GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

PAPER 68-48

STRATIGRAPHY AND STRUCTURE OF UPPER PALEOZOIC ROCKS, NORTHEAST DEASE LAKE MAP-AREA, BRITISH COLUMBIA (104 J)

(Report, 8 figures and Map 15-1968)

J. W. H. Monger

CANADA

GEOLOGICAL SURVEY

OF CANADA

PAPER 68-48

STRATIGRAPHY AND STRUCTURE OF UPPER PALEOZOIC ROCKS, NORTHEAST DEASE LAKE MAP-AREA, BRITISH COLUMBIA (104 J)

J. W. H. Monger

DEPARTMENT OF ENERGY, MINES AND RESOURCES

Available by mail from the Queen's Printer, Ottawa,

from Geological Survey of Canada,
601 Booth St., Ottawa,

and at the following Canadian Government bookshops:

HALIFAX
1735 Barrington Street

MONTREAL
Æterna-Vie Building, 1182 St. Catherine Street West

OTTAWA
Daly Building, Corner Mackenzie and Rideau

TORONTO
221 Yonge Street

WINNIPEG
Mall Center Building, 499 Portage Avenue

VANCOUVER
657 Granville Street

or through your bookseller

Price: $1.50 Catalogue No. M44-68-48

Price subject to change without notice

The Queen's Printer
Ottawa, Canada
1969

CONTENTS

	Page
Abstract	v
Introduction	1
Stratigraphy	1
Table of Formations	2
Kedahda Formation	3
Distribution and thickness	3
Lithology	3
Contact relations	8
Age and correlation	9
French Range Formation	10
Distribution and thickness	10
Lithology	11
Contact relations	15
Age and correlation	18
Teslin Formation	19
Distribution and thickness	19
Lithology	19
Depositional environment	23
Contact relations	23
Age and correlation	23
Facies belts	24
Ultrabasic to intermediate rocks	25
Nazcha and Shonektaw formations	26
Tuya Formation	28
Structure	28
Structural elements	28
Relationship of secondary minerals to minor structures	33
Major structures	33
Origin, significance and age of early structures	36
Tentative structural history	39
References	39

Table I.	Volume percentage of constituents of some sandstones of the Kedahda Formation	5
II.	Diagnostic fossils from the top of the Kedahda Formation	7
III.	Chemical analyses of some extrusive rocks of the French Range Formation, northeast Dease Lake map-area	13
IV.	Fossils from the Teslin Formation	16
V.	Volume percentage of constituents of some sandstones of the Nazcha Formation	27

Map 15-1968. Dease Lake (northeast quarter), British Columbia ..... in pocket

Page

Illustrations

Figure 1. Time relationships between units of the Cache Creek Group 9
2. Sedimentary structures in the Teslin Formation 21
3. 'Early' minor folds 30
4. Angle between 'early' and 'late' linear structures 31
5. Original orientation of 'early' linear structures 32
6. Equal area plots of structural elements 34
7. 'Late' minor folds 35
8. Intersection of 'early' and 'late' linear structures 38

ABSTRACT

Upper Paleozoic rocks of the Cache Creek Group in northeastern Dease Lake map-area (104 J) consist of the basal Kedahda Formation, the French Range Formation and the uppermost Teslin Formation. The Kedahda Formation is at least 5,000 feet thick and composed largely of chert and pelite, with minor interbedded volcanic sandstones and limestones towards the top. Its base is not exposed in the map-area, and it is conformably and diachronously overlain by the French Range Formation with mid-Permian (Leonardian and earliest Guadalupian) fossils at the contact. The French Range Formation consists of 3,000 to less than 1,000 feet of saussuritic, locally pillowed, basic flow rocks, intrusive equivalents, and pyroclastic rocks, and is conformably overlain by, and in part a facies equivalent of, the Teslin Formation. The Teslin Formation, composed of carbonate with locally abundant algal structures and fusulinids, is about 1,500 feet thick and ranges in age from Early Permian (Leonardian or possibly Wolfcampian) to Late Permian (late Guadalupian). The top of the formation is not recognized in the map-area, and lower Mesozoic volcanic rocks and sandstones are in fault-contact with the older rocks.

Upper Paleozoic rocks appear to have undergone two phases of deformation; (1) an early phase of probably isoclinal recumbent folding accompanied by low-grade regional metamorphism of the glaucophanitic type, best dated as post-Late Permian - pre-Late Triassic, was followed by (2) a later phase that affected both late Paleozoic and Mesozoic rocks. The later phase was accompanied by little or no regional metamorphism and is largely responsible for the present map-pattern.

STRATIGRAPHY AND STRUCTURE OF UPPER PALEOZOIC ROCKS, NORTHEAST DEASE LAKE MAP-AREA, BRITISH COLUMBIA (104 J)

INTRODUCTION

In northeast Dease Lake map-area (104 J) (bounded by latitudes 58°30' to 59°00' and longitudes 130°00' to 131°00') rocks of upper Paleozoic age are most common and their description is the principal object of this report. Lower Mesozoic rocks in the area are described briefly in order to compare their lithology and structure with that of the older rocks. The late Paleozoic rocks form the southeastern end of the northwest-trending structurally high belt of Permian and Pennsylvanian eugeosynclinal rocks in northwestern British Columbia and south-central Yukon called the Atlin Horst by Gabrielse and Wheeler (1961). These rocks are currently being studied by the writer with the ultimate object of providing late Paleozoic reference sections for the northern part of the western Cordillera.

This report is based on geological mapping on a scale of 1 inch to 1 mile undertaken mainly during the field season of 1966. H. Gabrielse advised on and discussed the problem with the writer.

First geological work in the area was by G.M. Dawson in 1887 who noted the presence of argillite-schists, limestones, rocks of volcanic origin and serpentine near Dease Lake. F.A. Kerr (1925) made the first geological map of the area on a scale of 1 inch to 2 miles, described rock units and proposed names for them. Subsequently Hanson and McNaughton (1935) incorporated Kerr's work in a smaller scale map of the region. Finally, Gabrielse *et al.* (1962) completed geological mapping on a scale of 1 inch to 4 miles in the Dease Lake map-area.

STRATIGRAPHY

The upper Paleozoic rocks in the map-area belong to the Cache Creek Group. The oldest rocks in this group are in part earliest Late Permian but are mainly older and make up the Kedahda Formation. This unit consists of chert, pelite, and minor volcanic sandstone and limestone and is more than 5,000 feet thick. Its base is not exposed in the map-area, and its upper contact is diachronous. Conformably overlying this is the French Range Formation, a succession of altered basic to intermediate flows and pyroclastic rocks that ranges in thickness from less than 1,000 feet to more than 3,000 feet. Youngest Paleozoic rocks are limestones forming the Teslin Formation, a unit predominantly of Middle to Late Permian age, but in part Early Permian, that is locally more than 1,500 feet thick. This unit conformably and gradationally overlies the French Range Formation, and is partly a facies equivalent.

Manuscript received: June 27, 1968.
Author's address: Geological Survey of Canada,
Room 102,
326 Howe Street,
Vancouver 1, B.C.

In fault-contact with these rocks are andesite and volcanic clastic rocks of the Shonektaw and Nazcha formations, that are of early Mesozoic (Late Triassic?) age. These rocks differ lithologically from the Permian volcanic rocks, and structurally from all upper Paleozoic rocks, in that they appear to have undergone only one phase of deformation, whereas upper Paleozoic rocks have been deformed twice.

Finally, local patches of basalt of latest Tertiary or Pleistocene age comprise the Tuya Formation in the map-area and lie with profound unconformity on the older rocks.

TABLE OF FORMATIONS

<table>
<tr><th>Era</th><th>Period or epoch</th><th>Formation and thickness (feet)</th><th>Lithology</th></tr>
<tr><td>Cenozoic</td><td>Latest Tertiary and Pleistocene</td><td>Tuya Formation</td><td>Basalt</td></tr>
<tr><td rowspan="5">Mesozoic</td><td colspan="3">Unconformity</td></tr>
<tr><td>Triassic</td><td>Shonektaw Formation</td><td>Augite andesite</td></tr>
<tr><td colspan="3">Probably conformable: Shonetaw and Nazcha formations may be facies equivalent in part</td></tr>
<tr><td>Triassic</td><td>Nazcha Formation</td><td>Volcanic sandstone, argillite, tuff, conglomerate and minor limestone</td></tr>
<tr><td colspan="3">Probable angular unconformity, although fault-contact in map-area</td></tr>
<tr><td rowspan="8">Paleozoic</td><td>Permian and later(?)</td><td>Ultrabasic to intermediate intrusions</td><td></td></tr>
<tr><td colspan="3">Intrusive contact</td></tr>
<tr><td>Permian</td><td>Cache Creek Group Teslin Formation 1,500±</td><td>Limestone, dolomitic limestone</td></tr>
<tr><td colspan="3">Conformable, diachronous contact, in part gradational</td></tr>
<tr><td>Permian</td><td>Cache Creek Group French Range Formation 2,000±</td><td>Altered, intermediate to basic flow rocks, their intrusive equivalents and pyroclastic rocks</td></tr>
<tr><td colspan="3">Conformable, diachronous contact, in part gradational</td></tr>
<tr><td></td><td>Cache Creek Group

Kedahda Formation 5,000±</td><td>Cherty phyllites, phyllitic cherts, chert, phyllite, volcanic sandstone, minor limestone</td></tr>
<tr><td>Base not seen</td><td></td><td></td></tr>
</table>

KEDAHDA FORMATION

The Kedahda Formation (units 1, 2, 3) a sequence conformably underlying the French Range Formation and consisting mainly of pelitic chert and cherty pelite, less abundant chert, pelite and volcanic sandstone, and minor limestone together with more metamorphosed equivalents, is the oldest unit in the map-area. This name was first applied by Watson and Mathews (1944, p. 15) to a unit of similar lithology that outcrops in southern Jennings River map-area (105 O) and which is the northwesterly continuation of the sequence in northeastern Dease Lake map-area. The term 'Kedahda Formation' partly replaces the loosely defined 'Dease Series' believed by Kerr (1925, p. 80A) to include all Paleozoic rocks in northeastern Dease Lake map-area, and corresponds to map-unit 3a of Gabrielse (1962). The name is informal as no type section of the formation was described by Watson and Mathews from the type area of Kedahda Lake, in Jennings River map-area, but is used here both for reasons of priority and to emphasize the widespread occurrence of the unit.

Distribution and Thickness

The Kedahda Formation is probably the most extensive formation in the map-area and outcrops over much of the plateau surrounding the French Range and in the valley occupied by Dease Lake. However, as it commonly underlies areas of low relief and is poorly exposed, the total outcrop area is less than that of most other units in the area.

The true thickness of the unit in the area is not known; its base is nowhere exposed and the common uniformity, lack of marker beds, complex structure, and generally poor exposure prevent even the exposed true thickness from being estimated. The minimum apparent thickness of the uncommonly well-exposed sequence in Dease Creek is estimated by the writer to be more than 5,000 feet. Kerr (1925, p. 84A) suggested that the total thickness of his Dease Series, which included the Permian limestone, was at least 10,000 feet, and Watson and Mathews (1944, p. 16) note that approximately 10,000 feet are exposed near the type locality.

Lithology

The Kedahda Formation in northeastern Dease Lake map-area consists mainly of cherty pelites and pelitic cherts with chert locally predominating towards the top of the formation. Sandstone is interbedded with the upper part of the formation in a zone trending northwesterly across the northern part of the area of Paleozoic rocks. The rocks around Dease Lake and in the lower part of Dease Creek are more metamorphosed than those elsewhere in the area and grade westward into cherty phyllites. Intercalated with these more metamorphosed rocks are chlorite-muscovite-albite schists. Limestones are interbedded with the upper part of the formation in Dease Creek and near Mount Rath.

Chert and pelite form the end members of a compositional series characteristic of probably more than 95 per cent of the rocks of the Kedahda Formation. Commonest are argillaceous or phyllitic cherts, with an estimated composition of between 75 per cent and 50 per cent chert, and cherty argillites or cherty phyllites, whose chert content is roughly between 50 per cent and 25 per cent. Gradational with these are slightly more metamorphosed equivalents, referred to below as phyllitic quartzites and quartzose phyllites, that occur in the eastern part of the area, particularly in the lower part of Dease Creek and around Dease Lake. Locally the end members of the series predominate; chert is abundant at the top of the formation and occurs just below French Range Formation, and soft, slightly calcareous phyllites outcrop near limestone in the formation in the upper part of Dease Creek. It is not possible to show these variations on the geological map.

The cherty argillites, cherty phyllites and argillaceous and phyllitic cherts are commonly thin-bedded and weather dark grey, brownish grey or tan. Typically, resistant beds of pale to medium grey argillaceous chert or chert, ranging in thickness from 1 inch to 3 inches and internally finely layered with darker, more argillaceous laminae, are interbedded with softer, dark grey or silver-grey, locally graphitic, argillaceous or phyllitic beds of variable thickness.

In the more metamorphosed equivalents of these rocks in lower Dease Creek and around Dease Lake, bedding is not easily recognizable. However, compositional layering consisting of pale grey to white quartzite layers, rarely greater than 1/2 inch thick, alternating with dark grey or silver-grey phyllitic laminae, is parallel with the contact of thin, interbedded limestones. The quartzite layers in these rocks are composed of a mosaic of anhedral, subequant quartz crystals, whose diameters vary from about 0.25 mm to 0.01 mm, with the coarse grains in places forming layers parallel with compositional layering. Plates of a brown mineral, probably stilpnomelane, are dispersed through the quartzite layers in some examples. Most of these plates are parallel with the foliation but some are randomly oriented. The phyllitic laminae consist largely of muscovite folia parallel with the compositional layering, and varying amounts of graphite. Brown-weathering carbonate porphyroblasts are randomly distributed through some of these rocks but are rarely abundant. In places the compositional layering is so disrupted by subsequent deformation associated with strain-slip cleavage that the rock appears to consist of small quartzite lenticles 'floating' in a phyllitic matrix.

With decreasing content of pelitic material, the pelitic chert grades either into ribbon chert, with thin beds of pure chert ranging from 1 inch to 3 inches in thickness separated by pelitic laminae, or, less commonly, into massive chert. These cherts are pale grey, white or buff and generally form the uppermost part of the formation. On and near Mount Rath, thin-bedded, dark red jasper composed of dense hematitic chert contains small circular bodies about 0.1 mm in diameter of clear, finely crystalline quartz that are probably recrystallized radiolarian tests. The jasper directly underlies the French Range Formation.

Pure argillaceous rock is relatively rare in the formation, and is commonly rusty weathering, dark grey or black and massively bedded. Soft, medium grey, calcareous phyllite is associated with limestone beds in the upper part of Dease Creek.

Volcanic sandstone (unit 3) is the most important of the remaining rock types in the formation. However, unit 3 probably contains less than 10 per cent sandstone interbedded with chert, pelitic chert and cherty pelite typical of the Kedahda Formation. These sandstones are believed to occur in the upper part of the formation because they outcrop just below the French Range Formation northwest of Killarney Lake and Vowell Mountain, and in the latter locally are interbedded with chert, typical of the uppermost part of the Kedahda Formation.

The volcanic sandstone is relatively poorly exposed, generally underlies the same areas of low relief as the rest of the formation, and mostly occurs in creek valleys as small isolated exposures alternating with outcrops of chert, pelitic chert and cherty pelite. Contacts between the sandstone and the fine-grained rocks are commonly covered, but in many places can be located to within 10 feet, and have been observed directly in Rath Creek, Delure Creek and on the west side of Dease Lake opposite Sawmill Point. All the contacts seen are normal stratigraphic contacts, with the sandstone interbedded in the finer grained rocks.

These sandstones are all shades of grey or greenish grey and weather brownish grey. They are hard, generally massive, and not graded. The maximum grain size varies from granule or very coarse sand-size to fine sand-size, with the coarser grade predominating. The grains are generally angular, sorting is poor or absent, and commonly there is a gradation from coarse to fine sand-sizes with little or no distinction between grains and matrix. Most of the fine-grained sandstones contain a penetrative secondary foliation parallel with the bedding that is manifested by 'flattening' of clasts in the plane of the foliation. Where this foliation is developed, distinction between grains and matrix is impossible and grain boundaries are indefinite and blurred.

TABLE I

Volume percentage of constituents of some sandstones of the Kedahda Formation

	1	2	3	4	5	6[3]	7[3]	8
Quartz	5.1	0.4	15.5	3.6	0.4	0.3	0.1	13.8
K-feldspar[1]	-	-	-	-	0.4	-	-	2.2
Plagioclase	6.1	1.9	55.5	10.8	8.9	-	-	30.1
Hornblende	8.7	30.8	-	5.0	10.6	9.4	28.7	4.8
Pyroxene	-	0.7	-	-	0.5	-	0.8	3.4
Rock fragments, matrix	79.2	65.0	28.1	79.1	78.8	-	-	42.2
Others[2]	0.9	1.2	0.9	1.5	0.4	90.3	70.4	3.5

Approximately 1,000 points counted per slide

1. Recognized by staining with sodium cobaltinitrite
2. Includes biotite, epidote, 'free' chlorite, carbonite, opaques, or irresolvable, fine-grained material in highly altered specimens
3. Highly altered specimen

These volcanic sandstones are composed, in decreasing order of abundance, of rock fragments, feldspars, hornblende and quartz (Table I). However, the composition of many clasts cannot be determined because of subsequent alteration, and in Table I rock fragments and matrix are grouped together because of the common difficulty of distinguishing between them. The rock fragments are mainly of volcanic origin, although many sandstones contain minor amounts of chert and argillite; angular chips of the latter up to 10 mm long are particularly prominent in some specimens. Typical volcanic clasts consist of either small felted or trachytic feldspar laths in a semi-opaque fine-grained matrix, or small euhedral hornblende and rare altered zoned plagioclase phenocrysts in a fine-grained, low birefringent, granular matrix. Feldspars are mainly plagioclase, although K-feldspar is present in amounts of generally less than 1 per cent in some sandstones from north of Thibert Creek and just east of Sawmill Point on Dease Lake. Although a few feldspars are fresh, most are altered, either wholly to saussurite or partly to sericite. A few altered feldspars appear originally to have been zoned. Determined compositions of plagioclase feldspars range from An_0 to An_{35}. Hornblende, identical to that in the volcanic clasts with pale yellow-green to dark olive-green pleochroism, varies widely in amount and is absent from a few sandstones. The quartz grains are invariably clear, commonly free of inclusions, and composed of a single crystal. Although most grains are angular, some are well-rounded and others both rounded and angular. The quartz and hornblende clasts are less susceptible to alteration than other major constituents and in some altered sandstones are the only identifiable primary grains. Minor constituents are augite (commonly less than 1 per cent), epidote, sphene, opaque minerals, patchy carbonate and chlorite.

These rocks are called volcanic sandstones as all determinable constituents appear to be of volcanic origin, with the exception of chert and argillite clasts which may well be of intraformational origin. Zoned plagioclase and hornblende, identical to those in associated volcanic clasts, and the form and nature of many quartz grains indicate that these greywackes are derived almost wholly from a volcanic source, probably a suite of andesitic-dacitic rocks.

Chlorite-muscovite-albite schists are interbedded and partly gradational with the quartzose phyllites and phyllitic quartzites in Dease Creek. They are all shades of grey-green, very fine grained and massive in outcrop but foliated in detail, with the foliation orientated parallel with the contacts. These rocks are called 'schists' rather than 'greenstones' to emphasize that they are foliated and completely reorganized by metamorphism, and that no relict primary constituents or textures remain. They consist of either chlorite and muscovite folia, parallel with the general foliation and alternating with albite (and minor quartz?) layers, or a largely undifferentiated aggregate of albite, chlorite and muscovite, with similarly oriented platy minerals. In some examples trains of opaque minerals parallel the foliation and in others, brownish, rusty weathering, carbonate porphyroblasts are abundant. The penetrative foliation parallel with platy minerals in many of these rocks has been disrupted by later strain-slip cleavage. Their origin is not known, but they are presumably altered interbedded tuffs or possibly greywackes.

Limestones in the Kedahda Formation (unit 2) are interbedded either with cherty and quartzose phyllites in the upper part of the formation or with cherts and volcanic rocks at the upper contact. Limestone interbedded with cherty phyllite is mainly in the upper part of Dease Creek. The largest body, more than 200 feet thick, is exposed on the north side of Dease Creek between the junctions of Buck and Lyons Gulches and can be traced eastwards across Lyons Gulch. The limestone is medium to dark grey, locally argillaceous, invariably crystalline and in places brecciated. No fossils have been found in it. From its position relative to the French Range Formation on Johnson Knolls it appears to be in the upper part of the Kedahda Formation. Limestone at the upper contact forms small pods and beds intercalated with chert and jasper at the top of the Kedahda Formation and with volcanic rocks at the base of the French Range Formation. On Mount Rath, it is typically buff or cream weathering and dolomitic or siliceous. In places it is fine grained and contains thin regular beds of jasper and chert and grades into them. Elsewhere it is a breccia composed of grey weathering medium- to fine-grained crystalline calcite clasts and, locally, angular jasper clasts in a buff weathering, fine-grained crystalline dolomitic limestone matrix. Many calcite clasts in these breccias appear to be recrystallized fusulinids. Some fusulinids preserved by selective silicification are of Leonardian age (Table II). Three miles south of the summit of Mount Rath, just east of Quartz Creek, buff, yellow or white weathering, locally tuffaceous, bioclastic limestone lenses and beds contain abundant fusulinids, crinoid columnals and brachiopods. These limestones occur in contact with cherts of the top of the Kedahda Formation, and also intercalated with agglomerate at the base of the French Range Formation. Although these limestone beds are homotaxial with the limestones on Mount Rath, and are correlated with them, they contain earliest Guadalupian fossils (Table II).

TABLE II

Diagnostic fossils from the top of the Kedahda Formation

G. S. C. Cat. No.	Loc. No.	Approx. Location	Name	Age
75292	1	3 miles S. W. of Mt. Rath	Pseudodoliolina sp. cf. P. ozawai Yabe and Hanzawa	Late Permian, probably early Guadalupian
75293	2	3 miles S. W. of Mt. Rath	Chusenella sp. Pseudodoliolina sp.	Late Permian, probably earliest Guadalupian
75393	3	NW side of Mt. Rath	Pseudofusulina cf. P. kueichowensis	Probably Leonardian

Fusulinids identified by C. A. Ross, Western Washington State College.

Serpentine and orange weathering carbonate are intercalated with the Kedahda Formation in several localities, but are abundant only along the Thibert Creek Fault that bounds the Paleozoic rocks of this area to the north. Several orange weathering carbonate bodies in lower Dease Creek are correlated on the basis of lithology with the serpentine and carbonate bodies along Thibert Creek. In upper Dease Creek, about 1 1/4 miles west of the confluence of Buck Gulch with Dease Creek, serpentine is associated with mylonite that is orange to buff weathering with black uniform laminae. Possibly the serpentine was injected along a fault associated with the mylonite.

Contact Relations

The Kedahda Formation is conformably overlain by the French Range Formation, and its base is nowhere exposed in the map-area. The upper contact is drawn at the base of the overlying volcanic rocks of the French Range Formation. In the northern part of the French Range, where flow rocks overlie cherts this contact can be delineated with precision; elsewhere pelitic cherts grade up into cherty tuff or cherts, volcanic rocks interdigitate, and the contact is somewhat arbitrary. This contact is diachronous, being of Leonardian or earliest Guadalupian age in the northern half of the French Range and possibly Wolfcampian in the southeastern part.

Evidence of conformity between the Kedahda and French Range formations is provided by the parallelism of bedding in the two units, interdigitation between them, and gradational contacts. Near the summit of Mount Rath, and at the northern end of the northeast-trending ridge 1 1/2 miles southeast of Mount Rath summit, massive greenstone of the basal French Range Formation conformably overlies thin-bedded chert and jasper containing limestone pods. Cherty phyllite and chert of the Kedahda Formation are exposed in several small creeks on the south side of Slate Creek Valley. These rocks contain beds of tuff and agglomerate, and, near the contact, a conformable breccia bed about 12 feet thick composed of angular limestone clasts, up to 1 foot long, and vesicular greenstone fragments. Overlying the breccia are a few feet of chert and argillite, separated by a covered interval from bluffs of massive greenstone forming the north side of the prominent greenstone ridge south of Slate Creek. Near the base of the greenstone are interbedded cherts and phyllites, in which the bedding is conformable with that in the underlying cherts. On the south side of the southeastern end of this greenstone ridge, phyllitic cherts of the Kedahda Formation pass up into thin-bedded greenstone that is conformably overlain by massive flow rocks capping the ridge. Still farther south in the French Range, tuffs of the French Range Formation grade downwards through cherty tuffs into pelitic cherts. The latter rocks may well be equivalent to the Kedahda Formation elsewhere in the map-area, but as they are relatively minor in extent and as their contacts with the tuffs are gradational they are mapped with the French Range Formation.

The local jasper, greenstone and limestone breccias within the uppermost part of the Kedahda Formation indicate that erosion did occur in the area. As they have never been seen at the contact, they are not believed to have any regional significance, but perhaps merely result from slumping of material from contemporaneous volcanic piles.

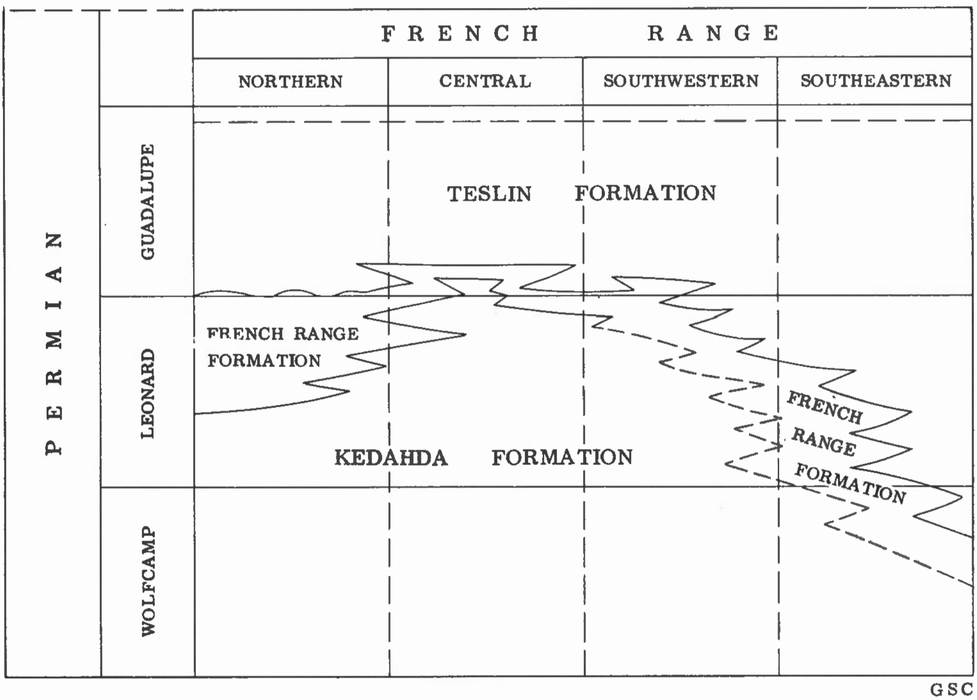


Figure 1. Time relationships between units of the Cache Creek Group, northeast Dease Lake map-area.

The upper contact is diachronous, as perhaps would be expected from its gradational and interdigitating nature. Limestones at the contact of the Kedahda Formation are of probable Leonardian, earliest and early Guadalupian age (Table II). The southeasternmost part of the French Range, 1 1/2 miles southwest of Little Dease Lake, however, contains a body of limestone of the Teslin Formation yielding "probable Leonardian, but could be Wolfcampian" fusulinids in addition to the late Leonardian to early Guadalupian fossils typical of the basal Teslin Formation elsewhere in the map-area (Table IV, fossil localities 8, 7). Presumably, volcanic rocks associated with this limestone are older, as nowhere in the map-area are they demonstrably younger than the entire Teslin Formation, and thus the age of the Kedahda Formation in this part of the map-area must be older still (Fig. 1).

Age and Correlation

Fusulinids from limestone at the top of the Kedahda Formation are of mid-Permian age (Table II).

No other fossils are known from the formation in this area, with the exception of radiolaria(?) in cherts interbedded with Leonardian limestone.

The formation is thus partly Lower Permian, and as it is apparently thick, and no stratigraphic breaks have been recognized within it, it may extend down into the Pennsylvanian in the map-area.

Rocks of similar lithology and age to the Kedahda Formation are widespread over an area that extends from the French Range along strike for 150 miles to the northwest, 80 miles to the east-southeast, and at least 80 miles across strike at its widest part. The Kedahda Formation in Dease Lake appears to be continuous with the type Kedahda Formation to the northwest, where limestones in the formation contain Permian fossils (Watson and Mathews, 1944, pp. 15-16). Still farther to the northwest, near Hall Lake, northeast Atlin map-area (104 N), the sequence of chert, argillite and minor greywacke that underlie mid-(?) to Late Permian limestone and greenstone is identical in lithology and similar in stratigraphic relationships and age to the Kedahda Formation in Dease Lake map-area (see Monger, 1968). Cherty phyllites below Permian limestone and greenstone near Dease Lake continue eastward into Cry Lake map-area (104 I) (Gabrielse, 1962). On the basis of lithology Watson and Mathews (1944, p. 16) correlated rocks of the Kedahda Formation with similar rocks outcropping 50 miles due north of Kedahda Lake, mapped by Lord (1944, p. 8). Poole (1958) restudied these rocks, giving them an Upper Mississippian and(?) younger age, as they conformably overlie limestone believed to be of Mississippian age. Later work has shown that fusulinids in this limestone are of Early Pennsylvanian age (H. Gabrielse, personal communication). This latter age thus gives some indication of the lower time limit of the Kedahda Formation. Of note, is a clast in a calcareous tuff of late Leonardian or Guadalupian age, from the contact of the French Range Formation, that contains Early Pennsylvanian fusulinids (Table IV), identical to those to the north (C. A. Ross, personal communication). It appears that Early Pennsylvanian rocks were present near the map-area at one time.

FRENCH RANGE FORMATION

The French Range Formation (units 4, 5, 6) comprises mid- to Upper Permian altered basic flow rocks or greenstones, their intrusive equivalents, and pyroclastic rocks with minor interbedded chert and argillite. These rocks were originally included by Kerr (1925, p. 86A) in the McLeod series, believed by him to be of probable Jurassic age, together with rocks later shown to be lower Mesozoic by Watson and Mathews (1944, pp. 17-20). As Kerr's unit included two unrelated, readily distinguishable, rock-stratigraphic units, it is discarded and the new term 'French Range Formation' proposed for the volcanic rocks in the French Range that comprise a readily mappable, distinctive and important part of the Cache Creek Group.

Distribution and Thickness

This formation underlies much of the higher part of the map-area, including the highest point, Mount Rath. Greenstones form prominent ridges and knolls of dark weathering rock, such as the ridge south of Slate Creek that retains its prominence for at least 12 miles along strike, whereas the topographic expression of the pyroclastic rocks is generally more subdued.

The apparent thickness of the formation is variable and this variation is probably due as much to primary thickness differences as to subsequent deformation, although some of this variation may be due to erosion that contributed greenstone clasts to breccias in the top of the Kedahda Formation. Northeast of Mount Rath, where the formation consists largely of pyroclastic rocks, it is much less than 1,000 feet thick. On Quartz Creek, 3 miles southwest of Mount Rath, it is about 2,000 feet thick and composed of both greenstones and pyroclastic rocks. Greenstones forming the prominent ridge south of Slate Creek have an apparent thickness of more than 3,000 feet and maintain this thickness for several miles along strike. In contrast, although greenstones underlying the triangulation station of elevation 5,398 feet in the southern part of the French Range appear to be at least 3,000 feet thick, less than 3 miles along strike to the northwest they are only about 200 feet thick. This variation appears to be primary, as the unit does not seem to have been cut out by faulting.

Lithology

Altered volcanic flow rocks or greenstones (unit 4) are the most abundant single rock type in the formation. They are all shades of grey-green, green-grey, yellow-green, or, less commonly, grey or maroon, and weather tan to dark grey brown. Generally, they are massive, very fine grained or aphanitic rocks that are locally amygdaloidal. Most are equigranular, although some are fine-grained porphyries. Neither bedding nor penetrative secondary foliations are well developed in these rocks, but attitudes may be determined in places from thin, interbedded tuff, chert or pelite layers. Locally, as on the ridge south of Slate Creek, the greenstones contain pillows 2 to 3 feet long, with interstitial chert, jasper or reddish crystalline limestone. Macroscopic secondary structures are localized discordant shear planes or faults and restricted foliated layers, probably resulting from shearing along incompetent interbedded tuff horizons and selvages of pillows.

The greenstones have undergone alteration that obscures their primary nature in varying degrees, although this alteration has rarely completely destroyed primary textures or produced new ones, and most secondary minerals are submicroscopic. Commonly, alteration is so extensive, and/or the rock originally so fine grained, that the bulk of the rock consists of largely optically irresolvable, semiopaque material in which chlorite, epidote, actinolite and feldspar have been detected with X-ray diffractometry. In some examples, transitional to better preserved rocks, a few vague feldspar outlines can be recognized. The least altered specimens contain up to 65 per cent of felted or locally trachytic, small (0.1 mm or less) altered feldspar laths that normally are recognizable as such only by their shape and textural relations. Also present are small clinopyroxene crystals in intergranular or subophitic relationship with the feldspars that may form more than 25 per cent of the whole rock or be absent but commonly comprise about 5 per cent to 10 per cent, interstitial chlorite and accessory opaque minerals. The feldspars are commonly wholly altered to semiopaque, finely granular saussurite, although under crossed nicols vague lamellar twins are visible in a few specimens. Extinction positions of these twins indicate that the feldspar is albite. A few less altered feldspar grains that are partly changed to secondary white mica have been determined as albite. The clinopyroxene is colourless to pale pink diopsidic augite, subhedral in form, and typically chemically unaltered, though highly fractured in many cases. It may be the only unchanged pyrogenic mineral in some of the more altered rocks. Very few pyroxenes contain patchy uralite or pale blue sodic amphibole, probably crossite, or are surrounded by a crossite rim. Chlorite is ubiquitous, occurring in the matrix, in altered feldspars and in veins and vesicles. Some opaque minerals in the little altered rocks are hematite; others have the skeletal habit of ilmenite and are invariably partly altered to leucoxene or finely granular sphene. Granules of sphene in the more altered rocks may be derived from the opaque minerals. These greenstones commonly contain chlorite, carbonate- or quartz-filled amygdules that in some cases are composite, with an outer rim of chlorite and a carbonate core, or the reverse. Granular epidote and radiating tufts of stilpnomelane occur at the carbonate/chlorite contact in a few composite amygdules. Most of these rocks are cut by veins of chlorite or carbonate or, less commonly, of quartz or albite. In a few localities chlorite veins contain pumpellyite, or granular epidote. Chemical analyses of these rocks show they are altered basalts (Table III).

Porphyritic and siliceous greenstones are two relatively rare varieties. The former are essentially similar to the rocks described previously but contain clinopyroxene phenocrysts up to 1 mm long or less commonly, pale green saussuritic feldspar up to 10 mm long. Siliceous greenstones form the base of the formation on the northwest-trending ridge 3 miles southwest of the summit of Mount Rath, in places on the south side of Slate Creek valley, and are interbedded with tuffs farther south in the French Range. These rocks are grey-green to greyish purple, locally mottled and banded, aphanitic, contain lenticles of chert and jasper and are much harder than the typical greenstones. In thin section they consist of an extremely fine-grained, low birefringent matrix, composed in large part of quartz and containing chlorite, up to 15 per cent very fine grained opaque minerals, and amygdules of quartz or chlorite and quartz. Minute fibrous clots of sodic amphibole, probably riebeckite, with dark blue to pale yellow pleochroism, are marginal to quartz amygdules in the groundmass of one specimen from the ridge 3 miles southwest of the summit of Mount Rath. Crossite-quartz schists with no primary texture remaining, in contrast to most of the rocks described above, are intercalated with greenstone and chert near the base of the French Range Formation at two localities on the north side of the ridge south of Slate Creek. These rocks are well to poorly foliated, extremely fine grained and resemble hard, bluish grey phyllites and argillites. They are composed of about 70 per cent finely granular, anhedral quartz grains and 30 per cent subparallel, acicular grains of sodic amphibole with grey to pale blue pleochroism. The sodic amphibole is crossite, with refractive indices ranging from 1.65 to 1.68 and zoned cleavage fragments that may be length fast at one end, length slow at the other, which possibly indicates the change in orientation of optic axes characteristic of crossite (see Borg, 1967). The plane containing most long axes of the crossite crystals is parallel with primary lithological layering, and is wrinkled, with the wrinkling causing breakage and distortion of the crossite crystals.

In summary, metamorphism generally has caused chemical rather than mechanical alteration of these rocks. That the latter does occur locally is shown by the broken and offset or bent twin lamellae of some feldspar phenocrysts, but such evidence is rare. Commonly, pyrogenic plagioclase is

TABLE III

Chemical analyses* of extrusive rocks of the French Range Formation, northeast Dease Lake map-area

	1	2	3	4	5	6
SiO_2	44.8	46.3	46.6	42.8	47.0	49.6
Al_2O_3	13.1	15.2	16.2	14.7	15.4	16.4
Fe_2O_3	0.7	3.8	2.3	3.1	0.5	0.6
FeO	11.2	7.0	7.9	9.2	10.1	8.8
CaO	8.9	8.8	11.4	9.7	4.8	8.6
MgO	6.1	8.5	6.8	8.8	7.6	4.8
Na_2O	4.3	3.4	2.1	2.9	3.3	4.0
K_2O	0.01	0.7	2.4	0.2	1.0	0.9
H_2O	3.7	4.2	0.6	5.1	5.4	3.0
TiO_2	2.31	1.65	1.35	1.62	4.47	1.35
P_2O_5	0.22	0.14	0.12	0.12	0.73	0.10
MnO	0.19	0.18	0.22	0.18	0.15	0.14
CO_2	2.5	0.1	0.2	0.01	0.3	0.01
Total	98.03	99.97	98.19	98.43	100.75	98.30

All specimens are fine-grained saussuritic flow rocks, with variable amounts of clinopyroxene.

1. From southwest side, Johnson Knolls.

2. From north side, southeastern end of prominent greenstone ridge south of Slate Creek.

3. From north side, prominent greenstone ridge south of Slate Creek and 1 mile southeast of peak of elevation 6,197 feet.

4. From east side, summit of Mount Rath.

5. From greenstone knoll, 1 1/2 miles south of summit of Mount Rath.

6. From 2 miles southeast of westernmost lake at head of Cody Creek.

* Analyses done by the rapid method by S. Courville in the laboratories of the Geological Survey of Canada.

altered to very fine grained actinolite, epidote(?) and albite and the opaque minerals to leucoxene(?) and sphene. Other secondary minerals that are distributed across the map-area but are not always present, are stilpnomelane, the sodic amphiboles crossite and riebeckite, and pumpellyite. Small stubby prisms of lawsonite are scattered through the matrix of typical altered greenstones from a locality 1 mile south-southwest of the triangulation station of elevation 6,197 feet on the ridge south of Slate Creek, but this mineral has been found nowhere else in the map-area. Occurrence of these minerals is shown on the map.

Altered diabases (unit 5) outcropping east of Dease Lake are believed to be the intrusive equivalents of flow rocks (unit 4) in the French Range Formation. Apart from being coarser grained than the typical greenstones they are texturally identical, consisting of felted, saussuritic plagioclase laths about 1 mm long with interstitial ferromagnesian and opaque minerals. Extinction positions of faint twin lamellae indicate that some of the feldspars are albite. These rocks differ primarily from the extrusive greenstones in that the interstitial material is uralitic hornblende, rather than pyroxene or chlorite. The opaque mineral is skeletal ilmenite(?) with associated leucoxene. The base of the body east of Dease Lake appears to be rusty weathering, black, peridotite, very similar to that on Porter Landing Mountain, just east of the north end of Dease Lake. Bodies of similar diabasic rocks are intercalated with fine-grained, presumably extrusive greenstones elsewhere in the map-area, but are too small to show on the map.

Pyroclastic rocks (unit 6) coloured yellow, grey-green, green and maroon are the remaining major component of the French Range Formation in the map-area. Like the greenstones, these pyroclastic rocks are highly altered chemically, but in addition they are invariably well foliated, with the result that primary textures may be even less well preserved. Nearly all of the pyroclastic rocks are semischists (Williams, Turner and Gilbert, 1958, p. 205) that retain many primary clasts; a few are true schists in which no trace of primary texture is retained.

The pyroclastic rocks are unsorted and consist of angular clasts of all sizes ranging downward from blocks more than 3 feet long in agglomerate exposed in Quartz Creek, 3 1/2 miles southwest of the summit of Mount Rath, although metamorphism commonly has obliterated clasts finer than sand size. No ignimbritic textures have been recognized in the formation by the writer, and if they were ever present they must have been relatively rare.

Lithic fragments predominate in these pyroclastic rocks. Commonest clasts are yellow-green to grey-green, locally amygdaloidal and aphanitic, and consist of semiopaque, optically irresolvable material. Some clasts contain very small felted or trachytic feldspar laths in a dark semiopaque matrix. A few clasts are porphyritic with euhedral, green feldspar phenocrysts up to 1 inch long in a maroon hematitic matrix. In addition to lithic fragments, some finer grained rocks contain euhedral feldspar crystals that are highly altered to secondary white mica and, in rare examples, subrectangular, embayed beta-quartz crystals. Limestone fragments are the principal nonvolcanic clasts in these rocks and are locally abundant.

Alteration of these pyroclastic rocks, as noted earlier, is both chemical and mechanical, in contrast to the greenstones, where chemical alteration prevails. The degree of mechanical alteration probably depends largely on primary grain size. An extreme example of this is on the southwest side of Johnson Knolls, where poorly foliated agglomerate is in proximity to chlorite-muscovite-albite-stilpnomelane schist. The agglomerate contains poorly 'flattened' clasts up to 2 inches long and retains much of its primary texture. The schist consists of chlorite and muscovite laminae alternating with albite and albite and carbonate laminae. No primary texture remains, but as the schist grades into well-foliated lapilli tuff it is presumably its finer grained equivalent. However, this advanced stage of reorganization is exceptional and the finest grained rocks generally are grey-green to maroon phyllites and slates, with scattered coarser grains, that grade, with increasing grain size, into the typical semischists. The degree of chemical alteration is similar to that of the greenstones with most of the alteration to semiopaque irresolvable material. Patchy secondary carbonate is far more common in these rocks than in the greenstones; much of this is possibly redistributed primary carbonate as these rocks originally may have been calcareous tuffs. Stilpnomelane is present at a few localities and appears to be a 'late' mineral as it forms radiating sheafs that are randomly orientated and grow across the foliation planes. However it precedes the later wrinkling and strainslip cleavage that deform the foliation in many places. Dark blue to opaque clots of riebeckite composed of minute acicular crystals, and dark green aegirine have formed in a quartz-bearing lapilli tuff exposed 2 miles south of the peak of elevation 6,197 feet on the ridge south of Slate Creek. Possibly the crossite-quartz schists, described above in the section of greenstones, were originally tuffs or cherty tuffs, but their primary nature is unknown.

These pyroclastic rocks grade through very common cherty tuff or argillaceous tuff to chert or argillite. In places chert and argillite occur within the formation, as on Quartz Creek, about 3 miles southwest of Mount Rath summit, but elsewhere, such as west of Little Dease Lake, they are probably in continuity with the Kedahda Formation. In the latter locality these rocks have not been distinguished on the map as they are of minor extent and the contact between the Kedahda and French Range formations is gradational.

A variety of metamorphic index minerals is developed in the French Range Formation. These minerals, crossite, riebeckite, stilpnomelane, pumpellyite, aegirine and lawsonite, are characteristic of the glaucophane schist facies or lawsonite-glaucophane facies of Winkler (1965, pp. 145-147). However, as they are only sporadically developed and as the common alteration is merely a downgrading of pyrogenic minerals to submicroscopic secondary minerals, most of these rocks are of lower grade than the glaucophane schist facies. They belong to the pumpellyite-chlorite facies of Seki (1961, p. 421), transitional to the glaucophane schist facies.

Contact Relations

The contact between the French Range Formation and the underlying Kedahda Formation has been described, and is conformable, locally gradational and diachronous. Fossils in limestone just below and at this contact are of Leonardian and earliest Guadalupian age (Table II).

The upper contact is with limestone of the Teslin Formation and is conformable and gradational in places where pyroclastic rocks underlie the contact. For example, in the southern part of the French Range, and also about 4 miles southeast of Mount Rath and just west of Killarney Lake, pyroclastic rocks of the French Range Formation grade through calcareous tuff to

TABLE IV

Fossils from the Teslin Formation

G. S. C. Cat. No.	Loc. No.	Approximate Location	Fusulinids	Age
75283	4	West side Johnson Knolls	Schwagerina sp. ? sp.	probably Permian
75284	5	1.4 miles N.W. of Little Dease Lake	Parafusulina ? sp.	Leonardian late Leonardian or early Guadalupian
75285	6	1.05 miles W. of Little Dease Lake	Neoschwagerina ? sp.	late Leonardian or[1] Guadalupian
75286	7	2.1 miles W.S.W. of Little Dease Lake	Neoschwagerina sp.	late Leonardian to early Guadalupian
75287	8	1.8 miles W.S.W. of Little Dease Lake	Chusenella ? sp. Schwagerina ? sp. Staffella ? sp. Monodiexodina ? sp.	probably Leonardian, but could be Wolfacamp
75288	9	2.2 miles W. of N. end of Killarney Lake	Neoschwagerina sp.	late Leonardian to early Guadalupian
75289	10	1.75 miles W. of northern end of Killarney Lake	Neoschwagerina sp.	late Leonardian to early Guadalupian
75290	11	In cirque, 2.5 miles W. of north end Killarney Lake	Yabeina sp. Reichelina sp.	Late Permian, probably late Guadalupian
75291	12	3.7 miles S.W. of summit of Mount Rath, on divide between Slate and Quartz creeks	Yabeina sp. Neoschwagerina sp.	Late Permian, probably late Guadalupian

75294	13	0.8 mile S.E. of 6,197 ft. peak, central French Range	Neoschwagerina sp.	Late Leonardian to early Guadalupian
75391	14	2 miles S.W. of 6,197 ft. peak, southern French Range	Yabeina sp. Schwagerina sp. Kahlerina sp. Chusenella sp. Reichelina sp.	Late Permian, Guadalupian
75392	15	1.5 miles S.W. of 6,197 ft. peak, southern French Range	Schwagerina sp. Afghanella sp. cf. A Schenki Thompson	probably Leonardian
75394	16	East side of Cassiar-Stewart Highway, 14.05 miles north of Junction with Telegraph Creek Road	Schwagerina	Leonardian
Corals				
75295	17	0.75 miles S.E. of 6,197 ft. peak, southern French Range	? waagenophyllid[2] coral indet.	
75296	18	Quartz Creek, 4 miles S.W. of Mount Rath	? waagenophyllid[2] coral indet.	
75297	19	Quartz Creek, 3.7 miles S.W. of Mount Rath	? waagenophyllid[2] coral indet.	

Fusulinids identified by C.A. Ross of Western Washington State College; corals identified by E.W. Bamber, Geological Survey of Canada.

Other fossil localities shown on map contain fusulinids that commonly are too poorly preserved to allow specific identification.

[1] This fossil occurs in the matrix of a calcareous tuff at the base of the formation. A limestone clast in this tuff contains Eostaffella sp., Millerella? Endothyra sp. of probable Morrowan age.

[2] Corals have recrystallized, and are too poorly preserved for definite identification. They give no indication of the position within the Permian of the rocks from which they were collected.

characteristic brown and buff weathering tuffaceous limestone comprising the basal Teslin Formation. Fusulinids, typically Neoschwagerina of late Leonardian to early Guadalupian age (Table IV) occur in both limestone and tuff in such places. This fusulinid fauna is quite different from the fusulinid faunas of similar age in limestone pods from the top of the Kedahda Formation given in Table II. Some of the small limestone pods in the southern part of the French Range may be stratigraphic pods rather than the structural ones shown in the cross-section, and if so, indicate interfingering and interlensing of the lower part of the Teslin Formation with the French Range Formation. This contact is diachronous as limestone mapped as Teslin Formation in the southeasternmost part of the French Range contains "probable Leonardian but could be Wolfcampian" fusulinids (Table IV), that are older than anything known from the French Range Formation (see Fig. 1). Although poor exposures obscure stratigraphic relationships in this part of the map-area, that this limestone belongs to the Teslin Formation is shown by the presence in the same body of the typical Neoschwagerina fauna.

The French Range Formation is nowhere younger than the youngest limestone of the Teslin Formation for the following reasons. Where the Teslin limestone is thick, it contains the fusulinid genus Yabeina of probable late Guadalupian age, whereas the gradational contact with the French Range Formation is invariably marked by the late Leonardian to early Guadalupian Neoschwagerina fauna. This late Guadalupian limestone is of a characteristic lithology everywhere in the map-area (see below) indicating widespread uniform conditions in the basin of deposition during late Guadalupian time. Nowhere is Yabeina associated with tuff or tuffaceous limestone, and no greenstone dykes have been seen cutting limestone containing Yabeina. It is therefore concluded that volcanism in the map-area had ceased during deposition of the youngest part of the Teslin Formation, whereas it was certainly active during deposition of the older part.

Age and Correlation

Fossils at the lower contact of the formation are of Leonardian and earliest Guadalupian age and at the upper contact of late Leonardian to early Guadalupian age. Since these fossils occur in a relatively restricted area it seems probable that deposition of the unit took place at a relatively rapid rate. A limestone clast of Early Pennsylvanian age, found in fusulinid-bearing calcareous tuff of Leonardian age, indicates that Early Pennsylvanian limestone was exposed and was being eroded in the region at this time and presumably denotes the presence of an unrecognized Permian unconformity somewhere in the region.

The French Range Formation extends northwesterly from the vicinity of Dease Lake to Tuya River, a distance of over 40 miles. Over 100 miles to the northwest, in the vicinity of Hall Lake, Atlin (104 N) map-area, volcanic rocks underlie limestone of the same age as that in the map-area (Monger, 1968, p. 34). Elsewhere, in southern Atlin and northern Tulsequah (104 K) map-areas, limestone was deposited in mid-Permian time, and volcanic rocks, although abundant, are either very late Permian or pre-Permian.

TESLIN FORMATION

The Teslin Formation (unit 7) is the youngest Paleozoic unit in the map-area and consists of limestone and dolomitic limestone of Middle to Late Permian age that conformably overlies and is partly a facies equivalent of the French Range Formation. Watson and Mathews (1944, p. 16) first applied the name Teslin Formation to limestone outcropping in Teslin River Valley in western Jennings River map-area (104 O) 70 miles northwest along strike from northeastern Dease Lake map-area. The similarity of the lithology and fossil content of the limestone described by Watson and Mathews to that in northeastern Dease Lake map-area leaves little doubt that they are the same unit.

Distribution and Thickness

The formation underlies higher parts of the map-area and forms ridges and knolls of white or pale grey rocks that are particularly noticeable as they are in strong contrast to the slightly more prominent, darker French Range rocks with which they are in contact.

Neither the present true thickness nor the original thickness of the formation are known, as it has undergone considerable deformation and the upper contact is either a fault or possibly a post-Permian erosion surface. Apparent thicknesses range up to the 2,000 feet of limestone exposed near Quartz Creek, 3 1/2 miles southwest of the summit of Mount Rath. North of Mount Rath and about 4 miles north of the triangulation station of elevation 5,398 feet in the southern part of the French Range, the formation is slightly less than 1,000 feet thick. In other places, rocks mapped as unit 7 form lenses within the French Range Formation and these are much thinner, but it is not known whether these lenses are of structural or stratigraphic origin, or both.

Lithology

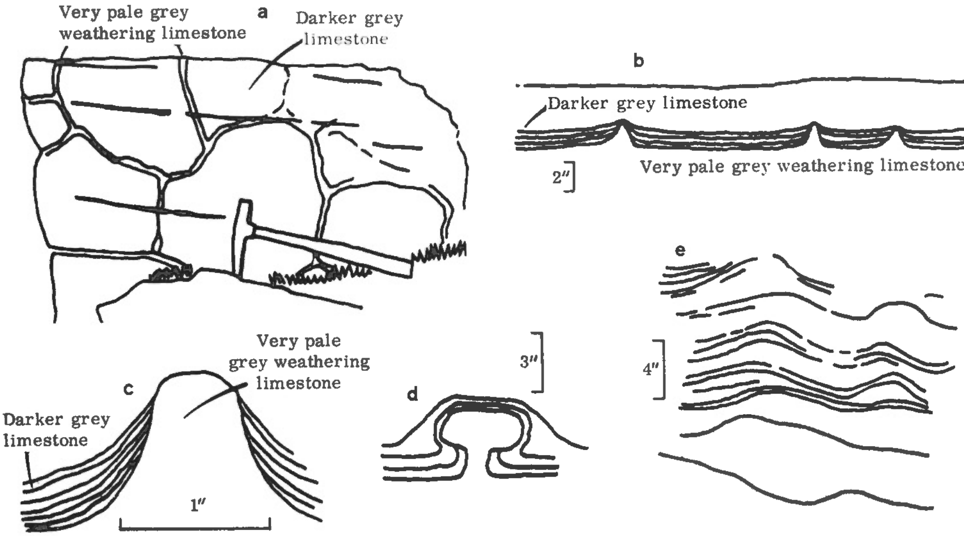
Recrystallization has wholly or partly destroyed much of the primary fabric of the carbonates making up the formation. Primary textures have been completely destroyed in perhaps 50 per cent of the formation in the map-area, leaving structureless limestone that is of fine to medium crystallinity (using the crystal size terminology of Folk, 1959, p. 19). Of the remainder, possibly 25 per cent has retained some traces of primary fabric because of selective dolomitization or silicification prior to recrystallization. Although dolomitization destroys the finest textural details, it seems that the dolomitized limestones are far more resistant to further recrystallization than the pure limestones. For example, dolomitized outer whorls of fusulinids are preserved, whereas the inner whorls which were not dolomitized are medium-crystalline calcite. Partial dolomitization has preserved textures in recrystallized breccia in which the clasts are grey calcite of medium-crystalline dolomitic limestone. In a few cases silicification has partly preserved primary textures. Silica nodules in limestone exposed above the east side of the Cassiar-Stewart Highway, 4 miles north of Nine Mile Point on Dease Lake, contain poorly preserved fusulinids. In contrast, fusulinids in the enclosing limestone are merely white patches of calcite, slightly coarser grained than the pale grey, medium-crystalline limestone enclosing them. Primary textures in the remaining 25 per cent of the formation are well preserved and are described below. As both recrystallized and unaltered carbonate are found together everywhere in the map-area, it may be that recrystallization is controlled by the primary lithology, in which case the rock types described below cannot be taken as representative of the lithology of the whole formation before recrystallization.

Primary lithologies in the formation are fine-grained limestone or dolomitic limestone, limestone breccia, tuffaceous limestone and extremely rare coarse bioclastic limestone.

The commonest primary lithology in the Teslin Formation in the map-area is hard, splintery, fetid, extremely fine grained, very dark grey massive limestone or dolomitic limestone, that characteristically weathers very pale grey. This limestone type is found everywhere in the map-area and comprises much of the unrecrystallized part of the formation away from the contact with the French Range Formation. This is presumably the same lithology as the "light grey weathering rock which is dark grey on fresh surface" described from the type-area of the Teslin Formation by Watson and Mathews (1944, p. 16).

Bedding in these rocks commonly ranges from 4 to 18 inches in thickness and is visible as faint banding in shades of pale grey on weathered surfaces. A single bed may grade from very pale grey to darker grey or may be very pale grey with a darker lamination marking the bedding plane. Mechanical grading is extremely rare, but locally the lowest(?) part of a bed contains small (1 mm or less) limestone, dolomitic limestone and fossil fragments in a fine-grained matrix. A few beds, such as some exposed on the east side of the cirque 3 miles southeast of Mount Rath, are completely laminated with slightly irregular laminae separating pale grey carbonate layers 1 mm to 5 mm thick. In places these laminae form domes up to 4 inches in diameter (Fig. 2e). Commonly such laminations are restricted to a darker horizon that forms one surface of a pale grey structureless limestone bed. In many localities these darker laminated layers are transected and deflected by structures 2 to 3 inches long that resemble small sedimentary dykes continuous with very pale grey carbonate beds (Fig. 2b). Exposed bedding surfaces penetrated by these dykes show a polygonal pattern closely resembling mud-cracks (Fig. 2a). Polygonal structures produced by short sandstone dykes penetrating overlying mud layers reported by Duzulyinski and Walton (1965, pp. 166, 167) are morphologically identical to the structures in these limestones. They cannot be interpreted as mud-cracks filled from above, even though mud-cracks could occur in the probable depositional environment of this limestone (see below) as in some examples where a thin, dark, anticlinal lamina separates the dyke from the overlying(?) bed. Other structures, rarely seen in recrystallized dolomitic limestone that grades into this fine-grained limestone, are spheroidal bodies ranging from 1 mm to 10 mm in diameter which have a concentric structure partly preserved by dolomitization. In one rock these bodies may be all of the same size or else grade from coarse to fine, and may be loosely packed or form more than 50 per cent of the rock.

Fossils visible in hand specimens of these rocks are large spheroidal fusulinids (Yabeina), up to 7 mm in diameter, and extremely rare small horn and colonial corals. The fusulinids are relatively rare in that they



a. Bedding plane showing polygonal pattern formed by 'injection' structures. traced from photo by D.W. Morrow, 1967).

b. 'Injection' structure cutting bedding plane laminations (from notebook sketch).

c. Detail of 'injection' structure (traced from hand specimen)

d. 'Bulbous' type of 'injection' structure (from sketch by D.W. Morrow, 1967).

e. Domal stromatolites in laminated limestone (traced from photo by D.W. Morrow, 1967)

Figure 2. Sedimentary structures in fine-grained limestone of the Teslin Formation.

are never evenly distributed in any one outcrop, but when present tend to be concentrated in one bed, where they comprise up to 1 per cent of the total volume of the bed. Despite their rarity, these fusulinids have been found in almost every locality where this primary limestone type occurs.

In thin section, these rocks consist of brownish grey, aphanocrystalline (4 microns or less) carbonate of varying degrees of opacity, with the densest, most opaque layers corresponding to macroscopically visible laminations. Scattered through this fine-grained carbonate are calcispheres, thin-walled spherical bodies that are mostly about 0.1 mm in diameter and that make up 5 per cent or more of the whole rock in some examples. Some thin sections contain variously oriented sections of dark-walled tubes filled with finely crystalline carbonate, that range from 0.08 mm to 0.03 mm in diameter, and closely resemble the algal tubes shown by Black (1933, Plate 22, Fig. 26). In places there are irregularly shaped, anastomosing patches of sparry calcite, layers of dense, angular, fine sand-size carbonate clasts (intraclasts) and small abundant coiled and rare uniserial foraminifera.

Some specimens contain dolomite rhombs that seemingly grow preferentially in certain horizons. These limestones contain little terrigenous material, but their dark colour when fresh and characteristic pale grey weathered appearance indicates they are sapropelic (see Carozzi, 1960, p. 214). That they are sapropelic is shown by Morrow (1967, p. 3) who found that an insoluble residue of one of these limestones comprised up to 13.15 per cent of the total weight and consisted of 'a black pitchy substance with an aromatic odour'. Some limestones contain thin chert layers generally less than 10 mm thick that parallel the bedding, and others contain argillite interbeds, but these are rare.

Carbonate breccias are relatively common in the formation but are of insignificant volume relative to the limestone described above. Breccias composed of angular lithic carbonate clasts and minor black chert fragments in a carbonate matrix, are associated with the fine-grained limestone described above and weather to a similar pale grey colour. Clasts range in size from a maximum of about 6 inches down to granules. Graded beds of granule breccia are locally interbedded with the fine limestone. As textures of the lithic clasts in the breccias are commonly variable, ranging from aphanitic dolomitic limestone to coarsely crystalline limestone in the same rock, the breccias typically are not pseudobreccias or solution breccias, but have been derived from a variety of limestone types. Pseudobreccias produced by recrystallization, however, occur locally and have been described by Morrow (1967). The clasts in most of these are roughly equidimensional and have no preferred orientation, but a few breccias consist of platy, fine-grained limestone clasts up to 2 inches in diameter and 1/4 inch thick that are aligned parallel to bedding. The relationship of these breccias to bedding is variable; some breccias cut bedding at high angles, with an irregular contact; others are conformable.

Breccias containing large limestone fragments are exposed along the southern contact of the greenstones forming the ridge south of Slate Creek. A breccia consisting of limestone clasts up to 1 foot in diameter in a limestone matrix containing crinoid columnals is exposed on the eastern side of the cirque 1 mile southeast of the triangulation station of elevation 6,197 feet. Fusulinids (Yabeina) are in the clasts and the matrix. To the northwest, 4 miles along strike, a breccia contains limestone clasts up to 10 feet long, argillite fragments 1 foot in diameter, and crinoid columnals in a calcareous tuff matrix.

Brown or tan weathering tuffaceous limestone occurs at the contact between the French Range Formation and Teslin Formation in many places and marks the transition between them. Many of these tuffaceous limestones resemble fine-grained breccias, with grey weathering calcite grains, either lithic fragments or fusulinids, in a brown weathering tuffaceous matrix.

Well-sorted bioclastic limestone has only been found in the Teslin Formation in one locality in the map-area, near the head of Argillite Creek, in the same body of limestone that contains the oldest fusulinids in the Teslin Formation. The rock is an encrinite, composed of small (less than 5 mm) crinoid ossicles that are closely packed, in a recrystallized matrix of calcite.

Depositional Environment

The environment of deposition of the Teslin Formation can be determined with more precision than that of any other unit of the Cache Creek Group in the map-area. The laminated carbonates associated with the common fine-grained limestone and dolomitic limestone are analogous to the carbonate mud and sand bound by organic mats of blue-green algae that are being deposited today on intertidal mud flats (Black, 1933; Ginsburg, et al., 1954). Such rocks have been called cryptalgalaminate carbonates (Aitken, 1967, p. 1170). Domed laminated carbonates (Fig. 2e) are called domal stromatolites by Aitken (1967, pp. 1166, 1167) who notes they occur on intermittently exposed tidal flats. Other evidence for the algal origin of these laminated rocks is the common presence of tubular structures that closely resemble the algal tubes described by Black (1933, Plate 22, Fig. 26), and the anastomosing patches of sparry calcite that are infilled voids. However, most of the fine-grained rocks in the formation, although of similar composition to the lime-mud in the laminated rocks, either have no laminations or the laminations are restricted to thin dark layers marking bedding surfaces. These rocks were presumably deposited where the supply of lime-mud was greater than that for the laminated carbonates, but still in shallow water. The almost total absence of any sorted or washed sediments indicates that this was a protected environment, perhaps a shallow lagoon surrounded by islands or shoals of the near-contemporaneous volcanic rocks of the French Range Formation. However no evidence of any aerial volcanism has been found in these fine-grained rocks. The sporadically occurring fusulinids and corals, generally confined to one bed and absent from surrounding ones, may have been washed in by intermittent storms, and some breccias may be lime-mud torn up during severe storm action and redeposited. The platy limestone clasts in some breccias may be desiccated lime-mud fragments that have been redeposited. That these breccias are intraformational is indicated by the similarity of lithology of many clasts with that of the surrounding fine-grained limestone and by the presence in some breccias of the same fossils in the clasts as 'free' in the matrix.

Contact Relations

As noted earlier the lower contact of the formation is gradational with the underlying French Range Formation, and the penecontemporeneity of limestone pods in the top of the Kedahda Formation with the base of the Teslin Formation, shows that this contact is markedly diachronous, and that the French Range Formation was being deposited at the same time as the lower part of the Teslin Formation (Fig. 1). However, the total absence of volcanic material from the younger part of the Teslin Formation suggests that volcanism in the area ceased before deposition of these rocks.

Age and Correlation

The age of the Teslin Formation in the map-area ranges from Leonardian or possibly Wolfcampian to late Guadalupian (Table IV). Fusulinids in tuffaceous limestone at the base of the formation are of late Leonardian to early Guadalupian age. The fine-grained, locally laminated limestone that forms the bulk of the Teslin Formation in the map-area, contains late Guadalupian fusulinids. Leonardian or possibly Wolfcampian fusulinids in limestone mapped as Teslin Formation, 1.8 miles west-southwest of Little Dease Lake (Fossil locality 8) are anomalous as they occur in the same body of limestone as late Leonardian or early Guadalupian fossils at the contact with the French Range Formation, thus indicating that here the bulk of the limestone probably is older than much of the French Range Formation. Therefore the Teslin Formation in places in the south of the map-area may be time-equivalent to or older than those thin beds of limestone mapped as Kedahda Formation in the north.

Facies Belts

Limestones of similar age to the Teslin Formation in the map-area outcrop over much of the area underlain by upper Paleozoic rocks that extends from the map-area along strike to the northwest for 150 miles, to the southeast for 50 miles, and is 60 miles across strike at its widest point 80 miles west of the map-area (Aitken, 1959; Christie, 1957; Gabrielse, 1962 and Gabrielse et al., 1962; Mulligan, 1963; Souther, 1960; Watson and Mathews, 1944; Wheeler, 1961). Preliminary work indicates that limestone in this area is divisible into two generalized facies belts, a northeasterly one that includes the rocks of the map-area, and a southwesterly one beyond the map-area (see Monger, 1968).

The northeasterly belt is characterized by fine-grained, dark grey, pale grey weathering limestone, that is locally laminated and contains mid- to Late Permian fusulinids, of which the genus Yabeina is most common. Such rocks, which have been traced northwesterly from the map-area for 30 miles, outcrop in and around the type-area of the formation in southwestern Jennings River (104 O) map-area (Watson and Mathews, 1944; H. Gabrielse, personal communication), and still farther to the northwest at Hall Lake, northeastern Atlin (104 N) map-area, about 120 miles northwest of the map-area.

By contrast, the southwesterly belt exposed in northwestern Dease Lake (104 J), northeastern Tulsequah (104 K), and southern Atlin (104 N) map-areas contains much coarse bioclastic limestone, is much thicker, and contains fusulinids identified by C. A. Ross (personal communication) as being of Middle Pennsylvanian to Late Permian age. The fusulinid genus Yabeina occurs at the top of this limestone.

Near Blue River in McDame (104 P) map-area, about 60 miles north-northeast of the map-area, on the northeast side of the belt of crystalline rocks that form the axis of Cassiar Mountains, the predominantly volcanic Sylvester Group contains a local Permian limestone member (Wolfe, 1965, pp. 5-6). The fusulinid species in this limestone, subsequently identified by C. A. Ross (personal communication) is Parafusulina cf. P. antimonioensis Dunbar of Guadalupian age. The presence of this species is of note as it typically belongs to the 'southwestern United States' Permian fusulinid fauna, whereas fusulinid faunas of the same age in northeastern Dease Lake map-area are 'Tethyan' or 'Asiatic' fusulinid faunas, similar to those in Japan.

The paleogeographic implications of these data are as follows. The different Late Permian faunas in rocks southwest and northeast of the Cassiar Mountains indicate the existence of a faunal barrier in Late Permian time between the two areas. This inference is supported by the distribution of facies belts in the Permian limestone south of the Cassiar Mountains. The depositional site of the coarse bioclastic rocks to the southwest was probably an off-reef and reef environment, whereas the fine-grained, locally cryptalgalaminate rocks common in the northeastern belt were deposited in a protected lagoonal, perhaps intertidal environment. Thus there appears to have been in Late Permian time, a progression towards shallow water from southwest to northeast; continuation of this trend still farther to the northeast indicates land on the site of the axis of the present Cassiar Mountains. If a land barrier existed it was probably low, as no direct evidence of its existence has been found in the form of terriginous detritus in the Late Permian limestone.

ULTRABASIC TO INTERMEDIATE ROCKS

Small bodies of ultrabasic to intermediate rock outcrop mainly along the Thibert Creek Fault that runs northwesterly from the north end of Dease Lake and separates Paleozoic rocks to the south from Mesozoic rocks to the north. Although these rocks originally were believed to belong to two different Mesozoic lithologic units, the McLeod and Thibert Series (Kerr, 1925, pp. 84A, 89A), they were later incorporated by Gabrielse et al. (1962) in a single unit of possible Permian age.

The largest of these bodies underlies Porter Landing Mountain and is about 4 square miles in extent. This body is composite and consists of serpentinized peridotite, altered gabbro or dolerite, diabase and serpentinite. The serpentinite occurs along the southwest side of the body in contact with chert, cherty argillite, and greenstone and also forms dykes cutting the other rocks. It is dark green to black and commonly in fragments with slickensided or polished surfaces. Orange weathering carbonatized serpentinite is exposed on the east side of the mountain. Contiguous with the serpentinite on the southwest side of the mountain, and forming much of the body elsewhere is tan weathering serpentinized peridotite consisting of a black aphanitic matrix containing rusty or golden weathering euhedral 'basite' pseudomorphs after pyroxene, up to 5 mm long. Some of these rocks are completely serpentinized but retain original textures, whereas others contain relicts of primary minerals. The completely altered rocks consist of a matrix of serpentine (antigorite?) that displays a reticulated pattern in places outlined by grains of iron oxide, and 'bastite' pseudomorphs. In less altered specimens the matrix contains olivine crystals surrounded by serpentine, and patches of orthopyroxene occur in the pseudomorphs. In one specimen fibrous dark blue overgrowths of sodic amphibole (riebeckite?) surround the olivine and themselves are surrounded by serpentine. The tan weathering gabbroic or dioritic rocks are coarse grained, with a medium grain size just less than 5 mm and consist of about 50 per cent white feldspar grains and 50 per cent ferromagnesian minerals. Most feldspars are altered to semiopaque, brownish saussurite, but a few unaltered examples have a composition of An_{47} (determined from Carlsbad-albite twins). Ferromagnesian minerals are clinopyroxene, in part or wholly altered to either pale green-brown hornblende or else fibrous serpentine. The fine-grained diabasic rocks are similar in composition but closely resemble greenstones in the field.

Northwest of Porter Landing Mountain, numerous small outcrops of sheared serpentinite and carbonatized serpentinite outcrop in Thibert Creek, on Red Ledge Mountain and south of Mount Defot. Altered diabasic rocks exposed near the confluence of Delure and Thibert creeks contain uralitic hornblende, finely granular epidote, deep green aegirine, skeletal ilmenites partly altered to sphene, and prehnite veins.

Farther south, small carbonatized serpentinite bodies crop out on Dease Creek. On the east side of Dease Lake, southeast of Nine Mile Point, there are numerous small serpentinite bodies. Peridotite appears to underlie diabasic rocks (unit 5) believed to be intrusive equivalents of the flow rocks in the French Range Formation.

NAZCHA AND SHONEKTAW FORMATIONS

Lower Mesozoic volcanic clastic rocks, argillite, and minor limestone of the Nazcha Formation together with flow and pyroclastic rocks of the Shonektaw Formation, exposed in the northernmost part of the map-area, were briefly studied in order to compare and contrast their lithologies and structures with those of contiguous Permian rocks. These rocks were mapped originally by Kerr (1925) as being partly Mesozoic and partly Paleozoic in age. Subsequently, Watson and Mathews (1944, pp. 17-20) described them in more detail, gave evidence for their age and proposed the names Nazcha and Shonektaw Formation from type-localities in the Nazcha Hills and from Shonektaw Creek, respectively 20 and 44 miles northwest of the map-area.

The Nazcha Formation is of probable Late Triassic age and believed by Watson and Mathews (1944, pp. 18, 19) to underlie the Shonektaw Formation. Similar rocks extend to the northwest for 150 miles (Mulligan, 1963) and identical rocks outcrop south of the map-area (Gabrielse et al., 1962).

Rocks of the Nazcha Formation are well exposed on Defot Mountain, where they are predominantly massive, brown to tan weathering, dark grey-green or grey volcanic sandstones and argillites, with minor pebble and cobble conglomerate and local lenticles of crystalline limestone. The argillites contain a fracture cleavage that cross-cuts bedding. Some sandstone beds are graded, with the basal part consisting of very coarse volcanic sandstone, the bulk of the bed coarse sandstone, and the top, finely laminated siltstone and argillite. Other sandstone beds, however, locally contain internal crossbedding. The argillites commonly contain laminae or thin beds of siltstone or sandstone and small vermiform markings that are probably infilled worm burrows. The conglomerates consist of well-rounded cobbles or subrounded to angular pebbles of fine-grained feldspar porphyry, clinopyroxene- or hornblende-feldspar porphyry, fine-grained greenstone, shale and limestone, in a volcanic sandstone matrix that may comprise more than 50 per cent of the whole rock. On Ichthyosaur Mountain, 5 miles northwest of Defot Mountain, much of the formation consists of boulder and cobble conglomerate with minor sandstone, argillite, limestone and volcanic flow rocks. Clasts in the cobbles are commonly well rounded, up to 1 foot in diameter, and are largely of volcanic origin. Finely crystalline and sheared limestone forms a prominent bed on the northwest side of Ichthyosaur Mountain.

In thin sections, the sandstones and the matrix of the conglomerates consist of unsorted or poorly sorted angular lithic fragments, mainly of volcanic origin, but including some carbonate and chert clasts, clinopyroxenes, feldspars, and very minor quartz and hornblende grains (Table V). The lithic volcanic clasts are either fine-grained feldspar porphyries or augite feldspar porphyries. The former consist of abundant small, zoned euhedral plagioclase phenocrysts ranging from oligoclase to andesine and small clinopyroxene crystals in a fine granular matrix composed in part of K-feldspar. The latter comprise euhedral plagioclase and pyroxene phenocrysts in a matrix of trachytic and felted feldspar microlites. The clinopyroxene grains are pale green, commonly fresh and extremely abundant, comprising up to 30 per cent of some rocks. This is in marked contrast to volcanic sandstone in the Kedahda Formation where hornblende is the predominant ferromagnesian mineral and clinopyroxene is rare. Plagioclase feldspar (andesine) is fresh or altered to carbonate. Patchy carbonate is present throughout the matrix.

TABLE V

Volume percentage of constituents of some sandstones of the Nazcha Formation

	1	2	3
Quartz	0.7	1.3	0.5
K-feldspar[1]	11.9	16.4 (K-feldspar and Plagioclase)	12.2 (K-feldspar and Plagioclase)
Plagioclase	4.5		
Hornblende	0.7	0.4	-
Pyroxene	15.7	3.0	28.7
Rock fragments, matrix	39.4	78.4	52.5
Others[2]	27.1	0.5	6.1

500 to 1,000 points counted per slide

[1] Recognized by staining with sodium cobaltinitrite

[2] Includes carbonate, chlorite, muscovite, opaques, unknowns.

The Shonektaw Formation on the southwestern side of Coulahan Mountain consists of grey-green weathering, dark grey-green feldspar porphyry, pyroxene feldspar porphyry, and aphanitic flow rock with intercalated pyroclastic rocks. Most of the flow rocks are amygdaloidal and are superficially similar to flow rocks interbedded with conglomerates of the Nazcha Formation on Ichthyosaur Mountain. They differ in hand specimens from

Permian volcanic rocks as the former are typically porphyritic, whereas the latter are typically equigranular. These rocks commonly are considerably altered, possibly because of the proximity of dioritic and gabbroic intrusions (see Gabrielse et al., 1962), with clinopyroxenes wholly or partly changed to uralitic hornblende and feldspars to secondary white mica. Intercalated with these flow rocks are massive, lithic crystal tuffs composed of abundant euhedral oligoclase to andesine feldspars and chloritic clasts with pumiceous textures. In places, rhyolite porphyries with bipyramidal beta-quartz, pink euhedral K-feldspar, and green biotite intrude the flow rocks.

Although Watson and Mathews (1944, p. 18) on structural evidence, considered that the Shonektaw Formation overlies the Nazcha Formation the writer feels that the two units could be facies equivalent, with the Nazcha volcaniclastic rocks derived largely from volcanic rocks of the Shonektaw Formation.

TUYA FORMATION

Small patches of brown weathering, dark grey to black basalt flows that overlie upper Paleozoic rocks in parts of the map-area are correlated with the latest Tertiary and Pleistocene Tuya Formation (Kerr, 1925, p. 94A, Watson and Mathews, 1944, p. 28). In a few places, such as in the upper part of Dease Creek, about 1 mile east of Little Dease Lake, dykes that are feeders to these flows cut the older rocks.

STRUCTURE

Deformation, in part associated with regional metamorphism, affects all rocks in the map-area with the exception of the Tuya Formation. The upper Paleozoic rocks appear to have undergone an early and a late deformational phase, with low-grade regional metamorphism related to the early phase. In contrast, contiguous lower Mesozoic rocks have experienced only the late deformation phase and no regional metamorphism. The best evidence for an early deformation phase is a penetrative early foliation commonly parallel with bedding. Early minor folds are relatively rare and early major structures equivocal. The late deformation phase is shown by common late minor folds that deform all early structures. Locally developed cleavage related to these folds cuts the early structures. The geometry of the major structures in the map-area is compatible with that of the late minor folds.

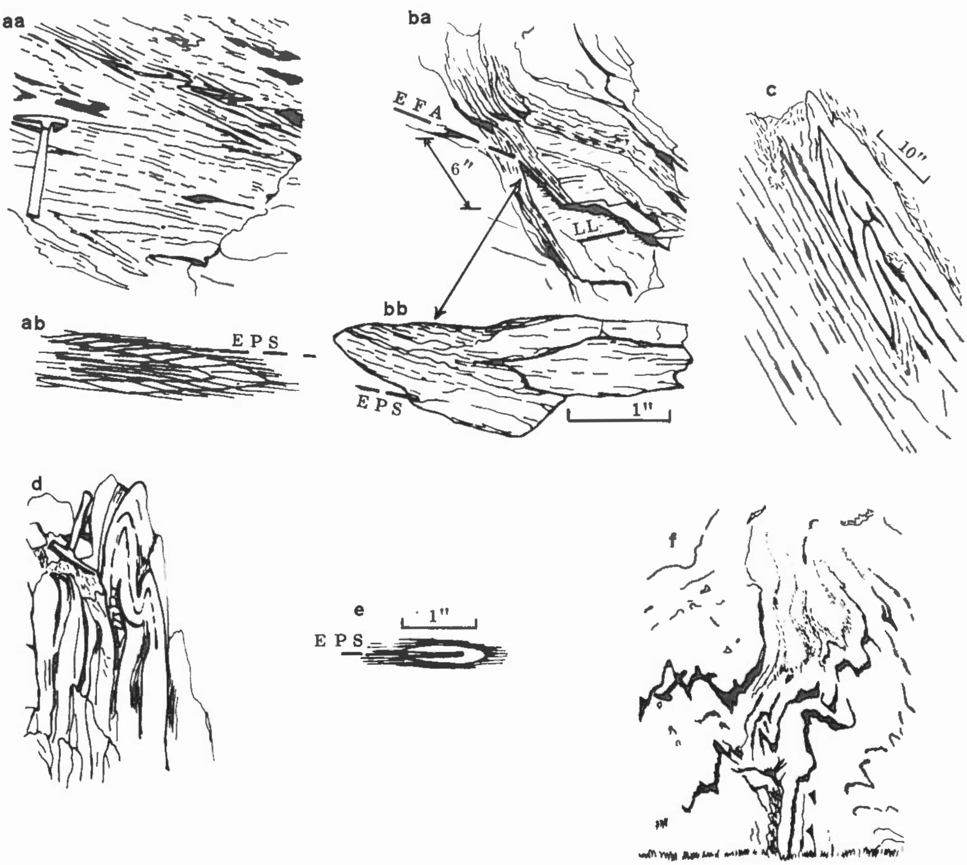
STRUCTURAL ELEMENTS

Approximately 1,600 attitudes of structural elements were recorded in this study, of which 37 per cent are bedding or primary compositional layering, 38 per cent early foliations, 6 per cent early lineations and fold axes, 4 per cent late planar structures and 15 per cent late lineations and fold axes. The data are irregularly distributed across the map-area as many of the best exposed rocks such as greenstones and limestones yield relatively little data, whereas the poorly exposed rocks of the Kedahda Formation gave a disproportionately large percentage of data, and for this reason no detailed structural analysis by subdivision of the map-area was attempted.

Bedding or primary compositional layering is variably developed in different rock types in the map-area. It is readily distinguished in most little altered rocks, particularly where lithological differences are marked, as with volcanic sandstone beds in predominant cherty phyllites. However, such a distinction is difficult in rocks of uniform lithology such as massive greenstones, and in altered rocks such as the phyllitic quartzites in Dease Creek. In the latter case, the rocks have a wholly metamorphic texture. They consist of alternating layers of interlocking quartz anhedra and perfectly oriented mica flakes which lie in the plane of the layering. This layering, in turn is parallel with the contacts of interbedded limestone and chlorite-muscovite-albite schist units. The problem is whether this metamorphic foliation is either recrystallized bedding, directly reflecting bedding in stratigraphically equivalent, chemically identical, thin-bedded cherty phyllites farther west in the map-area, or whether it is secondary, metamorphic layering resulting from complete transposition of bedding parallel with the axial surfaces of isoclinal recumbent folds. That the latter is the most probable alternative is suggested by the perfectly orientated micas and the presence of rare minor folds whose axial planes parallel this layering (Fig. 3a).

Early minor structures are foliation parallel or subparallel with bedding, linear structures produced by the intersection of this foliation with bedding, and rare minor folds.

The early foliation, which is deformed with bedding by the late deformation, is the best evidence of an early deformational phase, as it is developed in varying degrees in all but the most massive upper Paleozoic rocks. In thin-bedded cherty phyllites or phyllitic cherts of the Kedahda Formation this foliation is the cleavage of phyllitic layers between chert beds. It parallels the axial planes of rare, nearly isoclinal folds (Fig. 3ba). The foliation in stratigraphically equivalent quartzose phyllites in Dease Creek, described above, appears to be analogous to this foliation as it is parallel with the contacts of interbedded limestones and schists and to the axial planes of rare, tight folds (Fig. 3ab). The foliation of the interbedded fine-grained chlorite-muscovite-albite schists is parallel with the cleavage in the quartzose phyllites. Foliation commonly parallel with bedding is well developed in pyroclastic rocks of the French Range Formation. The finest-grained rocks are green or purple phyllites, but more common are foliated lapilli tuffs or semischists that retain some relict clasts. With increasing grain size, these rocks grade upwards into agglomerates and breccias with partly flattened clasts in a foliated matrix. No marked elongation of these clasts in any preferred direction has been recognized, merely flattening in the foliation plane of the matrix. More metamorphosed equivalents of these rocks occur locally on Johnson Knolls, where foliated lapilli tuffs or semischists grade into chlorite-muscovite-albite schists with layers of chlorite and muscovite crystals oriented in the plane of foliation, alternating with albite or albite and chlorite layers. Crossite-quartz schists, in which the long axes of the crossite crystals lie in the foliation plane parallel with primary lithological layering, are interbedded with unfoliated greenstones south of Slate Creek. Fine-grained sandstones in the Kedahda Formation are foliated parallel with bedding, whereas coarser sandstones are either poorly foliated, or, in the vicinity of Tuya River, unfoliated. Massive greenstones and limestones are



aa. Tight folds in phyllitic quartzite of the Kedahda Formation from the north bank of Dease Creek, about 1 mile west of its confluence with Buck Gulch (traced from photograph).

ab. Detail of fold from this locality, showing the relationship of the early planar structure (E P S) to the fold (from sketch in notebook).

ba. Tight fold in phyllitic chert of the Kedahda Formation from the east bank of Quartz Creek, about 4 miles southwest of the summit of Mount Rath. Diagram shows the relationship between the direction of the early fold axis (E F A) and late wrinkle lineation (L L). (Traced from photograph).

bb. Cross-section of fold from this locality, showing relationship between the early planar structure and folded bedding. (Traced from sawn-surface of hand-specimen).

c. Tight fold in thin-bedded tuffaceous chert mapped as French Range Formation, from south side of French Range, 3 miles west of north end of Little Dease Lake. (Traced from photograph).

d. Tight fold in thin-bedded phyllitic chert, mapped as French Range Formation, from the south side of the French Range, 2 miles southeast of peak of elevation 6,197 feet. (Traced from photograph).

e. Small intrafolial fold from quartzose phyllites of the Kedahda Formation on the north bank of Dease Creek, just east of its confluence with Buck Gulch, showing relationship to the early planar structure (from sketch in notebook).

f. 'Flow' type folds in crystalline limestone of the Teslin Formation outlined by black chert nodules. Fold on south side of French Range, $3\frac{1}{2}$ miles east-northeast of north end of Little Dease Lake (traced from photograph).

Figure 3. 'Early' minor folds.

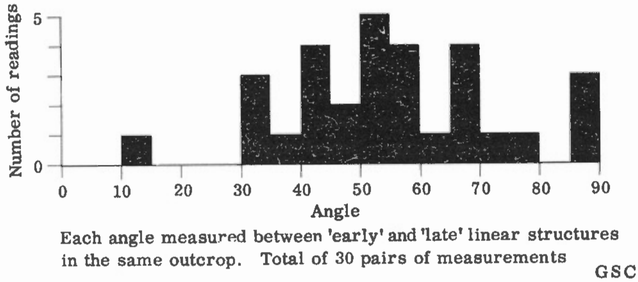


Figure 4. Angle between 'early' and 'late' linear structures.

unfoliated, although shearing around selvages of pillows and localized shear planes may have formed at the same time as early foliations in less massive rocks.

Early linear structures are the intersection of the early foliation with bedding or else axes of the minor folds described below. As bedding and foliation are nearly parallel, their intersection is commonly somewhat irregular and generally appears as vague compositional banding on early foliation planes, although in a few places where foliation cuts bedding at a high angle this lineation is well defined (Fig. 8b).

Early minor folds occur mainly in thin-bedded cherty phyllites and their metamorphosed equivalents, or cherty tuffs. They are surprisingly rare in view of the prevalance of the early foliation (approximately 2 per cent of the total recorded attitudes are early fold axes, against 38 per cent of the total for early foliation). These folds are nearly isoclinal, and commonly have sharp angular hinges and an axial-plane foliation that is the early foliation (Fig. 3aa). Small intrafolial 'hooks' in the quartzose phyllites in Dease Creek may be equivalent structures (Fig. 3e). Commonly there are no marker horizons to indicate the style of deformation in massive recrystallized limestones. Some recrystallized limestones, however, contain thin chert layers, parallel with the bedding in unrecrystallized rocks, that outline irregular flow(?) folds (Fig. 3). These folds in limestone are presumably early as their axes diverge considerably from those of later folds, which have a relatively constant orientation.

The orientation of early linear structures varies, both in space and in relationship to the late linear structures, which have a relatively constant orientation. Angles between early and late linear structures, recorded from the same outcrops, range from 15 degrees to 87 degrees, with most being between 30 degrees and 70 degrees (Fig. 4). Assuming a general vertical axial surface for the late structures and neglecting any distortion due to similar folding, simple unfolding of these early linear structures by rotation about the horizontal late fold axis indicates that the trend of the early structures was roughly north-south (Fig. 5).

Late minor structures are minor folds, wrinkle lineations and late foliations. In contrast to the early minor structures, late folds are very common whereas late foliations are associated only with minor folds and are locally developed and nonpenetrative at outcrop scale.

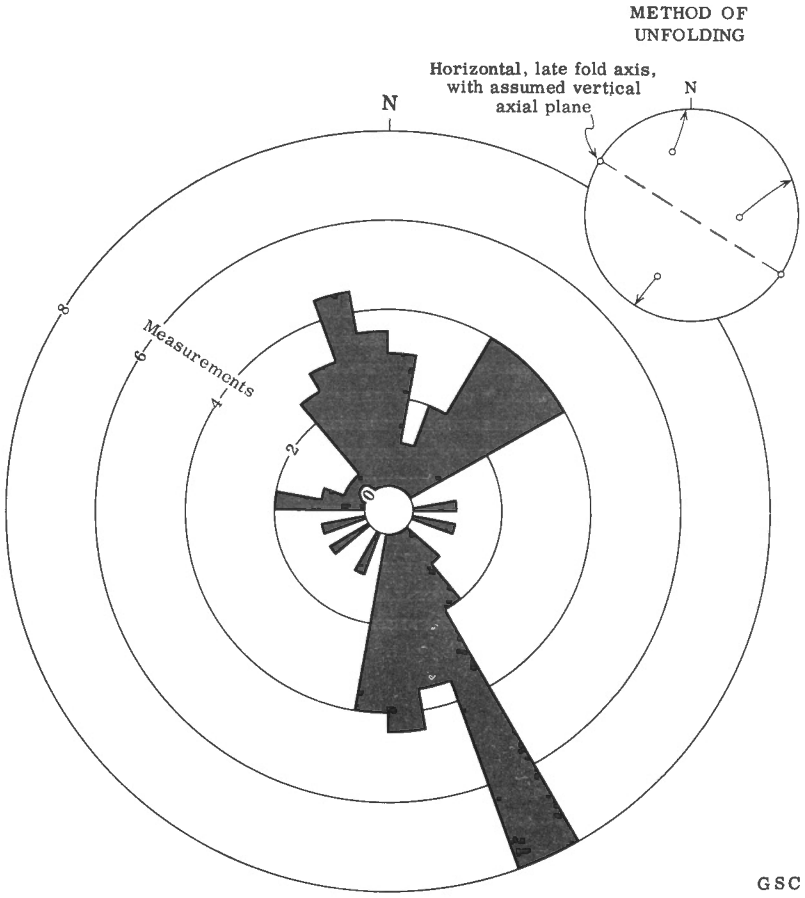


Figure 5. Original orientation of 'early' linear structures.

Late folds deform all structures described above, are best developed in well-foliated and/or thinly bedded rocks, and although common across the map-area, are sporadic, occurring in great abundance in some outcrops and absent from adjacent ones of identical lithology. These folds mostly have horizontal fold axes that trend between N. 70° W. and N. 55° W., the direction about which bedding and the early foliation have been folded (Fig. 6). The minor folds are irregular, asymmetrical, tight and open, and many are associated with high-angle thrusts of small displacement (Fig. 7). The sense of movement implied by the form of these asymmetrical folds is predominantly towards the south-southwest, although many folds have the opposite sense. Mesoscopic late folds are of all scales, ranging from near-microscopic wrinkles and crumples on early foliation planes to large step-like folds with amplitudes up to 100 feet, such as those exposed in the creek valley 1 mile southeast of the summit of Mount Rath.

Late planar structures are best developed in well-foliated rocks and are found only in association with the late folds. They are crenulation (or strain-slip) cleavages consisting of closely but variably spaced fractures dividing the rock into a series of slices within which earlier planar structures are crumpled or tightly folded (Figs. 7c, 7f). The angle between cleavage planes and the attitude of contiguous, undeformed earlier planar structures is generally around 70 degrees or, less commonly, about 30 degrees. In contrast to the earlier foliation, which is characterized by the growth of secondary minerals or even mineral segregation parallel with the foliation plane, little or no recrystallization is associated with the late planar structures. However, in some examples of phyllitic quartzite, micas aligned during the early deformation and later bent parallel to the late cleavage have grown, whereas those not parallel to the late cleavage have remained their original size.

The only secondary planar structure in argillite and siltstone of the Nazcha Formation is a fracture cleavage that has a trend similar to the crenulation cleavage in the Paleozoic rocks. Probably these are analogous structures formed at a similar metamorphic grade, as both are nonpenetrative at outcrop level and neither commonly involves recrystallization. Their different morphology may result from the fracture cleavage being produced in a rock whose fabric is mechanically isotropic, whereas the crenulation cleavage was formed in a well-foliated, strongly anisotropic rock.

Steeply dipping or vertical joints and rare kink band zones in rocks of the Kedahda Formation in Dease Creek may be related to the later period of deformation as they are parallel with the 'a-c' plane of the later folds. Vertical dykes of the Tuya Formation in the upper part of Dease Creek parallel these joints and were perhaps intruded along them.

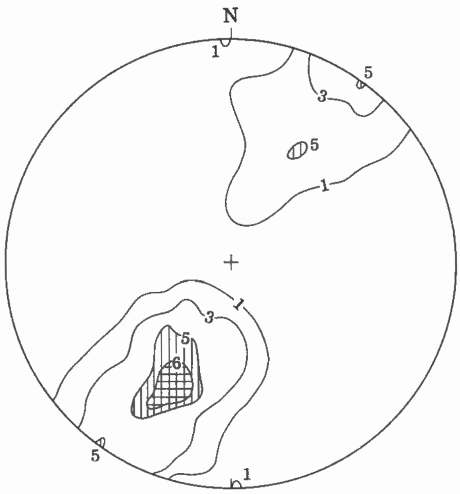
RELATIONSHIP OF SECONDARY MINERALS TO MINOR STRUCTURES

The parallelism of several minerals produces the early foliation in some rocks. These minerals are chlorite and muscovite in chlorite-muscovite-albite schists of the Kedahda and French Range formations, muscovite in phyllitic quartzite and cherty phyllite of the Kedahda Formation and crossite in crossite-quartz schists of the French Range Formation.

Stilpnomelane, where present in a foliated rock, is largely mimetic to the early foliation, or grows in randomly oriented, radiating sheafs. However, as stilpnomelane crystals are bent and broken by late folds and crenulation cleavages, the mineral appears to have formed in the interval between the two main deformational phases. The reported association of stilpnomelane with high-pressure metamorphic suites (e.g. Seki, 1958, pp. 247-252, Suzuki and Suzuki, 1959, p. 396, Winkler, 1965, p. 146) indicates that in the map-area it may have formed during the waning stages of the early deformation, which is associated with at least one 'high pressure' mineral, namely crossite, rather than later. Hutton (1938, p. 197) suggested that stilpnomelane forms during post-tectonic crystallization, on the basis of criteria similar to those here.

MAJOR STRUCTURES

Major structures deduced from mapping appear to be relatively simple and their orientation and style reflects that of the late minor structures. Lithologic units extend uninterrupted for several miles with a relatively

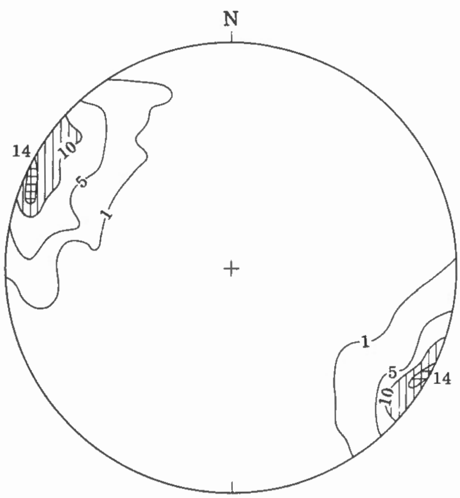


A

POLES TO BEDDING AND EARLY FOLIATION

904 poles from across map-area

Contours, 1%, 3%, 5%, 6%, per 1% area



B

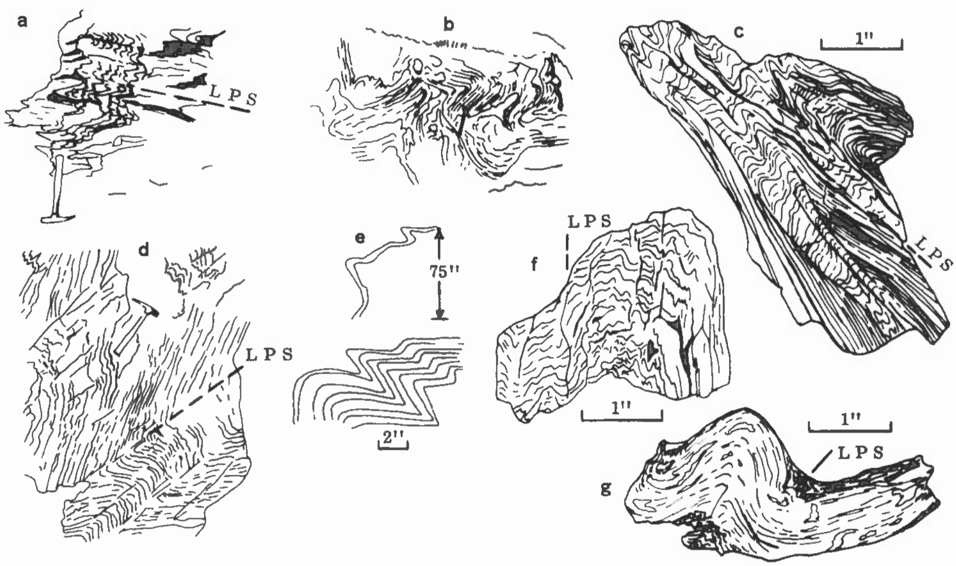
LATE MINOR FOLD AXES AND LATE LINEATIONS

165 points from across map-area

Contours, 1%, 5%, 10%, 14%, per 1% area

GSC

Figure 6. Equal area plots of structural elements.



a. Folds in thinly bedded phyllitic cherts mapped as French Range Formation from 1 mile due west of the outflow of Dease Creek from Little Dease Lake. Attitude of late planar structure denoted by L P S. (traced from photograph).

b. Irregular folds in shaly, thin-bedded limestone of the Teslin Formation from 2 miles east-northeast of the north end of Little Dease Lake (traced from photograph).

c. Folds in phyllitic quartzite of Kedahda Formation from approximately ½ mile north of northeast corner of Little Dease Lake (traced from sawn surface of hand specimen).

d. Folds in phyllitic quartzite of Kedahda Formation from the east side of Dease Lake, 3 miles north-northeast of Nine Mile Point (traced from photograph).

e. Folds in thin-bedded phyllitic chert of the Kedahda Formation, not far below contact with French Range Formation, on west side of creek, 1 mile south of the summit of Mount Rath (from sketch in notebook).

f. Folds in phyllitic quartzite of the Kedahda Formation from Dease Creek. 2 miles above its outflow into Dease Lake (traced from sawn-surface of hand specimen).

g. Folds in chlorite-muscovite-albite-stilpnomelane schist of the French Range Formation, southwest side of Johnson Knolls. Note crenulation cleavage in hinge of fold (traced from sawn-surface of hand specimen).

Figure 7. 'Late' minor folds.

constant trend of about N. 55° W. that parallels the axes of many late minor folds. The style of the major structures, irregular asymmetric folds associated with high-angle faults, is compatible with the style of the late minor folds.

The relative importance of folding and faulting is not known. Very detailed mapping of some small limestone pods in the southern part of the French Range indicates that they are synformal structures. In contrast, in other places where the rocks are well exposed, as in the cirque 3 miles southeast of the summit of Mount Rath, the contacts between different lithologic units are faults.

The faults described below are major structures, and all trend west-northwesterly, approximately parallel with the trend of late minor fold axes. Most important is the Thibert Creek Fault separating upper Paleozoic from lower Mesozoic rocks in the northern part of the map-area. This fault is nearly vertical and marked by small serpentinite or carbonatized serpentine intrusions. On the north side of Mount Rath, a steeply dipping fault juxtaposes Leonardian cherts, limestone pods and greenstones of the uppermost Kedahda and basal Teslin formations with late Guadalupian limestone of the Teslin Formation. This fault may have developed along the transition zone between the thick highly competent greenstones of the French Range Formation capping Mount Rath, and the thin, less competent tuff and cherty tuff of the same formation on the north side of the fault. The fault crossing the upper part of Quartz Creek and separating the Teslin Formation to the north from rocks mapped as Kedahda Formation to the south is assumed. The assumption is based on the similarity of lithology and stratigraphic position of rocks south of the fault to the Kedahda Formation elsewhere.

On the south side of the eastern end of the greenstone ridge south of Slate Creek, 2.5 miles west-northwest of Little Dease Lake, Kedahda-type cherts and phyllites conformably underlie greenstones of the French Range Formation and are in fault-contact with Teslin limestone to the south. This fault is assumed to continue to the northwest and to separate greenstone on the north side of the fault from tuff of the same formation and overlying limestone on the south. Like the fault north of Mount Rath, this fault may be governed by a marked facies change from thick very competent greenstones to the north to thinner, relatively incompetent tuff and limestone to the south. Although numerous other faults are probably present in the southern part of the French Range, the structure is interpreted as a series of synforms containing Teslin limestone, rather than an imbricate structure with numerous high-angle faults. The former interpretation is supported in some places by detailed mapping.

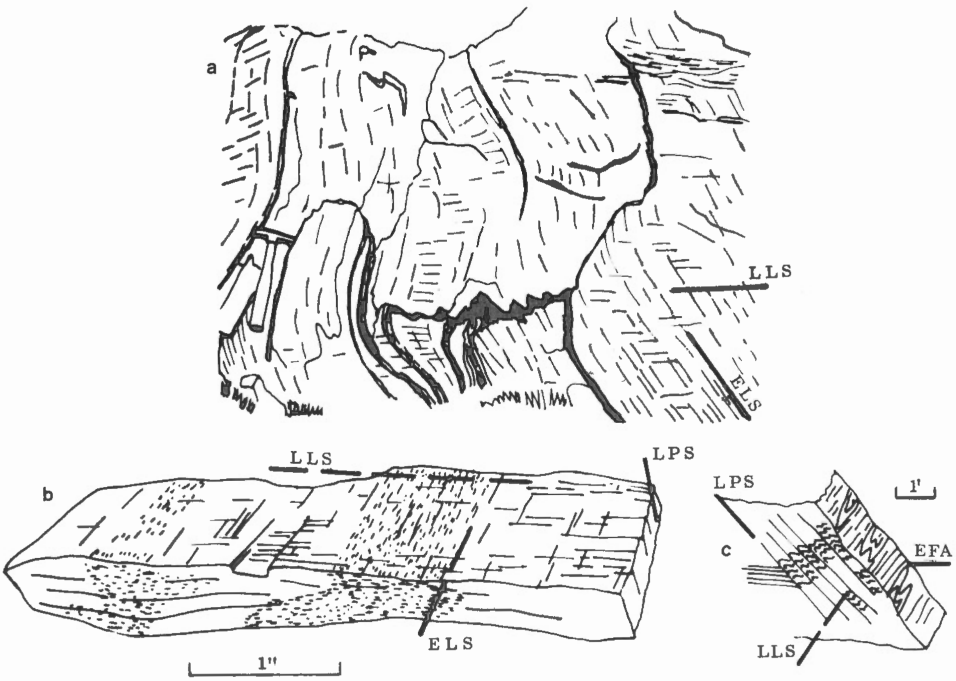
ORIGIN, SIGNIFICANCE, AND AGE OF EARLY STRUCTURES

The best evidence of an early deformation phase in the map-area is the presence of a folded foliation parallel with bedding in upper Paleozoic rocks. This foliation is penetrative on all scales and manifested by slaty or phyllitic cleavage in fine-grained rocks, growth and segregation of secondary minerals, and flattening of clasts in coarse-grained rocks. Metamorphism related to this foliation is more intense than any related to the folds which deform it. The origin of this foliation, its significance with respect to major structures, and its age are uncertain.

The nature of the early foliation suggests that it was formed during a period of isoclinal folding rather than by bedding-plane slip. This foliation conceivably could be bedding-plane foliation produced in incompetent layers by flexural-slip folding of the competent layers, with its formation enhanced by a preferred primary orientation of platy minerals parallel to bedding. Such an origin seems to account reasonably for the widespread development of phyllitic surfaces in the pelitic layers of thin-bedded phyllitic cherts of the Kedahda Formation, particularly as isoclinal folds with axial surfaces parallel to bedding are never abundant in these rocks. Unequivocal bedding-plane foliation described from little altered sedimentary rocks by de Sitter (1959, p. 95) is developed either at the contact of competent with incompetent beds or on thin layers within beds and is not penetrative on all scales, as is the early foliation in most rocks in the map-area. Therefore, this type of foliation does not seem to be compatible with the totally reorganized fabric of phyllitic rocks in Dease Creek, the mineral segregation in contiguous chlorite-muscovite schists, the general penetrative cleavage and flattening of clasts in pyroclastic rocks, the penetrative cleavage in sandstones interbedded with far less competent cherty-phyllites, and, particularly, locally discordant early foliation and bedding (Fig. 8b). The relatively rare, nearly isoclinal folds, called early folds, are equivocal evidence for an early period of tight folding, even where they are refolded. Possibly they could be relicts of recumbent folds formed by slumping or possibly true drag folds produced during flexural-slip deformation. However, as these folds typically contain an axial-plane foliation that is parallel with the early foliation, they are believed to be tight folds produced during the early deformation phase.

Early major structures must have been recumbent folds and possibly related thrusts or slides. As noted earlier, a discordance exists between recorded early and late fold axes and linear structures. Late linear structures have a relatively constant azimuth of about N. 65° W., whereas the orientation of early structures varies considerably but shows a rough north-south trend if the effects of the late deformation are removed (Fig. 5). If this discordance is valid, then the only way in which the present distribution of bedding and foliations shown in Figure 6a can be explained is if the early folds were recumbent and essentially flat-lying prior to the later deformation. If this interpretation is correct, then the possibility exists that some of the major faults paralleling the contacts of lithological units in the Cache Creek Group do not result from the late deformation, but are refolded thrusts and slides.

The early structures appear to have formed in post-Late Permian pre-Late Triassic time. In terms of metamorphism and deformation, the deformational phase producing these structures was the major one in the map-area. Rocks of the Nazcha and Shonektaw formations are less affected by deformation than upper Paleozoic rocks, a contrast that is particularly noticeable south of Defot Mountain, where cherty phyllites, phyllites and sheared cherty tuffs of the Kedahda Formation are in fault-contact with argillites and sandstones of the Nazcha Formation. Fine-grained clastic rocks of the Nazcha Formation contain a steeply dipping, southeast-trending fracture cleavage that cross-cuts bedding, and clasts in coarser rocks are not 'flattened'. In contrast, the older rocks contain early foliation parallel with bedding, cross-cut by later crenulation cleavage that trends in the same direction as, and is probably analogous to, fracture cleavage in the Mesozoic rocks. Moreover, the 'glaucophanitic' mineral assemblages in the Permian



a. Late gentle folds, with axes parallel to a wrinkle lineation or late linear structure (L L S) in thin-bedded cherty tuffs. The early linear structure (E L S) on the deformed bedding surface is produced by the intersection of bedding with the early planar structure, and manifested as faint compositional banding. From French Range Formation, about 3 miles east- northeast of north end of Little Dease Lake (traced from photograph).

b. Foliated cherty tuff of the French Range Formation, from Metahag Creek, $4\frac{1}{2}$ miles northeast of its confluence with Tuya River, showing coarser-grained bedding cross-cutting the early planar structure, which is the predominant cleavage surface. Intersection of bedding and the early planar structure produces the early linear structure (ELS). A wrinkle lineation (LLS) on the cleavage surface is related to a late cleavage (LPS). The early linear structure trends N60° E, and the wrinkle lineation N60° W (sketched from sawn hand specimen).

c. Thin-bedded cherts, mapped as French Range Formation, from Metahag Creek, 1 mile from its confluence with Tuya River, showing tight, early folds, the direction of the early fold axes (EFA), and the attitude of the late crenulation cleavage (LPS) and late wrinkle lineation (LLS). Early fold axes trend N30° E, late wrinkle lineation N60° W (from sketch in notebook).

Figure 8. Intersection of 'early' and 'late' linear structures.

rocks, formed at the same time as the early foliation, have not been recognized in the Mesozoic rocks. Potassium-argon dating of crossite from crossite-quartz schists of the French Range Formation currently is being attempted in order to provide direct evidence of the age of the early deformation.

TENTATIVE STRUCTURAL HISTORY

An initial post-Late Permian - pre-Late Triassic phase of recumbent folding on roughly north-south axes, accompanied(?) by thrust faulting and sliding, produced a penetrative foliation in upper Paleozoic rocks. It was accompanied by low grade metamorphism of the glaucophanitic-type. This phase was followed in post-Triassic time by deformation that produced northwest-trending folds and(?) faults that largely govern the present distribution of Paleozoic and Mesozoic rocks in the map-area. No detectable metamorphism accompanied this later stage.

REFERENCES

Aitken, J. D.

1959: Atlin map-area, British Columbia; Geol. Surv. Can., Mem. 307.

1967: Classification and environmental significance of cryptalgal limestones and dolomites, with illustrations from the Cambrian and Ordovician of southwestern Alberta; J. Sed. Petrol., vol. 37, pp. 1163-1178.

Black, M.

1933: The algal sediments of Andros Island, Bahamas; Phil. Trans. Roy. Soc. London, Ser. B, vol. 222, pp. 165-192.

Borg, I. Y.

1967: Optical properties and cell parameters in the glaucophane-riebeckite series; Contrib. Mineral. Petrol., vol. 15, pp. 67-92.

Carozzi, A. V.

1960: Microscopic sedimentary petrography; John Wiley and Sons, New York, 485 pp.

Christie, R. L.

1957: Bennett, British Columbia; Geol. Surv. Can., Map 19-1957.

Dawson, G. M.

1887: Report on an exploration in the Yukon District, N. W. T., and adjacent northern portions of British Columbia; Geol. Surv. Can., Ann. Rept. Pt. 1, pp. 6B-277B.

Dzulinski, S., and Walton, E. K.

1965: Sedimentary features of flysch and greywackes; Elsevier Publishing Co., Amsterdam, London, New York, 274 pp.

Folk, R. L.
1959: Practical petrographic classification of limestones; Bull. Am. Assoc. Petrol. Geol., vol. 43, pp. 1-38.

Gabrielse, H.
1962: Cry Lake, British Columbia; Geol. Surv. Can., Map 29-1962.

Gabrielse, H., and Wheeler, J. O.
1961: Tectonic framework of southern Yukon and northwestern British Columbia; Geol. Surv. Can., Paper 60-24.

Gabrielse, H., Souther, J. G., and Roots, E. F.
1962: Dease Lake, British Columbia; Geol. Surv. Can., Map 21-1962.

Ginsburg, R. N., Isham, L. B., Bein, S. J., and Kuperburg, J.
1954: Laminated algal sediments of South Florida, and their recognition in the fossil record; University of Miami, Marine Laboratory, Unpubl. Rept., No. 54-21, 33 pp.

Hanson, G., and McNaughton, D. A.
1935: Eagle-McDame area, Cassiar District, British Columbia; Geol. Surv. Can., Mem. 194.

Hutton, C. O.
1938: The stilpnomelane group of minerals; Mineral. Mag., vol. 25.

Kerr, F. A.
1925: Dease Lake area, Cassiar District, British Columbia; Geol. Surv. Can., Summ. Rept. 1925, Pt. A, pp. 75-99.

Lord, C. S.
1944: Geological reconnaissance along the Alaska highway between Watson Lake and Teslin River, Yukon and British Columbia; Geol. Surv. Can., Paper 44-25.

Monger, J. W. H.
1968: Atlin Horst, British Columbia (104 J, K, N); Geol. Surv. Can., Paper 68-1, Pt. A, pp. 34-36.

Morrow, D. W.
1967: The environment of deposition of a Pèrmian limestone, Dease Lake area, British Columbia; Univ. British Columbia, Unpubl. Bachelor thesis, 23 pp.

Mulligan, R.
1963: Geology of Teslin map-area, Yukon Territory; Geol. Surv. Can., Mem. 326.

Poole, W. H.
1958: Wolf Lake, Yukon Territory; Geol. Surv. Can., Map 22-1957.

Seki, Y.
1958: Glaucophanitic regional metamorphism in the Kanto Mountains, central Japan; Japan J. Geol. Geogr., vol. 29, pp. 223-258.

1961: Pumpellyite in low grade metamorphism; J. Petrol., vol. 2, pp. 407-423.

Sitter, L.U. de
1959: Structural geology; McGraw-Hill Book Co., Inc., London, New York, Toronto, 552 pp.

Souther, J.G.
1960: Tulsequah, British Columbia; Geol. Surv. Can., Map 6-1960.

Suzuki, J., and Suzuki, Y.
1959: Petrographic study of the Kamuikotan metamorphic complex in Hokkaido, Japan; J. Fac. Sci. Hokkaido Univ., vol. 10, pp. 349-446.

Watson, K. Dep., and Mathews, W.H.
1944: The Tuya-Teslin area, northern British Columbia; British Columbia Dept. Mines, Bull. 19.

Wheeler, J.O.
1961: Whitehorse map-area, Yukon Territory; Geol. Surv. Can., Mem. 312.

Williams, H., Turner, F.J., and Gilbert, C.M.
1958: Petrography; W.H. Freeman and Company, San Francisco, 406 pp.

Winkler, H.G.F.
1965: Petrogenesis of metamorphic rocks; Springer-Verlag, New York Inc., 220 pp.

Wolfe, W.J.
1965: The Blue River ultramafic intrusion, Cassiar District, British Columbia; Geol. Surv. Can., Paper 64-48.