressure of 1 atmosphere, no data were available on the transition temperatures at other pressures. The writer sought the advice of G. C. B. Cave, Chief of the Analytical Branch of the British Columbia Department of Mines, who became interested in the problem and subsequently carried out an investigation of the chemistry involved. As a result of this research, Cave has found that approximate values for the transition temperatures of gypsum at various pressures can be derived by a thermodynamic treatment of the solubility data of Posnjak. He has plotted this information on a preliminary graph† which, with his permission, is included in this report (*see* Fig. 7). This preliminary graph shows the transition temperature of gypsum to anhydrite in the presence of a saturated aqueous solution as a function of pressure. Also shown in the graph is a line representing the variation in the temperature and pressure of the earth with change in depth, assuming a thermal gradient of 30 degrees centigrade per 1,000 metres and a surface temperature of 16 degrees centigrade. It can be seen that this line intersects the transition curve at a depth of approximately 1,075 metres (3,500 feet). In other words, at this thermal gradient gypsum passes from its field of stability into that of anhydrite at a depth of about 3,500 feet, and in the presence of an aqueous solution should be slowly converted to anhydrite. If higher thermal gradients or higher surface temperatures are assumed, then the transformation should take place at shallower depths. For example, in Louisiana, where the average thermal gradient is about 42 degrees per 1,000 metres and the average surface soil temperature is about 19 degrees, the transition of gypsum to anhydrite should take place at approximately 2,000 feet. This depth is in accord with the greatest depth at which gypsum has been recorded in wells in Louisiana. Goldman (1952, p. 61), in his detailed study of gypsum-anhydrite caprock of the Sulphur salt dome in Louisiana, makes the following observation which is pertinent in this connection: "In well 194, a fairly sharp boundary between the zones in which gypsum and

* A few old drill logs report gypsum to depths of 3,000 feet, but the identifications have since been questioned.

† The method used to obtain the graph is summarized by Dr. Cave in Appendix C, p. 80.

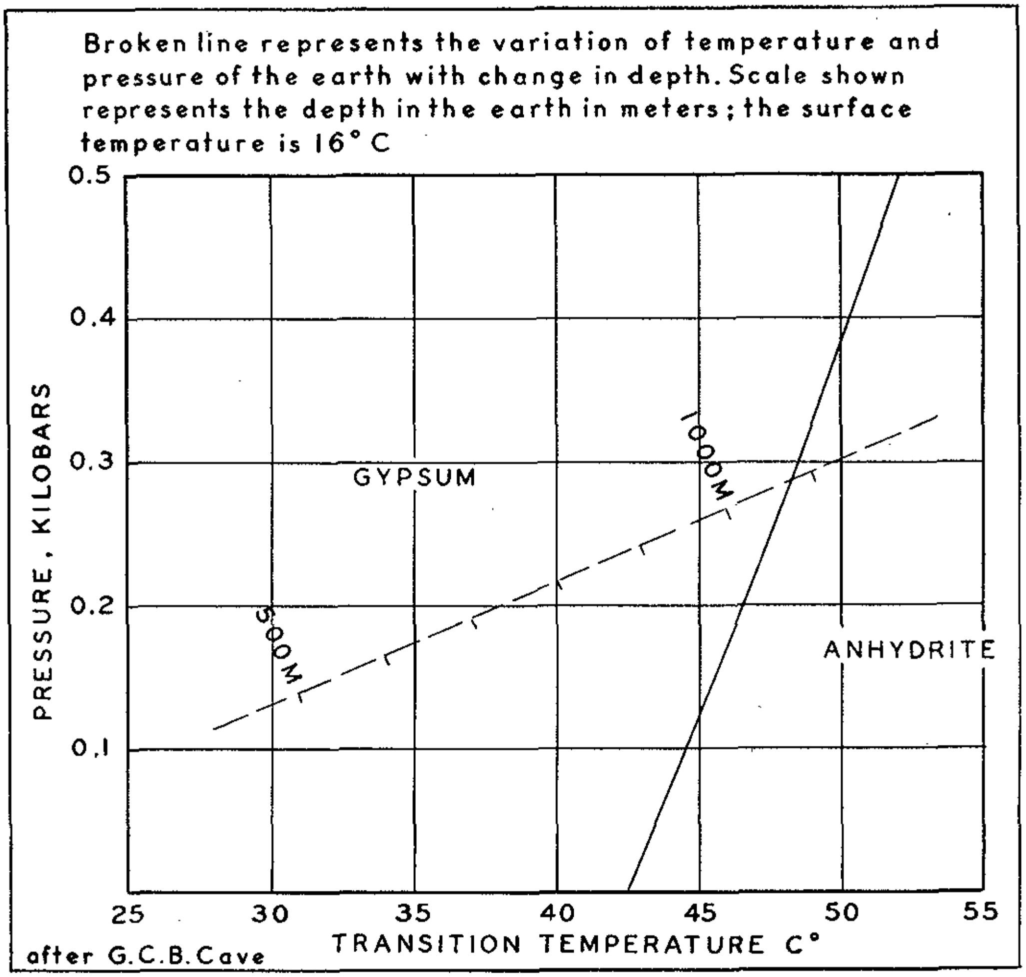

Figure 7. Preliminary graph of the transition temperature of gypsum to anhydrite.

anhydrite, respectively, are stable seems to be at a depth of about 1,183 feet. Above this, gypsum is common and unrelated to regeneration; below it, gypsum is uncommon, and every gypsum body is extensively regenerated. It may, therefore, be assumed that, under the pressures, temperatures, and ground-water conditions affecting this cap rock, gypsum is generally stable above this boundary and anhydrite below it."

The foregoing considers only the case where a water solution is in contact with the gypsum. In nature, water trapped within gypsum at the time of deposition would contain some dissolved salts. Also, most ground-waters during circulation become contaminated with dissolved salts. It is therefore probable that a solution in contact with gypsum at depth would be somewhat saline. In view of this, it is necessary to consider what effect salt solution would have on the solubilities of gypsum and anhydrite and on the transition temperatures of gypsum.

Posnjak (1940) has shown that in the presence of a synthetic sea-water solution at 30 degrees centigrade the solubilities of both anhydrite and gypsum are increased and that a transition of gypsum to anhydrite should take place at this temperature. This represents a lowering of 12 degrees in the transition temperature at atmospheric pressure. Unfortunately, the transition temperatures have not been worked out for other pressures nor are many data available on the solubilities of gypsum in salt solutions at other temperatures. However, inasmuch as the transition point at one atmosphere is lowered by the presence of a salt solution, it seems probable that it will also be lowered at higher pressure, or at least lowered within the range of pressure considered in Figure 7. If this inference be correct, then a salt solution will have the effect of displacing the transition curve of Figure 7 toward the left and will indicate a transition of gypsum to anhydrite at shallower depths than those estimated for a water solution. The extent to which the depth of transition would be lessened would depend on the slope of the salt-solution curve and on the salinity of the solution. Estimates based on the present data suggest that the depth may be lowered as much as 50 per cent.

Since the completion of Cave's investigation, a paper on the equilibrium relations between anhydrite and gypsum has been published by MacDonald (1953). The results derived are substantially the same as those derived by Cave for the case shown in Figure 7. However, MacDonald also considers the case where a differential pressure is acting on the solid and liquid phases. In general, such an environment provides a lower transition temperature for gypsum than one in which the pressure on the liquid and solid phases is the same. MacDonald also presents some new data on the dependence of the dehydration temperature of gypsum on concentration of sodium chloride in solution. His results tend to substantiate the foregoing considerations.

The chemical data so briefly discussed lead to the following general conclusions:—

(1) The transition of gypsum to anhydrite at depth is in agreement with the stability relationships of the two minerals. According to the present approximate figures, gypsum should be converted to anhydrite at depths between 2,000 and 3,500 feet in the presence of a water solution. In the presence of a salt solution the transition probably would take place at shallower depths.

(2) At atmospheric pressure, normal surface temperatures, and in the presence of a water solution, anhydrite is unstable (really, metastable). It is therefore to be expected that slow conversion of either primary or secondary anhydrite to gypsum should take place at or near the surface.

(3) The occurrence of primary gypsum deposits appears to indicate that stable temperatures have prevailed subsequent to their formation, at a depth of burial probably less than 2,000 feet.

This last conclusion applied to the primary deposit of the Stanford Range may have a significant bearing on the post-Middle Devonian history of the area. It is known that the Burnais formation is probably 1,000 feet thick and the overlying Middle Devonian Harrogate formation is about 300 to 600 feet thick. These represent an aggregate thickness of about 1,500 feet overlying the lower gypsum beds of the Burnais. Since these beds show no evidence of ever having been converted to anhydrite, it seems probable that they were never buried much more deeply than they are at the present time. In other words, the primary character of the Burnais gypsum beds appears to indicate a post-Middle Devonian history of non-deposition rather than one of continued deposition and large subsequent erosion (*see* discussion on stratigraphic interpretations, p. 52).

This deduction is based on the primary character of the gypsum and on the chemical data presented above. It is faced, however, with one major difficulty. The deposits along the Kootenay River and on Windermere Creek are at elevations of approximately 3,000 and 4,000 feet respectively, and they occur in areas with a local relief of between 3,000 and 5,000 feet. The relief is presumably post-Laramide in age, and, consequently, at the end of the Laramide orogeny the gypsum now exposed would appear to have been covered by a thickness of rock approximately equal to the present local relief. Although this load could have been almost entirely structural in nature, the depth of burial should have been sufficient to have converted the present primary deposits of gypsum to anhydrite. Not enough data are available on the Mesozoic and Cenozoic history of this part of the Rocky Mountains or on the rate of conversion of gypsum to anhydrite to resolve this seeming incongruity at the present time.

Reserves of Gypsum in the Stanford Range

Within the Stanford Range a tremendous amount of commercial gypsum is available. A very conservative estimate would place the amount of gypsum that could be mined under present economic conditions by quarry methods at approximately 500,000,000 tons. The total reserves are probably several times this figure.

Guides to Gypsum Deposits

Up to the present time, sink holes have proved an unerring guide to the occurrence of gypsum. Not only do they make it possible to trace the distribution of gypsum in covered areas, but in many instances they contain the only natural outcrops of gypsum to be found in such areas.

Although gypsite is an infallible guide to the occurrence of gypsum, care must be taken that white glacial silt is not mistaken for gypsite. However, the silt is invariably calcareous and the two may be readily distinguished by testing with dilute hydrochloric acid.

Conglomerate and hardpan are most commonly developed in areas underlain by gypsum but serve only to a limited extent as guides because they are not entirely restricted to such areas.

The vegetation in areas underlain by gypsum is in places significant. Around Windermere Creek quarry it has been found that where growths of small fir and poplar occur, hardpan or conglomerate overlies the gypsum. On the other hand, where large, openly spaced fir-trees are present, gypsite or uncemented earth cover the gypsum. On the divide between Windermere Creek and Burnais Creek, where the gypsum outcrops or has only a thin covering of overburden, the trees developed on it are larger and more widely spaced than are the trees growing on ground underlain by other rocks. These changes in the vegetation can clearly be seen on the ground and in aerial photographs.

Occurrences

Gypsum beds of the Burnais formation occur within the map-area at six localities, only three of which are sufficiently accessible to be of commercial importance. These localities are (*a*) between Stoddart and Shuswap Creeks, (*b*) along Windermere and Burnais Creeks, and (*c*) along Kootenay River.

Stoddart Creek-Shuswap Creek

At this locality the gypsum is confined to a small down-dropped fault block that lies between the Redwall fault on the east and a smaller less conspicuous fault on the west. The smaller fault brings the gypsum beds into juxtaposition with strata of the McKay group and the Beaverfoot-Brisco formation.

The outcrops of gypsum are found chiefly in the bottoms of sink holes on the divide area between the two creeks. Some large outcrops occur north of the divide between elevations of 5,000 and 6,000 feet, on the slope that leads down to Shuswap Creek.

Windermere Creek-Burnais Creek

The deposits in this locality are the second largest in the map-area and are the only ones being mined at the present time. In this locality the Burnais formation underlies an area of about 6 square miles, much of which is low covered ground adjacent to the two creeks. Natural outcrops are scarce and are confined to a few of the larger sink holes on Windermere Creek, a small area adjacent to No. 1 quarry, the divide area between Windermere and Burnais Creeks, and some of the sink holes at the head of Burnais Creek.

Columbia Gypsum Products Quarry.—No. 1 quarry of Columbia Gypsum Products, Inc., is situated just north of Windermere Creek and about 10 miles by road from

Athalmer, the nearest railway station. It is on a gently sloping, timbered hillside at an elevation of 4,100 feet.

Figure 8 shows the location of the quarry and the geology of the area in the vicinity of it.

For the most part, the ground adjacent to the quarry is heavily covered. Exposures are restricted to exploratory trenches, a few large sink holes, and the deep gully on the east side of Figure 8. Little is definitely known about the structure, and, as a result, there is some doubt concerning the stratigraphy. On the east side of the deep gully there are two small exposures of nodular limestone and limy shale which contain abundant fossils of the Harrogate formation. The Harrogate exposures are separated by a small covered interval from a considerable thickness of gypsum which appears to underlie the limestone concordantly. This gypsum member outcrops in the gully and has been traced northwestward for more than 3,500 feet by exploratory trenches and sink holes. It is conformably underlain, in a large sink hole 1,100 feet east of the quarry, by dark fetid limestone typical of the Burnais formation. The limestone appears to be underlain in turn by a second member of gypsum which, in the immediate vicinity of the quarry, is split by a 50-foot member of interbedded limestone and gypsum (shown as limestone on Fig. 8). This second gypsum member forms a northwest-trending band exposed in the large sink hole southeast of the quarry and by several trenches northwest of it. The two gypsum bands diverge slightly toward the northwest with a concomitant increase in the width of the limestone band between them. Another band of Burnais formation limestone occurs in the southwest corner of the mapped area, but, because of its very different attitude and the presence of shearing in the adjacent gypsum, a fault is believed to lie between it and the second gypsum band.

It is not known whether the stratigraphy is as indicated or whether the second gypsum band is a structural repetition of the first. Repetition could be due to folding into an almost isoclinal southeast-plunging anticline that is overturned to the southwest, or it could be due to primary thickening of the limestone. It is also possible, though not probable, that the two bands represent a structural repetition produced by faulting. The available evidence favours repetition by folding because several dragfolds and some of the primary structures exposed in the quarry all suggest that the beds at the quarry are overturned. The evidence, however, is not conclusive.

The quarry is within part of the second or southwestern band of gypsum. The bedding strikes northwest and dips rather regularly about 70 degrees to the northeast. The beds here may be overturned, but the following stratigraphic description is given in ascending order of beds from southwest to northeast.

A total stratigraphic thickness of about 500 feet is exposed in the quarry face and in near-by trenches. The lower 300 feet consists of poorly laminated gypsum which is highly contorted and slightly stained by iron oxide near the base. The rock in this section averages between 80 and 90 per cent gypsum, which is slightly too impure to be of commercial use at the present time. This lower gypsum is overlain by a 50-foot member consisting of alternating thin beds of black fetid limestone and normal laminated gypsum and occasional thin beds of limestone-gypsum breccia. This calcareous member is overlain by 115 feet of well-laminated gypsum which in turn is overlain by an unknown thickness of thin-bedded dark-grey limestones of the Burnais formation.

The entire present production comes from the upper or northeastern gypsum band which averages about 92 per cent gypsum. The overburden ranges from a few inches to more than 10 feet and consists of hardpan, conglomerate, gypsite, or earth. Local pockets of overburden occur within the upper 20 feet of the gypsum and fill solution-widened joints or collapsed solution caverns.

In 1953 the quarry face measured about 110 by 110 feet and was being mined in 16-foot benches. The broken rock was loaded by a 1½-yard shovel and hauled by truck to a crushing plant nearby (*see* Plate XVII). The crushed and sized product was hauled by truck about 9½ miles to the railway siding at Athalmer. All quarrying and hauling was done under contract.

Other Outcrops.—Two miles southeast of the quarry a very large compound sink hole is now occupied by a small lake, known locally as Lost Lake. Around the south and west sides of the sink hole, gypsum forms very extensive outcrops, in one of which a continuous stratigraphic thickness of gypsum in excess of 600 feet is exposed. The gypsum outcrops fairly continuously for one-half mile to the northwest of Lost Lake but beyond is deeply covered with overburden.

Other large outcrops of gypsum at about 5,000 feet elevation on the divide between Windermere and Burnais Creeks indicate a band about 500 feet thick. Immediately to the east of this band there is a small outcrop of limestone that resembles part of the Burnais formation and overlies the gypsum with apparent conformability. One thousand feet farther east, across an area of deep overburden, a group of sink holes suggests the presence of a second band of gypsum, also about 500 feet thick. It is not known whether this is a separate band or a structural repetition of the first.

Outcrops have been found also at the head of Burnais Creek in many of the numerous sink holes. Stripping and trenching there have revealed that the overburden, which is mostly uncemented earth and gypsite, ranges from 2 to 6 feet deep.

Kootenay River Locality

The most extensive deposits of gypsum within the map-area are along the Kootenay River, from 5 to 9½ miles northeast of Canal Flats. The deposits are so enormous that in one place the east bank of the river for more than three-quarters of a mile consists of a continuous cliff of gypsum that ranges from 10 to 220 feet high (*see* Plate XIV).

Besides the gypsum along the river, other large outcrops occur farther up valley slopes, forming a series of rather abnormal cigar-shaped ridges. The ridges extend from 3,100 feet to about 3,700 feet in elevation, and are separated from each other by deep drift-filled gullies. The overburden on ridge crests at elevations above 3,300 feet is as a rule less than 3 feet deep, but on crests at lower elevations or along the sides of ridges it is commonly much deeper. The overburden normally consists of gypsite, uncemented earth, or gravel, but in a few places it is Recent conglomerate.

Gypsum outcrops in sink holes along the east bank of the Kootenay River and on both sides of Nine Mile Creek. One very large sink hole on the north side of Nine Mile Creek about 1½ miles above its mouth exposes a 70-foot cliff of gypsum for a distance of about 250 feet. This gypsum, unlike that in other occurrences, is highly dragfolded.

Gypsum is exposed along the banks of a steep gully that enters Nine Mile Creek from the north side about 1 mile above its mouth. Between this gully and the large sink hole described in the last paragraph a number of small patches of gypsite have been found, suggesting that the gypsum extends continuously between the two localities under a light mantle of overburden.

Western Gypsum Products Limited Quarry.—Western Gypsum Products Limited opened up a small quarry about a quarter of a mile west of the Kootenay River at a point half a mile south of the mouth of Nine Mile Creek. The quarry is reached by a road a quarter of a mile long that leaves the main Kootenay River road at a point about 8½ miles from Canal Flats.

The quarry has been cut westward into a steep hillside, exposing a face of gypsum about 100 feet long and 20 to 50 feet high. A further advance of the quarry westward is not possible because at its present limit a major northeasterly trending fault brings Upper Cambrian beds of the Sabine formation into contact with the gypsum. The gypsum is the normal well-laminated variety except for numerous lenses, blebs, and irregular areas of white massive gypsum that are distributed throughout. In some places these show cross-cutting relationships with the laminated gypsum, but in other places the contact between the two is gradational. In addition to the zones of massive gypsum there are irregular zones of brecciated gypsum, highly contorted gypsum, and, nearer the fault, zones of secondary limestone-gypsum breccia.

A few trial carloads were shipped from the quarry during the summer of 1951, but no work has been done since. The average shipping grade from the quarry could not be maintained above 85 per cent without a certain amount of hand-picking.

Other Workings.—Columbia Gypsum Products, Inc. has done some diamond drilling and considerable stripping and trenching on its Kootenay River claims. Much of this work has been in an area at about 3,400 feet elevation, about half a mile south of the quarry of Western Gypsum Products Limited. Two roads provide access to trenches excavated on several of the previously mentioned cigar-shaped ridges. One of these trenches gives a fairly complete section through a 400-foot stratigraphic thickness of gypsum. Sample 13 (*see* Appendix C) was taken from part of this section.

Exposures of gypsum have also been observed on the divide between Madias and Tatley Creeks and on a ridge one-half mile southwest of Tegart Pass. Gypsum is believed also to underlie an area in the vicinity of Pedley Pass (*see* p. 26).

BARITE

Several small deposits of barite occur in the Stanford Range. One of these, currently owned by Tom Cameron, is about 4 miles southeast of Windermere. It is on the moderately steep western slope of the Stanford Range about 300 feet higher than the upper terrace level of the Columbia Valley. It is reached via the access road to Tegart's ranch and by an abandoned logging-road which branches off about 1½ miles east of the main highway. A quarter of a mile of trail leads to the showing from the end of the logging-road.

A number of trenches and some stripping expose the barite in patches over an irregularly shaped area of about 1,000 square feet. The barite occurs as a number of pods and lenses within the massive Upper Jubilee dolomite. Most of these contain numerous inclusions of white chert and buff-weathering recrystallized dolomite. The barite is mostly white, although certain irregularly distributed zones are stained light brown by secondary iron oxide derived from the inclusions and host rock. A few specks of galena were seen, as well as a few small patches of malachite and azurite.

Another showing on the same property is about 1,000 feet southeast of the foregoing and 300 feet higher. A 3-foot barite vein is exposed by scattered pits over a total length of about 60 feet. The barite is buff to light brown in colour due to iron oxide staining, and contains more copper impurities than the other showing.

Other occurrences of barite were found on the ridge to the north of Windermere Creek and at an elevation of about 6,000 feet on the mountain that lies 2 miles northeast of Pedley Mountain.

In all cases the barite appears to be hydrothermal and to have been introduced with minor amounts of copper and lead minerals.

METALLIC-MINERAL DEPOSITS

A few prospects of copper and silver-lead-zinc mineralization occur within the map-area, but no commercial deposits are known at the present time. The Lucien and the Swansea are the most significant of the prospects and the only two that have had work done on them during the past ten years.

Lucien

The Lucien showing was discovered in the summer of 1952 by Lucien Jimmy, of the Kootenay Indian Reservation. It is about 5 miles southeast of Windermere on the western slope of the Stanford Range at an elevation of about 4,500 feet. Its position is indicated on Figure 2. At the present time no recognizable trail leads to the showing.

Stripping operations have uncovered what appears to be an isolated pod of mineralized dolomite that ranges from 2 to 15 feet in width and outcrops over a slope distance of 35 feet. The ore zone is surrounded by massive Jubilee dolomite, except on the west side where it is covered by talus. The ore consists of brownish, highly oxidized brecciated dolomite that is partly replaced by galena. A channel sample taken across a width of 9.8 feet assayed: Gold, trace; silver, 0.9 oz. per ton; lead, 6.3 per cent; zinc, 0.9 per cent.

Swansea

The Swansea showing is at an elevation of 5,100 feet on the eastern shoulder of Swansea Mountain. It is reached by the trail leading to the Forest Service lookout cabin on Swansea Mountain. Mineralization occurs within the Upper Jubilee dolomite in a brecciated zone that lies just east of a large northerly striking fault. Copper minerals, chiefly malachite and azurite with some bornite and chalcopyrite, occur along narrow discontinuous stringers within the calcite and hematite cement of the breccia. Assays as high as 17.5 per cent copper have been reported.*

About the turn of the century a considerable amount of work was done on the showing and a few hundred tons of ore was shipped. The ground was relocated in 1946 by Sheep Creek Gold Mines Limited, who did some diamond drilling in 1947 with inconclusive results.

* *Minister of Mines, B.C.*, Ann. Rept., 1898, p. 1039.

APPENDIX A.—MEASURED SECTIONS

UNDIVIDED LOWER AND MIDDLE CAMBRIAN
(Cranbrook and Burton Formations)

The following section was measured on the southeast flank of Mount DeSmet:—

Conformable contact with Lower Jubilee dolomite.	Thickness (Feet)
Burton Formation (345 Feet Thick)	
Light buff, well-bedded dolomite. Sandy near base	16
Coarse-grained sandstone. Calcareous cement. Weathers tan to light buff	20
White fine-grained quartzite. Numerous grains and patches of limonite. Over-all colour of weathered surface is light brown	86
Grey shale—a few interbeds of brown quartzite	11
Dolomitic sandstone with scattered interbeds of grey shale	8
Thin-bedded sandstone, mostly brownish and cross-bedded. Beds 1 to 15 inches thick	70
Alternating beds of sandstone and shale ½ to 2 inches thick	6
Cross-bedded brown sandstone in beds 1 to 2 feet thick	10
Interbedded brown sandstone and sandy shale, thin-bedded	33
Mostly green and red papery shales, with occasional interbeds of brown or grey sandstone	41
White and buff quartzite	12
Grey and greenish papery shales	6
Thin-bedded brownish sandstone	7
Massive white quartzite	6
Whitish-grey dolomite	1
Laminated brownish sandstone in beds 3 to 12 inches thick	12
Cranbrook Formation (260 Feet Thick)	
Mostly white blocky quartzite, weathering a mottled brown and white. Beds 6 inches to 2 feet thick and very regular. Cross-bedding common. Mostly fine grained	260
Contact concordant with reddish and blue-grey slates of the Horsethief Creek formation.	

No fossils were found in this section.

LOWER JUBILEE DOLOMITE (945 FEET THICK)

A complete section of the Jubilee dolomite is exposed on the south flank and face of Fairmont Mountain.

Arbitrary contact with Upper Jubilee.	Thickness (Feet)
Well-bedded light-grey dolomite. Laminæ indistinct, although present in most beds. Upper 20 feet gradational to Upper Jubilee	82
Dark-grey well-laminated dolomite. Slump structures and cross-bedding features common in laminæ	47
Medium- to thick-bedded light-grey dolomite. Laminations indistinct except in occasional beds. Numerous white dolomite stringers near top	235

	Thickness (Feet)
Light-grey finely laminated dolomite. Beds 18 inches to 2 feet thick. A very light grey, almost whitish-weathering bed every 20 to 30 feet. Numerous scattered white chert nodules, the weathering-out of which produces rough weathered surfaces. At 560 feet from base of section a 3-inch bed of dark buff chert	180
Dark-grey-weathering dolomite. Coarse lamination at bottom becomes progressively more scarce toward top of interval. Beds 2 to 6 feet thick. In top 50 feet are two 1-foot beds containing lace-like masses of white chert which constitute as much as 60 per cent of volume	158
Medium- to thin-bedded light-grey dolomite. All beds finely laminated	112
Alternating beds of whitish-weathering finely laminated dolomite and dark-grey-weathering coarsely laminated dolomite. Beds 1 foot to 3 feet thick. Dark beds are more coarse grained and contain occasional grains of quartz. Sporadic nodules of white or black chert, most of which are elliptical, elongated parallel with the bedding	102
Limestone, dark grey, with a mottled weathered surface due to selective dolomitization. Beds 2 to 4 feet thick. A few disk-shaped nodules of buff chert	10
Thin-bedded, dark grey, buff-weathering dolomite. Some beds well laminated—twenty laminations per inch	19
Concordant contact with pebble conglomerate bed at top of Horsethief Creek formation.	

McKAY GROUP (2,348 FEET EXPOSED)

A good, although incomplete, section of the McKay Group is exposed in the Central fault block on an easterly trending ridge 1½ miles southeast of Indianhead Mountain. The following section was measured eastward along the ridge from the contact with the overlying Beaverfoot-Brisco formation:—

	Thickness (Feet)
Concordant contact with Beaverfoot-Brisco formation.	
Bluish-grey limestone with laminæ of buff-coloured dolomitic limestone. Lenses and stringers of white chert common. Differential erosion produces characteristic weathered surface	176
Medium-bedded light bluish-grey limestone	16
Bluish-grey limestone with ¼- to ½-inch thick laminæ of buff-coloured dolomite. Toward base the laminæ are thinner and less abundant, producing a more or less mottled effect	839
Bluish-grey limestone. Mottled weathered surface due to selective dolomitization. Some white chert nodules	104
Light brownish-grey dolomite. Beds 6 to 8 inches thick	95
Bluish-grey limestone. Beds 6 to 12 inches thick	34
Bluish-grey conglomeratic limestone. Elongated ellipsoidal fragments cemented by buff-coloured dolomite	88
Medium-bedded bluish-grey limestone with pods and lenses of white chert. Chert lenses mostly 1 to 2 inches thick and from 1 inch to 6 feet long	81
Bluish-grey limestone. Mottled appearance due to irregularly distributed dolomite which weathers a buff colour	77

	Thickness (Feet)
Mainly limestone with interbedded limy shales	121
Alternating limy shales and bluish-grey limestones. Limestone beds range from 2 to 12 inches thick; mud cracks, cross-bedding, and intraformation conglomerates common; some oscillation ripple-marks. Shales make up more than 60 per cent of the unit; in places they are highly cleaved	547
Light-grey fissile shale	15
Mostly thin-bedded bluish-grey limestone with thin interbeds of brownish shale. Intraformational conglomerate beds and mud cracks common	155

The lowest horizon in the section is at the axis of a major anticline, but by tracing the horizon northward to the northeast flank of Indianhead Mountain it was estimated that an additional 1,500 feet of limy shales with interbedded bluish-grey limestone occurs beneath it, with the base not exposed. No other sections that were continuous for more than 2,000 feet were noted.

BEAVERFOOT-BRISCO FORMATION (2,008 FEET)

The best section of the Beaverfoot-Brisco formation is exposed along the ridge to the west of Pedley Pass. The following section was measured upward from the Wonah at that locality. All fossil determinations are by B. F. Howell.

	Thickness (Feet)
The top of the section is covered, but the succeeding 700 feet is believed to belong to the Burnais formation. Above this covered interval is a 180-foot section of the Harrogate formation.	
Limestone, highly magnesian, highly weathered to an ochre yellow—has rotten cellular form. Thick irregular beds	10
Dolomite, grey to grey brown and pinkish grey, weathers light grey; well bedded	26
Dolomite, well bedded, pinkish grey, weathering light buff	28
Dolomite, well and regularly bedded, grey weathering	39
Dolomite, medium bedded, faint pinkish grey, weathering light buff	24
Fragmental limestone, in part slightly magnesian. Fragments are very angular and are cemented by calcareous argillite. Bedding very indistinct. Weathers light blue grey, with streaks of brown and buff	30
Interbedded light blue-grey limestone and dark-grey dolomite. Locally well laminated	15
Glassia variabilis Whiteaves. Small trilobite, unidentified.	
Dolomite, well bedded; weathers a creamy or light-buff colour	8
Bluish-grey limestone interbedded with buff-grey dolomite. Beds 2 to 10 inches thick. Many of the limestone beds are selectively dolomitized, resulting in a pebbly or nodular appearance	36
Interbedded limestone and shale. Limestone, in 1- to 4-inch beds, is dark blue-grey, weathering light grey. Shale is black and partly calcareous	100
Favosites sp.	
Monograptus walcottorum Ruedemann.	
Glassia variabilis Whiteaves.	

	Thickness (Feet)
Brachiopod cf. *Reticularia septentrionalis* Whiteaves.	
Bryozoan, genus undetermined.	
Stems of an unidentified crinoid.	
Phacopid trilobite (pygidium), genus undetermined.	
Calymenid trilobite, genus undertermined (pygidium).	
Large trilobite, unidentified (thorax).	
Small trilobite, unidentified.	
Black shale, fissile, slightly calcareous	50
Monograptus walcottorum Ruedemann.	
Monograptus marri Perner.	
Monograptus columbianus Ruedemann.	
Limestone, slightly magnesian, weathering to a rough grey-brown colour. Medium bedded. Occasional small masses of pyrite, now largely oxidized	42
Limestone, dark grey and fetid, interbedded with highly calcareous brownish-grey dolomitic limestone	17
Limestone, blue grey to brownish grey, alternate fine and massive beds. Some beds are selectively dolomitized	50
Limestone, brownish grey and thinly bedded	175
Limestone, selectively dolomitized throughout. Limestone weathers light blue grey and is less resistant than the buff-weathering dolomitic zones. Medium to thick bedded. Fossils common	497
Favosites.	
Streptelasma sp.	
Paleofavosites.	
Dolomite, dense, thickly bedded, dark grey, weathering bluish grey. Fragmentary fossils and calcite "eyes"	83
Dolomite, dense, thinly bedded, dark grey to blue black, weathering dark brown. Bedding surfaces rough	30
Approximate top of Beaverfoot formation (Richmond).	
Limestone, weathers to mottled appearance due to selective dolomitization. Over-all weathered colour is light grey to buff. Sporadic beds of dark-grey brown-weathering dolomitic limestone. Some chert nodules. Fossils not abundant	211
Collection at 738 feet:	
Orthis marshalli Wilson.	
Resserella ignota (Sardeson).	
Howell comments on these: "*Resserella ignota* is a species which occurs in the Bighorn Formation of Montana and is of Richmondian Age."	
Dolomite, medium to thick bedded. Dark grey-brown on fresh surface, weathering light buff-grey. Stringers and nodules of chert common. Some cup-corals	95
Dolomitic limestone, thinly bedded, dark grey, weathering light grey to whitish. Rusty-weathering black chert nodules common. Fine lamination visible on weathered surfaces	46
Dolomite, medium bedded, dark grey-brown, weathering light grey to whitish. Upper part mottled. Occasional cup corals	46
Dolomite, light grey brown, weathering to light blue grey. Weathered surface rough due to blebs, stringers, and grains of crystalline dolomite	42

	Thickness (Feet)
Dolomite, thick bedded to massive; weathers to light-grey mottled colour	68
Dolomite, medium bedded, dark brownish grey. Weathers to brownish grey. Chert fairly abundant as irregular blebs and lenses which are commonly elongated parallel with the bedding	77
Actinoceras complanum Wilson.	
Favosites.	
Halysites cf. *microporous* Whitfield.	
Dolomite, medium bedded, dark blue grey to dark brownish grey; weathers light grey. Crinoid stem fragments common	44
Limestone, slightly magnesian, with prominent dolomitic laminæ. Weathers light blue grey. Poorly bedded	60
Streptelasma prolongatum Wilson.	
Streptelasma distinctum Wilson.	
Actinoceras complanum Wilson.	
Halysites cf. *microporus* Whitfield.	
Halysites nobustus Wilson.	
Rafinesquina sp.	
Cryptophagus sp.	
Favosites.	
Maclurites.	
Nautiloid.	
Dolomite, thick bedded, weathers grey, scattered fossils	61
Streptelasma distinctum Wilson.	
Streptelasma prolongatum Wilson.	
Dolomite, thin bedded, brownish grey. Occasional irregular blebs of granular chert	15
Concordant contact with Wonah quartzite.	

BURNAIS FORMATION

A partial section of one of the calcareous members of the Burnais formation was measured on the west bank of the Kootenay River 1 mile north of the mouth of Nine Mile Creek.

	Thickness (Feet)
Top not exposed.	
Limestone, black, blocky, but finely laminated. Fetid	5
"Shale," consisting of very thin laminæ of impure calcite separated by films of carbon, the whole being impregnated with gypsum. Gypsum may be secondary	5
Limestone, massive, blue grey and fetid	2
"Shale," consisting of very thin laminæ of impure calcite separated by films of carbon, the whole being impregnated with gypsum. Gypsum may be secondary	10
Limestone, massive, blue grey and fetid	8
Gypsum, finely laminated. Calcareous near top	6
Interbedded limestone and calcareous, black, paper-thin shale. Limestone, nearly black, in 2-inch beds, book-like in appearance. Whole member weathers black	18
Limestone, well and regularly bedded in 6- to 10-inch beds	3
Shale, brown and slightly silty. Very calcareous and gypsiferous. Some pyrite. Weathers into paper-thin sheets	2

	Thickness (Feet)
Limestone, blue grey and fetid. Beds 3 to 6 inches thick and slightly nodular. Some pyrite	5
Alternating grey limestone and wafer-thin calcareous shales. Thinly bedded. Weathers grey	8
Limestone, nodular, dark grey	2
Gap—covered, but with sparse outcrops of nodular dark-grey limestone	25
Limestone, nodular, dark grey	2
Limestone and calcareous shale interbedded as before	2
Base not seen	103

A small outcrop of limestone of the Harrogate formation occurs on Dry Creek, a tributary of the Kootenay River. Underlying this limestone, the following section is exposed. It is believed to represent a calcareous member of the Burnais formation.

	Thickness (Feet)
Top covered.	
Typical Harrogate formation—nodular limestone, dark purplish grey, some intercalations of shale. Very fossiliferous. Attitude—315 degrees, dip 63 degrees northeast	40
Covered	150
Finely bedded dark-grey limestone and dark-grey dolomite. Attitude—335 degrees, dip 55 degrees northeast	5
Dolomite—dense, dark grey, buff weathering, interbedded with light-greenish limy shale	25
Covered—float mostly red and green shales	46
Massive buff-weathering dolomite	2
Reddish and greenish shale, variegated in part	42
Red and greenish variegated dolomite interbedded with red and greenish shale. Dolomite is dense, massive—in beds 6 to 20 inches thick	21
Reddish and greenish variegated shales	6
Interbedded limestone and greenish-grey shale	11
Light-green limy shale with 3-inch interbeds of dark-grey limestone	9
Dolomite—dense, very dark grey, not fetid; in beds 4 to 12 inches thick	13
Base not exposed.	

HARROGATE FORMATION

Partial sections of the Harrogate were found at four localities within the Stanford Range. Because of the interest in the Middle Devonian of the Rocky Mountains, three of these are included although they are fragmentary and incomplete.

Pedley Pass Locality.—The Harrogate section is a continuation of the Beaverfoot-Brisco section described above. A 700-foot stratigraphic gap occurs between the two formations and is believed to be occupied by the Burnais formation.

	Thickness (Feet)
Top eroded.	
Limestone, dark purplish grey and nodular. Unit poorly exposed. Very fossiliferous (*see* Pedley Pass collection, Appendix B)	70[1]
Concealed	70[1]

[1] Approximate.

	Thickness (Feet)
Dolomite, dense, medium to finely bedded. Dark-grey semi-lithographic texture, weathers to a light whitish grey. Numerous small chert nodules	40
Base covered.	

Windermere Creek Locality.—A small exposure of Harrogate formation was uncovered by stripping operations in a deep gully one-quarter mile east of the No. 1 quarry on Windermere Creek. The section there is as follows:—

	Thickness (Feet)
Top covered.	
Nodular limestone with some shaly interbeds. Highly weathered	5
Concealed	10
Nodular limestone with interbedded calcareous shale. Limestone is dark grey and fetid with numerous shaly partings. Highly weathered. Very fossiliferous	15
Limestone, slightly nodular. Occasional dark brown shaly partings. Limestone is dark grey	24
Covered	200
Burnais formation, gypsum	300+
Base covered.	

Fairmont Ridge Locality.—This section was estimated. It is cut off at the top and bottom by faults.

	Thickness (Feet)
Fault contact at top of section.	
Nodular limestone with interbeds and intercalations of buff-grey calcareous shale. Fossiliferous—collection made (*see* Appendix B)	40
Limestone, bluish grey, well bedded	50
Dark-grey nodular limestone with interbeds and intercalations of buff-grey calcareous shale. Fossiliferous—collection made (*see* Appendix B)	200
Base cut off by fault.	

APPENDIX B.—PALÆONTOLOGY

McKAY GROUP

No information can be added to the work of Evans (1932, pp. 126–134) on the palæontology of the McKay group strata. However, since Evans's report on the " Brisco-Dogtooth Map-area " is now out of print, his table of " Fossil Zones in McKay Strata " is included in this Appendix for easy reference.

FOSSIL ZONES IN McKAY STRATA

Chazy	*Orthis* *Phyllograptus* [1]*Ampyx* *Isoteloides*	Zone 8
	Orthis [1]*Megalaspis* *Ampyx* *Orthis*	Zone 7
Beekmantown	*Amphion* [1]*Diplograptus* possibly *dentatus*	Zone 6
	[1]*Xenostegium* *Plectorthis* *Gastropod* *Shumardia* [1]*Megalaspis* *Plectorthis* *Gastropods*	Zone 5
Ordovician (Ozarkian of Ulrich)	[1]*Ozarkispira* *Xenostegium* *Ellesmeroceras?* *Bellefontia?* *Isoteloides* *Plectorthis*	Zone 4
	Obolus *Syntrophia* *Hystricurus* [1]*Kainella* *Apatokephalus* *Keytella*	Zone 3
	Ozarkispira *Isoteloides* *Symphysurina* [1]*Symphysurina* *Lingulella* [1]*Symphysurina*	Zone 2
Upper Cambrian	[1]*Dikelocephalus* (*Briscoia* zone reported from same beds by Walcott (1924, page 45))	Zone 1

The successive faunal zones are named after the most characteristic and constant fossil of each zone. These are marked [1] in the above list and repeated for easy reference below.

Ampyx—zone 8; *Megalaspis*—zone 7; *Diplograptus*—zone 6; *Xenostegium*—zone 5; *Ozarkispira*—zone 4; *Kainella*—zone 3; *Symphysurina*—zone 2; and *Dikelocephalus*—zone 1.

SABINE FORMATION

The following species were identified in each of three separate collections taken from exposures of the Sabine formation to the east of Fairmont Hot Springs (all determinations are by B. F. Howell):—

Briscoia sinclairensis Walcott.
Prosaukia sp.
Ptychaspis cf. *P. miniscaensis* Hall.
Ptychaspis cf. *P. asiatica* Ressor and Endo.
Obolus cf. *O. leda* Walcott.
Lingulella cf. *L. desiderata* (Walcott).

Concerning these fossils, Howell says:—

"*Ptychaspis miniscaensis* is a trilobite found in the Franconian of Wisconsin. '*Ptychaspis*' *asiatica* is found in the Upper Cambrian Yenchou formation of Manchuria. It is not a true *Ptychaspis*, for it has raised ridges on its glabella and fixed cheeks, but Ressor and Endo called it '*Ptychaspis*,' and no other name has yet been given it."

In one of the three collections the following additional fossils were identified:—

Mesonomia iophon Walcott.
Glyptotrophia cf. *G. imbricata* Ulrich and Cooper.
Fragments of crinoids.
Plates of cystoids.

Howell reported that *Mesonomia iophon* was described by Walcott (1924) from the Mons formation at various localities in British Columbia and Alberta.

Glyptotrophia imbricata was described by Ulrich and Cooper (1938) from the Mons of Alberta.

The writer queried Dr. Howell about the presence of crinoids in the Upper Cambrian and he replied as follows:—

"I know that the text-books state that crinoids do not appear until the Ordovician; but a few are known from the upper part of the Upper Cambrian. These crinoids of yours are among the oldest crinoids known. My identification of them as crinoids, rather than cystoids, is based on segments of the stem alone; but I think that some of these segments from this locality are those of crinoids, not cystoids."

GLENOGLE SHALE

Two miles south of Pedley Pass the writer examined a section of the Glenogle consisting of a 120-foot thickness of black shales. Only the upper 65 feet contained fossils, which are reported on by Howell as follows:—

Collection 12 feet below the Wonah:—

Didymograptus nicholsoni planus Elles and Wood.
Glossograptus horridus Ruedemann.
Trigonograptus ensiformis (Hall).
Phyllograptus anna ultimas Ruedemann.
Didymograptus extensus Brongniart.
Diplograptus dentatus.
Isograptus furcula Ruedemann.
Lasiograptus (Hallograptus) inutilis (Hall).

According to Ruedemann (1947) all these species are representative of the Third Deep Kill zone.

Collection made 18 feet below Wonah:—

Trigonograptus ensiformis (Hall).
Glossograptus horridus Ruedemann.
Lasiograptus (Hallograptus) echinatus (Ruedemann).
Lasiograptus (Hallograptus) inutilis (Hall).
Isograptus furcula Ruedemann.
Isograptus walcottorum Ruedemann.

Lasiograptus Hallograptus echinatus is reported in the Third Deep Kill zone of Walker's Mount Tegart collections as *Glossograptus echinatus.*

Collection 44 feet below the Wonah:—

Glossograptus horridus Ruedemann.
Lasiograptus (Hallograptus) echinatus major Ruedemann.
Lasiograptus (Hallograptus) inutilis (Hall).
Isograptus furcula Ruedemann.
Didymograptus patulus Hall.
Didymograptus spinosus Ruedemann.

The last two species have not been reported previously from collections in the Stanford Range, but they are found in the Third Deep Kill zone of the Glenogle in the Brisco Range (Ruedemann, 1947).

Collection 65 feet below Wonah:—

Phyllograptus anna Hall.
Glossograptus horridus Ruedemann.
Lasiograptus (Hallograptus) echinatus major Ruedemann.
Climacograptus pungens Ruedemann.
Didymograptus patulus Hall.
Lasiograptus (Hallograptus) inutilis (Hall).
Isograptus furcula Ruedemann.

All these species have been reported previously from the Third Deep Kill zone in the Glenogle Shale.

BEAVERFOOT-BRISCO FORMATION

Mount Glenn Locality.—A collection from the lower 100 feet of the Beaverfoot-Brisco formation on Mount Glenn contained the following fossils:—

CORALS

Halysites delicatulus Wilson.
Favosites cf. *favosus* (Goldfuss).
Diphyphyllum? primum Wilson.
Streptelasma, species undetermined.
Streptelasma fragile Wilson.
Streptelasma distinctum Wilson.
Streptelasma prolongatum Wilson.
Large coral, genus and species undetermined.

CRINOIDS

Segments of crinoid stems, unidentified.

CEPHALOPOD

Fragments of an orthoceratoid cephalopod, unidentified.

BRACHIOPODS

Two poorly preserved brachiopods.

This is a typical Richmond fauna.

Pedley Pass Locality.—Fossils identified from the Pedley Pass locality are listed in their appropriate positions in the measured section, Appendix A, page 68.

Swansea Mountain Locality.—A collection from the Beaverfoot-Brisco on Swansea Mountain, 200 feet above the base, contained the following fossils:—

Streptelasma prolongatum Wilson.
Streptelasma sp.
Streptelasma distinctum Wilson.
Crinoid stems.
Diphyphyllum primum Wilson.
Dinorthis columbia Wilson.
Resserella cf. *ignota* (Sardeson).

Howell reports that "*Resserella ignota* is found in the Bighorn dolomite of Montana and is Richmond in age."

Fossils were collected from the Silurian portion of the unit, about 1,500 feet above the base, 1 mile south of Indianhead Mountain. Howell reports as follows:—

BRACHIOPOD

Glassia variabilis Whiteaves.

TRILOBITES

Cheirurus, species undetermined (pygidium).
Trilobite, genus undetermined (free cheek).
Trilobite, genus undetermined (pygidium).
Another unidentified trilobite (pygidium).
Cross sections of unidentified trilobites.

The unidentified trilobite pygidia are probably pygidia of an *Encrinurus* and of a Phacopid; but I cannot be certain about their genera. Both they and the free cheek are small.

Another collection from the same beds, but a mile south of the one above, contained the following fossils, also identified by Howell:—

CRINOID

Calyx and stem segments of a very small, unidentified crinoid.

BRACHIOPODS

Glassia variabilis Whiteaves.
Brachiopod, genus undetermined.

TRILOBITES

Acaste cf. *downingiæ* (Murchison).
Calymenid trilobite, genus undetermined (pygidium).
Phacopid trilobite, genus undetermined (eye and pygidia).
Trilobite, genus and species undetermined.

This fauna is probably the one that is recorded from Tegart Mountain, as is listed in the middle of page 33 of Walker's Windermere paper.

HARROGATE FORMATION

Pedley Pass Locality.—Fossils collected from the Harrogate approximately 2,850 feet above the Wonah quartzite were identified by Howell as follows:—

Thamnopora sp.
Productella sp.
Productella sp.
Ambocœlia meristoides (Meek).
Atrypa artica Warren.
Large brachiopod, genus and species undetermined.
Small brachiopod, genus and species undetermined.
Leiopteria sp.
Lenopteria sp.
Pelecypod, genus and species undetermined.
Small Dalmanitid trilobite, genus and species undetermined. (Pygidia.)

Dr. Howell reports: "I assume that this collection is from the Harrogate formation. It is Medial Devonian in age. . . ."

Fairmont Ridge Locality.—Fossils collected from the top nodular limestone member on Fairmont Ridge have been identified by Howell as follows:—

CORALS

Thamnopora cf. *cervicornis* de Blainville.
Heliophyllum, species undetermined.
Disphyllum cf. *stramineum* (Billings).

BRACHIOPODS

Schizophoria mcfarlanei (Meek).
Ambocœlia meristoides (Meek).
Atrypa artica Warren.
Brachiopods, 2 species, undetermined.

TRILOBITE

Small Dalmanitid, genus and species undetermined.

CRINOID

Segment of a stem of an unidentified crinoid.

The following fossils were identified from the lower nodular limestone member on Fairmont Ridge:—

CORALS

Thamnopora cf. *cervicornis* de Blainville.
Thamnopora, species undetermined.

Atrypa artica Warren.
Productella, species undetermined.
Ambocœlia meristoides (Meek).
Schizophoria mcfarlanei (Meek).

The *Productella* in this collection is probably the same as one of the two species of *Productella* in the Pedley Pass collection. The *Ambocœlia* is the same as the *Ambocœlia* in the Pedley Pass and Dry Creek collections. The formation must therefore be the same.

Remarking on both collections Dr. Howell says: "These fossils are of Medial Devonian age, and I assume that they are from the Harrogate formation."

Dry Creek Locality.—Fossils collected from exposures on Dry Creek were identified by H. G. Bassett as follows:—

Schizophoria mcfarlanei (Meek).
"*Martiniopsis*" cf. *M. sublineata* (Meek).
(Sometimes called *Ambocœlia*).
Atrypa cf. *A. artica* Warren.
Zaphrentid coral?
Productella sp.
Cystiphor coral.

Windermere Creek Locality.—From a gully one-quarter mile east of No. 1 quarry the following fossils were collected (identification by H. G. Bassett):—

"*Martiniopsis*" cf. *M. sublineata* (Meek).
Atrypa cf. *A. artica* Warren.
Productella sp.
Spirorbis sp.
Orthocerid cephalopod.
Pelecypod.
Conical gastropod.

Remarking on the last two collections, Bassett states:—

"The collections listed above contain similar faunas which strongly resemble the type Harrogate fauna. The *Schizophoria, 'Martiniopsis,'* and *Atrypa* elements are difficult to identify specifically due to their nature and also because of poor preservation; these forms, however, bear a close resemblance to species from the Ramparts, Presquile and Pine Point formations in the Northwest Territories. This resemblance would be weak evidence in favour of assigning the containing beds to the Middle Devonian.

"The cystiphor coral from Dry Creek corroborates this age assignment, for this type of coral has not been found in beds younger than Middle Devonian."

APPENDIX C.—CHEMICAL ANALYSES*

(All figures represent percentages.)

A chip sample across 70 feet of Upper Jubilee dolomite from an outcrop 1 mile south of the Indian church on the Kootenay Indian Reservation showed the following analysis (Sample No. 1): SiO_2, 1.82; Fe_2O_3, 0.30; Al_2O_3, 0.48; S, *nil;* CaO, 29.98; MgO, 20.84; CO_2, 46.10; P_2O_5, 0.02.

Chemical analyses of metamorphosed McKay (Nos. 2 to 5), highly sheared McKay (No. 6), slightly sheared McKay (No. 7), and unsheared McKay group rocks (Nos. 8 and 9) are as follows:—

Sample No.	SiO_2	Fe_2O_3	Al_2O_3 and P_2O_5	S	CaO	MgO	CO_2	Na_2O	K_2O
2	56.02	6.65	21.00	0.10	2.47	2.88	2.03	2.05	2.93
3	57.74	3.82	13.54	0.10	8.59	2.18	7.02	2.67	2.86
4	50.50	4.93	14.36	0.24	10.61	3.14	8.58	1.05	3.31
5	49.64	4.67	15.68	0.21	10.50	2.85	8.28	1.70	3.06
6	49.46	4.93	11.94	0.18	12.52	3.83	10.64	1.62	1.78
7	36.70	2.94	8.50	0.14	25.00	2.97	20.08	1.02	1.44
8	26.16	2.07	5.20	0.15	33.64	2.25	26.82	0.70	0.97
9	22.06	1.29	3.66	0.18	37.35	1.79	29.86	0.70	0.87

Sample Locations

Sample No. Description

2. Grab sample of phyllite collected on the Palliser River 30 feet west of the eastern contact of the phyllite.
3. Grab sample from a 60-foot width of the phyllite on the Kootenay River near the mouth of the Cross River.
4. Grab sample of phyllite from exposures along the Kootenay River opposite the mouth of the Palliser River.
5. Grab samples of phyllite collected at intervals across a half-mile width along Highway No. 1 to the west of Leanchoil.
6. Grab sample of highly sheared McKay group rocks on Elk Creek.
7. Grab sample of sheared McKay group limestones and shales, 2½ miles northeast of Gibraltar Rock.
8. Grab samples of unsheared McKay group limestones, limestone conglomerates, and shales from east of Tegart Pass.
9. Grab samples of McKay group rocks taken at intervals across 500 feet of strata in exposures 1 mile north of Fadeaway Creek.

* Analyses by G. C. B. Cave, Chief Analyst, British Columbia Department of Mines Laboratory.

Chemical Analyses of Gypsum Samples[1]

Sample No.	SiO_2	Al_2O_3	Fe_2O_3	MgO	CO_2	C	CaO	SO_3	H_2O	$CaSO_4 \cdot 2H_2O$
10	0.88	0.23	0.07	1.59	3.31	0.09	32.07	42.66	18.99	91.3
11	0.67	0.14	0.06	0.95	1.79	0.12	32.28	44.25	19.50	95.0
12	1.21	0.26	0.13	1.54	3.49	0.21	32.11	42.06	18.73	90.3
13	0.51	0.19	0.06	0.85	1.97	0.14	32.34	44.16	19.61	94.1
14	0.61	0.25	0.06	1.25	2.49	0.62	32.26	43.36	19.22	92.3
15	0.62	*Nil*	0.06	1.02	2.42	....	32.36	43.69	19.22	93.0
16	0.50	*Nil*	0.03	1.02	1.82	....	32.22	44.37	19.63	94.5
17	2.60	0.53	0.14	3.35	6.79	0.20	31.31	37.83	16.86	81.0
18	1.94	0.41	0.19	5.24	12.88	0.15	32.26	32.33	14.39	69.5
19	11.76	2.25	0.83	9.61	18.11	0.71	26.24	20.75	9.22	44.3
20	10.57	1.99	0.57	7.41	14.57	0.60	27.13	25.22	11.14	53.7
21	3.96	0.82	0.53	3.86	7.16	....	30.08	36.94	16.62	79.3
22	5.32	0.88	0.42	6.49	12.89	....	29.62	30.27	13.37	65.6
23[2]	1.95	0.40	0.19	2.56	5.27	....	31.76	39.77	17.83	85.5
24[2]	0.59	0.13	0.08	1.50	3.02	....	32.63	42.78	19.19	92.0
25[2]	0.69	0.27	0.07	0.97	1.87	....	31.60	44.38	19.78	95.0
26[2]	1.11	0.13	0.16	1.08	2.18	....	32.22	43.41	19.32	93.2
27[2]	1.95	0.41	0.19	2.09	4.05	....	31.66	41.04	18.29	87.9
28[2]	9.04	1.85	0.67	7.04	13.42	....	27.90	26.58	12.01	57.2
29[2]	0.55	0.09	0.06	1.39	2.59	....	32.41	43.42	19.29	92.7
30[2]	0.50	0.08	0.06	1.29	2.78	....	32.51	43.33	19.29	92.6
31[2]	2.00	0.38	0.19	2.12	4.39	....	31.84	40.63	18.15	87.0
32[2]	0.36	0.05	0.05	1.16	2.24	....	32.45	43.84	19.59	93.9
33[2]	0.54	0.08	0.04	0.81	1.62	....	32.50	44.32	19.88	95.1
34[3]	0.14	0.01	0.03	1.13	2.06	....	32.42	44.54	19.85	95.8
35[3]	1.34	0.21	0.11	1.79	3.60	....	31.80	42.18	18.82	90.6
36[3]	4.75	0.81	0.26	4.27	8.18	....	29.85	35.43	15.82	76.6
37[3]	1.41	0.21	0.05	2.00	4.52	....	31.85	41.19	18.26	87.3
38[3]	0.44	0.08	0.03	0.57	1.10	....	32.12	45.38	20.24	97.7
39[3]	0.59	0.08	0.04	0.91	1.66	....	32.19	44.54	19.85	95.3
40[3]	3.54	0.61	0.26	2.70	7.92	....	31.55	35.07	16.78	73.5
41[3]	1.03	0.13	0.09	1.30	2.46	....	31.97	43.59	19.42	93.2
42[3]	0.94	0.13	0.03	1.40	3.12	....	32.22	42.89	19.17	93.3
43[3]	0.83	0.15	0.09	1.19	3.08	....	32.51	42.89	19.12	92.3

[1] Moisture content determined at 45° centigrade not shown.
[2] Samples taken by J. W. McCammon.
[3] Samples taken by J. M. Cummings.

Sample Locations

The following are descriptions of the samples taken by the writer, McCammon (1950), and Cummings (1948). The locations of Samples Nos. 23 to 39, inclusive, are shown on Figure 8.

Sample No. Description

10. Chip sample across 19 feet of gypsum on Kootenay River, 1 mile north of Nine Mile Creek. Well-laminated gypsum.
11. Chip sample across 17 feet of beds overlying those of Sample No. 10.
12. Chip sample from sink hole 1 mile south of Nine Mile Creek on east bank of Kootenay River. Well-laminated gypsum.
13. Chip sample across 18 feet of well-laminated gypsum exposed in trench of Columbia Gypsum on west side of Kootenay River 1 mile southeast of the mouth of Nine Mile Creek.
14. Chip sample across 10 feet of well-laminated gypsum in exposures on divide between Windermere and Burnais Creeks.
15. Chip sample across 30 feet of well-laminated gypsum in a trench at the head of Burnais Creek.
16. Chip sample across 25 feet of well-laminated gypsum in another trench at the head of Burnais Creek.
17. Chip sample across 44 feet of weathered gypsum on east bank of Kootenay River opposite the mouth of Dry Creek.
18. Chip sample across 120 feet of weathered gypsum at same locality as Sample No. 17.
19. Grab sample of contorted, poorly laminated gypsum from exposure on east side of Kootenay River, 2 miles south of Nine Mile Creek.

20. Second grab sample at same locality as Sample No. 19.
21. Sample of gypsum breccia from Western Gypsum Products Limited quarry near Kootenay River.
22. Chip sample across 85 feet of dragfolded, poorly laminated gypsum in large sink-hole exposure 2 miles up Nine Mile Creek.
23. Across 70 feet of strata.
24. Across 90 feet of strata.
25. Across 33 feet of strata.
26. Across 5 feet of strata.
27. Across 4 feet of strata.
28. Across 8 feet of strata.
29. Across 5 feet of strata.
30. Across 21 feet of strata.
31. Across 10 feet of strata.
32. Across 7 feet of strata.
33. Across 8 feet of strata.
34. Chip sample from cut, 300 feet along strike, cream to white gypsum.
35. Chip sample, 50 feet across strike, creamy-white gypsum.
36. Chip sample across 10 feet, from pit on lower margin of deposit.
37. Creamy-white, more massive gypsum directly below Sample No. 40 in pits.
38. From cliff, across 25 feet, grey gypsum.
39. From sink hole, across 40 feet, grey gypsum.
40. Cream gypsite, composite from several pits, 2 to 3 feet below surface.
41. From sink hole about 3,000 feet southeast of quarry, across 15 feet, grey gypsum.
42. From same sink hole as Sample No. 41, across 40 feet, grey gypsum.
43. From same sink hole as Samples Nos. 41 and 42, check sample below weathered surface.

TEMPERATURE-PRESSURE RELATIONSHIPS OF GYPSUM AND ANHYDRITE

The following explanatory notes have been written by Dr. G. C. B. Cave to accompany his preliminary graph of the transition temperature of gypsum to anhydrite in the presence of a saturated aqueous solution, as a function of pressure:—

"A Preliminary Study of the Effect of Pressure on the Transition Temperature of Gypsum to Anhydrite in the Presence of a Saturated Aqueous Solution.

" It can readily be shown for a system consisting of a solid in equilibrium with a saturated electrolytic solution in which the dissolved solid ionizes that at any chosen temperature—

$$(1) \quad \frac{dm}{dP} = \frac{(V^s - \overline{V})\, m}{\nu RT \left[1 + m \left(\frac{\delta \ln \gamma_{\pm}}{\delta m} \right)_{PT} \right]}$$

where m is the molal solubility of the solid at the chosen temperature.

P is the pressure at equilibrium.

V^s is the molal volume of the solid at the chosen temperature.

$\overline{V}$ is the partial molal volume of the solute in solution at the particular temperature, pressure, and molality.

ν is the number of ions into which the solute dissociates.

R is the gas constant per mol.

T is the absolute temperature.

$\gamma_{\pm}$ is the mean molal activity coefficient, at the particular temperature, pressure, and molality.

δ denotes partial differentiation.

"Equation (1) has also been used by Gibson (1). For the present purpose it was applied separately to the two systems gypsum-saturated aqueous solution and anhydrite-saturated aqueous solution. It can be transformed into equation (2), after making certain assumptions; examples of these are that in the range of pressures, temperatures, and concentrations employed the partial molal volume of the water is constant; that in this same range of pressures and temperatures the mean molal activity coefficient of calcium sulphate is constant and equal to that of zinc sulphate at the same molality; and that the molal volumes of solid gypsum and solid anhydrite are constant.

Then—

$$(2) \quad \phi = \ln \frac{m_h^P}{m_a^P} = \ln \frac{m_h^o}{m_a^o} + \frac{(V_h^s - V_a^s - 2\overline{V}_w)\, P}{0.6\, \nu RT} \quad (T = \text{constant})$$

where the subscript h denotes gypsum, the subscript a denotes anhydrite, the superscript zero denotes the solubility at a pressure of 1 bar, and the superscript P denotes the solubility at a pressure of P kilobars.

"All the data were available for computing the values of ϕ at various temperatures between 25° and 55° centigrade; the solubilities of gypsum and anhydrite at a pressure of 1 bar were taken from the data of Posnjak (2). The values of ϕ were therefore computed, and plotted as functions of temperature, for four different pressures; namely, 0.1, 0.25, 0.4, and 0.5 kilobars. Four graphs were thus obtained—one for each pressure. From each graph the temperature at which $\phi = 0$ was found. This is the transition temperature for gypsum to anhydrite, at the particular pressure. The values of these transition temperatures were then plotted against the corresponding pressures; only along this equilibrium curve can the univariant system gypsum-anhydrite-saturated aqueous solution exist in equilibrium.

"The equilibrium curve which is presented is an approximate one. It represents only an initial, preliminary attempt to establish the relation between the transition temperature of gypsum and the pressure. The various assumptions which were made during the derivation of equation (2) are currently being studied. Further, when the necessary data become available, it is proposed that the elegant thermodynamic method described by Adams (3) be applied to the present system.

"The effect of the presence of other electrolytes in the equilibrium solution is being studied. On thermodynamic grounds, a change in the transition temperature is to be expected when the concentration of an indifferent electrolyte in the solution is changed, at constant pressure. Data on the solubility of gypsum in solutions of sodium chloride as a function of temperature are scanty (4, 5, 6); similar data on the solubility of anhydrite do not appear to exist. Consequently, the present approximate method of calculating the transition curve from solubility data cannot very safely be extended to the case where an indifferent electrolyte is present in the aqueous phase. However, suppose it is assumed that the slope of the curve which relates the solubility of anhydrite to the temperature is not a function of the concentration of an indifferent electrolyte in the aqueous phase. Then the addition of an electrolyte would cause the equilibrium curve (P-T curve) for the system gypsum-anhydrite-saturated aqueous solution to be displaced along the temperature axis to lower temperatures, without much alteration in the slope of the curve.

"*Bibliography*

"(1) Amer. Jour. Sci., Vol. 35A, p. 49 (1938).
"(2) Amer. Jour. Sci., Vol. 35A, p. 247 (1938).
"(3) Amer. Jour. Sci., Vol. 35A, p. 1 (1938).
"(4) Amer. Jour. Sci., Vol. 238, p. 559 (1940).
"(5) A. Seidell, 'Solubilities of Inorganic and Metal Organic Compounds,' Vol. I, D. Van Nostrand Co. Inc., New York, N.Y., 1940, p. 340.
"(6) Chemical Abstracts (A.C.S.), 45, 4126h (1951)."

INDEX

VICTORIA, B.C.
Printed by DON McDIARMID, Printer to the Queen's Most Excellent Majesty
1954

1,800-554-9290

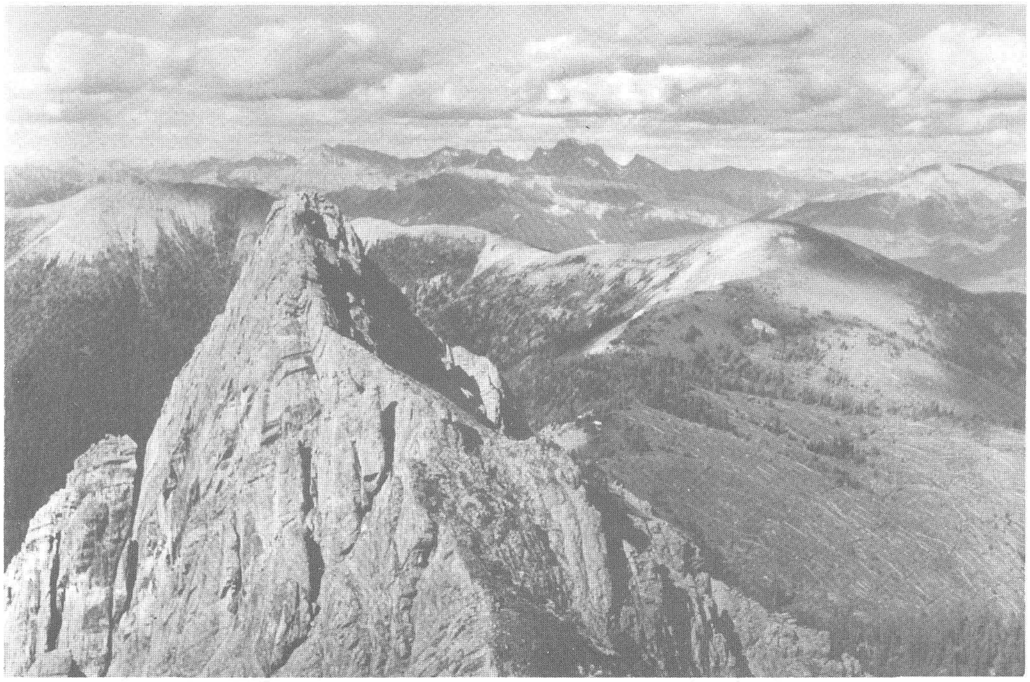

Plate II. Looking northeast across the Stanford Range. Pedley Pass in the right middle ground.

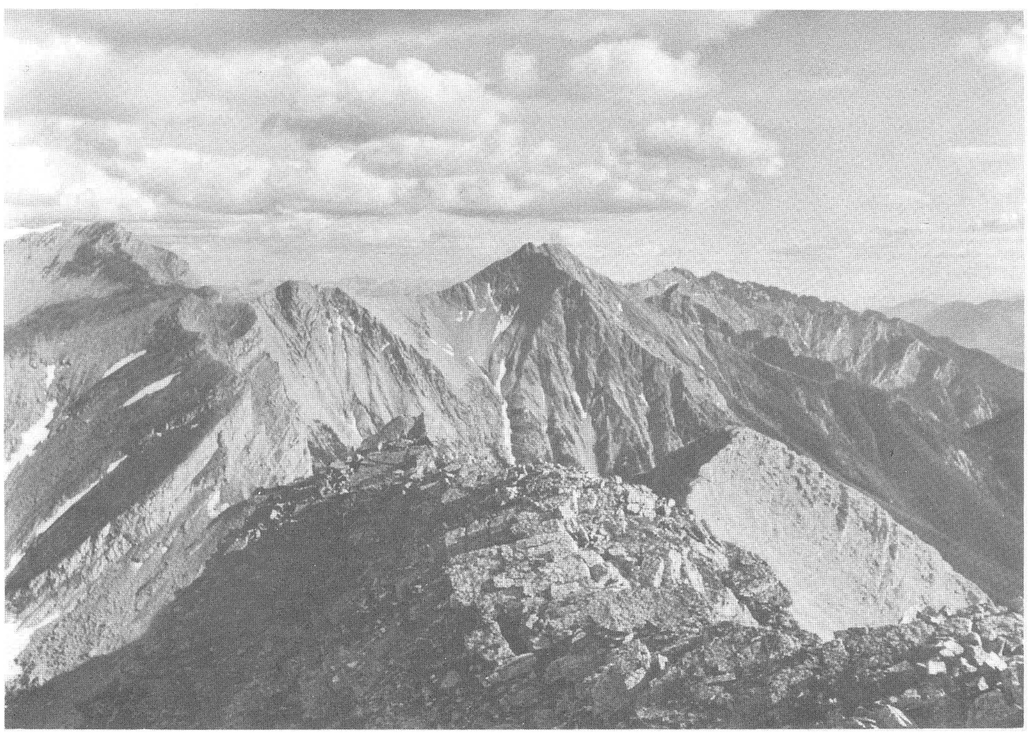

Plate III. Looking south across Madias Basin to Indianhead Mountain.

Plate IV. Typical laminated character of Lower Jubilee dolomite.

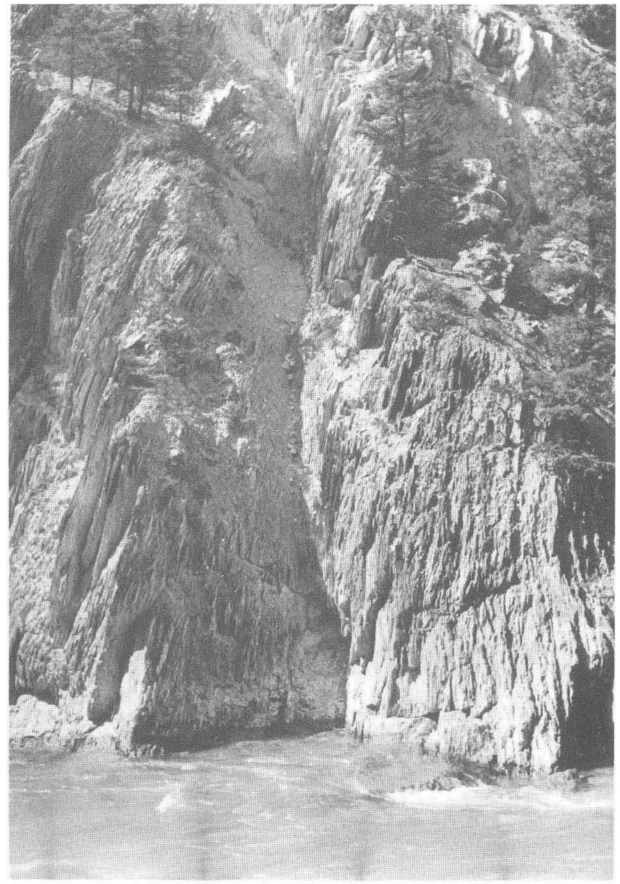

Plate V. Calcareous chloritic phyllite in the canyon of the White River.

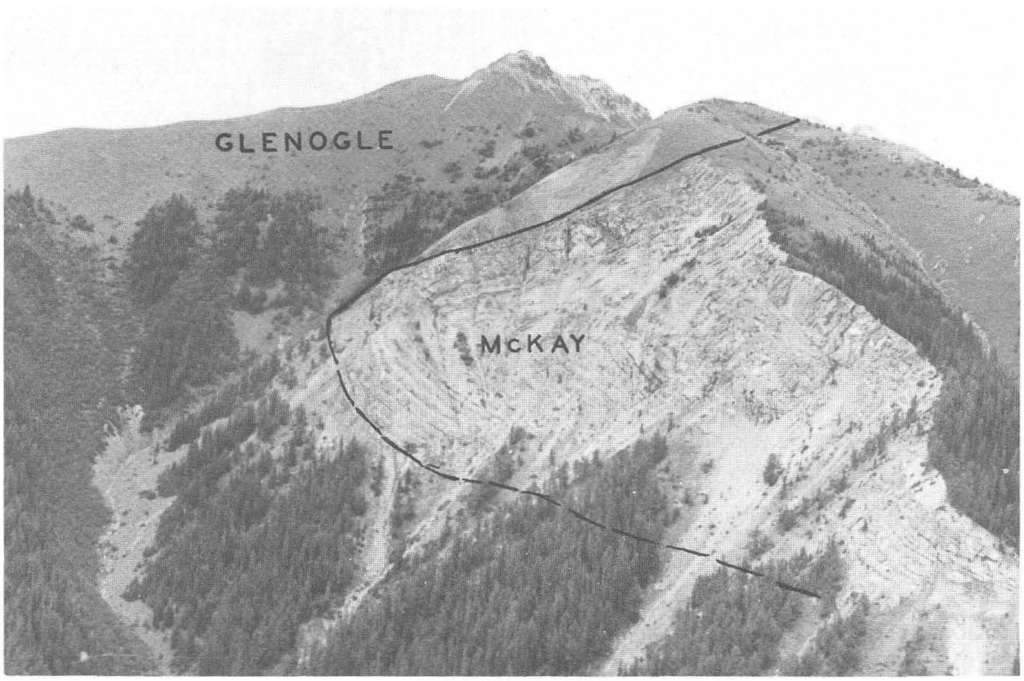

Plate VI. Recumbent fold on major overturned limb in the eastern fault block. North side of Bear Creek.

Plate VII. Dragfolded anticline of McKay strata on the eastern flank of Indianhead Mountain. Looking east.

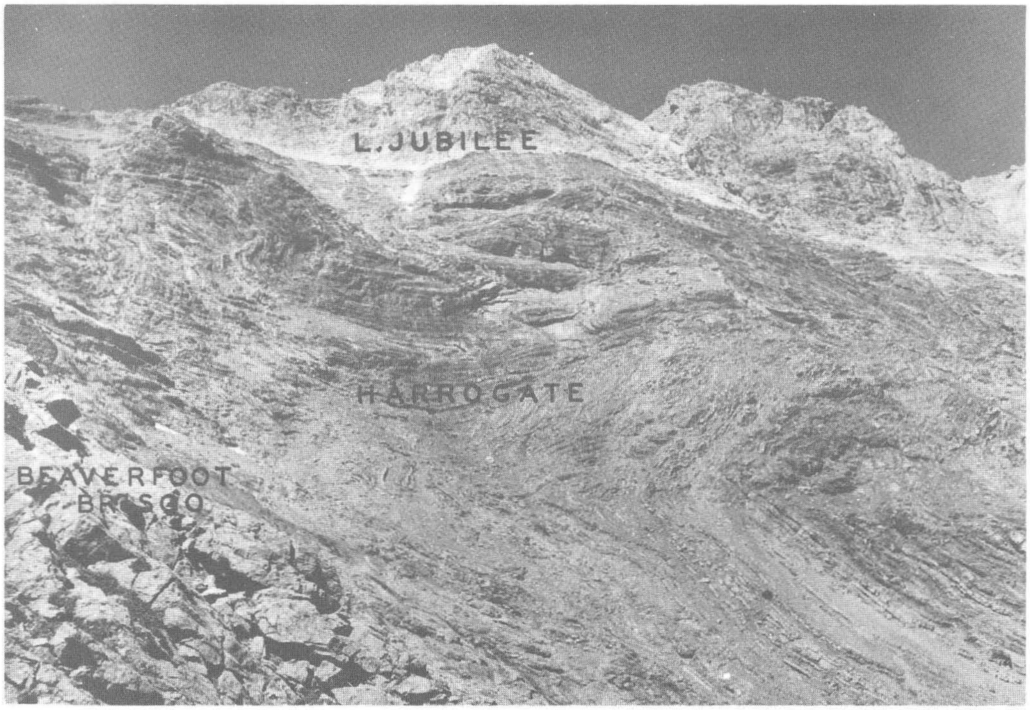

Plate VIII. Block of contorted Harrogate formation down-dropped between Lower Jubilee dolomite and Beaverfoot-Brisco formation on Fairmont Ridge.

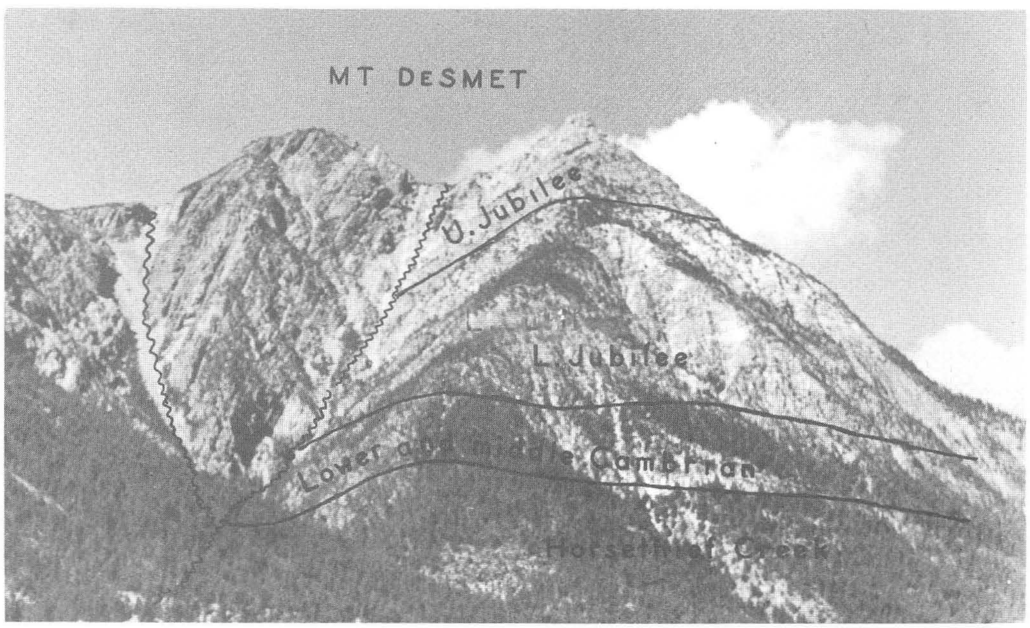

Plate IX. Faulted anticline on Mount DeSmet. Looking northwest.

Plate X. " Hoodoos " of Redwall fault breccia on the divide between Mary-Anne and Tatley Creeks. The breccia zone is 1,400 feet wide. Looking north.

Plate XI. Junction of Kootenay and White Rivers. Showing mouth of White River canyon and the main terrace of the Kootenay River.

Plate XII. Looking south at a compressed anticline on Hawk Ridge, east of Vermilion River. The fold is overturned toward the northeast.

Plate XIII. Contorted Goodsir (?) formation above a southwest-dipping thrust fault near the head of Palliser River. Looking west.

Plate XIV. Flat-lying gypsum forming a cliff more than 200 feet high on Kootenay River, 1 mile north of Nine Mile Creek. White-weathering gypsite overlies the gypsum.

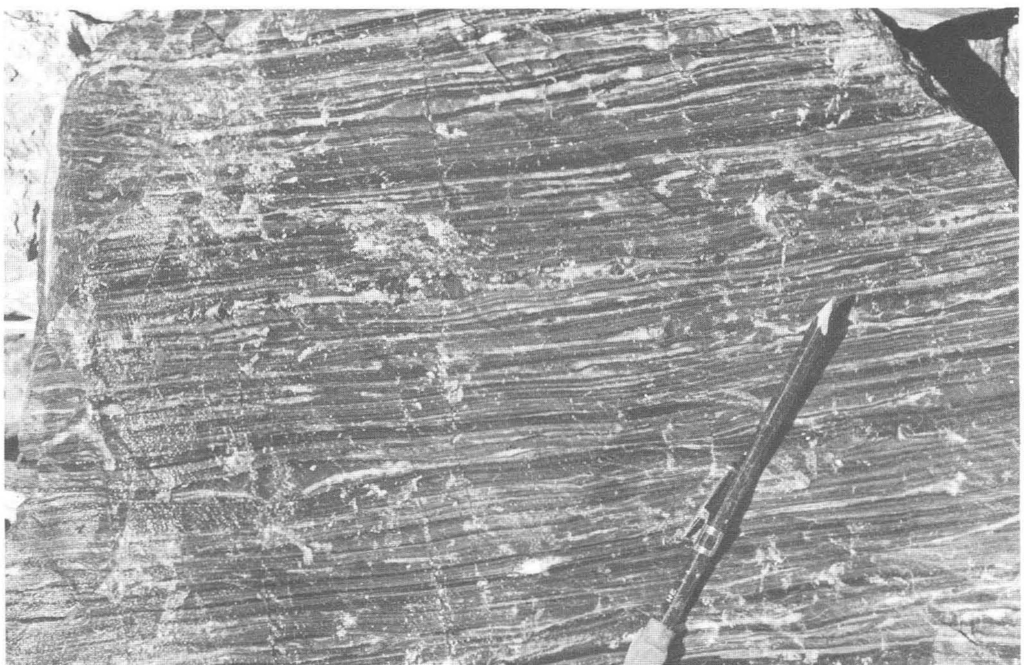

Plate XV. Well-laminated gypsum at quarry on Windermere Creek.

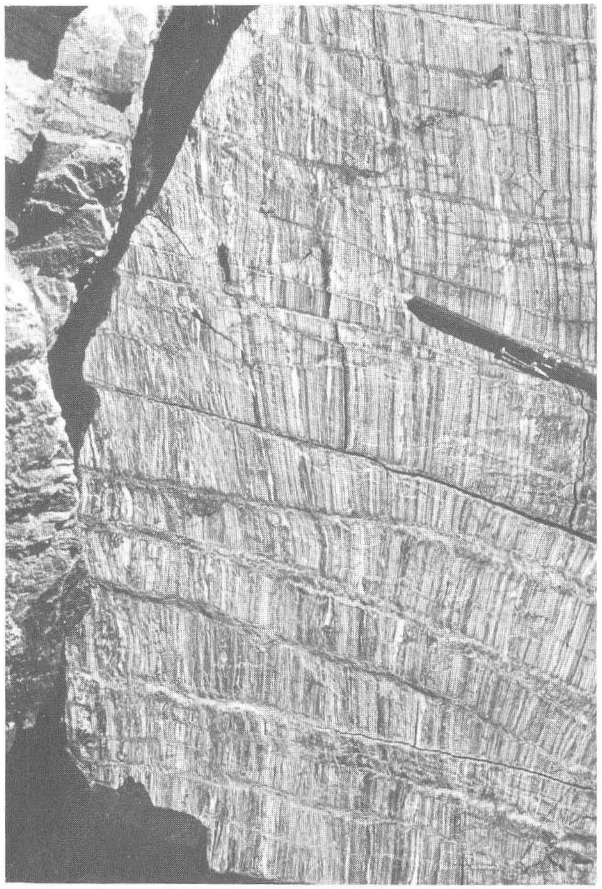

Plate XVI. Closely spaced joints in well-laminated gypsum on Windermere Creek. Many of the joints are filled with secondary gypsum.

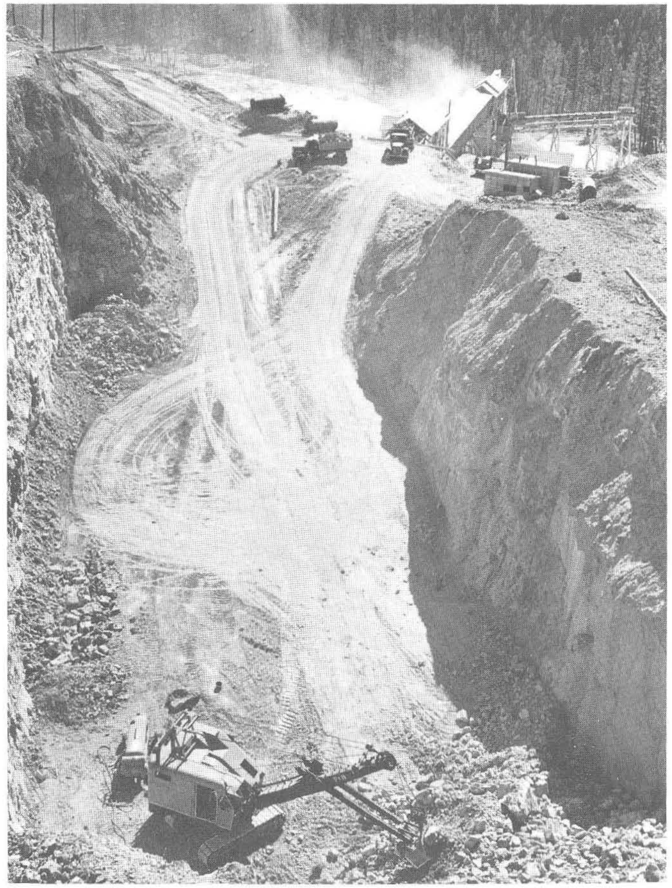

Plate XVII. Columbia Gypsum Products quarry on Windermere Creek. (J. M. Cummings photo.)


FIGURE 2
GEOLOGICAL MAP
OF THE
STANFORD RANGE
KOOTENAY DISTRICT
BRITISH COLUMBIA
1954
Geology by G.G.L.Henderson
Scale 1 0 1 2 Miles
Contour interval 500 feet
LEGEND
BEDROCK CONCEALED: Mainly stream and glacial deposits
MIDDLE DEVONIAN
14 HARROGATE FORMATION: Limestone and shale
SILURIAN AND/OR MIDDLE DEVONIAN
13 BURNAIS FORMATION: Mainly gypsum
12 BURNAIS FORMATION INFERRED
ORDOVICIAN AND SILURIAN
11 BEAVERFOOT-BRISCO FORMATION: Dolomite and limestone
ORDOVICIAN
10 WONAH QUARTZITE: Quartzite
9 GLENOGLE SHALE: Black shale
UPPER CAMBRIAN AND ORDOVICIAN
8 McKAY GROUP UNDIVIDED: Limestone, limestone conglomerate, shale
7 SABINE FORMATION: Limestone and argillite
6 METAMORPHOSED McKAY GROUP: Mylonite, phyllonite, phyllite
MIDDLE AND/OR UPPER CAMBRIAN
5 JUBILEE FORMATION UNDIVIDED
4 UPPER JUBILEE DOLOMITE: Massive dolomite
3 LOWER JUBILEE DOLOMITE: Laminated dolomite
LOWER AND MIDDLE CAMBRIAN
2 CRANBROOK AND BURTON FORMATIONS UNDIVIDED: Quartzite, sandstone, shale
PROTEROZOIC
1 HORSETHIEF CREEK FORMATION: Slate, quartzite, conglomerate
Geological boundary
defined
approximate
assumed
Attitude of bedding
inclined, vertical, horizontal, overturned
Fault
defined
approximate
assumed
Attitude of cleavage
inclined, vertical
Plunge of fold axis
Fossil locality
Quarry, prospect
Outcrop
KOOTENAY NATIONAL PARK
PARK BOUNDARY
PINTO MTN.
SWANSEA MTN.
ATHALMER
MT. BRIAN
FOURPOINTS MTN.
WINDERMERE
WINDERMERE LAKE
TEGART PASS
MT. TEGART
PEDLEY PASS
INDIANHEAD MTN.
PEDLEY MTN.
NAPPE MTN.
KOOTENAY RIVER
FAIRMONT HOT SPRINGS
COLUMBIA R.
GIBRALTAR ROCK
FAIRMONT MTN.
COLUMBIA LAKE
MT. DESMET
MT. GLENN
MT. SABINE
MT. GRAINGER
CANAL FLATS
50°30'
50°15'
115°45'
116°00'
To accompany B.C. Department of Mines
Bulletin 35: Geology of the Stanford Range
1954
#35 ①

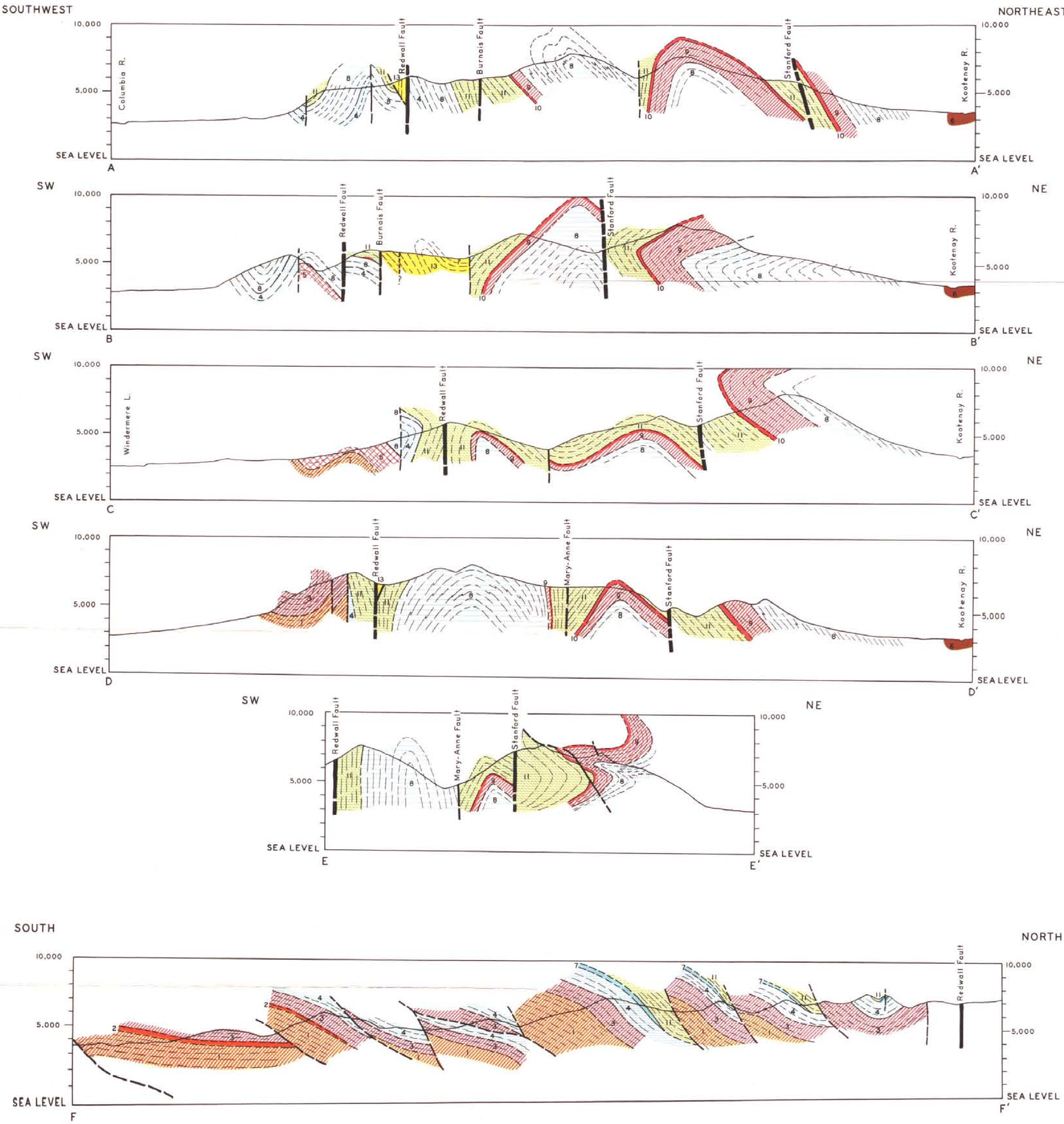

FIGURE 3

GEOLOGICAL CROSS-SECTIONS OF THE STANFORD RANGE

For legend see Figure 2

#35 (2)

Scale 1 0 1 2 Miles

To accompany B.C. Department of Mines
Bulletin 35: Geology of the Stanford Range
1954

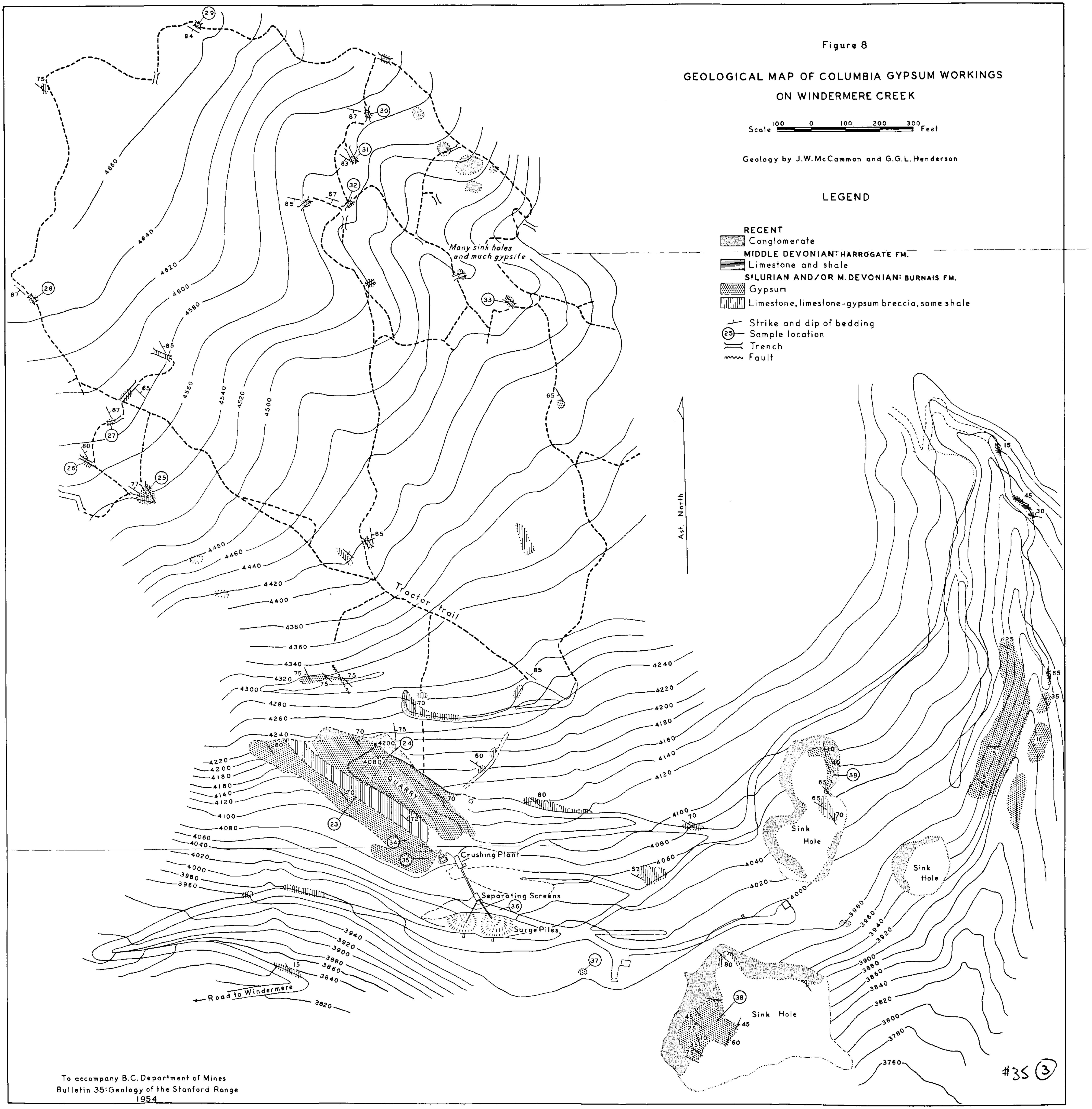

Figure 8

GEOLOGICAL MAP OF COLUMBIA GYPSUM WORKINGS ON WINDERMERE CREEK

To accompany B.C. Department of Mines Bulletin 35: Geology of the Stanford Range 1954