MEMOIR 340

KLUANE LAKE MAP-AREA, YUKON TERRITORY (115G, 115F E½)

J. E. Muller

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KLUANE LAKE MAP-AREA,
YUKON TERRITORY
(115G, 115F E½)

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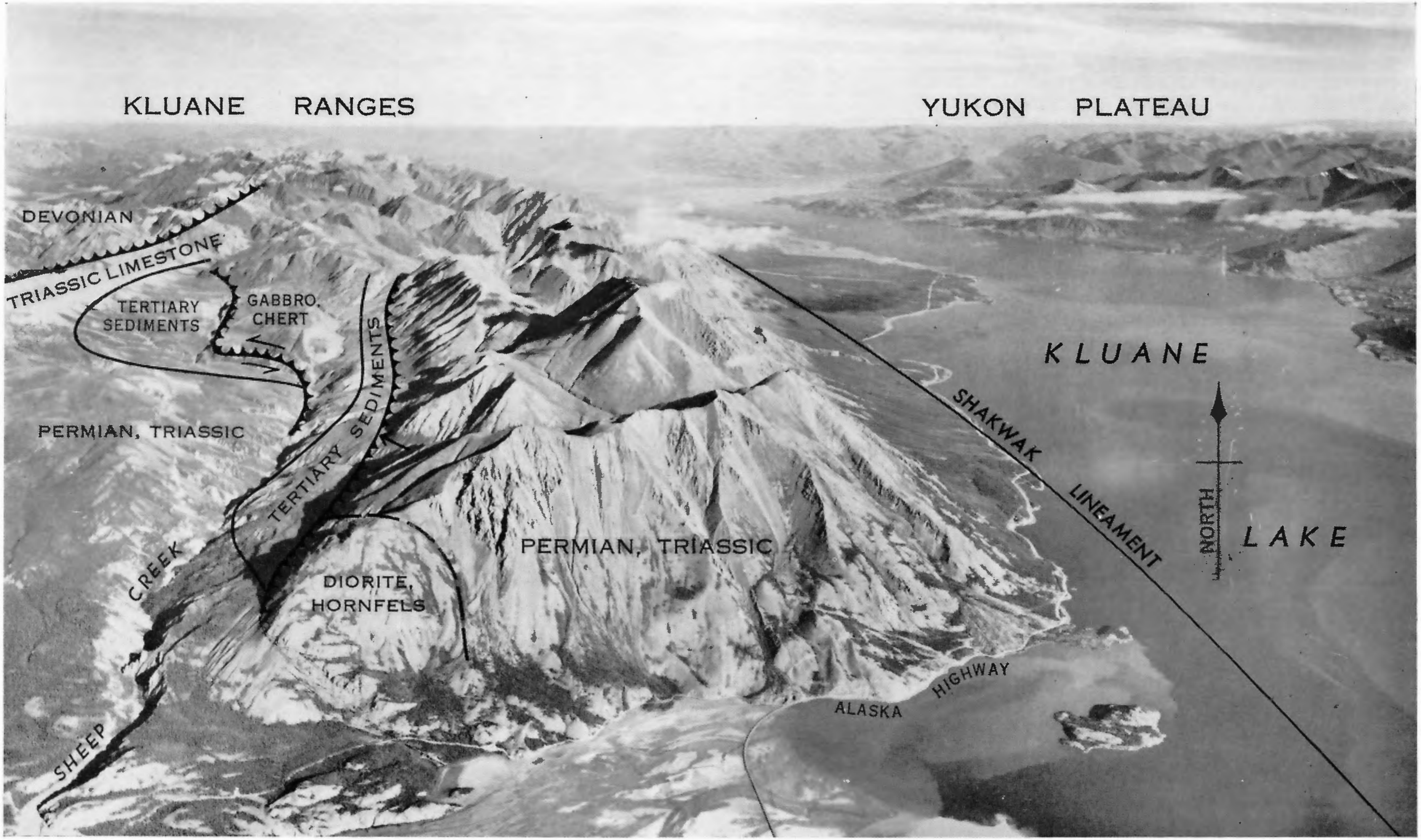

PLATE I. Kluane Lake, Kluane Ranges, and Yukon Plateau. Alaska Highway with Slims River bridge. Duke River fault and Tertiary flat overthrusts. Note also glacial silt filling Slims River and south end of lake. (RCAF, T6–117R)

GEOLOGICAL SURVEY
OF CANADA

MEMOIR 340

KLUANE LAKE MAP-AREA, YUKON TERRITORY

(115G, 115F E½)

By
J. E. Muller

DEPARTMENT OF
ENERGY, MINES AND RESOURCES
CANADA

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PREFACE

Kluane Lake map-area straddles two of the major geological provinces of southeastern Yukon. In each, the stratigraphic succession is different, the imposed structures are different, and the occurrences of ore minerals are different.

In this report the author presents the results of a reconnaissance geological survey of the map-area, and describes and discusses the rather complex succession of sedimentary, volcanic, metamorphic, and plutonic rocks that occupies each part. He also describes the structures and mineral deposits, and attempts to trace the history of events that produced the phenomena observed.

Finally the author presents the evidence for three separate and successive glacial episodes.

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

OTTAWA, December 3, 1963

MEMOIR 340 — Kartenbereich Kluane Lake (Yukonterritorium).
Von J. E. Muller

Beschreibt eine Reihe spätpaläozoischer und mesozoischer Sedimentär-, Eruptiv- und Batholithgesteine. Drei Glazialperioden sind zu erkennen.

ТРУД 340 — Клуане-Лейкский лист геологической карты, Юконская территория.
Дж. Е. Мюллер

Описывает поздне-палеозойские и мезозойские осадочные, вулканические и интрузивные (баталитовые) породы района в их геологической последовательности. Выделяет три периода оледенения.

CONTENTS

CHAPTER I

CHAPTER II

CHAPTER III

Illustrations

KLUANE LAKE MAP-AREA, YUKON TERRITORY

Abstract

Kluane Lake map-area in southwest Yukon Territory embraces some 6,900 square miles of St. Elias Mountains and Yukon Plateau, separated by Shakwak Trench. Yukon Complex metamorphic rocks, with granodiorite of Ruby Range batholith and some smaller bodies, mainly underlie Yukon Plateau. The probably Precambrian and early Palaeozoic schists were metamorphosed and granitized in Mesozoic and perhaps early Tertiary time. Minor Mesozoic volcanic rocks, some granite, and abundant rhyolite also occur in Nisling Range.

Eugeosynclinal deposits of St. Elias Mountains have yielded Middle Devonian, Lower Permian, Upper Triassic, and Jura-Cretaceous fossils. The volcanic rocks are pre-Permian, Permian, and Triassic; carbonate-clastic sequences are Devonian, Lower Permian, and Upper Triassic; and a greywacke-argillite sequence is Upper Jurassic to Lower Cretaceous.

Folding perhaps preceded Permian sedimentation, and orogeny with granitic intrusion terminated the geosyncline in Cretaceous time. Paleocene or Eocene plant-bearing beds of conglomerate, sandstone, shale, and coal are followed by a thick succession of basaltic lava and tuff, and are pierced by a few felsitic plugs.

Shakwak lineament is believed to be a major hinge line reflecting mainly vertical movements between the St. Elias geosyncline and Yukon geanticline. Duke River thrust is an important break, affecting all rocks including Tertiary beds. In Kluane Ranges low-angle thrusts have placed older rocks on Tertiary.

Three glaciations, showing increase in topographic expression coupled with decreasing age and extent, are tentatively mapped; the oldest may be pre-Wisconsin.

The explosion centre of 1,500-year-old volcanic ash covering much of Yukon and Alaska may be at the foot of Natazhat Glacier.

Mineral deposits, so far of minor importance, are placer-gold, possibly concentrated from till, nickel-copper sulphides near peridotite occurrences, native copper in Triassic lavas, a few tungsten and molybdenite showings in granitic rocks, gypsum in Devonian? and Triassic formations, and coal in Tertiary sediments.

Résumé

La région du lac Klouane, dans le sud-ouest du Yukon, comprend quelque 6,900 milles carrés des montagnes Saint-Élie et du plateau du Yukon et est coupée par le fossé Shakwak. Le plateau du Yukon est composé en grande partie de roches métamorphiques du complexe du Yukon ainsi que de granodiorite du batholithe Ruby Range et de quelques autres massifs de moindre importance. Les schistes, qui datent probablement du Précambrien et du Paléozoïque inférieur, ont été métamorphisés et granitisés au Mésozoïque et peut-être au Tertiaire inférieur. On trouve aussi dans la chaîne Nisling un peu de roche volcanique du Mésozoïque, du granite et beaucoup de rhyolite.

Les gisements eugéosynclinaux du massif Saint-Élie renferment des fossiles du Dévonien moyen, du Permien inférieur, du Trias supérieur et du Juracrétacé. Les roches volcaniques remontent au Prépermien, au Permien et au Trias. Les successions carbonatées-clastiques sont du Dévonien, du Permien inférieur et du Trias supérieur. La succession de grauwacke et d'argillite s'échelonne du Jurassique supérieur au Crétacé inférieur.

Un plissement a peut-être précédé la sédimentation du Permien et une orogenèse accompagnée d'intrusion granitique a complété le géosynclinal à l'époque du Crétacé. Des couches de conglomérats, de grès, d'argile et de charbon porteuses de plantes fossiles du Paléocène et de l'Éocène sont suivies d'une succession épaisse de lave et de tuf basaltiques et percées de quelques plutons felsitiques.

Le fossé Shakwak serait une charnière importante montrant principalement des mouvements verticaux entre le géosynclinal Saint-Élie et le géanticlinal du Yukon. La faille de la rivière Duke est une discontinuité importante qui a eu une influence sur toutes les roches y compris les couches du Tertiaire. Dans la chaîne Klouane des chevauchements à angle faible ont placé des roches plus anciennes sur des couches du Tertiaire.

On a essayé de cartographier trois glaciations dont les vestiges topographiques vont croissants, mais dont l'âge et l'étendue sont décroissants. La plus ancienne pourrait être du Préwisconsin.

Le centre d'explosion, qui a produit la cendre volcanique (vieille de 1,500 ans) couvrant la majeure partie du Yukon et de l'Alaska, pourrait se situer au pied du glacier Natazhat.

On compte parmi les gisements minéraux, encore de peu d'importance, des placers aurifères, dont la concentration s'est faite probablement à partir de moraine, des sulfures de nickel-cuivre près de gisements de péridotite, du cuivre natif dans les laves du Trias, quelques traces de tungstène et de molybdénite dans les roches granitiques, du gypse dans les formations du Dévonien? et du Trias et du charbon dans les sédiments du Tertiaire.

Chapter I

INTRODUCTION

Kluane Lake map-area is in the mountains of southwest Yukon, bounded by the 61st and 62nd parallels of latitude and the 138th and 141st (Alaska Boundary) meridians longitude. In its roughly 6,900 square miles of territory, reconnaissance geological mapping was carried out by the writer in the years 1950–53, 1956, and 1957. A triangular southwest part, embracing the Icefield Ranges with some of Canada's highest mountains, was not mapped.

Shakwak Trench, a major trunk valley containing most of Kluane Lake, transects the area from southeast to northwest and is an old travel route, now followed by the Alaska Highway, and telephone, telegraph, and pipelines to Alaska. All settlements are in this valley, along the Highway.

About 1903, Kluane, or Silver City, at the south end of Kluane Lake and at the end of a wagon road from Whitehorse, was the centre of activity of the Kluane mining district. It had a post office, RCMP station, and Mining Recorder's office, but has been abandoned for many years. Burwash Landing was established in 1903 by two Alsatians, Eugene and Louis Jacquot, and named after Major Lockwood Burwash, a mining recorder of that time. The Jacquots, who started as placer miners, became well known in pre-war years as outfitters and guides for big-game hunting parties in the St. Elias Mountains. Most of the Indian population of the area lives in this settlement. White inhabitants in the area are now mainly the owners of several roadhouses, or are employed in the maintenance of the highway, communications, or pipelines. Most of them live in the areas of the telegraph repeater stations Destruction Bay on Kluane Lake, and Koidern near White River.

Around the turn of the century, the area attracted the interest of placer miners, many of whom passed through on their way to the Chisana River area in Alaska. Some good placer ground was found in various places, but no real bonanzas. Copper was known to native Indians before 1900, and was first staked on White River in 1905. Other occurrences in the Tatamagouche and Quill Creeks area were discovered and staked about 1914.

The better access provided by the Alaska Highway enhanced activity by prospectors and mining companies after the Second World War. A staking rush occurred in 1952 and 1953, when copper–nickel deposits were found on a tributary of Quill Creek. Several exploration companies took up claims all along Kluane Ranges and explored them by geophysical methods and diamond drilling. Hudson Bay Mining and Smelting Co., Limited, did extensive drilling and underground

MS. received May 1963

work on its Quill Creek property, but suspended operations in October 1956. Underground exploration work on the property of Canalask Nickel Mines, Limited, on White River, was also abandoned May 1958. Placer gold has been produced in recent years from Burwash, Bullion, Gladstone, and Wade Creeks.

The area west of the Alaska Highway and south of White River forms part of the Kluane Game Preserve.

Physical Features

The physiography of the region has been fully described and various subdivisions have been named by H. S. Bostock (1948, 1952). Kluane Lake map-area contains parts of two major physiographic divisions, Yukon Plateau in the northeast and St. Elias Mountains in the southwest. They are separated by the 5- to 10-mile-wide Shakwak Trench, whose deepest part is occupied by Kluane Lake, at an elevation of about 2,575 feet.

The front ranges of St. Elias Mountains, 'Kluane Ranges', rise steeply from Shakwak Trench to a maximum elevation of about 8,500 feet. They are deeply dissected by V-shaped transverse valleys, and broken by the major gaps of Slims River, Duke River and the adjoining Burwash Uplands, and Donjek, Koidern, and White Rivers. The part between Slims and Duke Rivers contains several alpine glaciers.

West of Kluane Ranges, a chain of valleys and plateau surfaces, with a maximum elevation of 5,000 feet, has been called the Duke Depression. Its main components are the plateau west of Generc River, Wolverine Plateau, and Burwash Uplands; the last two names were first used on a preliminary map of the area (Muller, 1953). The possible physiographic significance of this old valley surface is discussed in Chapter II.

The Icefield Ranges form the backbone of St. Elias Mountains, one subdivision being the Donjek Range, east of Donjek River. They are a region of vast icefields, large valley glaciers, and high peaks such as Mount Lucania (17,147 feet), Mount Wood (15,885 feet), Mount Steele (16,644 feet), and Mount Walsh (14,780 feet). The largest valley glaciers within the area, issuing from the Icefield Ranges, are Klutlan Glacier, feeding Generc River, east branch of White River; Steele Glacier; and Donjek Glacier, feeding Donjek River. Another branch of Donjek River, upstream from Donjek Glacier, originates in Kluane Glacier. The size of the icefields and distributary glaciers decreases eastward, and only a few small icefields are present in the higher parts of Donjek Range.

White, Generc, and Donjek Rivers are typical glacial rivers. Their milky waters, in braided and ever-shifting channels, continuously deposit large amounts of silt, sand, and boulders on wide flood plains in valleys formerly occupied by large glaciers. Slims River, which together with Kaskawulsh River drains Kaskawulsh Glacier, is a similar stream that enters Kluane Lake at the south border of the map-area.

Both Donjek River and Slims River valleys have frequent dust-storms generated by strong off-glacier winds. The fine glacial silts in the wide valleys, unprotected by vegetation, are often blown up in dense dust-clouds, as high as a thousand feet above the valley bottom, and in the valley of Slims River they probably contribute considerably to the silting-up of the lower end of Kluane Lake, a process that is taking place very rapidly. A 1905 topographic map shows Kluane Lake reaching to about a mile above the present Alaska Highway bridge. Since then water and wind have filled the area above the bridge and causeway, and are now filling the lake below the bridge.

Donjek Range is mainly drained by Duke River and Burwash Creek, both partly glacier-fed. Kluane Ranges are mainly drained by short streams entering Kluane Lake, Kluane River, or Donjek River, via wide gravel bars on the floor of Shakwak Trench. Kluane Lake drains through Kluane, Donjek, and White Rivers into Yukon River and thus into the Pacific Ocean.

The region northeast of Shakwak Trench presents a very different topography, characteristic of the whole belt of country known as Yukon Plateau (Bostock, 1948). It has a more subdued relief, with commonly rounded or flat mountain tops at elevations of 4,000 to 6,000 feet. Peaks up to 7,000 feet with unoccupied cirques occur on some intrusive masses. This region is transected by a reticulate system of valleys. Few of the larger ones originate in mountains, instead most connect through low passes with valleys draining in the opposite direction.

In this region, subdivisions of the plateau recognized by Bostock (1948, 1952) are Ruby Range, directly northeast of Shakwak Trench and cut by many glacial valleys containing past or present finger lakes, and farther to the northeast the more subdued Nisling Range. The valleys of Talbot and Tincup Creeks may be considered as the dividing line between these two ranges.

Except for the disappearance of the ice, the morphology of this region has changed little since Pleistocene times. The valleys are mostly filled with lakes, swamps, and sluggish streams, and little erosion or aggradation takes place. This is in sharp contrast with the St. Elias Mountains, where rejuvenation of the relief has been considerable in late- and post-Pleistocene time.

Flora and Fauna

The forest cover of the area is light, with an upper limit at about 4,000 feet. Permafrost commonly occurs very close to the surface, forcing the trees to grow a shallow, easily uprooted, horizontal matted system of roots. Black spruce is probably the most common tree, but white spruce, balsam, poplar, and white poplar grow in areas with better drainage. The larger valleys, Shakwak, Donjek, Kluane, and Nisling, contain the most timber, but trees of more than one-foot diameter are rare. The upper reaches of the major valleys are treeless above 4,000 feet, except for some alders and willows. For any but light camps, these areas are unsuitable, unless fuel and tentpoles are packed in.

Dense, nearly impenetrable thickets of alders are common on exposed northern slopes. The non-timbered parts of the valleys are covered with grass (often the 'niggerheads' or 'bunchgrass' variety), groundbirch, and willows; they afford in most places sufficient horsefeed. Above timber-line, between about 4,000 and 5,000

98818—2

feet, horsefeed may be abundant from July on. Above 5,000 feet, vegetation is very scanty. Of wild fruits, only blueberries are plentiful; red currants occur in some places.

Compared to other parts of the Canadian Cordillera, game is not plentiful. However, the institution of the Kluane Game Preserve, comprising the area west of Alaska Highway and Haines road in Yukon Territory up to White River, has resulted in an increase in game population. Undoubtedly the White or Dall Sheep outnumber all other large game. They graze usually in high alpine meadows where, at the approach of danger, they clamber to safety over rough and precipitous slopes with incredible ease and speed. They are especially common in the high mountains of Kluane and Donjek Ranges, but may also be expected in Ruby and Nisling Ranges wherever steep, craggy mountain faces occur. A herd of about 50 was seen south of Talbot Creek in 1953, and several equally large herds were seen in the Kluane Ranges in 1956 and 1957. Moose were seen mainly in the swampy valleys in the northeast half of the area, but are not plentiful. Caribou, in groups of four to six, were seen on only two occasions on Wolverine Plateau and Burwash Uplands, but were more plentiful in the White River area in 1957. Grizzly bears are more common than black bears. A very large dark brown specimen sighted at a distance south of Wade Creek may have been a Kodiak bear. Other mammals seen occasionally were otter, red fox, coyote, ground squirrel (abundant), whistler, chipmunk, beaver, muskrat, porcupine, rockrabbit, snowshoe rabbit. Ptarmigan, grouse, and several varieties of ducks were the most commonly noted game birds. Kluane Lake is well stocked with lake trout, up to 50 pounds, whitefish, and grayling. Grayling is also the most common fish in the smaller lakes and non-glacial streams.

Lists and descriptions of mammals and birds in the area may be found in the publications of Rand (1945, 1946) and Godfrey (1951).

Climate

Most of the following data are taken from *The climate of British Columbia and the Yukon Territory*, by Kendrew and Kerr (1955).

A main factor in the climate is the location of the area on and beyond the northeast slopes of the high St. Elias Mountains. These mountains form an effective barrier against moist and relatively warm air from the Pacific Ocean, and thus, despite its proximity to the sea, the area has a continental climate. The other important factor is the latitude, where long winters, with periods of daylight shortening to less than six hours, contrast strongly with the short summer, when the sun is above the horizon for a maximum of more than 19 hours.

Snag weather station, on White River 28 miles north of the map-area, has won fame for its record minimum temperature of −81°F; minima below −60°F have been recorded from November through March. Mean daily temperatures are below freezing from October through April, with a minimum of −15 degrees in December. Apparently cold air comes down from the icefields and remains stagnant in low basins, such as the Snag area; temperatures are probably slightly higher along the Alaska Highway, in Shakwak Trench. In the months of June and July, with their long periods of daylight, temperatures may rise relatively high, the June and July mean temperatures for Snag are 54° and 57°F, with an absolute maximum of 88°F. In the writer's experience, only these two months may have unpleasantly hot days; August is usually cool and towards September nightly frost is common.

Precipitation is light: the mean total of eight years for Snag is 16.2 inches, for Aishihik, 30 miles east of the map-area, it is only 10.1 inches of rain and snow. Snow has been recorded in all months except June and July at Snag. The writer has experienced snowfalls in each month of the summer, and in early September snow commonly remains on the ground for several days after a fall.

Wind and clouds might also affect exploration work in the area. Strong winds often occur in Shakwak Trench, especially in August and September. These whip up high waves on Kluane Lake, making navigation with small boats dangerous or impossible. On several such occasions, the writer's party has been windbound. Low clouds often cover the St. Elias Mountains, and only on really clear days can these mountains be seen in their full majesty from a distance. Cloud conditions however rarely impeded the work, unless coupled with occasional heavy rainfall. Shakwak Trench often has a clear sky while clouds lie over the mountains on either side.

Accessibility

The area may be reached over the Alaska Highway by car or bus. Travel to Burwash Landing is also possible by aircraft. Pontoon-planes may land on Kluane Lake, though often the water may be too rough. There is an 8,000-foot landing strip at M.P. 1095, 2 miles north of Burwash, and a smaller one at Silver Creek.

Roadhouses along the Highway that provide eating and sleeping accommodation are Silver Creek, M.P. 1054; Destruction Bay, M.P. 1083; Burwash Landing, M.P. 1093; Joe's Airport Lodge, M.P. 1095; and White River Lodge, M.P. 1168.

For travelling within the area, motor cars are of limited use. Besides the Alaska Highway, there are only a few stretches of barely usable road. One road, an abandoned part of the Highway, leads along the north shore of Slims River to the mouth of Sheep Creek. From there it is at times possible with four-wheel-drive vehicles to reach Bullion Creek. Another road leads from Duke River bridge to the old Dickson homestead, at the outlet of Kluane Lake into Kluane River. Most of this road is on solid gravel, but the end is through swamp and may be impassable when wet.

A rough road leads about 5 miles up Burwash Creek to The Burwash Mining Company placer operation. Lastly, rough roads were constructed by Hudson Bay Mining Co. up Quill Creek to the nickel showings on Nickel Creek and by Canalask Nickel Mines to the property on White River.

Pack-horses are still a practical means of transportation within the area. Helicopters, though not used when mapping the area, would be eminently suitable, and have been used successfully by mining companies. Except for the high, rugged, glacier-covered region in the southwest corner, the entire area is readily accessible

98818—2½

with pack-horses. Trails are poor or non-existent, but forest vegetation is light and most valleys may be travelled without much trail cutting. Southwest of the Alaska Highway, Donjek and Duke Rivers afford good travelling for pack-horses on the gravel bars or in places on old trails through timber. Thus, Kluane Glacier may be reached via the mouth of Wade Creek, either from Duke River bridge and the trail over Burwash Uplands, or from the Donjek bridge along the east side of Donjek River, and thence by trail past Donjek Glacier. The valleys of Lynx, Wolverine, Steele[1], Ptarmigan, Halfbreed, and Grizzly Creeks may also be traversed with little trouble. Travel up Donjek Glacier is impossible with horses, and backpacking over rough ice and lateral moraines is necessary. The canyon valley of Spring Creek is also difficult of access. Donjek River should be forded with pack-horses where the water has been most widely split into numerous shallow channels. Advantage should always be taken of the considerably smaller volume of water in the early morning. The channels shift continuously, and it is advisable to have a scouting party with saddle-horses try the crossing route before taking the whole pack-string across. The writer's party crossed between the fans of Steele and Spring Creeks and at two places upstream of Donjek Glacier, generally without having to swim the horses. The old pre-Alaska Highway ford on the route between Burwash Landing via Teepee Lake to White River was south of Wolverine Creek. North of Donjek bridge, older topographic maps show the trail from White River to Nisling River crossing Donjek River about 7 miles northeast of the mouth of Kluane River. Steele Creek is difficult to ford with horses, as the fast flowing, brown, muddy water completely obscures the large round boulders and the holes behind them. It is impossible to ford this stream on foot, as already noted by R. P. Sharp (1943). All other larger tributaries may usually be forded with horses but may at times be difficult or impossible to cross on foot.

Whereas only the major valleys afford good travelling routes in the St. Elias Mountains, a network of interconnected valleys gives easy access with pack-horses to all parts of the Yukon Plateau area northeast of Shakwak Trench. Swamps, ponds, and seemingly bottomless meadow creeks are relatively minor obstacles. Several lakes there could be used to land pontoon-aircraft, principally Toshingermann Lakes, Tincup Lake, and Dogpack Lake. Smaller lakes are Grace Lake, Serpenthead Lake, Redtail Lake, and the lakes at the head of Gladstone Creek.

Kluane River was crossed many times by the writer's party at the Dickson homestead near outlet of Kluane Lake. The horses swam, and men and gear were ferried across by boat. This river is navigable for fast boats with little draft, but was not used for this purpose by the writer's party. A small sternwheeler is reported to have come up once via White, Donjek, and Kluane Rivers to Kluane Lake.

Kluane Lake, with Brooks and Talbot Arms, affords a means of convenient transport by boat to many points in the area. However, when using small craft with an outboard motor one must expect to be windbound frequently. High winds often funnel through Slims River valley down on the lake and may in a short time stir up

[1]Recently the names Steele Creek and Steele Glacier have been officially given by The Canadian Permanent Committee on Geographical Names to the creek and glacier named Wolf Creek and Wolf Creek Glacier in earlier publications.

large waves. At such times the treestump-covered shallows at Kluane River inlet are especially treacherous.

Previous Geological Work

The first two geologists to pass through the area and report on some of the geology were officers of the United States Geological Survey. C. W. Hayes accompanied Frederick Schwatka in 1891 on an exploration trip, mostly on foot, from Juneau northwestward to Selkirk on the Yukon, and westward to the Copper River region (Hayes, 1892). A. H. Brooks travelled with pack-horses through the area in 1899 on a trip from Pyramid Harbor to White River and thence to Eagle City. Despite the difficulty of existence and transportation in this, at the time, practically uninhabited country, Brooks collected much geological information about the region. His report (1900) contains a reconnaissance geological map covering part of Kluane Lake area. Both Hayes and Brooks reported on the occurrence of native copper on "Klet-san-dek" (Copper) or Kletsan Creek, near the Alaska Boundary, in those times used by the Indians for making rough implements.

J. B. Tyrrell (1899) of the Geological Survey of Canada, travelled in 1898 through the northeast corner of the area on a trip from Aishihik to the Nisling and White Rivers, but did not report on the geology.

Mapping by the Geological Survey of Canada was started in 1904 by R. G. McConnell. Though most of his report deals with placer gold, the main points of the bedrock geology were brought out in his report and map (1905). The White River region was mapped by D. D. Cairnes in 1913 and described in GSC Memoir 50 and accompanying map (1915b). Cairnes visited the area again in the course of a general exploratory investigation of southwestern Yukon (1915a). Here again most attention was paid to gold-placer workings and the occurrences of copper and coal, but additional bedrock geology was incorporated in a revision of McConnell's Kluane Lake geological map.

The Woods Yukon expeditions of 1935 and 1941, sponsored by the American Geographical Society and led by Walter A. Wood, made successive ascents of Mount Steele, Mount Wood, and Mount Walsh, using Steele (Wolf) Creek as avenue of approach (Wood, 1936, 1942). The geology of Steele Creek was studied by R. P. Sharp, geologist attached to the second expedition (Sharp, 1943). H. S. Bostock of the Geological Survey carried out a geological reconnaissance along the Alaska Highway in 1945. The resulting memoir (Bostock, 1952) and map incorporate all earlier published work, as well as unpublished information obtained from an exploration company.

Field Work and Acknowledgments

Field work in the area between the 138th and 140th meridians was started in 1950 and continued on through 1953. Circumstances then prevented its resumption on Kluane Lake map-area until 1956, when it was possible to finish the field work there. Work on Teepee Lake map-area, between the 140th and 141st meridians, was started by R. L. Christie in 1953 and resumed by the writer in 1957. The work was mainly in the north half of this area; no geological work was done in the high Icefield Ranges to the south. Map 1177A accompanying this report includes both of the original map-areas under the name Kluane Lake, embracing the area between longitude 138 degrees and the Alaska Border at 141 degrees, and between latitudes 61 and 62 degrees.

The writer was assisted in the field by N. P. Elphinstone, A. L. Evans, and J. R. Woodcock in 1950; J. F. Allan and G. O. Callow in 1951; W. E. Dawson, E. D. Johannson, and J. E. Wise in 1952; B. J. Burley and B. H. Holmes in 1953; H. L. Doane, J. N. Hillerud, and J. H. Neese in 1956; and A. R. Berger, G. F. Shillington, and M. G. Williams in 1957.

Thanks are also due to those who served as packers and cooks, with special mention of William G. Brewster and Paul Birckel, both of Haines Junction, Yukon Territory, who gave effective cooperation for many years.

Generous assistance and hospitality received from many owners of highway lodges, from the staffs of Hudson Bay Exploration Company and Canalask Nickel Mines, and from the game warden of the Kluane Game Preserve, Mr. J. Langevin, are gratefully acknowledged.

Chapter II

GLACIATION

In the course of the Pleistocene epoch most of the area was at some time covered with ice, and many parts were glaciated several times. The information on the glacial history has been compiled from an extensive study of the morphology visible on aerial photographs, aided by scattered field observations obtained in the course of reconnaissance bedrock mapping.

Many of the landforms typical of mountain glaciation are present, such as, cirques, glaciated valleys, and glaciated highlands. The accompanying glacial map attempts to show the extent and elevation of the ice at several stages, together with the most prominent visible moraines, drumlins, rock drumlins, and major grooves, and such deglaciation features as marginal channels, notches in spurs, and edges of terraced deposits.

Limits of Glaciation

The edge of the former valley glaciers, as shown on the map, is generally marked by the scouring limit ("Schliffgrenze" of German-speaking glaciologists). Below this line the rocks are smooth, above it they are rough, and, especially for the latest glaciation, the line is clearly visible in the field and on photographs. End moraines and lateral moraines are also direct indicators of ice-limits, and the highest of a group of marginal channels (Pl. III) or notches (Pls. V, VI, VII) may be used as a close approximation of the maximum ice-level. In the plateau areas, the edges of former nunataks are commonly marked by distinctive shoulders. Even if the former plateau became later dissected by streams, the abrupt change of slope in the remaining spurs may still indicate the former ice-margin.

A few of the ice-margins shown on the map have been inferred indirectly from ice-limits in adjacent valleys and are drawn along the appropriate topographic contours.

Correlating the observable glacier limits into systems of icefields and glaciers was found to be possible only by assuming at least three progressively less extensive ice-sheets, each terminating in numerous valley glaciers. The upper limit of each younger ice-sheet would be 1,000 to 1,500 feet below that of the preceding one.

Under the rules of the official code of stratigraphic nomenclature, these presumed glaciations cannot be formally so named. However, for the purpose of this discussion the inferred ice-sheets and advances are informally identified by local geographic names.

Nisling Ice-sheet

This is the only ice-sheet that covered large parts of Nisling Range. Its separate identity and extent are based on traces of glaciation above the level and beyond the extent of the relatively well marked Ruby ice-sheet. Residual erratic material, from small pebbles to enormous granite blocks, is scattered on many plateau surfaces but no morainal topography can be seen except for a possible recessional moraine on Tyrrell Creek. These features and marginal channels and notches are the only unmistakable topographic evidence for glaciation to this extent. Additional features are broad, flat-domed hills, in places with castellated outcrops or with faint northwest-striking, possibly drumlinoid, ridges. Castellated outcrops indeed are not uncommon on elevated surfaces within the area assumed to have been covered by Nisling ice, and not glaciated again later. Probable nunatak areas stand above the general plateau level with sharp increase of slope. Nisling ice covered the present plateau surfaces of Ruby Range, leaving many nunatak areas, and was responsible for many high notches in the spurs of Kluane Ranges. The plateau surface west of the head of Koidern River, the higher part of Wolverine Plateau, smaller plateaux north and south of Granite Creek, and the table mountain west of Ptarmigan Creek were probably covered by the Nisling ice-sheet. The Icefield Ranges were no doubt covered, but there later erosion has left no traces of this glaciation. The average ice-level was about 6,000 feet over the northeast part of St. Elias Mountains and 5,000 feet over Yukon Plateau.

Because of the general northwest direction of the major ice-channels and of the distribution of the nunatak areas that remained above the projected surface of the Nisling ice-sheet, it is possible that the main movement of this ice was northwest, except in the higher St. Elias Mountains. Most transport no doubt occurred through Shakwak Trench, the adjacent Duke Depression, the depression between Ruby and Nisling Ranges, and other northwest-trending valleys. It is suggested that the northerly trending valleys (Generc, St. Clare, middle parts of Donjek and Duke, Kluane, Brooks Arm, and Talbot Arm) may have been excavated mainly after retreat of the Nisling ice by resequent streams, followed by later glaciations.

Some very large erratics, 10 feet or more across and commonly of light coloured, coarse-grained granite with large feldspars, occur on Burwash Uplands and Wolverine Plateau to about 5,500 feet elevation, and on the plateau west of the valley of Tchawsahmon Creek. Many such boulders have also been washed down into gorges cutting the escarpments of these plateaux. A granitic boulder with estimated size of 10x10x20 feet was seen at 5,200-foot elevation on the ridge between Wolverine and Lynx Creeks. A large boulder also occurs above 4,500 feet and southwest of point 5414 between Kluane and Donjek Rivers. These boulders are considered to have been placed there by the advancing Nisling ice. They generally do not resemble rocks of the Kluane Ranges intrusions and could have been derived from the Icefield Ranges to the southwest, or, in view of the suggested general northwestward ice-movement, from the Coast Mountains to the southeast. Erratics, found by Wheeler (1963), at an elevation of 7,200 feet on Outpost Mountain, just south of Kluane Lake on castellated outcrops of quartz diorite, and assigned by him to 'an earlier' ice-sheet were evidently also left by Nisling ice. In the Central Alaska Range (Wahrhaftig, 1958), the Browne glaciation is also solely represented by large, mainly granitic, erratics at high levels.

Ruby Ice-sheet

Traces of this ice-sheet are well defined in Ruby Range, for which it is named, and also in parts of Nisling and Kluane Ranges. Terminal moraines (Pl. VII), kame terraces, and well-developed marginal channels (Pl. III) are in many places good indicators of the ice-limit. Rock drumlins and large-scale grooves are visible in aerial photographs (Pl. VI) on many low-lying outcrop areas, whereas knob-and-basin topography and drumlins are in evidence in many valleys. Much of the morainal topography has, however, been smoothed by the waters of lakes that occupied formerly glaciated areas, and by later erosion.

Glaciated valleys are the most common expression of this glaciation, in contrast to the glaciated plateau surfaces of the preceding one. Northeast of Shakwak Trench, many upland surfaces showing traces of the older ice-sheet are incised by later glacial valleys and cirques. Remnants of lateral moraines and rough, unpolished upper parts of valley walls indicate that the valley ice stood some 500 to 1,000 feet below the earlier, more extensive, ice-sheet (Pls. III, V). Glaciers originated from the higher parts of Ruby and Kluane Ranges, and a rough correlation may be established between the size of the former glaciers and the elevation of the uplands at their source. Thus extensive highland areas above the present 6,000-foot topographic contours in Donjek, Kluane, and Ruby Ranges produced valley glaciers many miles long and a mile or more wide, but upland areas in Kluane, Ruby, and Nisling Ranges, at present between 5,000 and 6,000 feet elevation, gave rise to alpine glaciers a few miles long at most. Regarding small glaciers, it should be mentioned that cirques shown from airphotos to have well-defined ground and end moraines, craggy walls, and perhaps tarns and thresholds, are assigned to the later St. Elias advance. Cirques missing these features, and apparently modified by long subareal erosion, are considered to be roughly contemporaneous to the Ruby ice-sheet. In the otherwise unglaciated areas, some well-worn cirques may actually be of Nisling age.

Map 1178A shows the general level of small Ruby cirques to be at about the 5,500-foot contour on northeast faces of Ruby and Kluane Ranges, and slightly higher on southwest faces. In Nisling Range cirques of alpine glaciers, up to a few miles long, occur about the present 5,000-foot level.

Major valleys within Kluane Ranges and the adjacent plateau surfaces of Duke Depression are carved down below the Nisling erosion surface, leaving traces of the latter only near the summits. These valleys are all incised by deep post-Ruby canyons and, south of Halfbreed Creek, the original glacial trough has been nearly eliminated.

In most parts of Icefield Ranges, erosion during the younger St. Elias ice-advance and by recent glaciers and glacier streams has completely destroyed the surface produced by Ruby ice. However, the elevation of this surface is in places indicated by a series of level spurs and the edge by their sharp upward bend towards the main mountain mass (Pl. X B). The largest remnants of glaciated surfaces are east and south of the snout of the present Donjek Glacier, above 5,500 feet (Pls. IX B, X A), and east and west of the snout of Klutlan Glacier, above 4,000 feet.

Icefield Ranges were covered by a mountain ice-sheet, probably similar to, but higher than, the present-day ice-cover. Filling the valleys to a much higher level, the ice-sheet stood at the 7,500-foot contour on a line roughly running from the present terminus of Kluane Glacier to the junction of Klutlan and Brabazon Glaciers.

Many ice-channels, but mainly those of Donjek and Generc Valleys, carried the ice to the Duke Depression. Along this chain of valleys and highlands, separated from Shakwak Trench by Kluane Ranges, the ice was a few miles wide and above the 6,000-foot level on upper Duke Valley, but was 20 miles wide at the 5,000-foot level in the Generc-White River basin. The larger subsequent valleys within Kluane Ranges of upper Koidern River, Edith, Lynx, Arch, Tatamagouche, Halfbreed, and Sheep Creeks were filled to between 4,000 and 5,000 feet with overflow ice entering from Duke Depression and Shakwak Trench. This ice was augmented by ice from a few small glaciers within the ranges.

Shakwak Trench evidently contained a major icefield, standing at the 5,000-foot level in the southeast and descending to 4,000 feet in the northwest. A general northwesterly ice-flow in Shakwak Trench is indicated by this ice-gradient and by the alignment of drumlins. Much of this ice therefore entered the map-area from the higher parts of Shakwak Trench to the southeast. This flow was however considerably reinforced by ice-streams entering laterally through the Slims, Duke, Donjek, and White River gaps in Kluane Ranges, and by minor amounts of ice generated in those ranges.

On the northeast side of Shakwak Trench, much of the ice flowed northward through the gaps of Talbot and Brooks Arms, Kluane and Donjek Rivers, and several other gaps through the lower end of Ruby Range. North-trending striations and grooves mark the lateral outflow from Shakwak Trench in several places. The ice also moved up into the upper Koidern valley in the Kluane Ranges.

Within Ruby Range the ice-inflow from Shakwak Trench was reinforced by ice generated in local centres, and stood above the 5,000-foot level in the southeast and below 4,000 feet in the northwest. Thence it entered into a network of intercommunicating valleys in Nisling Range, ending in several glacier tongues descending to 3,000 feet elevations. A prominent terminal moraine occurs on Talbot Creek; another less conspicuous moraine, probably representing a recessive stage, was noted on Gladstone Creek at the mouth of Swanson Creek.

North of the map-area a large lobe of ice, issuing from Shakwak Trench and through Nisling Range, occupied Wellesley Basin.

After the retreat of Ruby ice, deep stream canyons were cut in many valleys of St. Elias Mountains, though none was formed in Ruby Range. Some of these canyons have persisted to the present, but others were widened by glaciers of the following St. Elias ice-advance.

The major drainage channels of the area probably became established during and after the retreat of the Ruby ice-sheet. At the maximum ice extension, melt-water of the large Wellesley lobe north of the area discharged into White and Donjek Rivers near their junction. Nisling River, near the edge of the lobe, drained the Aishihik lobe to the east of the area, while Onion, Rhyolite, Dwarf Birch, and Tyrrell Creeks were fed by smaller lobes issuing from Ruby Range. Their valleys were filled with extensive flood plains of gravel that have hardly been incised since that time.

Mention should be made of the asymmetrical transverse profile of these valleys. On slopes with southern exposures there was apparently enough frost-weathering to preserve steep rocky escarpments, rising with sharp edge from the flood plain. On the slopes with northern exposures weathering had a different effect, and creep and solifluction gave long, gentle slopes grading with hardly a break into the flood plain.

St. Elias Glacial Advance

Valley glaciers of the St. Elias advance are confined to St. Elias Mountains. These glaciers are tentatively correlated with alpine glaciers that left sharp cirques with a very fresh and recent appearance and with well-defined end moraines. The upper limit, indicated by these cirques, is at about 5,500 feet elevation in Nisling Range and at 6,000 feet in Ruby Range and the north part of Kluane Ranges. Klutlan Glacier, reinforced by the glaciers of St. Clare Creek, Count Creek, and Brooke Creek valleys, pushed into the valley of Tchawsahmon Creek at an elevation of 3,500 feet and left a fresh morainal topography. It also sent one tongue through Kluane Ranges but probably barely entered Shakwak Trench. Possibly one tongue of ice also flowed into the Teepee Lake valley.

Above Donjek Glacier, the glaciated floors of Bighorn Creek and other valleys have been incised deeply at the junction with the main valley, but are for the most part fully preserved. The terraced profile of the valley walls is particularly evident in this region (Pl. IX B). Highest surfaces are those levelled by the Ruby ice-sheet, middle surfaces during the St. Elias advance, and the present valley bottom was established by sub-recent advances. The glacial valleys of Spring, Steele, and Cement Creeks were deeply incised after retreat of the St. Elias ice, and high glaciated surfaces on the south side of Steele Creek appear to be correlative to this later glaciation. It may be noted that Sharp (1943) considered the moraines of these higher surfaces to be late Wisconsin.

One ice-tongue is inferred to have entered Wolverine Valley. The section of glacial deposits given below was seen in a gully north of Wolverine Creek, below the mouth of Lynx Creek:

	Feet
Boulder-till	50 +
Sand and gravel, well-bedded, pebbles and cobbles in lower part, cobbles and boulders in upper part	33
Sand, fine- to medium-grained, locally clayey, current-bedding in upper part	13
Sand, fine, clayey	9
Shale, silty, soft, faint bedding	34
Siltstone, soft, slightly micaceous, in one-inch beds	2
Clay, with a few sand lenses	1
Boulder-till, pebbles and small boulders to 2 feet diameter	60

Both tills are of similar freshness and therefore probably represent two stages of glaciation, separated by fluvioglacial deposits marking the beginning of the later advance. The earlier till could have been deposited by Ruby ice.

The lower course of Donjek Glacier at this stage is not well defined. It is inferred to have dropped to the 3,000-foot level at the entrance of Shakwak Trench.

Conspicuous stream channels running northwest from Donjek Valley to Shakwak Trench and cut into a valley floor previously drumlinized by Ruby ice, may well have issued from this glacier snout. However, in Shakwak Trench there is no evidence of the glacier terminus, apart from some small, possibly morainal, ridges parallel with the west bank of Donjek River and some ridges south of Reed Creek. The morainal material may have been carried away by Donjek River or by lake waters.

A system of glaciers occupied Duke River and tributary valleys and left some well-defined marginal features west of the present lower course of the river. Small valley glaciers probably issued from the higher parts of Kluane Ranges and Kaskawulsh Glacier no doubt entered Shakwak Trench. Little evidence of terminal moraines of any of these glaciers is however visible in Shakwak Trench.

The latest advance of Russell Glacier, the source of White River, may also be referred to this glacial advance. Though not shown on the map, an ice-tongue may have entered the map-area down to the upper canyon of White River. Capps (1916b) used an exposure of 39 feet of peat, overlying unconsolidated and unoxidized boulder till in a cutbank of White River, to determine the age of the till. From various sets of horizontal tree-roots that grew successively from tree-stems, keeping pace with rising permafrost, and from correlative tree-ring counts, he calculated a growth of peat of one foot in 200 years. This indicated an age of 8,000 years for the till. Sub-recent volcanic ash from the same exposure, 7 feet below the top of the peat, was similarly calculated to be 1,400 years old. Radiocarbon dating confirms this age estimate for the ash layer and thus lends credence to the 8,000 year age of the till.

Post-Glacial Lake Stages

Bedded deposits of silt and sand are common in valley bottoms throughout the area, and indicate the extent and elevation of post-glacial lakes. They are exposed in cutbanks of present and former lakes and streams. The maximum lake level is evident in many places along Shakwak Trench, Talbot and Brooks Arms, Kluane River, and other valleys in the north part of the area. One or more shorelines can be recognized in airphotos along valley walls, as the upper limits of lake deposits form slight terraces and coincide with a line of apices of gravel cones, clearly marked by more abundant vegetation. The throats of many small gorges have also been cut down exactly to this line.

The maximum elevation of lake levels and deposits has not been accurately measured, but throughout the area a level above 3,000 feet is suggested. A higher level at about 3,500 feet is also indicated by a line of delta cones along Shakwak Trench and Talbot Creek valley.

Lake silts over 100 feet thick, with ice-freighted striated cobbles, occur on Cultus Creek well above the 3,000-foot topographic contour and indicate a lake connection through Cultus Creek and Jarvis River valleys to glacial Lake Kloo, which according to Kindle (1953) stood at an elevation of about 3,000 feet.

A section exposed at the mouth of Gladstone Creek (visible in the distance on Pl. VI), is as follows:

Sand	2 feet
White volcanic ash	1 inch
Sand	15 feet
Boulder 'till'	25 feet
Sand and varved silt, some pebbles	170 feet
Boulder till, cobble size	80 feet

The upper till (?) has no well-marked contact with the underlying silts, and contains only a few boulders one foot or more in diameter. It is perhaps a lake deposit like the one on Cultus Creek, with ice-freighted boulders. It may represent the St. Elias advance. The lower till was most probably left by the Ruby ice-sheet.

Thick deposits of lake silts and gravels also occur on Bullion Creek at elevations to more than 4,000 feet. They may have accumulated in a lake dammed by the extended Kaskawulsh Glacier.

To the north the lakes probably covered Wellesley Basin, and according to Moffit (1954) a large lake covered the upper Tanana Valley.

The presence of ice-freighted boulders in the lake silts suggests that the lakes were impounded by St. Elias ice. However, the available data do not indicate how they could have been dammed up to the 3,000-foot level.

Correlation

In only a few reports on nearby areas has a subdivision of the Pleistocene glaciation into stages been attempted. In the central Alaska Range, Wahrhaftig (1958) made a detailed field study of glacial deposits in the Nenana River region and concluded that there were three main glaciations. The oldest "Browne glaciation" is characterized by "scattered boulders and blocks of granite on some of the higher mountains on either side of Nenana River." The blocks are up to 40 feet in diameter and occur at elevations close to 4,000 feet. The evidence for this glaciation thus corresponds to features of the Nisling ice-sheet, but it is interpreted as products of a local lobe, issuing from the Alaska Range through an old glacial Nenana Valley. Browne glaciation erratics were however found in small numbers on highlands beyond this inferred lobe and a much wider extent of the Nisling ice-sheet and ice transport parallel with the mountain ranges could perhaps be suggested.

The Healy glaciation of the Nenana area, the most far-reaching glaciation with fairly well preserved but considerably smoothed out morainal deposits, may correspond to the Ruby ice-sheet. The last extensive glaciation, the Riley Creek glaciation, shows a fresh moraine topography and suggests the St. Elias advance. The main glaciation recognized in many parts of Yukon Territory and British Columbia is probably correlative to the Ruby ice-sheet. The St. Elias advance may well have been confined to the higher mountain ranges that carry icefields and valley glaciers to the present.

An attempt at correlation with the North American Pleistocene succession is hardly warranted. Wahrhaftig (1958) suggested that the Browne glaciation is pre-Wisconsin, possibly Kansan or Nebraskan. A pre-Wisconsin age is also most likely for the Nisling ice-sheet. No correlation is given for the Healy glaciation, but the Riley glaciation, on the basis of a radiocarbon age of 10.560 ± 200 years is late Wisconsin (Mankato). A late Wisconsin age is conceivable also for the St. Elias advance. Sharp (1943) tentatively attributed such an age to the "older Moraines" of Steele (Wolf) Creek which constitute part of the St. Elias limit. Thus the age of the Ruby ice-sheet, intermediate in age between Nisling ice-sheet and St. Elias advance, may be early Wisconsin (Iowan?). A pre-Wisconsin age is less likely, in view of its fair topographic preservation.

Recent Glacier Movements

A subrecent advance of Kluane Glacier in the upper Donjek Valley is indicated by a trough, scoured below the St. Elias level of glaciation. Most other subrecent advances of existing glaciers, though clearly visible on aerial photographs, have not been shown separately on Map 1178A. Most present glaciers in the area are clearly stagnant and wasting away, especially the large ones, Donjek, Spring, and Steele Glaciers. The snouts of the Spring and Steele Glaciers in particular are covered with debris, there are superglacial streams, and the ice surface is dotted with holes.

A comparison of vertical aerial photographs of the Donjek Glacier snout taken in the summers of 1947 and of 1956 shows a retreat in the nine-year period of 2,000 feet to the southeast. The extent of the last advance is also clearly shown by an end moraine, about 3,000 feet northwest of the 1947 edge. If the rate of retreat were constant, this last advance occurred around 1930. A fairly recent advance of the glacier dammed off the upper Donjek Valley, forming a lake behind the glacier snout. Terraces of this lake are present on the moraine at the "heel" of the glacier and on the valley walls, showing that the lake was over 100 feet deep near the glacier and extended to a little distance above the mouth of Bighorn Creek. In 1952 the rim of this lake was still marked by a sharp line, especially noticeable from across the valley, below which only poplars up to about 25 years old, but no spruce, grew. Though the recent existence of this lake seems to be thus indicated, the writer was unable to obtain any confirmation of this date from those few who had visited the area in that time. Informants of McConnell (1905) knew of a valley existing beyond Donjek Glacier, but did not mention a large lake.

An exception to the general retreat of glaciers is the glacier at the head of Bighorn Creek. Comparison of 1947 and 1956 aerial photographs shows an advance of at least half a mile in that time interval. In the later photograph, the surface of the glacier is noticeably arched and crevassed in comparison to the 1947 surface, or the present surface of nearby glaciers. The advance was due only to flow from the west branch of the glacier; the east branch is freshly crevassed only at the junction by lateral pressure by the west branch, and is relatively smooth above that point. The cause of the advance is therefore very local and not climatic.

Chapter III

GENERAL GEOLOGY

Kluane Lake area is divided by Shakwak Trench into two distinct geographic and geologic regions. To the southwest, St. Elias Mountains consist of a eugeosynclinal assemblage of sedimentary, volcanic, and intrusive rocks, where fossils, though not abundant, have established ages ranging from Devonian to early Tertiary. To the northeast, Yukon Plateau is for a large part underlain by granitic rocks and associated migmatites and gneisses. Sedimentary and volcanic rocks are also present, but are metamorphosed in the low to medium grade and have not yielded any fossils. There, only generalized belts of lithologically similar rocks have been distinguished, partly based on degree of metamorphism and partly on essential differences in composition.

In the table of formations the metamorphic rocks of Yukon Complex are, following the usual procedure, placed at the bottom without implying that they are necessarily older than the Devonian Kaskawulsh Group of St. Elias Mountains. Tentatively, volcanic rocks of Nisling Range are placed in the Mesozoic, granitic rocks of Ruby Range are opposite to those of Kluane Ranges, and the Nisling Range "alaskite" and related rhyolites are placed opposite to the Donjek Range intrusions.

Yukon Complex

Name and Definition

The name Yukon Group was introduced by D. D. Cairnes (1914a) in a preliminary report on the geology of the Yukon-Alaska boundary, as follows:

> What are considered to be the oldest rocks in the district are the members of the Yukon Group, which are developed only in the vicinity of Yukon River. These are probably of Pre-Cambrian age, and are mainly quartzite, schists, schistose amphibolites, and mica schists, but include also occasional beds of limestone.
>
> Another group of rocks, the Tindir Group, which is possibly also of Pre-Cambrian, and is at least of Pre-Middle Cambrian age . . . composed mainly of dolomites, quartzites, shales, sandstones, and associated greenstones . . . is thought to be younger than the members of the Yukon Group.

The name Yukon Group has been used ever since in Geological Survey and other reports for the metamorphic rocks of Yukon Plateau, but in later publications a Precambrian and younger age has generally been indicated. In accordance with the present code of stratigraphic nomenclature the term "Yukon Complex" is

Table of Formations

Era	Period or Epoch	Group or Formation	Lithology
		ST. ELIAS MOUNTAINS	
CENOZOIC	RECENT		Glacial moraines; gravel, sand, silt; volcanic ash
	PLEISTOCENE	St. Elias glacial advance	Glacial drift with pronounced glacial topography
		Ruby ice-sheet	Glacial drift, with subdued topography on elevated valleys and plateaux
		Nisling ice-sheet	No drift, large remnant granitic boulders on some plateaux
		RELATIONSHIP UNCERTAIN, SOME VOLCANIC ROCKS MAY BE PLEISTOCENE	
	TERTIARY AND ? PLEISTOCENE	Tertiary Intrusions	Porphyritic latite, trachyte, rhyolite, gabbro
		INTRUSIVE CONTACT, MAY BE PRE-UPPER ST. CLARE GROUP	
		St. Clare Group — Upper part	Volcanic-boulder gravel and conglomerate; minor tuff, sandstone, shale, lava
		St. Clare Group — Lower part	Basalt and andesite, massive or vesicular, agglomerate, breccia, tuff; reddish brown
		CONFORMABLE, TRANSITIONAL CONTACT	
	PALEOCENE OR EOCENE	Amphitheatre Formation	Sandstone, sand, conglomerate, gravel, shale, coal
		ANGULAR UNCONFORMITY	
MESOZOIC AND ? CENOZOIC	MESOZOIC AND/OR TERTIARY	'Donjek Ranges intrusions'	Alaskite, granite, quartz monzonite, rhyolite
MESOZOIC	CRETACEOUS AND ? JURASSIC	'Kluane Ranges intrusions'	Granodiorite, and quartz diorite, related hybrid contact rocks
		INTRUSIVE OR MIGMATITE CONTACT	
	LOWER CRETACEOUS AND UPPER JURASSIC	Dezadeash Group	Greywacke, argillite; minor conglomerate, limestone
		DISCONFORMITY	
	UPPER AND ? MIDDLE TRIASSIC	Mush Lake Group — Sedimentary Division	Thin-bedded silty limestone; massive limestone
		Mush Lake Group — Volcanic Division	Mainly amygdaloidal purple and dark green basalt and andesite, minor argillite, limestone

	DISCONFORMITY WITH CACHE CREEK GROUP			
	INTRUSIVE CONTACT WITH KLUANE RANGES INTRUSIONS			
	PERMIAN AND ? TRIASSIC	Basic and Ultrabasic Intrusions		Gabbro, peridotite
	LOWER PERMIAN AND ? PENNSYLVANIAN	Cache Creek Group	Sedimentary Division	Limestone, chert, argillite, greywacke, grit, conglomerate
			Volcanic Division	Volcanic breccia and conglomerate, graded-bedded tuff, altered to greenstone
	ANGULAR UNCONFORMITY ?			
PALAEOZOIC	MISSISSIPPIAN AND/OR DEVONIAN	Greenschist complex		Greenstone, chlorite schist, schistose greywacke, slate, phyllite; minor sheared conglomerate, marble. May include rocks of Kaskawulsh and Cache Creek Groups
		CONFORMABLE CONTACT ?		
	MIDDLE AND UPPER DEVONIAN	Kaskawulsh Group		Marble, slate; minor phyllite, greenstone
	YUKON PLATEAU			
CENOZOIC	RECENT			Gravel, sand, silt, volcanic ash
	PLEISTOCENE	Ruby ice-advance		Glacial drift with subdued topography, main valley bottoms
		Nisling glaciation		No drift, large granitic remnant boulders only, rounded, castellated highlands
	UNCONFORMITY			
MESOZOIC	MESOZOIC AND/OR TERTIARY	Nisling Range 'Alaskite'		Alaskite, granite, rhyolite
	JURASSIC AND ? CRETACEOUS	Nisling Range 'granodiorite'; Ruby Range batholith		Granodiorite, quartz diorite, minor diorite and gabbro, with related gneiss and migmatite
		INTRUSIVE CONTACT		
	TRIASSIC AND ? LATER	Nisling Range volcanic rocks		Porphyritic andesite, latite, rhyolite, related tuff and breccia
	UNCONFORMITY			
	PRECAMBRIAN AND LATER	Yukon Complex		Quartz–chlorite–sericite schist, epidote–actinolite greenstone, recrystallized limestone, quartzite, slate, quartz-mica schist Quartz–sericite–chlorite schist; minor quartzite Quartz–biotite schist, in places with garnet, quartz–feldspar–biotite gneiss, quartzite, amphibolite

preferable. This modification also brings into focus its similarity with the Wolverine and Shuswap complexes in British Columbia.

General Subdivisions and Their Distribution

The backbone of Yukon Plateau in the map-area is Ruby Range. It is underlain by granodiorite and allied rocks that may be considered as the northern extension of the Coast Intrusions and which are described later in conjunction with the granitic rocks of St. Elias Mountains.

To the southwest these granitic rocks are fringed with quartz–biotite schist and gneiss (1) occurring in a belt stretching from south of Gladstone Creek to north of Kluane Lake. Another strip of these rocks occurs in the southeast corner of the area and grades southwestward towards Shakwak Trench into a narrow strip of granitic rocks. A uniformly north-dipping sequence of chlorite–sericite schist (2) underlies most of the area from Gladstone Creek to Cultus Creek between the two belts of quartz–biotite schist. To the south they appear to overlie the quartz–biotite schist, but they may be separated from the northerly band by a fault.

West of Brooks Valley, an assemblage of metamorphic rocks (3) occupies the place of the granitic rocks that underlie Ruby Range to the east. They are characterized by mappable bands of recrystallized limestone (3a), together with quartz–muscovite schist, epidote–amphibolite, and some metamorphosed ultrabasic rocks. Similar rocks occur as roof pendants in the Ruby Range batholith. To the north of this group of rocks, various areas of slate, impure quartzite, and quartz–mica schist with minor limestone occur. Although correlation is uncertain, these rocks have been included with map-unit 1. The metamorphic rocks in the northeast corner of the area, that are part of Nisling Range, are also included in this group.The actual extent of their outcrops is very limited because of the abundance of rhyolitic dykes that intrude them. Nisling Range also contains volcanic and granitic rocks, but these are tentatively correlated and discussed later with the rocks of Mesozoic and Tertiary age.

Lithology

Metamorphic Rocks South of Ruby Range Batholith

Two belts of quartz–biotite schist and gneiss (1), north of Kluane Lake, exhibit a generally uniform lithology. Cliff faces and outcrops are evenly dark brown. The foliation is distinct, grading from a fine schistosity to a coarse gneissic texture with alternating quartz–feldspar and biotite bands several millimetres thick, but the fissility is poor. Border zones, between metamorphic and granitic rocks, display all stages of transition from schist, through gneiss to foliated granodiorite. Many gneissic rocks are intermediate between true metamorphic and true plutonic rocks and may be termed migmatites.

Thin sections of quartz–biotite schists and gneisses show the light coloured bands to be a quartz mosaic with scattered patches of feldspar that include quartz grains and graphite. The dark layers are irregular, consisting mainly of biotite and less chlorite. Magnetite, apatite, and a little zircon are accessory constituents. Garnet is a main constituent of part of this unit and increases in grain size with the transition from schist to gneiss from pinpoints to porphyroblasts one centimetre or more in size. In thin section these rocks also show irregular quartz–andesine layers alternating with foliae of biotite draped around the garnets.

Staurolite gneiss was noted in several places on Outlet Hill north of the lake outlet to Kluane River. The dark coloured rock has irregular, wavy, and broken gneissic banding a few millimetres thick, and shows irregular, yellow glassy patches of staurolite. The thin section shows the light bands to consist partly of quartz mosaic with clear quartz to about ½ mm in size, and partly of oligoclase, in places with polysynthetic twinning and many inclusions of quartz, graphitic material, and some sericite. Streaks of opaque material were apparently left undisturbed by the growth of the plagioclase crystals that include them. The dark bands in the rock are mainly crenulated biotite, to about 2 mm long, and with many streaks of graphitic material. Staurolite occurs in irregular crystal aggregates, and minor amounts of garnet and tourmaline are also present, all less than 1 mm in size.

Along the contact between the northern belt and the belt of quartz–sericite schist (2) to the south, metamorphosed basic and ultrabasic rocks occur at several places in the ridges south of Gladstone Creek, but were not mapped as a separate unit. They occur as black, massive, fine-grained, non-schistose amphibolite or as coarse-grained actinolite schist, with light green actinolite fibres more than an inch long in fan-like arrangement. On the east border of the map-area, at the head of Alie Creek, medium-grained gabbro occurs, which in thin section shows labradorite to 2 mm in size, considerable quartz, biotite, brown pleochroic hornblende, and minor titanite. Other parts of this mass show an increasing amount of garnet, up to half an inch in size, until this mineral forms the bulk of the rock. The thin sections suggest that the garnet has grown at the expense of hornblende and biotite.

The quartz–sericite schists (2) between the two belts of quartz–biotite schist (1) are also uniform dark coloured sequences, with regular schistosity generally parallel with the original bedding. They are commonly cut by veins of quartz a few inches to several feet thick. The rocks are mainly dark silvery grey, glossy schists with fair fissility and a knotty schistosity surface. They may contain lenticular laminae of quartz up to about 2 mm thick. The thin section reveals bands of quartz mosaic with wavy extinction and some albite up to 1 mm in size with much fine graphite dust, interlayered with chlorite–sericite laminae. Considerable graphitic material occurs throughout, and grains of tourmaline and a colourless unidentified mineral are accessory constituents. Some rocks also contain a certain amount of carbonate.

Metamorphic Rocks Within and West of Ruby Range Batholith

An assemblage of rocks (3) distinguished by bands of recrystallized limestone, mica schist, and amphibolite, occurs as roof pendants in the Ruby Range batholith. West of Brooks Valley the granitic rocks are much reduced in width and their place is taken by this rock unit. The more prominent bands of limestone (3a) have been shown separately on the geological map. In outcrops they are a coarse crystalline, white to grey limestone, thinly bedded to massive, with uneven honeycombed weathered surface with harder siliceous laminae standing out in relief. The freshly broken rock locally has a bituminous smell.

A major component of the assemblage consists of light greenish grey phyllitic schists with good fissility. The microscope shows alternating laminae of quartz mosaic, and muscovite and chlorite, with many round grains of untwinned albite. Pyrite and other opaque matter are scattered throughout. Other samples of somewhat higher metamorphic grade contain muscovite and biotite together with quartz. Rutile may be a minor constituent. Quartz–muscovite–biotite schist with one-inch porphyroblasts of andalusite occurs north of Mineral Creek. Quartz–mica–garnet schist occurs locally, and amphibolite is also common in this group of rocks. The hand specimens are black-green, fine-grained rocks with poor to well-developed schistosity. Thin sections reveal green to yellow-green, pleochroic, acicular hornblende up to about $\frac{1}{2}$ mm long, together with quartz and plagioclase as main constituents. The latter is commonly oligoclase, but albite and also microcline occur. Epidote occurs abundantly in small grains in several samples. Garnets to 1 mm in size were also found in some specimens. Dark green phyllitic schist of lower metamorphic rank consists mainly of actinolite, with patches of carbonate and some rutile and magnetite.

In a few places small intrusive masses of dunite, not separately mapped, occur in this part of the Yukon Complex. They were seen on the ridge east of the mouth of Duke River, and as glaciated knobs in the valley south of Dogpack Lake. They are coarse-grained, dark bluish rocks, with a rough, reddish brown weathered surface. Thin sections show a monomineralic assemblage of olivine, remarkably fresh but with the characteristic triangular network of serpentine fibres. Patches of fibrous serpentine also occur.

Probably related to these rocks is an occurrence of pyroxenite in a gully north of the valley linking the south end of Tincup Lake and Kluane River. This is a dark green, coarse-grained rock, exhibiting in thin section fresh, faintly reddish pyroxenes to about 5 mm across, with a little calcite and fibrous serpentine. Mortar structure and wavy extinction are prominent in this specimen. Another mass of ultrabasic rocks occurs on the ridge east of Donjek River and about 6 miles north of the Alaska Highway.

Metamorphic Rocks North of Ruby Range Batholith

Metamorphic rocks in the northeast corner of the map-area, in Nisling Range, are less well exposed than those to the south, as they are mainly in the unglaciated area. The schist is also in many places subordinate to the intruding rhyolitic dykes, and may be represented on the surface only by scattered rubble.

These rocks are, for a large part, impure quartzite, slate, and greywacke with low to medium degree of recrystallization. Laminated graphitic quartzite is common. The hand specimen is a sooty black, graphitic, crudely laminated, hard siliceous rock. The thin section shows a mosaic of interlocking quartz grains with size sorting– from 0.1 to 0.5 mm – giving well-defined layering. Fine opaque dust is scattered throughout. Laminated micaceous quartzite contains paper-thin, dark micaceous laminae and under the microscope exhibits very fine muscovite, chlorite and some rutile, in laminae as well as scattered grains. Rodded quartzite was also seen in many places. It occurs as brown quartzite plates with very strong parallel ribbing and single pencil-like rods. The ribbing is commonly horizontal and parallel with the regional strike. Thin sections show a mosaic of quartz, to $\frac{1}{2}$ mm in size, very fine biotite and muscovite, to 0.1 mm in size, and opaque matter. Such rocks, of a quartzitic to a hornfelsic nature, are most common in the region near the junction of Kluane and Donjek Rivers. Farther east, quartz–mica schist, in part with garnet, similar to the schists south of Ruby Range batholith, and amphibolite are common wherever areas of schist occur between intrusive rocks.

Metamorphism

Many of the rocks of the Yukon Complex are of low-grade metamorphic rank. These quartz–chlorite–sericite–albite or albite–epidote–chlorite–actinolite assemblages correspond to the chlorite subfacies of the greenschist facies of Turner and Verhoogen (1960). Other fine-grained greenschists, containing also biotite and garnet, probably represent the higher subfacies of the greenschist facies.

The quartz–plagioclase–biotite (garnet) schists and gneisses, bordering the large granitic masses, and the plagioclase amphibolites, mainly in the northern parts of the area, represent the lower staurolite–almandine subfacies of the almandine–amphibolite facies.

Structural Relations

South of the Ruby Range batholith the general structure of the Yukon Complex appears to be as follows. East of the south end of Kluane Lake a band of granitic rocks, a few miles wide, flanks Shakwak Trench. Northeastward it grades into quartz–biotite schist and gneiss (1), dipping regularly northeast. To the north these are succeeded by the sequence of quartz–sericite schist (2), also with a uniform northeast dip. Northeastward, the succession, therefore, shows decreasing metamorphism.

In the high ridges south of Gladstone Creek the contact between the quartz–chlorite–sericite schist (2) and quartz–biotite schist (1) is probably a fault, and is marked by the metamorphosed basic and ultrabasic rock discussed before. A southward thrust fault is suggested by the generally northerly dips and the circumstance that the rocks to the north are from a deeper zone of metamorphism. Northward the metamorphic rocks merge gradually into the granitic rocks of the Ruby Range batholith.

The limestone-bearing rocks (3) cover an extensive area west of Brooks Valley, but east of that valley, on the crest of the batholith, they occur only as roof pendants. The abruptness of the change at the valley suggests that it may mark the site of a normal fault.

North of the batholith, the structure is dominated by small intrusions and dykes. The schists still have a general west to northwest trend, but relationships are obscure. A westerly trend is common to several of the smaller intrusive bodies, whereas the rhyolitic dykes show a consistent strike that varies only few degrees from due north.

Origin and Age

The metamorphic rocks to the south of Ruby Range are nearly all low- to medium-grade quartz–mica schists. They were probably derived from sandstone, shaly sandstone, and shale, that were deposited in a non-volcanic environment. The rocks within and north of Ruby Range contain a considerable amount of metamorphosed volcanic rocks, greywacke, and limestone, that presumably originated in eugeosynclinal environment.

The age of the Yukon Complex and its Alaskan equivalent, The Birch Creek Schist, was formerly held to be Precambrian (?) (e.g., Cairnes, 1915a; Mertie, 1937) but has recently been regarded as Precambrian and later (Bostock, 1952; Kindle, 1952; Wheeler, 1961), with varying emphasis on a Precambrian or a younger age. No direct geological information on this point was obtained in the map-area.

Regional considerations having a bearing on the age of the rocks and the (possibly much younger) age of their metamorphism are as follows: The Yukon Complex constitutes part of the Yukon-Tanana geanticline (Payne, 1955) bounded by Shakwak and Tintina lineaments (Muller, 1958b). Southward the geanticline is split into two crystalline belts, separated by the Tagish belt of mainly Mesozoic volcanic and sedimentary rocks, intruded by granite plutons (Gabrielse and Wheeler, 1961). The western crystalline belt is flanked to the southwest by the St. Elias belt, containing eugeosynclinal assemblages of Devonian to Cretaceous age. The eastern crystalline belt is bordered by the eastern belt of mainly stratified rocks, embodying Pelly, Cassiar, and northern Rocky Mountains. According to Gabrielse and Wheeler, the latter belt was relatively stable until late Devonian time, but then developed typical eugeosynclinal characteristics. The Rampart trough in Alaska, which bounds the Yukon-Tanana geanticline to the northwest, contains Mississippian, Devonian, and Ordovician rocks of eugeosynclinal character. Thus the metamorphic complex is surrounded by regions where formations of pre-Ordovician age do not contain volcanic rocks, those of Ordovician and Devonian age contain volcanic rocks in some regions, and those of Mississippian age are all in part volcanic. It may be suggested, that in the Yukon Complex too, a similar change from non-volcanic to volcanic deposition occurred in middle Palaeozoic time. Thus units (1) and (2), of clastic, non-volcanic origin, are more likely of pre-Mississippian, and perhaps pre-Ordovician age, whereas unit (3), containing metamorphosed volcanic rocks, is probably Ordovician or younger.

Age of Metamorphism

Potassium-argon age determinations on minerals of recrystallized rocks may be an important aid to determine their time of final metamorphism. Some K-Ar age determinations were made in the Geological Survey Isotope laboratory on micas from Yukon Complex rocks within and outside of the map-area (Lowdon, 1960, 1961, 1963). Results are as follows:

GSC 59-11 Biotite from quartz–plagioclase–biotite–garnet schist, west of Venus Creek, 61°17′N, 138°07′W; 140 million years; Upper Jurassic according to 1960 Kulp and Holmes time-scales.

GSC 61-41 Biotite from highly folded, fine-grained quartz–biotite gneiss on Aishihik road, Mile post 30, 136°57′W, 61°14′N (Aishihik map-area); 147 m.y.; Upper Jurassic.

Biotite from intrusive rock near GSC 59-11 yielded 176 m.y.; Lower Jurassic. Several other samples from granitic and gneissic rocks of the complex, to be quoted later, gave dates around 60 m.y.; Paleocene.

Outside Kluane Lake map-area sericite schist from the eastern crystalline belt, in the Teslin area, gave 214 m.y. and 222 m.y.; Upper Permian and lowermost Triassic (GSC 59-9 and GSC 61-42). Muscovite in schist (Klondike Schist) from the Ogilvie and Sixty Mile areas gave 138 and 175 m.y.; Upper and Lower Jurassic (GSC 60-33 and GSC 61-40).

Recently published isotopic ages from the Birch Creek Schist in Alaska (Wasserburg, *et al.*, 1962) have yielded K-Ar ages ranging from 177 to 187 m.y. (Upper Triassic to Lower Jurassic), and also some lower Palaeozoic ages.

These few dates are by no means sufficient to draw definite conclusions. At best they may be used as indications of a multiple history of the metamorphic Yukon Complex. Metamorphism would appear to have occurred in latest Palaeozoic, Late Jurassic, and earliest Tertiary time. The rocks yielding young ages may have been affected by several phases of recrystallization and there is some suggestion of a cumulative effect if we compare the relatively low-grade metamorphism of rocks yielding late Palaeozoic ages with the gneissic rocks yielding early Tertiary ages.

Latest Palaeozoic metamorphism, not yet demonstrated with age determinations in the map-area, might be connected with a possible early Triassic orogeny, suggested by the considerable hiatus between Lower Permian and Upper Triassic sediments occurring throughout the Western Cordillera.

Similarly, late Jurassic metamorphism in southwestern Yukon would correspond to temporary emergence of the St. Elias geosyncline, as well as to partial emergence of the Whitehorse trough, as demonstrated by the absence of much of the Jurassic sequence. Orogeny has not been demonstrated for this time but is hinted at by the subsequent deposition of the Dezadeash greywacke sequence west of the crystalline belt in the St. Elias geosyncline, and the Tantalus conglomerate in the Whitehorse basin to the east.

Lastly, the youngest phase of crystallization that apparently gave rise to granitic and gneissic rocks of the Yukon Complex might be identified with the orogeny that caused the severe folding of the Dezadeash Group and with the emplacement of the Kluane Ranges intrusions. However, a Paleocene age of Kluane Ranges intrusions would leave little time for erosion prior to unconformable deposition of the Paleocene or Eocene Amphitheatre sediments. The ages of the intrusions are discussed in the relevant sections of this report.

Further information on isotopic ages is to be expected, but a general conclusion consistent with the geological evidence may be made. The crystalline complex originated in an axial zone, repeatedly subject to orogenic conditions inducing recrystallization, during a long time interval, possibly stretching from Palaeozoic to early Tertiary time.

Kaskawulsh Group

Name and Definition

The oldest sedimentary rocks, not included in the Yukon Group, were described by E. D. Kindle (1952) in Dezadeash area, southeast of Kluane Lake area, as follows: "Sedimentary rocks, consisting largely of crystalline limestone, but with intercalated zones of black and brown slates, quartzite, and argillites, form rugged northwesterly trending mountain slopes along the north side of Kaskawulsh River, north of the mouth of Dusty River.... It is proposed that this group of sedimentary rocks be named the Kaskawulsh Group as they are best exposed on the north side of Kaskawulsh River."

A Carboniferous age was tentatively assigned to these rocks, because of their similarity to rocks of that age to the north in Kluane Lake area, and to the south in Rainy Hollow area. Since then fossils have been found in many places in the same belt of rocks by J. O. Wheeler and the writer. Except for one Permian fossil locality near the north side of Kaskawulsh River, all diagnostic collections are of Middle and Upper Devonian age. The age of the Kaskawulsh Group is therefore redefined as Middle and Upper Devonian, with the provision that rocks of Mississippian and Permian age may have been included in the mapping.

Distribution

West of Donjek River the formation is exposed in the deep valley and canyon of Spring Creek, where it occurs in a northeast-trending belt, about 4 miles wide. An isolated occurrence of Devonian limestone on the upper part of Steele (Wolf Creek) Glacier is reported by Sharp (1943). East of Donjek River, limestone and slaty argillite on Hoge Creek have also been included in this group, and some rocks southeast of the foot of Donjek Glacier may also belong to it. The belt appears again on the west side of Duke River and Dickson Creek, and continues along Bullion Creek.

Lithology and Thickness

The most distinctive member is a succession of sheared and recrystallized limestone or marble interbedded with argillite, which on Spring Creek has a roughly estimated thickness of 2,500 feet. It commonly stands out because of its light grey, light brown, and reddish weathering colours and its rough topography of spires and ridges. It occurs in grey and light grey weathering, massive and irregularly jointed, thick beds or in alternating 3- to 6-inch beds of limestone and platy black argillite. The darker bands commonly exhibit a network of calcite veinlets. The marble occurs also as a light brown to reddish weathering, hard, massive breccia. Beds with *Amphipora* are fairly common, and even when distorted these are easily recognized as white tubes and oval cross-sections in black matrix.

At the mouth of Spring Creek, the limestone has been metamorphosed to diopside marble. The rock is bluish grey, medium to coarsely crystalline, with scattered radial bundles of tremolite and nests of calcite. Seen in thin section it comprises mainly colourless diopside in euhedral crystals up to 2 mm long. Tremolite occurs sparingly in bundles of very fine needles, to about 1 mm long. The matrix is calcite in irregular grains and aggregates of very small quartz grains.

On Spring Creek the limestone appears to be underlain by at least 2,000 feet of mainly black argillite and slate, with minor brownish, medium-grained, platy quartzite, in places with numerous quartz veinlets along bedding planes. The argillites contain a noticeable amount of iron, probably as sulphides, for in many gullies the water flowing through the black slates is commonly rusty, and has left incrustations of iron oxide on the rocks in the stream bed.

Structure

The structure of the group is only broadly known, for although it is well exposed within and south of the area, it has been traversed in few places due to generally rugged topography.

On Bullion Creek, it forms a steeply southwest-dipping sequence of rocks, possibly duplicated by folding and faulting, together with the overlying greenschist complex, and constitutes the upper plate of the Duke River thrust. It continues northwestward along Duke River, where it is largely covered by Tertiary rocks, and farther north it is interrupted by the Donjek Range intrusions. The limestone and argillite are seen again on Hoge Creek and appear once more across Donjek River along Spring Creek. There the sequence exhibits moderate to steep dips, swinging from southwest to northwest in the upper part of this deep gorge. North of the mouth of Spring Creek, the Donjek Valley wall exhibits a recumbent anticline in these rocks.

Alternatively the Kaskawulsh limestone north of Steele Creek could be considered as the continuation of the Bullion Creek–Duke River belt, and the Spring Creek belt as the continuation of the limestone southeast of the Donjek Glacier snout. In either, the salient features of the structure are the 90-degree turn in trend of the rocks and the local interruption of the belts by the crystalline rocks of the Donjek Range intrusions.

The degree of metamorphism clearly distinguishes the Kaskawulsh and greenschist complex rocks from the Permian and later rocks, and suggests a pre-Permian disturbance. Such an older orogeny might be responsible for the divergent trend of the group in this part of the map-area. Or it might be suggested that the Donjek Range intrusions are responsible for the 90-degree turn of the rocks. Either they might have actively disrupted existing structure during intrusion, or they might have acted as passive buttresses modifying the pattern of post-intrusion folding. Although neither possibility can be discounted entirely, a pre-Permian folding phase, followed by later folding and intrusion in Tertiary time, with ultimate faulting along the Duke River thrust, is here preferred.

According to present information, the Kaskawulsh Group contains the oldest fossiliferous formation in the map-area. It has not been found in contact with older sedimentary or volcanic rocks, or on a crystalline basement. As the Yukon Complex was mainly metamorphosed in late or post-Palaeozoic time, it is unlikely but not impossible that it served as a basement for the Devonian deposits of the St. Elias geosyncline.

Age

The age of the Kaskawulsh Group is based on fossils obtained by J. O. Wheeler in Kaskawulsh area and by the writer in Kluane Lake area. Identifications and comments on the collections obtained by the writer are by D. J. McLaren of the Geological Survey.

GSC locality 21409. Float of limestone, lower part of Spring Creek:
rod algae?
Alveolites sp.
favositid corals
Syringopora sp.
large tetracoral
Recrystallization has destroyed the structure of all the specimens and accurate identification is impossible. The assemblage is probably Devonian, but a Silurian or Mississippian age cannot positively be excluded. The species of *Syringopora* resembles, in gross characters, a form of Middle Devonian age, found in similar rocks in the Dease Series of McDame map-area, B.C.

GSC locality 28314. East slope of Bullion Creek, below Metalline Creek:
Amphipora?

GSC locality 28315. Bullion Creek, 500 feet above mouth of Little Creek:
Amphipora?
favositid corals cf. *Thamnopora*
No positive age can be suggested for these collections. Either lot could be of Devonian age and I think this is perhaps the most probable, but the possibility of their being Silurian can most definitely not be excluded.

Only those collections by J. O. Wheeler in Kaskawulsh area that are more diagnostic than those made by the writer are given below. They, also, were identified and commented on by D. J. McLaren, as follows:

GSC locality 23473. Limestone at elevation 3,800 feet, ½ mile west of mouth of Bullion Creek:
Thamnopora sp.
Probably Devonian

GSC locality 23474. Uppermost limestone, elevation 7,200 feet, 1½ miles west of mouth of Bullion Creek:
Tabulophyllum sp.
Probably Devonian, possibly Upper Devonian

GSC locality 23475. Limestone at elevation 3,400 feet on north side of Kaskawulsh River, opposite mouth of Disappointment River:
Favosites sp.
Syringopora sp.
Possibly Middle Devonian

GSC locality 23477. Buff weathering limestone near summit of 6,000-foot peak on north side of Kaskawulsh River, opposite mouth of Disappointment River:
Alveolites sp.
Atrypa large sp.
Spinatrypa sp.

nautiloid
crinoid fragments
Devonian, possibly Upper Devonian

GSC locality 25054. West wall of Shakwak Trench, elevation 6,550 feet, 10 miles west of Sulphur Lake:

Amphipora traces
non-columellate colonial corals
spongophyllids?
Probably Devonian

GSC locality 25056. West wall of Shakwak Trench, elevation 6,800 feet, 10 miles west of Sulphur Lake:

stromatoporoid
Disphyllum ex gr. *D. goldfussi* (Geinitz)

This limestone contains fragments of tabulate corals and the rugose coral identified above. The species *Disphyllum goldfussi* occurs in the Middle Devonian of Europe. The age of this collection is probably Devonian, possibly Middle Devonian.

GSC locality 25049. West wall of Shakwak Trench, elevation 6,850 feet, 10 miles west of Sulphur Lake:

Stachyodes sp.
Chaetetes sp.
Thamnopora sp.

The collection is probably Devonian. The *Chaetetes* in section bears some resemblance to a form, known in the Middle Devonian in the Ram River region, N.W.T.

GSC locality 25046. Moraine on glacier at head of Telluride Creek:

stromatolites
Amphipora?
Thamnopora sp.
cystiphylloid coral

The collection is probably Devonian. The coral is not quite well enough preserved to be positive that it is a *Cystiphylloides* and therefore Middle Devonian, or a *Cystiphyllum* and therefore Silurian. *Amphipora* and the *Thamnopora* species, however, do suggest a Devonian age.

GSC locality 25052. Above Kaskawulsh River between Lost Cache and Canyon Creeks, at elevation 7,260 feet:

Receptaculites sp.
Schizophoria sp.
Atrypa sp.
"*Reticularia*" sp.

Although these are only casts and internal moulds, all badly distorted, identification down to genera is possible. The "*Reticularia*" species may belong to an undescribed genus and bears a strong resemblance to a form found in the

Middle Devonian of southern Ellesmere and Bathurst Islands. Positive correlation is, however, not possible. The collection is definitely of Devonian age, and may be Middle Devonian.

The Carboniferous age, tentatively assigned to the Kaskawulsh Group by E. D. Kindle (1952), was based on Carboniferous corals, reported from Bullion Creek by McConnell (1905), and a Permian (?) fossil, collected by Watson (1948) south of Dezadeash area. Though his collection could not be found for re-examination, there is little doubt that McConnell's corals on Bullion Creek are the same as those now identified as Devonian. The weight of evidence in the Kluane Lake and Kaskawulsh areas is therefore in favour of the Devonian age of the Kaskawulsh Group.

Correlation

The Kaskawulsh Group can be traced intermittently from Steele (Wolf Creek) Glacier and Spring Creek, west of Donjek River through Hoge Creek, Duke River, Dickson Creek, and Bullion Creek into the Kluane Ranges between Kaskawulsh River and Shakwak Trench. It continues with scattered occurrences along the Duke Depression in Dezadeash area, and leads into a limestone–argillite–schist group of rocks, mapped by Watson (1948) in Rainy Hollow area as Permo-Carboniferous. This age was based on a small fossil collection, which, according to W. A. Bell of the Geological Survey, contained "one unidentifiable productid (?) which indicates only Carboniferous or Permian" (Watson, 1948). It has been the experience, both in the Kaskawulsh area and in the eastern Alaska Range (Moffit, 1954), that limestones with Permian fossils are in places faulted together with Devonian limestones, and that these cannot be separated unless diagnostic fossils are found in them. This condition may also occur in Rainy Hollow area where part of the "Permo-Carboniferous" may be correlative to the Kaskawulsh Group.

Farther south, in the Alaskan Alexander Archipelago, Middle and Upper Devonian rocks are widespread (Buddington and Chapin, 1929, p. 94). There too stratigraphic relations are not well established, but it appears that fossiliferous massive limestone occurs at the top of the succession, underlain by a group of slate, greywacke, and conglomerate beds, underlain in turn by interbedded lavas, tuffs, and clastic beds.

West of Kluane Lake area, Devonian occurs again in the eastern Alaska Range (Moffit, 1954). They are in part limestone with scanty Middle and Upper Devonian fossils, but mainly slate, schist, quartzite, and conglomerate. Farther west again, Devonian limestone has been described by Capps (1940) in the Alaska Railroad region.

It appears therefore that Middle and Upper Devonian carbonate and clastic sediments were deposited throughout the St. Elias geosyncline, locus of the present Alaska–St. Elias Mountain chain.

The Kaskawulsh Group rocks are closely related in space to a volcanic–clastic sequence, consisting mainly of greenstone and chloritic schist. These rocks are treated separately under the next heading, as their age relationship to the Devonian rocks is uncertain.

Greenschist Complex

Distribution

Low-grade metamorphic rocks, generally of greenschist facies and derived from clastic sedimentary and volcanic bedded rocks, occupy most of the high mountains to the south of the belt of Kaskawulsh Group rocks, as well as those south of Steele (Wolf) Creek. Also included are rocks of the amphibolite facies previously assigned to the Yukon Complex (Muller, 1954). These occur in the mountains bordering the upper part of Donjek River valley, above the glacier snout, and their higher degree of metamorphism may be due to contact metamorphism by nearby intrusions.

No group name is proposed for these rocks, as they have only a few general characteristics in common, and the lack of fossils prohibits precise definition of age.

Lithology and Metamorphism

The rocks of Donjek Range and of the mountains south of Steele Creek are largely slates and schists with minor massive greenstone, and exhibit low-grade metamorphism corresponding to the greenschist facies (quartz–albite–muscovite–chlorite subfacies of Turner and Verhoogen). Black, grey, and brown colours predominate in the schists of clastic, non-volcanic origin, and chlorite and sericite are the main metamorphic minerals. Light and dark green colours, due to the presence of chlorite or actinolite, are prominent in the rocks of probable volcanic origin.

Schists derived from argillaceous sediments are mainly black and brown slates and lustrous grey and light green phyllites. These rocks have good to perfect schistosity, commonly at an angle to the bedding plane, which only locally can be detected by changes in grain size. The schistosity plane may be glossy, due to varying amounts of sericite. It is smooth in the fine-grained schists, and rough in the coarser ones where sericite films are draped over the larger grains. In many places, the schistosity plane has fine corrugations, a few millimetres in amplitude.

The phyllites and slates grade into coarser grained schistose rocks, derived from greywackes, and perhaps volcanic tuffs. These rocks generally have a greenish grey colour. The schistosity is rough and may be poorly developed, as it must cut across the larger mineral fragments. Some rocks contain cubes of pyrite or pseudomorphs after pyrite up to a quarter inch across.

In thin sections the rock is seen to contain angular quartz and albite fragments, with sericite, chlorite, calcite, and minor epidote. In the finer grained phyllitic rocks, the mica minerals are arranged in more or less distinct laminae.

Highly deformed conglomerates are exposed in gullies southwest of Bullion Creek. They contain pebbles and cobbles of limestone and argillite, flattened and squeezed out in the plane of schistosity.

Volcanic greenstones occur together with the above rocks in Donjek Range. They are medium green, massive to poorly schistose rocks, probably derived from andesitic lavas and tuffs. Thin sections show fine-grained and finely layered assemblages of epidote, zoisite, actinolite, quartz, calcite, and albite. Some rocks contain pseudomorphs of diopside consisting of actinolite, locally with a core of the original mineral.

Contact metamorphic rocks near the Donjek Range intrusions, and corresponding to the albite–epidote–hornfels and hornblende–hornfels facies of Turner and Verhoogen, are also included in this group. The sediments are largely quartzite, slaty quartzite, and banded hornfels, with well-preserved bedding and little or no schistosity; they are grey to reddish. Thin sections show quartz with chlorite, muscovite, biotite, and opaque matter in grains about 0.1 mm in size, and actinolite, epidote, and diopside. The rocks are possibly of tuffaceous origin. Banding probably represents original layering and is mainly due to differences in biotite content.

Spotted slates are also common. Under the microscope the spots appear to be hard lumps with much carbonaceous matter displacing films of biotite and muscovite.

Hornfels, derived from basic igneous rocks, is a massive to roughly schistose, medium to dark green rock, exhibiting in thin section mainly biotite, hornblende, and albite, with minor quartz and epidote.

Structural Relations

Because of the predominant schistosity in this group of rocks, bedding planes are rarely discernible. The schistosity generally dips to the southwest in Donjek Range, and it is possible that several parallel fault slices occur there. The thin limestone band in the mountain range west of Bullion Creek is interpreted as Kaskawulsh limestone overriding the greenschist complex, and overlain by these rocks. Alternatively, Wheeler (1963) considers the schistose conglomerate and greywacke to underlie this band normally and to be part of the Devonian Kaskawulsh Group.

The greenschist complex between Spring Creek and Steele Creek follows the swing to the west and southwest taken by the strike of the Kaskawulsh Group to the south. It is inferred to overlie this group in a synclinal structure. Structural relationships therefore seem to indicate that the greenschist complex overlies the Kaskawulsh Group. This superposition is also assumed by Sharp (1943) and Wheeler (pers. com.)

Origin, Age, and Correlation

The original rocks of this complex were shale, greywacke, conglomerate, and probably andesitic lava and tuff. They are the same kind of eugeosynclinal assemblage that was deposited intermittently in the St. Elias geosyncline until early Cretaceous time. Thermal and dynamic metamorphism have obscured their original characteristics and forbid any definite correlation. The rocks may be metamorphic equivalents of Permian and Mesozoic formations, but correlation with the Strelna Formation of Moffit (1938) in the Chitina River region of adjacent Alaskan territory is an alternative possibility. The Strelna Formation appears to be similar in lithology and general relationships, and is believed to be of Mississippian age. But it must be noted that the fossils in that formation were obtained from limestones and no limestone occurs in the greenschist complex under discussion.

The rocks of the amphibolite facies in the upper Donjek area are more metamorphosed than the greenschist complex in the Bullion Creek–Duke River–Steele Creek belt. For this reason, in a first preliminary map (1954) they were assigned to the Yukon Group. This interpretation is now revised, as the metamorphism appears to be local rather than regional, and related to the Donjek intrusions.

To the south in Kaskawulsh area around the headwaters of Duke River and Canada Creek, Wheeler (1963) mapped a sequence of greywacke and argillite that may be of Cretaceous age, lithologically similar to Cretaceous rocks in Dezadeash area. Although separated from them by an area of intrusive and metamorphic rocks, such rocks and their metamorphic equivalents may be present in the upper Donjek region. There may even be a continuous belt of Dezadeash Group rocks with intrusive bodies and their contact aureoles from Bates Lake in Dezadeash area, along the southwest side of Kaskawulsh River, to the region of upper Donjek River and Bighorn Creek. In this regard it should be noted that the contact metamorphic zone of banded hornfels, schist, and amphibolite, surrounding a granitic intrusion in Cretaceous rocks north of White River are similar to some upper Donjek rocks. Further tentative correlations may be made between the greenschist complex and the Wrangell-Revillagigedo belt of metamorphic rocks in southeastern Alaska (Buddington and Chapin, 1929). The latter rocks, largely schistose greenstone and phyllite, with limestone, slate, chert, and some granitic and gneissic rock, are thought to be mainly Carboniferous. On the far eastern side of the Cordilleran geosynclinal area, separated from St. Elias Mountains by two belts of crystalline rocks, is another trough with lithologically similar eugeosynclinal rocks, bracketed between Middle Devonian and Middle Mississippian beds (Gabrielse and Wheeler, 1961). These similarities encourage the assumption of a Devonian-Mississippian age for the major part of the greenschist complex.

Cache Creek Group

Name, Definition, and Occurrence

The name Cache Creek Group is classical in Canadian Cordilleran geology, having been introduced in 1872 by A. R. C. Selwyn for a sequence of volcanic and sedimentary rocks of Carboniferous age in the Cariboo District. It has been widely used, and is generally ascribed to a thick succession of greenstone (altered basic lava and tuff), chert, argillite, conglomerate, and limestone of Pennsylvanian to Permian age (Armstrong, 1949; Duffell and McTaggart, 1952; Aitken, 1959). The name has not yet been used for the late Palaeozoic sequences of Yukon Territory, and, with some hesitation, it is here introduced into the stratigraphic column of the St. Elias geosyncline. However, as the sequence has not yet been accurately defined in Kluane Lake area, there are arguments in favour of using the old, broad, general term rather than introducing a new name.

Where fossil-bearing Permian rocks are absent or stratigraphic relationships obscure, distinction in the field between Cache Creek and Mush Lake volcanic rocks is uncertain. Thus some areas, on preliminary maps (Muller, 1954, 1958) assigned to the Permian, are now included in the Triassic sequence.

The group may be divided into a sedimentary sequence and an underlying, mainly pyroclastic, succession. All volcanic rocks occurring above Permian sediments are considered to belong to the Mush Lake Group, though perhaps some of these, in highly disturbed areas, may have been mapped with the Cache Creek Group.

The Cache Creek Group forms much of the frontal part of Kluane Ranges, facing Shakwak Trench. There deep canyons give good exposures of these rocks and reveal their structural complexity. No reliable section could be measured anywhere, but the general succession from Cache Creek Group volcanic rocks through Permian sediments to Mush Lake volcanic rocks is best exposed between Burwash and Quill Creeks. The Cache Creek Group also occurs on Donjek River, north of Hoge and Steele Creeks, and west of the valley of Tchawsahmon Creek.

Lithology and Metamorphism of the Volcanic Division

The volcanic rocks (10) are mainly altered andesitic (?) tuffs and breccias, and many exposed sections contain only pyroclastic material, with no recognizable lava flows. The tuffs are medium- to fine-grained, light grey to light green and rusty brown. Many show graded bedding, each graded unit having a thickness between one inch and one foot, and changing from coarse, dark green and brown at the bottom to fine, light grey and white at the top. The fine-grained tuffs especially are commonly hard and cherty and have smooth, closely spaced, joint faces perpendicular to the banding. Coarser agglomerates carry angular or subrounded fragments, one inch to more than one foot in size. On some weathered or wet rock faces the fragments are discernible by their colour (which is lighter than that of the matrix) and by their amygdules or phenocrysts. In other places, especially on the ridges, the fragmental nature of the rock may be barely noticeable.

Under the microscope many tuffs exhibit a mineral assemblage consisting of saussuritized and albitized plagioclase, chlorite, and epidote, with some magnetite, carbonate, and quartz. The tuffaceous nature is apparent from the angular, broken fragments of feldspar and well-outlined fragments of lava containing feldspar microlites or small vesicles.

Latite tuffs, containing orthoclase as well as plagioclase, occur on the ridges north and south of the upper part of Lynx Creek. They are light green to dark reddish and green rocks, ranging from fine, cherty, laminated, and well-bedded tuffs to coarser agglomerate. Thin sections show angular fragments of plagioclase, perthitic orthoclase, and volcanic rock in a fine matrix of feldspar and epidote.

A 2,000-foot sequence of volcanic conglomerate exposed on the ridge north of the mouth of Hoge Creek has also been included in this unit. The base is in faulted contact with limestone of probable Devonian age and the top grades into greywacke and pebbly conglomerate that, in the upper part, contain several coquina layers with Permian brachiopods and coral fragments. The rock contains mainly green pebbles and cobbles of altered andesite in a purple matrix, but lava flows are missing in this section.

Most extrusive rocks are probably altered andesite, though altered basalt and latite also occur. They are dense to fine-grained, mainly greyish to yellowish green rocks. Many have white or light green, 1 to 2 mm long plagioclase phenocrysts. Disseminated pyrite is also a common megascopic constituent. Many flows contain dark green or black amygdules, and red jasper occurs in irregular masses. Megascopic structures occurring locally are flow-banding, light green to white chilled tops up to one inch thick, and pillows.

Thin sections commonly show randomly oriented feldspar laths, less than ½ mm long with fine flakes of chlorite and grains of epidote. Plagioclase phenocrysts are up to 2 mm long and occur singly or in clusters. All plagioclase is saussuritized and is murky with fine disseminated chlorite and epidote. Its clear parts have a refraction index below Canada balsam, indicating albite. Polysynthetic twinning is still discernible in most phenocrysts. Quartz may be present as a byproduct of alteration. In most thin sections examined, recognizable crystals of dark constituents either are absent or occur only in minor amounts. They are commonly altered to an assemblage of actinolite fibres (uralite) or an epidote–chlorite–serpentine mixture. Most rocks contain finely disseminated iron ore, probably mainly pyrite and magnetite. Amygdules contain epidote, carbonate, chlorite, and chalcedony, partly in radial aggregates.

Alteration does not permit close identification of the plagioclase constituents, and consequently the classification of the rocks is to some extent uncertain, however they were probably of andesitic composition. Basaltic rocks would be more likely to exhibit some phenocrysts of dark constituents and more acidic flows should contain some potash feldspar. Such rocks do occur, but are limited mainly to dykes and pyroclastic deposits.

Dykes cannot everywhere be distinguished from flows, but some are recognized by their crosscutting relations and commonly coarser porphyritic character. A porphyritic uralite basalt occurs in many places as dykes in Permian volcanic sedimentary rocks, and also as fragments in agglomerates. Fragments from agglomerate underlying Permian sedimentary rocks east of Quill Creek are light green porphyritic rocks with uralite phenocrysts up to a quarter of an inch in size and smaller light green feldspars. Thin sections show the dark phenocrysts to be completely altered to actinolite–epidote–chlorite, and the plagioclase mostly to epidote. Smaller serpentinized olivine crystals are also present in a greenstone matrix. A dyke from west of Lynx Creek, occurring in volcanic breccia, is a greenish black, fine-grained rock, and exhibits under the microscope a sub-diabasic assemblage of sericitized but partly fresh labradorite and small fresh grains of diopside and hornblende, all to about ½ mm long, with scattered magnetite and interstitial chlorite.

Metamorphism up to greenschist facies is apparently common in Cache Creek Group volcanic rocks. Though many of them have preserved the texture of the original extrusive or pyroclastic rocks, others have undergone tectonic shearing and compression and been converted to chlorite schist. No sections were measured, but the exposed sequences of the volcanic division in Kluane and Donjek Ranges are estimated to be not more than 3,000 feet thick. The contact with the succeeding sedimentary division is gradational with a transition zone of interbedded volcanic and sedimentary rocks.

98818—4

Lithology of the Sedimentary Division

Clastic and carbonate sedimentary rocks, locally containing abundant fossils, occur together with the volcanic succession in Kluane Ranges, the northern part of Donjek Range with a continuation west of Donjek River, and in small areas on both sides of White River, near the Alaska Boundary. They may constitute a continuous sequence with the volcanic rocks described above, with an upward increase in the amount of sedimentary rocks and a parallel decrease in volcanic material.

The following section, with roughly estimated thicknesses, occurs north of Hoge Creek, between a fault contact with Devonian limestone and overlying Triassic sedimentary and volcanic rocks.

	Thickness (feet)
TRIASSIC ROCKS	
Volcanic rocks, much altered, probably including some contact-metamorphic sediments. The rocks are gabbroic, and may be intrusive sills.	
CACHE CREEK GROUP	
Cherty limestone, black, light yellowish brown weathering, thick-bedded......	500
Limestone, silty, bluish grey, irregularly bedded, splintery; containing black chert	150
Greywacke, greenish grey, brown weathering, contains many layers of coquina with brachiopod shells still retaining mother-of-pearl....................	500
Greywacke, coarse- to medium-grained, and chert-pebble conglomerate, pebbles decreasing in quantity upwards. Upper part of unit contains only a few lenses with pebbles and fragments of corals, brachiopods, and some plant stems..	600
Greywacke, coarse- to medium-grained, grey, light yellowish brown weathering, with pebbly greywacke and chert-pebble conglomerate..................	350
Greywacke, coarse-grained, dark brown, and chert-pebble conglomerate, a few thick beds of volcanic conglomerate. Several boulders are coarse-grained gabbroic rock..	350
Volcanic conglomerate, with mainly greenstone boulders and pebbles in a reddish brown tuffaceous matrix. Bedding mostly obscure. A few layers of chert-pebble conglomerate and dense, cherty tuff......................	2,000

The estimated 2,000 feet of volcanic conglomerate at the base of this section is provisionally included with the volcanic sequence described previously.

Between Burwash and Quill Creeks, an estimated 3,000 feet of sedimentary rocks occurs above the volcanic division and below Triassic volcanic rocks. These rocks are mainly argillite, greywacke, and fine conglomerate with pebbles of chert and argillite, in places with graded bedding in the lower part. In the upper part, limestone with corals, massive cherty limestone, and chert beds of various colours are prominent. Locally they contain sills and dykes of medium- to coarse-grained diabasic rocks. A similar succession also occurs in the front range between Koidern and White Rivers.

A 500-foot thickness of Permian limestone occurs at the head of Kletsan Creek, at the Alaska Boundary, underlying Triassic sedimentary and volcanic rocks. It is thick-bedded (6 inches to 3 feet), fine-grained to dense limestone, with grey-to-buff-mottled weathering surface, and contains some crinoid stems up to a quarter of an inch in diameter. The base of this limestone is not exposed at the locality, but on Cross Creek, 25 miles to the northwest in Alaska, 250 feet of Permian limestone overlies about 1,200 feet of greywacke, argillite, and conglomerate (Moffit, 1954, p. 112). The limestone of the Alaskan section is shown to be overlain by more than 1,000 feet of black, unfossiliferous argillite and slate assigned to the Permian. In view of the occurrence of Triassic fossils in black argillite above the limestone of Kletsan Creek, the Cross Creek upper argillites may well be Triassic also. This bench of several hundred feet of limestone may have a distinct stratigraphic position at the top of the Permian sedimentary sequence.

Structural Relations

The rocks of the Cache Creek Group, especially those of the volcanic division, are in many places intensely faulted and disturbed. Along the Kluane Ranges front shear planes and schistosity are roughly parallel with Shakwak Trench. These conditions suggest northeastward thrusting against Yukon Complex rocks along the inferred fault marking Shakwak lineament at the base of the Kluane Ranges. Farther southwest, the base of the group has not been recognized, and its contact relationships with the presumably underlying greenschist complex are unknown.

It might be argued that in this part of the St. Elias Mountains pre-Tertiary strata are apparently divided, by their structure, into two major groups: the pre-Permian rocks, and the beds of Permian and younger age. The groups have no mutual contact except along Duke River thrust. The older group is more complex in structure, appears to be isoclinally folded, and west of Donjek River exhibits an abnormal southwest trend not seen in the structures of the younger rocks. The younger rocks show some more or less regular stratigraphic successions, whereas in the older group the original sequence appears to be entirely unrecognizable. There is also a difference in metamorphism; the pre-Permian rocks exhibit a general low-grade regional metamorphism and local thermal metamorphism, the younger group shows only local thermal or dynamic metamorphism. These differences are considered to be an indication of a sub-Permian unconformity.

It should be mentioned that an unconformity between Permian and older Palaeozoic metamorphic rocks has also been reported by Sharp (1943) from the Steele (Wolf) Creek area. Though concurring with this interpretation, the writer was unable to recognize an angular discordance between gabbro, intrusive into the Palaeozoic schist, and the Permian sequence. As mentioned in the relevant sections, most gabbroic rocks in the area intrude Permian rocks, but some of those on Steele Creek may be of Tertiary age.

In the eastern Alaska Range, Moffit (1954), although admitting the lack of field evidence, concluded that Permian volcanic rocks were deposited unconformably on the eroded surface of Devonian or older beds in the Chisana district and on Mississippian or older beds in the Chistochina district.

98818—4½

Mode of Origin

The lithology of the Cache Creek Group may be summarized as a progression from volcanic flows and breccias through conglomerates, greywacke, and argillite, to limestone and chert. It suggests a eugeosynclinal basin with initially active, but later dormant, volcanic centres. They first supplied tuffs and breccias and later, by erosion of the volcanoes, conglomerate, greywacke, and argillite. Greywacke and tuff with graded bedding were deposited in deeper parts of the basin by turbidity currents. The chert and coral limestone of the upper parts may indicate re-emergence during volcanic quiescence in anticipation of complete emergence in early Triassic time.

Age

Fossils occur in many places in the Permian sediments of Kluane Lake area and adjacent areas in Alaska. Fossil localities are indicated on the accompanying geological map; the identifications and comments on these groups of collections by P. Harker of the Geological Survey are given below.

GSC locality 17514. Head of tributary of Maple Creek, between Tatamagouche and Wade Creeks, lat. 61°24′, long. 139°29′:
Productus (*Linoproductus*) cf. *P. weyprechti* Toula
Productus spp.

GSC locality 28311. Same locality as above, collected in 1956:
Derbyia sp.
Linoproductus sp. ex gp. *L. cora*
Linoproductus sp. cf. *L. weyprechti* Toula
Productus sp. indet.
Neospirifer aff. *N. fasciger* Keyserling
Neospirifer sp. ex gp. *N. cameratus*
Spirifer sp. indet.
large pelecypod fragment

GSC locality 17513. Wade Creek, about ½ mile upstream from junction with Maple Creek, lat. 61°25′, long. 139°34′:
Neospirifer—camaratus group
Spirifer alatus Schlotheim
Productus uralicus Tschern.
Productus (*Waagenoconchus*) *humboldti* d'Orbigny
Productus (*Linoproductus*) *cora* d'Orbigny
Productus (*Linoproductus*) *weyprechti* Toula
Productus spp.
Spirifer spp.

GSC locality 20271. Same locality as above:
Productus sp. cf. *P. humboldti* d'Orbigny
Productus (*Linoproductus*) *weyprechti* Toula
Marginifera? sp.

Chonetes sp.
Rhynchopora sp. cf. *R. nikitini* Tschern.
Aviculopecten sp.
Pecten (*Pseudamusium*) *ufaensis ?* Tschern.
Bellerophon sp. B
small unidentified pelecypods

GSC locality 17517. Slide at head of tributary of Donjek River, between Cement and Steele Creeks, lat. 61°22′, long. 139°47′:
Spirijerella saranae var. *arctica* Haughton
Streptorhynchus sp.
Rhynchopora sp. cf. *R. nikitini* Tschern.
Martinia sp.
Chonetes sp.
Productus weyprechti Toula
Productus uralicus Tschern.
(*Productus neoinflatus* Licharew)
Productus cf. *P. irginae* Stuckenberg
Productus (*Linoproductus*) *cora* d'Orbigny
Echinoconchus sp.
Squamularia cf. *S. perplexa* McChesney
Aviculopecten sp. cf. *A.* (*Acanthopecten*) *elegantulus* Stuckenberg
Polypora sp.
"*Chaetetes*" sp.
crinoid stems
crinoid calyces? (poorly preserved material)

The collections (made in 1950) contain elements of the typical Arctic Permian fauna of northern Europe and the Arctic Islands. *Spiriferella saranae* var. *arctica* and *Productus* cf. *weyprechti* are especially characteristic. Spiriferids of the *camaratus* group occur in the Pennsylvanian of North America and productids of the *inflatus* (*uralicus*) group also occur in the upper Carboniferous but both groups range up into the Permian. Considered as a whole the fauna indicates a Lower Permian age for the strata.

GSC locality 28313. Top of ridge between Tatamagouche Creek and Shakwak Trench, lat. 61°26′, long. 139°22′:
Syringopora sp.
Caninia sp. aff. *C. kiaeri* (Holtedahl)
Caninia sp. aff. *C. ovibos* (Salter)

GSC locality 20276. Top of ridge between Tatamagouche Creek and Shakwak Trench, lat. 61°26′, long. 139°23′:
Productus sp. ex gp. *P. cancrini* Verneuil
Neophricodothyris sp. cf. *N. indica* Waagen
Linoproductus sp.
Chonetina? sp.

Stachella sp.
"*Platysoma*" sp. cf. *P. indicum* Waagen
Allorisma sp. (large species with prominent concentric ridges; possibly close to *A. komiensis* Maslennikow)
several small, smooth unidentified pelecypods
Bellerophon sp. A

GSC locality 20278. Top of ridge between Tatamagouche Creek and Shakwak Trench, lat. 61°27′; long. 139°26′:
clisiophyllid corals
'*Chaetetes*'

GSC locality 20279. Gully north of second canyon of Burwash Creek, 10 miles upstream from Highway bridge, lat. 61°22′; long. 139°24′:
Linoproductus sp. ex gp. "*P. cora*"
Neospirifer cameratus Morton
Spirifer alatus Schlotheim

GSC locality 28310. Ridge east of Burwash Glacier, lat. 61°17′; long. 139°27′:
Productus sp. ex gp. *Productus arcticus-neoinflatus*
Productus sp.
Neospirifer sp.

GSC locality 20274. About 3 miles up Hoge Creek, lat. 61°17′; long. 139°32′:
crinoid stems
'*Chaetetes*'
bryozoa
fusulinid? fragments

These collections (1951, 1956) have distinct affinities with the Lower Permian of the Arctic Islands and northern Europe. Though there are many specimens similar to those collected in 1950, the collection does not include any *spiriferellas* of the *S. saranae* group, or any typical productids of the '*Uralicus*' type. Some species represented are known to occur in the upper Carboniferous, such as the spiriferids of the '*cameratus*' group, but the overall affinities of the fauna lie with those of the Lower Permian. It seems likely that several horizons within the Lower Permian are represented in the collections, but further detailed collecting would be necessary in order to establish a local stratigraphic succession.

GSC locality 31391. Kluane Ranges, north of mouth of Sergerent Creek, lat. 61°47′, long. 140°13′:
corals, probably large caniniids as in No. 31394
pelecypod? indet.

GSC locality 31411. Kluane Ranges, north of mouth of Sergerent Creek, lat. 61°48′, long. 140°14′:
Neospirifer sp.

bryozoan fragments
small pelecypods indet.

GSC locality 31402. Kluane Ranges, north tributary of Hazel Creek, lat. 61°53′, long. 140°25′:

'*Productus*' sp.
Rhynchopora? sp.
Cleiothyridina sp.
Neospirifer ex gp. *cameratus* (Morton)
bryozoan fragments
small indeterminate gastropods and pelecypods

These collections (1957) are all probably of about the same age. They appear to be different from the collections described below. They could be Permian or Pennsylvanian and it is not possible to determine their age relative to the other group of collections.

GSC locality 31401. Kluane Ranges, just east of White River canyon, lat. 61°55′, long. 140°29′:

Syringopora? sp.
corals, somewhat crushed, possibly *Corwenia* sp.
lophophyllid? corals

GSC locality 31398. Saddle in Slaggard Ridge, north of Y-shaped lake, lat. 61°47′, long. 140°46′:

corals indet
'*Productus*' sp. possibly the same as
P. weyprechti Toula of previous collections
Spiriferella cf. *S. keilhavii* (von Buch)

GSC locality 31399. White River Upper Canyon, about 1,000 feet upstream from old cabins, in lower shales, lat. 61°47′, long. 140°48′:

Caninia? sp.
bryozoan fragments

GSC locality 31397. Limestone south of forks of Kletsan Creek, lat. 61°35′, long. 140°59′:

lophophyllid? corals
Dictyoclostus sp.
Waagenoconcha cf. *W. parvispinosa* Cooper
Kochiproductus cf. *K. freboldi* (Stephanson)
Neospirifer ex gp. *cameratus* (Morton)
fusulinids, possibly *Parafusulina* sp. Highly silicified and with fine structures largely obliterated.

GSC locality 31394. West fork of Kletsan Creek, lat. 61°36′, long. 140°59′:

Clisiophyllum? sp.
Caninia cf. *C. ovibos* (Salter)

Collections 31397, 31394, 31391 and 31398 (1957) are probably all of about the same age and their fossils represent a single broad faunal assemblage of Permian age. The genus *Spiriferella* is typically Permian, and its species are common and characteristic of the Lower Permian of the boreal regions. The fusulinids from 31397 are silicified and probably not specifically identifiable. They are, however, undoubtedly of Permian age. It is unlikely that these forms would occur in Upper Permian strata. Collection 31399 may be of the same age as the others.

Reference should also be made to many earlier fossil collections from the White River district and Nutzotin Mountains. On the Canadian side they were made by D. D. Cairnes (1915b); on the Alaskan side by F. H. Moffit and several other geologists, and listed by Moffit (1954). Identification of all these collections, many of them rich in species, was made by G. H. Girty of the United States Geological Survey. They were found to be more closely related to the Permian of Russia than to that of more southern parts of North America, and provisionally assigned to that system.

Harker and Thorsteinsson (1960, p. 18) correlated fossil collections made by the writer in Kluane Lake area with the fauna of the Assistance Formation of the Permian of Grinnell Peninsula in the Canadian Arctic Archipelago. They also recognized a marked similarity to that formation in Moffit's cumulative list of Alaskan faunas (Moffit, 1938, 1954). The age of the Assistance Formation is determined as Svalbardian, a newly established stage of the Lower Permian occurring above the Artinskian, and roughly equivalent to the upper part of the Leonard of the western United States.

Present palaeontological opinion therefore sets the age of the sedimentary division of the Cache Creek Group as approximately Leonardian. But clearly this separate province of Permian strata deserves closer study. The volcanic division may be Lower Permian, or perhaps Pennsylvanian.

Correlation

The Permian sequence described from Alaska Range (Moffit, 1954) contains mainly clastic beds and minor volcanic rocks and limestone. In the Chistochina area the succession contains fine-grained lavas in the lower part, overlain by tuff, gritty calcareous sandstone, and massive and thin-bedded limestone, together with black shale and little sandstone in the upper part. The total thickness was earlier estimated by Mendenhall (1905) to be between 6,000 and 7,000 feet.

The Takhandit limestone, on Yukon and Nation Rivers at the Yukon–Alaska border, some 250 miles north of the Kluane Lake region occurrences, contains large faunal assemblages which Girty in 1930 (*in* Mertie, 1930, p. 129) referred to the Artinskian, or Lower Permian and also equated with the White River occurrences. This limestone, over 500 feet thick, contains abundant fossils and overlies the probably continental Nation River Formation, which contains mainly sandstone, conglomerate, and some coal. No volcanic Permian rocks are known from this area, which is separated from the St. Elias–Alaska Range geosynclinal belt by the metamorphic Yukon Complex.

In southeastern Alaska, Buddington and Chapin (1929) have distinguished two divisions of the Permian, of which the lower one contains lava and tuff, together with conglomerate, sandstone, shale, and limestone, and on the basis of fossils has been assigned to the lower part of the Permian, or perhaps Pennsylvanian.

Permian volcanic rocks are also known from farther east in Whitehorse and Atlin areas (Wheeler, 1961; and Aitken, 1959). Farther south, in British Columbia, the general succession of the Permian Cache Creek Formation is roughly comparable to that of southwest Yukon and eastern Alaska (e.g., Armstrong, 1949; Duffell and McTaggart, 1952; Roots, 1954). The lower part consists mainly of volcanic rocks, the middle part is mostly a clastic assemblage, and at the top is several hundred to a few thousand feet of carbonate rocks. Only in the Fort St. James area, Armstrong (1949) placed the limestone at the bottom of the sequence and the volcanic rocks in the higher parts. Summing up the palaeontological evidence (p. 46) he stated, "that the limestone lithological division includes strata in part of probable Upper Pennsylvanian age, in part of Lower Permian age, and in part of Middle Permian age." Duffell and McTaggart (1952), discussing the age of the Cache Creek limestone in the type Ashcroft area, concluded that the palaeontological evidence "indicates that much of the Cache Creek Group in Ashcroft area is of Middle and possibly Upper Permian age. The lower limit of the group, which is not well defined, may be at some horizon in the Pennsylvanian."

Summing up, it seems probable that Lower Permian sedimentation, preceded by extrusion of volcanic flows and breccias, occurred in a sea covering much at least of the present western and interior Cordillera, and connected with an extensive arctic basin.

Basic and Ultrabasic Intrusions

Distribution

Sills, dykes, and small intrusive bodies of basic and ultrabasic rocks are common throughout most of Kluane Ranges and in Donjek Range. They also occur on both sides of Donjek River and at the Alaska Boundary and are everywhere spatially related to occurrences of Permian and (?) Triassic sediments and tuffs. The bodies are generally tabular and nearly concordant with the enclosing strata. The thickness varies from less than one hundred feet to several thousand; the width of narrow bodies has been exaggerated on the geological map, and gabbro and peridotite have not been separated.

Most of the gabbroic rocks are probably intrusive, but, in the field, it is not everywhere possible to distinguish between fine-grained sills and lava flows. The writer has, without making detailed measurements, gained the impression that the volume of gabbro is at least equal to that of peridotite. However, detailed mapping by various exploration geologists suggests, rather, a predominance of peridotite.

Lithology of the Gabbros

The gabbros are generally fine- to medium-grained, dark green rocks, showing, under the hand lens, light green, glossy feldspar and dark green augite. The rocks are in places mottled with patches of serpentine, several millimetres in diameter.

Under the microscope they generally exhibit an assemblage of plagioclase and diopsidic augite with diabasic texture. No hypersthene or enstatite was noted—a feature common with eastern Alaskan complexes. Plagioclase occurs in euhedral to subhedral crystals, one to two millimetres long. In many thin sections examined it is completely albitized, but some sections exhibit unaltered labradorite, distinguished by a high index of refraction and maximum extinction angle of 45 degrees and more. The feldspars are partly sericitized in some specimens and contain much epidote and chlorite in others. In thin section, diopside is seen to be colourless to light brown, with a fine network of cleavages. It is commonly interstitial, but may occur as euhedral crystals. In many instances hornblende has partly or entirely replaced diopside. Quartz may be a minor interstitial accessory. Chlorite, epidote, and zoisite occur as secondary minerals, and many specimens contain blebs of serpentine. Very coarse grained gabbro was noted on the south side of Steele Creek, 2½ miles upstream from Donjek Valley. The outcrops and blocks of a slide exhibit rounded fragments of gabbro, with greenish white feldspars up to an inch in size, in a matrix of finer grained gabbro and peridotite. A thin section of medium-grained gabbro from this locality shows a subdiabasic assemblage of feldspar, diopside, hornblende, and minor iron ores. Labradorite, up to 10 mm long, is fresh and has about 65 per cent anorthite, as determined on albite-carlsbad twins. Diopside is partly replaced by aggregates and larger, optically uniform masses, of light green hornblende.

Lithology of the Peridotites

The name peridotite is used here in the broad sense of Ruckmick and Noble (1959) for ultrabasic rocks composed mainly of olivine (40–90%) and pyroxene (10–60%).

Peridotite occurs as a massive, pitch-black rock, with an irregular blocky fracture. In cliff faces and on some aerial photographs, it is easily distinguished by its dark colour. Rock slides of peridotite consist of massive blocks with smooth slickensides and covered with a veneer of glossy antigorite. Minor asbestos occurs in a few places.

The hand specimen is generally a medium-grained, dull black rock with a dark greenish cast. In thin section, a sample from the head of Halfbreed Creek shows densely packed, stubby grains of olivine up to 3 mm long that are completely serpentinized. Unaltered diopside is a minor constituent, interstitial between olivine crystals but showing optical continuity across several olivine grains. Minor biotite and chlorite occur in some cavities. A medium green, medium-grained pyroxenite occurs together with this peridotite. Under the microscope it exhibits a monomineralic assemblage of nearly euhedral prisms of diopside, up to 2 mm long, with very minor magnetite and serpentine.

Greenish black olivine pyroxenite from Duke River, near Ptarmigan Creek, contains fibrous diallage in excess of olivine. The texture is poikilitic with olivines up to 1 mm long included in diallage. The latter is for a large part reconstituted into fibrous hornblende (actinolite?) and chlorite. It contains sharply delineated brown-red pleochroic patches, optically continuous with the colourless part. Biotite or phlogopite forms about 10 per cent of the rock and contains considerable iron ore. Some peridotites are completely altered to serpentine and show, in thin section, radial aggregates of antigorite and light yellow fibrous masses of chrysotile.

The peridotites of Quill Creek and White River have been described by Campbell (1960). In the Quill Creek area he found

> . . . rocks ranging from those consisting of 90 per cent olivine, 5 per cent augite, 3 per cent magnetite, and 2 per cent chromite, to those composed of 75 per cent pyroxene, 20 per cent olivine, 3 per cent magnetite, and 2 per cent chromite.
>
> At White River the peridotite varies from a composition of 85 per cent olivine, 10 per cent augite and 5 per cent black oxides along the foot-wall, and by gradation passes into a rock consisting of 70 per cent olivine, 25 per cent augite, and 5 per cent black oxides near the hanging-wall.

Layering, reported from some eastern Alaskan localities (e.g., Noble and Taylor, 1960), was observed only on Duke River, below Granite Creek. There peridotite and gabbro occur in half-inch alternating layers that are cut obliquely by dykes of peridotite. Intrusion, partly in *lit-par-lit* fashion, of peridotite into gabbro, seems indicated. The occurrence of inclusions of coarse-grained gabbro in peridotite and fine-grained gabbro mentioned previously also suggests this sequence of intrusion. The more detailed Alaskan studies have for most occurrences definitely shown that intrusion of gabbro preceded emplacement of peridotite.

Campbell (1960) is of a somewhat different opinion in regard to the Quill Creek rocks; he considers that peridotite was intruded first, and the gabbro intruded only after folding of the peridotite and enclosing sediments. His argument appears to be based on slight chemical variations in the sills, suggesting gravitational differentiation in a flat-lying sill. The general concordance of commonly steeply dipping bedded rocks and enclosed peridotite, as well as gabbro sills, is indeed compatible with intrusion before folding. But since, according to the writer's field observations, the two types of sills are generally parallel, there is no evidence for a folding period intervening between emplacement of peridotite and intrusion of gabbro. Furthermore, the field evidence mentioned previously indicates rather that gabbro preceded peridotite.

As is common in similar rocks in other regions, there is little evidence that the wall-rocks have been affected by thermal metamorphism. At best they have been hardened and bleached into light coloured, cherty rocks. If the intruding magma was of high temperature, the lack of metamorphism suggests fast cooling, possibly as a result of small volume and nearness to the surface.

Structural Relations

The basic and ultrabasic bodies of the area are roughly concordant with the intruded Permian (and Triassic?) sedimentary and volcanic rocks, commonly with steep to vertical attitudes. Most of them are sills of a few hundred feet thick and their size has been exaggerated on the accompanying map, some do attain widths of about a mile, as on Steele (Wolf) Creek, Duke River, and Halfbreed Creek. Commonly gabbro and peridotite occur together, but in discrete bodies with sharp contact.

The exposures on Duke River also reveal fairly sharp contact relations between peridotite and biotite granodiorite. The marginal phase of the granitic rock is light coloured and fine grained. It contains a few inclusions of peridotite and some dark masses of hornblende diorite that are obviously "granitized" xenoliths of ultrabasic rock.

The intrusions are confined to the Cache Creek Group volcanic-sedimentary rock sequence and the basal part of the Mush Lake Group. Together they occur within a belt along the southwest side of the Shakwak lineament. Regionally they form part of the western of two distinct belts of ultramafic complexes, extending from southwest Alaska through southwest Yukon into southeastern Alaska, and possibly on into Oregon and California (Noble and Taylor, 1960).

Origin

Even though the Kluane Lake area ultrabasic intrusions are commonly tabular rather than equidimensional, as those studied and described by Noble and Taylor (1960), a common mode of origin is probable. The Alaskan detailed studies have shown that gabbro and the various kinds of peridotite were intruded consecutively, with gabbro preceding peridotite. Various points of field evidence, such as distinct petrographic and mineralogical differences without transitional types, and invariably sharp contacts between gabbros and ultramafic rocks, argue against differentiation by crystal fractionation after emplacement.

Multiple intrusion, with peridotite following gabbro, is compatible with field evidence in Kluane Lake area. Also, intrusion of fluid peridotite magma, perhaps carrying crystals of olivine, is the only mechanism that could have formed these thin tabular bodies. No evidence was discovered in the map-area indicating solid intrusion, it may have occurred locally, but not exclusively. For the Alaskan intrusions Taylor and Noble infer that the magmas were generated by fractional melting of subcrustal 'mantle' material, but do not consider the possibility of solid intrusion.

It is probable that these magmas were the carriers of the copper-nickel sulphides, associated with the ultrabasic bodies in several places.

Age

The age of the gabbros and peridotites can only be defined within wide limits. They intrude sedimentary-volcanic sequences assigned to the Cache Creek Group, and are therefore Permian or younger. Sills of gabbro, but none of peridotite, occur in the Middle (?) and Upper Triassic section of Kletsan Creek, and neither was seen in Triassic sedimentary rocks elsewhere in the area or in Jurassic-Cretaceous strata. They are intruded in places by granitic rocks of Cretaceous (and Jurassic?) age. Relations in the Kluane Lake area therefore suggest a Permian or early Triassic age, and this age is tentatively adopted.

It should be noted, however, that in Dezadeash area Kindle (1952) described peridotite that intruded Lower Cretaceous strata. He believed they are "older than the granite stocks, and were probably intruded in mid-Cretaceous time." It is possible perhaps that the contacts of these rocks, which are intensely sheared in some places, are tectonic rather than intrusive, and therefore do not necessarily indicate a Cretaceous age for the ultrabasic rocks.

The Alaskan ultrabasic rocks have also been tentatively dated (Noble and Taylor, 1960) as probably early Cretaceous. This age is mainly based on intrusive relationships with granitic rocks: they show in all instances that the latter are younger. Where rocks intruded by the ultrabasic bodies are described, they appear to be metamorphic rocks assigned to the Wrangell-Revillagigedo belt (Ruckmick and Noble, 1959). Since these rocks are of undefined Palaeozoic to Mesozoic age, the age of the Alaskan ultrabasic rocks could also be older than Cretaceous.

On general consideration it is probable that the basic and ultrabasic rocks, occurring in a belt west of the Coast Mountains, were all emplaced more or less concurrently. But the time of emplacement within this belt can as yet be defined only broadly between early Permian and early Cretaceous.

Mush Lake Group

Name and Definition

The name Mush Lake Group was proposed by E. D. Kindle (1952) for "a thick assemblage of volcanic and sedimentary rocks" in Dezadeash map-area. These rocks consist mainly of "fine-grained flows of green andesite, spotted with small dark hornblende crystals and with scattered calcite-filled amygdules" but also contain finely laminated light green tuffs, slates, and greywacke. A belt of limestone and marble, about 3,500 feet thick, was included in the group as a separate map-unit. No fossils were found, but as these rocks occur between Permo-Carboniferous and Lower Cretaceous strata, they were "tentatively considered to be of Triassic or Jurassic age."

In Kluane Lake area the finding of Triassic marine fossils has permitted closer dating of the Mush Lake Group. It may now be defined as a succession of mainly basic volcanic rocks of Karnian (early Late Triassic) and older age, overlain by Upper Triassic non-volcanic sediments. In this work the group will, therefore, be divided in a lower volcanic division and an upper sedimentary division[1].

More detailed mapping will no doubt permit formal division of the Mush Lake Group into several formations.

Distribution

The Mush Lake Group underlies a large part of Kluane front range between Donjek and Slims Rivers. There some of the high peaks consist of resistant basalt and andesite of the volcanic division, whereas others are formed of similar, less altered, products of Tertiary volcanism. The volcanic rocks of Kluane Ranges between Donjek and White Rivers have, on the accompanying geological map,

[1]It will be noted that this arrangement is somewhat different from that of preceding preliminary maps (Muller, 1954 and 1958). In the former the volcanic division was not separated from Permian volcanic rocks; in the latter some volcanic rocks were placed above the Triassic sediments.

mainly been assigned to the older group of Permian and earlier volcanic rocks, but the Mush Lake Group is present also. Another discontinuous belt of these rocks occurs between the forks of White and Generc Rivers and the Alaska border. It probably continues southeastward under the Tertiary cover and reappears in the Donjek River area directly north of Steele and Hoge Creeks, and again in the middle Duke River area. The isolated area of Mush Lake rocks on Kletsan Creek, at the Alaska border, appears to be the single representative of a third belt of Triassic rocks, significant because of the fossils occurring below and within the volcanic sequence.

Lithology and Thickness

Volcanic Division

Basaltic and andesitic lavas and associated pyroclastic rocks occur in abundance in St. Elias Mountains and belong to three of four major groups, namely those of pre-Permian, Permian, Triassic, and Tertiary age. The Tertiary volcanic rocks are easily distinguished by their red-brown colour, lack of alteration, and horizontal or moderately folded attitudes. Most of the older volcanic rocks are however much altered, and highly folded and faulted. In general, they must be distinguished on the basis of petrography, as only in a few places are they clearly related to fossiliferous strata. Features that have been used to separate them are the predominant light green and grey colours of the Palaeozoic lavas as against the abundant purple and dark green amygdaloidal flows of the Mesozoic rocks. Microscopically the older volcanic formation generally contains amphibole as a primary or alteration mineral or no dark minerals at all, whereas the younger formation commonly contains pyroxene.

Lava flows form much of the volcanic division, and occur in large tracts of typical dark green and purple craggy ridges. They are mainly amygdaloidal and to a lesser extent porphyritic, with feldspar phenocrysts up to 1 mm long. Pillow structures have been observed in several places.

Most thin sections reveal a diabasic or random assemblage of plagioclase, up to 1 mm long, and smaller grains of diopside. The plagioclase is commonly albitized, but in some sections unaltered plagioclase occurs. According to the extinction angles on albite or albite-carlsbad twins, the composition is labradorite. The albitic plagioclase commonly contains finely divided epidote, chlorite, and sericite. Some specimens are glomeroporphyritic and the feldspars are in clusters of up to 2 mm. Diopside occurs as a main or, less commonly, minor constituent, in stubby, anhedral, near-colourless to pale yellow crystals, up to $\frac{1}{2}$ mm in size. The amygdules (in places several millimetres across) and interstices are filled with carbonate, chalcedony, magnetite, hematite, chlorite, and epidote.

Pyroclastic rocks are also common in this division. They are in part subangular agglomerates with fragments several inches across of volcanic rock embedded in a tuffaceous matrix, and in part fine-grained tuffs. In these again dark green and purple colours prevail. In many places the fragmental nature is only apparent on certain weathered surfaces, elsewhere the rock is indistinguishable from massive volcanic flows. The microscope reveals an assemblage of volcanic fragments, distinguished by amygdaloidal or fine trachytic texture, together with individual, obviously broken, crystals of plagioclase and diopside, in a fine matrix of chlorite, epidote, carbonate, and fine semiopaque material.

Minor intercalations of black and reddish brown argillite and reddish grey tuffaceous limestone occur throughout the volcanic part of the Mush Lake Group.

The thickness of this division has nowhere been measured, but north of Tatamagouche Creek a minimum of 5,000 feet of mainly basic flows, overlain by a thin sedimentary succession, occurs between sediments of the Cache Creek Group and those of the Dezadeash Group.

The following section of the basal part of the Mush Lake Group was measured with the barometer on the mountains at the head of Kletsan Creek. It occurs on the most southwesterly fault block containing Triassic strata and apparently differs from more easterly Triassic sections in having a larger amount of sedimentary material, possibly in part Middle Triassic, underlying and interbedded with Mush Lake volcanic rocks.

	Thickness (feet) Unit	Total from base
Andesitic flows, red to purple, with large, white, irregularly shaped amygdules; dense, finely porphyritic, dark grey flows; red and grey, fine-grained tuffs........More than	2,000	3,040
Argillite, grey and black, brittle, closely jointed, forming fine rubble; minor greywacke, fine-grained to gritty........	100	1,040
Dark grey, finely crystalline, fresh looking basaltic flows........	20	940
Limestone, black and grey, shaly to silty, with *Halobia*, *Atractites*? and trachyceratid ammonites. Probably early Upper Triassic (Karnian).....	80	920
Basaltic flows, with some dykes of augite porphyry; locally with calcite amygdules. Some interbeds, a few feet thick, of black, limy argillite.....	180	840
Limestone, with black, shaly and grey, silty interbeds, and laminae, about 2 inches thick........	20	660
Basaltic flows, dark greenish grey, dark rusty weathering, slightly porphyritic, on top finely amygdaloidal........	120	640
Cherty argillite, black-grey, and minor black argillite, interbedded with flows. Some flows of feldspar-augite porphyry, augite crystals up to 1/9 inch long; some fine-grained, light brown felsite........	40	520
Basaltic flows, fine-grained, interbedded with minor amounts of laminated and banded cherty tuffs........	410	480
Tuff, light to dark green, cherty, and felsite, light reddish brown, porphyritic with feldspars up to 1/16 inch in size........	10	70
Tuff, light to dark green, dense and cherty........	20	60
Basaltic lava, fine- to medium-grained, dark greenish grey, reddish brown weathering........	40	40
On the adjacent ridge, the Permian limestone is directly overlain by poorly exposed shaly siltstone, black, calcareous, and thinly laminated. Many bedding surfaces are covered with imprints of pelecypods (?*Daonella*). Possibly Middle Triassic.		
— Disconformity —		
Limestone, thick-bedded (6 inches to 3 feet), fine-grained to dense, slightly crinoidal (Permian, *see* pp. 36, 37)		

Thin sections, taken from samples of basalt at several levels, show unaltered and clear ophitic assemblages of mainly labradorite and diopside, minor magnetite, and locally chromite, carbonate, and serpentine. Labradorite crystals are $\frac{1}{2}$ mm to 3 mm long and contain, according to determinations on albite-carlsbad twins, 65 to 75 per cent anorthite.

It should be noted that some of the volcanic rocks may be sills rather than flows. They are similar in composition to the gabbroic intrusive rocks described in the preceding section, but differ markedly in their unaltered state of preservation.

Sedimentary Division

Two Upper Triassic sedimentary units, not yet formally distinguished as formations, have been recognized in Kluane Lake map-area. They are most prominently developed in a synclinal belt of rocks exposed west and east of Donjek River, just north of Steele and Hoge Creeks to the head of Burwash Creek, and again on either side of Duke River and on to Ptarmigan Creek. The lower unit consists of massive limestone of probable Karnian age, the upper one is thinly bedded, shaly limestone and shale with *Monotis subcircularis*, indicating mid-Upper Triassic (Norian) age.

The limestone is about 500 feet thick, and in the field as well as on aerial photographs (Pl. II), it is readily distinguished by its light colour and jagged topography. It is generally finely crystalline with brown-grey to black, fresh surface and rusty yellow and reddish weathering colours. The rock is commonly massive, irregularly and closely jointed, with indistinct bedding. In many places, it is brecciated and shot through with white or light red veinlets. In a few occurrences, layers of black chert nodules were seen interbedded with the limestone.

The upper limestone-argillite unit is a highly incompetent formation that everywhere exhibits complex folding and crumpling. The maximum thickness could not be established, but may be about 1,000 feet. The formation consists of thin-bedded, shaly limestone, and calcareous, locally silty shale. Fresh surfaces are dark grey to black, and the calcareous layers weather medium grey. Thicknesses of individual layers range from 6 to 12 inches for the limestone layers, from $\frac{1}{2}$ inch to 2 inches for the shaly beds. Differential weathering of the softer shales makes the limestone stand out in distinct relief.

The Kluane front range, between Donjek and Slims Rivers, also contains some shaly and carbonate beds assigned to the upper part of the Mush Lake Group. Only in one locality on Tatamagouche Creek they yielded fossils, of probably Triassic age. The sediments of these farthest east occurrences are much disturbed and probably much thinner than in the Donjek-Duke River belt, and no subdivision into two units can be made. In several places, small bodies of gypsum and anhydrite occur with the carbonate; the large deposit on Bullion Creek may well be part of the Mush Lake succession.

Metamorphism

Incipient metamorphism, corresponding to the greenschist facies or possibly the lowest 'zeolitic facies', recently named by Turner and Verhoogen (1960), is common to most Mush Lake volcanic rocks. In most thin sections examined the plagioclase is completely albitized and epidote, chlorite, carbonate, chalcedony, and prehnite are common secondary minerals. Metamorphism was not complete, as much of the pyroxene and some of the labradorite plagioclase have been preserved. Nor has any schistosity been developed except locally along fault zones. The rocks may be termed spilitic basalts, if spilitization is considered to be a result of incipient metamorphism, common to many eugeosynclinal volcanic rocks and possibly due to the reaction with seawater during or soon after intrusion.

Structural and Contact Relations

The Mush Lake Group occurs in several parallel synclinal structures separated by thrust faults. In most places the competent volcanic rocks form the limbs, and less competent limestone and very incompetent shales and argillites, including some of Cretaceous age, occur in the axial zones. Intense small-scale folding is a general characteristic of the uppermost Triassic shales and is also well known in their Alaskan equivalent, the McCarthy Formation.

The basal contact of the group is best established in the Kletsan Creek section (described earlier). There Lower Permian limestone is directly overlain by some 1,000 feet of interbedded sedimentary and volcanic rocks, carrying possible Middle (?) Triassic fossils in the basal part and early Late Triassic fossils in the upper part. As Upper Permian and Lower Triassic beds are missing, an unconformity is clearly indicated. In sections farther east in Donjek and Kluane Ranges Permian beds are limestone, interbedded with argillite, chert, and some conglomerate, whereas the lowest Triassic beds are lava flows, in places interbedded with argillite. There the contact between Permian and Triassic beds is generally not clearly defined, but again there is no indication that Upper Permian or Lower Triassic beds are present, and the existence of the disconformity, so generally known throughout large parts of the Cordillera, is once again indicated.

Relative to the contact between volcanic and sedimentary divisions of the Mush Lake Group, it may be noted that in the Donjek area, where the sediments are thickest the volcanic rocks are thin, whereas in the front range a thick section of volcanic rocks is overlain by a thin sequence of sediments. Moveover, the available fossil evidence indicates that both volcanic rocks and limestone are of Karnian age. Limestone and lava flows may therefore be stratigraphic equivalents in part, and the contact may be time transgressive.

Origin

The volcanic and sedimentary rocks of this group were probably deposited in a marine eugeosynclinal environment. A volcanic archipelago may have existed, where lavas, tuffs, and carbonate clastic rocks were deposited side by side and in vertical alternation. The interbedding of marine sediments and lavas, and perhaps pillow structures and spilitization, suggest submarine extrusion. It is probable that the sources of these several thousand feet of basic lavas and minor pyroclastic and sedimentary deposits were within the St. Elias geosyncline. According to Wheeler

98818—5

(1959, 1961), another volcanic belt must have existed during late Triassic time along the axis of the present Coast Mountains, supplying volcanic material to the Whitehorse trough to the east. This volcanic belt might be expected to have occupied part of the northeast corner of the map-area. Volcanic rocks of Nisling Ranges, discussed later, may be remnants of this volcanic belt.

Age

The age of the Mush Lake Group has been determined from various small fossil collections. These were identified and commented on by E. T. Tozer of the Geological Survey, except for numbers 20272, 20273, and 20277 which were determined by F. H. McLearn of the Geological Survey.

GSC locality 31403. Ridge south of forks of Kletsan Creek at bottom of the described section, lat. 61°34′55″, long. 140°58′35″:
Daonella? sp. indet.

The shells in lot 31403, tentatively identified as *Daonella*, are possibly of Middle Triassic age. However, they are not well preserved and their dating should not be considered as well founded. If the shells truly represent *Daonella*, they represent the first discovery of Middle Triassic fossils in southern Yukon.

GSC locality 31404. About 920 feet above base of described section, lat. 61°34′40″, long. 140°58′35″:
Halobia sp. ex gr. *Rugosa* Gümbel
trachyceratid ammonite indet.
Atractites? sp.

GSC locality 31406. Ridge south of forks at Kletsan Creek, same beds as 31404, lat. 61°34′55″, long. 140°58′50″:
Halobia sp. indet.
Sirenites sp. indet.

Lots 31404 and 31406 are of Upper Triassic age, and probably early Upper Triassic (Karnian). The beds from which these fossils were obtained are certainly older than the *Monotis subcircularis* beds that are so widely distributed in the Cordillera.

The sequence of volcanic and sedimentary rocks of Kletsan Creek is therefore early Upper Triassic (Karnian) at the top and perhaps Middle Triassic at the bottom.

GSC locality 17515. Donjek River, east bank, across from Steele Creek, lat. 61°20′40″, long. 139°41′00″:

This collection contains a small pteriid, possibly *Pteria polaris* (Kittl), and some fragmentary shells of *Halobia*. Although these fossils are not well preserved, they may be dated as Triassic and they are probably Karnian (mid-Upper Triassic). The beds that yielded this collection are probably older than the *Monotis* beds that are known from Kluane Lake area.

GSC locality 20272. A mile up gully on east side of Donjek River, 7 miles south of Wade Creek, lat. 61°19′45″, long. 139°41′00″:

Monotis subcircularis Gabb

GSC locality 20273. One mile up gully, ½ mile southeast of locality 20272 (float).

Monotis subcircularis Gabb

GSC locality 28311. Ridge west of Burwash Glacier, south of limestone band, lat. 61°17′50″, long. 139°28′10″:

Monotis subcircularis Gabb

The collections containing *Monotis subcircularis* Gabb are of mid-Upper Triassic (Norian) age.

GSC locality 20277. 4½ miles up Tatamagouche Creek, lat. 61°24′25″, long. 139°25′05″:

corals

large gastropod

"Mesozoic, probably Triassic"

It should be mentioned here that McConnell (1906) refers to the occurrence of *Monotis subcircularis* in "a band of dark shales outcropping near the centre of the lower canyon of Burwash Creek." This index fossil was not found in this location during the present mapping work, nor could the original specimens be located in the Geological Survey collections. If authentic, it is the only known occurrence of mid-Upper Triassic fossils in the Kluane front range.

The collection suggests the following succession within the Mush Lake Group:

A) Thin-bedded calcareous shale and shaly limestone with *Monotis subcircularis* Gabb in Donjek–Duke River area, possibly also in Tatamagouche area: mid-Upper Triassic, Norian.

B) Limestone of Donjek and Duke River regions; volcanic rocks of Kletsan Creek area with part of underlying volcanic–sedimentary sequence; perhaps most of volcanic rocks and overlying carbonate clastic rocks of Kluane front range: early Upper Triassic, Karnian.

C) Lower part of volcanic–sedimentary sequence of Kletsan Creek area; possibly lower part of volcanic rocks of Kluane Ranges, overlying Permian sediments: possibly Middle Triassic.

Correlation

Middle Triassic deposits were until recently unknown in the western Cordillera, though they are extensively represented in the Rocky Mountains and Foothills region (e.g., Tozer, 1961). Recently they have been reported by Souther (1959) from the Chutine area, northwestern British Columbia. There *Daonella* "occurs in black calcareous siltstone, several hundred feet above the Permian limestone." The beds are overlain by a volcanic–sedimentary sequence with thick conglomerates similar to fossiliferous Upper Triassic strata elsewhere. Middle and Upper Triassic may be separated by an unconformity (J.G. Souther, oral com.). It is conceivable that sediments of late Middle Triassic age are more widespread in the western Cordillera than generally believed, but they have not yet been recognized.

98818—5½

Upper Triassic sequences are known from many parts of British Columbia, Yukon, and Alaska (McLearn, 1953; Reeside, *et al.*, 1957). In most occurrences, basic volcanic rocks underlie, and are in part interbedded with, early Upper Triassic (Karnian) sedimentary rocks, whereas calcareous shales with the mid-Upper Triassic (Norian) index fossil *Monotis subcircularis* Gabb form the top of the sequence.

Volcanism appears to have been more extensive in Karnian than Norian time, and in the latter it is believed to have been limited to the western part of the Whitehorse trough (Gabrielse and Wheeler, 1961).

Only two regions near Kluane Lake area, where the Triassic stratigraphy is well known, are mentioned. In the Chitina River valley region of Alaska (Moffit, 1938) the sequence is similar to that of Kluane Lake area. There the Nikolai greenstone is a volcanic succession probably not less than 5,000 feet thick. It is of undetermined Permian to Triassic age but appears to correspond to the volcanic division of the Mush Lake Group. The overlying Nizina and Chitistone limestones, with combined thickness of 3,000 feet, contain a Karnian fauna and may be equaled to the limestone of the Donjek–Duke Rivers area. The late Upper Triassic (Norian) McCarthy Formation with the index fossil *Monotis subcircularis* is no doubt equivalent to the limestone-shale sequence with the same fossils in the Kluane Lake region.

The Whitehorse trough in Yukon Territory is separated from the St. Elias geosyncline by the northern part of the Coast Mountains. Tozer (1958) there established the Triassic stratigraphy of the Lewes River Group on a succession of faunas in Laberge area. He distinguished a sequence of formations, consisting mainly of limestone and minor clastic sediments, probably underlain by a volcanic sequence. In Whitehorse map-area Wheeler (1961) found "late Norian . . . limestone underlain by 2,500 feet of conglomerate and volcanic greywacke grading downward into volcanic breccia with intercalated andesite and basalt flows." These rocks lie disconformably on clastic beds containing an early Norian or late Karnian *Halobia* fauna.

The available evidence points to similar development of the Triassic in large parts of the Cordilleran eugeosyncline, with volcanism and minor sedimentation in Karnian and perhaps Middle Triassic time, to mainly sedimentary deposition with local volcanism in late Triassic (Norian) time.

Dezadeash Group

Name

The name Dezadeash Series was used by R. G. McConnell (1905) for "a great series of tuffaceous beds," probably younger than the Carboniferous beds he recognized, and occurring in the mountains bordering Dezadeash River. E. D. Kindle (1952) modified the name to Dezadeash Group and described the sequence as comprising "slate, greywacke, argillite, quartzite, chert, impure limestone, grit, conglomerate, tuffaceous sandstone, and bedded volcanic tuffs," probably more than 12,000 feet thick.

A collection of Neocomian *Buchia* from Dezadeash beds established the age of the group as Lower Cretaceous.

Distribution

Cretaceous sediments form only a small part of Kluane Ranges in Kluane Lake map-area, in contrast to Dezadeash map-area where they have been mapped over nearly the full width of that range. In Kluane Lake map-area they are confined to the part of the Kluane Ranges between Slims and Donjek Rivers; they have not been identified between Donjek and White Rivers, but have been recognized again west of there. They also occur west of Tchawsahmon Lake, on both sides of the Alaska Boundary. Beyond the border they are of wide extent and form most of the Nutzotin and Mentasta Mountains, physiographic continuations of Kluane Ranges. In Kluane Lake map-area, no Cretaceous rocks have been identified southwest of Kluane Ranges. In the Kaskawulsh map-area, directly to the south, Wheeler (1963) has included graded bedded greywacke and slate on Duke River and Canada Creek with Devonian rocks, but suggests that they may actually be of Cretaceous age. Similarly, parts of Donjek Range in Kluane Lake area, mapped as Devonian to Mississippian, may belong to the Dezadeash Group.

Lithology and Thickness

The Dezadeash Group consists mainly of a sequence of dull, dark grey to black, argillite and greywacke. Many thousands of feet of these somber coloured beds is well displayed southeast and northwest of the map-area in Auriol Range and Nutzotin Range, where the group forms entire mountain ranges.

In places, where the original bedding has not been obscured by cleavage, graded bedding is commonly visible throughout any section. Individual graded units consist of a dark brown, sandy lower part, grading upward to a black, argillaceous upper part. These beds are generally 1 inch to 6 inches thick, but may attain several feet. A direct relationship is apparent between the thickness and coarseness of the bottom layer and the thickness of the whole unit. Load-casts, flutings, and slump bedding are other observed bedding features. Some of the arenaceous beds are calcareous, and a few thin beds of limestone occur. Calcareous ironstone concretions, as much as a foot or more in diameter, are common in parts of the section.

A thin section of greywacke exhibits angular pieces of quartz and feldspar in a matrix of carbonate and chlorite. Tuffaceous beds, occurring sparingly, exhibit in thin section much albitized or sericitized plagioclase and minor altered pyroxene.

Conglomerates occur in several places. A basal conglomerate, consisting of mainly limestone and minor volcanic boulders, overlies Mush Lake limestone west of Halfbreed Creek. On Bock's Creek similar conglomerate also contains mainly limestone cobbles up to 4 inches in diameter and smaller pebbles of green volcanic rock and light coloured granitic rock. A thin section shows that the volcanic rocks contain mainly albitized feldspar and minor pyroxene. They may be derived from the Mush Lake Group. The granitic rocks are hornblende-biotite granodiorite and leucogranite and must have been derived from pre-Cretaceous granite intrusions. All pebbles show strain and cataclastic texture. The argillite matrix shows microscopic laminations of brown-black indeterminate material with scattered fragments, probably of quartz, feldspar, and epidote. Intraformational conglomerates with angular argillite fragments are also common.

Within Kluane Lake map-area the Dezadeash Group occurs in narrow synclinal zones; its maximum thickness is probably not represented. The greatest measurable thickness seen by the writer barely exceeds 1,000 feet of flat-lying beds and occurs on Hump Mountain, at the north edge of the map-area.

Structural and Contact Relations

The Dezadeash Group occurs in the axial zones of synclines, probably complicated by faults, of Kluane Ranges and commonly exhibits strong internal folding. The beds overlie Mush Lake argillite, limestone, or volcanic rocks, in places with a basal conglomerate. The respective ages of the Mush Lake and Dezadeash beds leave no doubt that the contact is disconformable, but no angular unconformity has been demonstrated. In the northeast corner of the map-area, the group is in intrusive contact with late Mesozoic or early Tertiary granitic rocks.

Metamorphism

In many occurrences within the map-area intense folding has imparted to the Dezadeash beds a strong cleavage, obscuring the original bedding and locally converting the rocks to soft, glossy slates.

Conversion to pelitic hornfels at the contact of granitic intrusions is notable in the northeast corner of the map-area. Commonly the thin banding of the sediments has been accentuated by metamorphism into conspicuous white-black striping. A thin section of a very fine grained banded hornfels shows that some graded bedding and crossbedding is still preserved. The finest grained beds are mainly indeterminate opaque matter, the coarser ones contain scattered quartz grains, up to 0.05 mm in size, but consist mainly of biotite, ? epidote, and ? tremolite, all 0.02 mm or less. Biotite is concentrated in darker bands, epidote in the lighter ones.

Origin

The sedimentary facies of the Dezadeash Group is one that occurs in many geosynclinal regions throughout the world. It has been called the "greywacke series" (Krynine, 1948) or, following the usage favoured by many European geologists, "flysch facies". Sujkowski (1957) defines flysch as "a facies denomination for a marine deposit composed of innumerable alternations of sharply divided pelitic and psammitic layers. Other rocks in the deposit are accidental, and in particular pure limestones are rarely present. The series commonly attain thicknesses of thousands of feet and were deposited in geosynclinal areas." This definition fits the Dezadeash Group sediments in all respects.

Kuenen (1950, 1958) and several others have in many papers suggested that the clastic material of these thick argillite–greywacke or flysch sequences was probably transported into the deeper water of the eugeosyncline by turbidity currents. Such currents might have carried material from distant sources, rather than from adjacent rising island chains.

It has been remarked (Dunbar and Rodgers, 1957) that the original flysch deposits are non-volcanic, and therefore cannot be considered as eugeosynclinal deposits. This observation applies to the Dezadeash Group and to many other greywacke sequences as well. One might suggest, however, that they represent a stage of development of the eugeosyncline, where volcanic activity had substantially decreased or ceased entirely. Kuenen (1958) included in his definition of flysch, the attribute "preparoxismal" and de Sitter (1956), quoting Tercier, considered it as "the facies which just precedes the main paroxysmal phase of a mountain chain." North American writers (e.g., Dunbar and Rodgers, 1957), although objecting to the indiscriminate use of "flysch" for any pre-orogenic sediment, appeared to consider greywacke sequences as typical of the geosynclinal realm, accumulated far from the platform, and before final compression. The Dezadeash Group, laid down in the early Cretaceous and folded and intruded in late Cretaceous time, fully conforms to this concept.

Deposition of the Dezadeash Group probably occurred in this fashion in deeper water off the continental shelf. The emerged Yukon Complex to the east may have supplied much of the material and is the most likely source of granitic pebbles. However, substantial amounts of volcanic detritus may also have been derived from volcanic islands within the St. Elias geosyncline.

Age

The strata of the Dezadeash Group, like similar greywacke sequences described from elsewhere, are largely unfossiliferous, but have yielded a few scattered fossil specimens or collections. *Buchia* (until recently called "*Aucella*") is by far the predominant genus of pelecypods present, its various species permit fairly detailed stratigraphic subdivision and correlation. H. Frebold examined and commented on the following specimen:

GSC location 20275. One half mile up north tributary of Tatamagouche Creek, $3\frac{1}{2}$ miles up from Burwash Creek; lat. 61°24′50″, long. 139°23′45″:

"Belemnites" (*Pachyteuthis*?) sp. indet.

The unsatisfactorily preserved form belongs to the upper part of the Jurassic or to the Lower Cretaceous.

The other identifications and comments are by J. A. Jeletzky.

GSC location 28690. Float in tributary of Congdon Creek, near pass to Nines Creek; lat. 61°07′, long. 138°43′:

Buchia cf. *Buchia okensis* Pavlow

Buchia subokensis Pavlow or

Buchia trigonoides Lahusen

Although very poorly preserved and distorted, the fossils of this lot definitely belong to the group of large, rugose *Buchia* forms, which abound in the latest Jurassic and earliest Cretaceous rocks of North America and northern Eurasia. These *Buchia* forms are not known to range either below or above these beds and so indicate upper Tithonian (= Purbeckian) or early Berriasian

(= Infravalanginian) age for the rocks containing them.

The *Buchia* forms discussed here characterize the Peninsula Formation of the Harrison Lake area in southern British Columbia, the unnamed lowermost Cretaceous rocks of the west coast of Vancouver Island and the unnamed uppermost Jurassic and lowermost Cretaceous rocks of Aklavik Range, N.W.T. All these formations are considered to be of the same age as the rocks containing the fossil lot discussed here.

It must be stressed emphatically that the preservation of fossils of the lot 28690 precludes its reference specifically to either early Berriasian or upper Tithonian time, and can only be dated as of the uppermost Jurassic or lowermost Cretaceous age.

GSC location 31407. A gully ½ mile east of the Border Monument 178; lat. 61°56′40″, long. 140°59′10″:

Buchia cf. *Buchia okensis* Pavlow or
Buchia subokensis Pavlow or
Buchia trigonoides Lahusen

GSC location 31408. A gully ½ mile east of the Border Monument 178; lat. 61°56′30″, long. 140°59′10″:

Buchia crassa Pavlow et var.
Buchia cf. *terebratuloides* Lahusen
pelecypod, genus and species indet.

GSC location 31409. A gully ½ mile east of the Border Monument 178; lat. 61°56′25″, long. 140°58′40″:

Buchia cf. *trigonoides* Lahusen or
Buchia fischeri (d'Orbigny)

GSC location 31410. A gully ½ mile east of the Border Monument 178; lat. 61°56′15″, long. 140°58′40″:

Poor belemnite fragments probably belonging either to *Pachyteuthis* or to *Acroteuthis*

Fossil lot No. 31407 contains exactly the same fauna as the lot No. 28690, and is considered to be of the same general age.

Fossil lot 31409 contains *Buchia* of the same general type as lots 31407 and 28690 but even less well preserved. The *Buchia* of lot 31409 seems to resemble more closely the upper Tithonian (= uppermost Jurassic) than the early Berriasian (= lowermost Cretaceous) members of this group of species, but are too poorly preserved to be certain. Lot 31409 can therefore only be dated as of the same general age as lots 31407 and 28690.

Fossil lot 31408 contains readily determinable *Buchia crassa* Pavlow and its varieties. It is therefore of early Lower Cretaceous age and appreciably younger than lots 28690, 31407, and 31409. The occurrence of *Buchia crassa* Pavlow in lot 31408 is deemed to be sufficient to date this lot as of lower to early middle Valanginian age. It cannot be of Berriasian (= Infravalanginian) or middle to upper Valanginian age. It should be noted, however, that on the

North American continent a number of beds dated as upper Valanginian on the occurrence of "*Dichotomites*" *mutabilis* Stanton and *Buchia crassicollis* Keyserling s. lato (including *Buchia crassa* Pavlow) are actually of the lower to early middle Valanginian age and approximately contemporary with the lot discussed here.

Lot 31410 can only be dated as Middle Jurassic to mid-Lower Cretaceous (not younger than the Barremian stage) on the basis of its poor belemnoid fragments.

In résumé nearly all diagnostic collections indicate a latest Jurassic (late Tithonian) to earliest Cretaceous (Berriasian) age; only lot 31408 is slightly younger Cretaceous (early to middle Valanginian). This lot is evidently from beds in a tight syncline of Cretaceous rocks, and is flanked to north and south by older, Jurassic to Cretaceous beds.

The belemnites of lot 31410 occur in conglomerate beds, together with cobbles of limestone and volcanic rocks, in the basal part of the Dezadeash Group. They overlie some limestone and argillite, and a thick section of volcanic rocks of the Mush Lake Group. The lower part of the Dezadeash Group is thus uppermost Jurassic to Lowermost Cretaceous. There is so far no evidence that the group contains beds younger than Valanginian.

Correlation

Greywacke sequences of the same age have been reported from the Nutzotin Range and other parts of Alaska Range (Imlay and Reeside, 1954). Buchias of Berriasian age were also found in greywackes in the central part of St. Elias Mountains, near McArthur Peak and 30 miles south of Kluane Lake map-area. The same beds also form a considerable part of Chugach Mountains farther west, and occur in several islands in southeastern Alaska (op. cit.). Conceivably continuous deposition of the greywacke sequence occurred in late Jurassic to early Cretaceous time in the entire belt west of the Coast–Tanana geanticline. Gabrielse and Wheeler (1961) believed that the latter was a tectonic land, separating the Cretaceous sea in the western belt from the Whitehorse basin, where the continental Tantalus Formation accumulated. The thick greywacke sequence of the Bowser basin of northwestern British Columbia, estimated to be up to 20,000 feet thick, is also of the same age as the Dezadeash Group and similar to it in lithology and the absence of volcanic rocks. There the sedimentary and tectonic environment of the non-volcanic greywacke sequence apparently extended far to the east of the present Coast Mountains.

Mesozoic and ? Tertiary Volcanic Rocks of Yukon Plateau

Lithology

Small areas of volcanic rocks in Nisling Range, on both sides of Onion Creek and on Dwarf Birch Creek, are probably of Mesozoic age. They are mainly andesitic and basaltic tuffs and breccias. The rocks are dark green and black, weathering light green and grey, and are either aphanitic or porphyritic, mainly with small white or light green plagioclase phenocrysts but locally with large hornblende crystals.

In many places they are pyroclastic, with angular fragments of volcanic rock and chert, several inches in size, well displayed on the weathered surface. Thin sections examined, even those of rocks that megascopically appear to be massive flows, reveal a pyroclastic texture. They carry plagioclase phenocrysts several millimetres long of andesine or labradorite composition. These are generally clear, unaltered phenocrysts in fragments of older tuff and lava, or they are single, commonly cracked, broken, and angular crystals.

Corroded brown and light green hornblende and pseudomorphs of olivine or biotite changed into near-opaque substance may also occur. The matrix is clearly fragmental, with mainly fine plagioclase, hornblende, and magnetite in fragments or crystallites.

More siliceous volcanic rocks also occur. Light greenish grey latite, with small pink feldspar phenocrysts, shows in thin section larger stubby and cloudy albite and small quartz crystals, in a matrix of mainly micropegmatite.

Spherulitic and fluidal rhyolites were noted west of Tyrrell Creek. In hand specimens both are light coloured rocks. The former shows white spherulites about $\frac{1}{8}$ inch in diameter in a light grey matrix, the latter fine flow lamination with small quartz augen. Thin sections show mainly colourless spherulites, probably alkali feldspar and tridymite. Quartz is resorbed and rounded.

On the ridge between Rhyolite and Dwarf Birch Creeks welded tuffs occur, showing flat greenish grey lenses, paper-thin to $\frac{1}{8}$ inch thick, in parallel arrangement, and small white feldspars in a black matrix. Thin sections show mainly glassy brown material with fluidal texture. Very fine grained, grey and light green banded tuffs with local crossbedding were also noted in that vicinity.

Age and Correlation

Though exposures are limited and structure complex, the volcanic rocks are evidently younger than the surrounding Yukon Complex schist. The boss of granite and alaskite east of Dwarf Birch Creek and the volcanic rocks surrounding it could perhaps be interpreted as a volcanic centre of eruption, where andesite breccias accumulated initially and were subsequently intruded by rhyolite dykes and a central granitic plug, with some extrusion of rhyolitic flows and breccias.

The volcanic rocks are also older than the Nisling Range granodiorite that intrudes them. There is some lithological resemblance between Nisling volcanic rocks and Triassic volcanic rocks of the St. Elias region. Though the former are mainly dykes and tuffs and the latter mainly flows, there is similarity in petrographic composition and degree of alteration, whereas they are distinctly different from Tertiary volcanic rocks. The volcanic rocks of Sifton Mountains in Dezadeash map-area appear to be on trend with the Nisling volcanic rocks. According to Kindle (1952), they are also similar to Mush Lake rocks and perhaps of like age. On the other hand a lithological description by Bostock (1936) of the Mount

Nansen volcanic rocks of Dawson Range, directly north of Nisling Range, also suggests lithological similarity with those of Nisling Range. They are greenish grey to black rocks, speckled with light coloured feldspar phenocrysts, and consist largely of tuffs and breccias of andesitic to dacitic composition. But Bostock (1936) concluded that the Mount Nansen rocks occur unconformably on the Jurassic Laberge Group, and are late Jurassic to early Cretaceous. Wheeler (1961) inferred that in late Triassic time a source area for the volcanic material shed into the Whitehorse trough "lay along the axis of the Coast intrusions." The volcanic rocks of Nisling Range could be remnants of this belt.

In view of these considerations, the basic volcanic rocks of the Nisling Range are of late Triassic age and perhaps extend into the Cretaceous. As in St. Elias Mountains acidic volcanic rocks are mainly Tertiary, it is possible that the Nisling Range rhyolitic rocks are also Tertiary.

Granitic Rocks of Yukon Plateau

Distribution

Granitic rocks occupy about half the area of Yukon Plateau. Ruby Range batholith is the largest granitic body, and underlies most of that range east from its intersection with Shakwak Trench; beyond the map-area it passes into the granitic rocks east of Whitehorse. It consists largely of hornblende-biotite granodiorite. In the easterly part of Ruby Range, at the heads of Gladstone, Raft, and Talbot Creeks, is a stock of alaskite.

Along the northern border of the map-area, Nisling Range is largely underlain by bodies of granodiorite and quartz–monzonite that may have their main development in the unmapped Snag map-area. This range contains also several smaller bosses of alaskite and granite, elongated in an east–west direction and accompanied by rhyolitic dyke-swarms cutting older granitic rocks and Yukon Complex schists.

A small body of granitic rock occupies the southeast corner of the map-area.

Lithology of Ruby Range Batholith

Hornblende-biotite granodiorite and quartz diorite are the main components of Ruby Range batholith. Diorite and gabbro also occur, but may be considered as intermediate stages in the assimilation of wall-rock and included xenoliths. The granitic rocks grade laterally into gneisses of similar composition and thence to quartz–mica schist of the Yukon Complex. Boundaries between these rock types are gradational, and generally gneissic rocks with a dominantly granitic texture and subordinate foliation have been mapped as granitic rock and rocks with a dominantly foliated texture have been mapped with the Yukon Complex.

Modal analyses of Ruby Range batholith rocks are shown in Table I and Figure 2, and the location of samples is shown on Figure 1. Rock names are, with slight modifications, according to the system of Johannsen (1932-39).

It will be noted that the petrography is similar to that of the Kluane Ranges intrusions. The hornblende–biotite granodiorite is a medium- to coarse-grained granitic rock, and exhibits gneissic foliation in transition zones between plutonic rocks and mica schist. The overall tone of the rock is light grey, due to a mafic mineral content varying from 5 to 20 per cent. In hand specimens glassy, and locally smoky, quartz, white feldspar, greenish black hornblende, and brownish black biotite may be recognized.

Thin sections exhibit a granitic hypidiomorphic texture. In gneissic rocks from transition areas, grain boundaries are mortared or sutured, indicating movement within the crystalline rock, and possibly recrystallization, and in these the texture is more appropriately described as granoblastic. The rocks are fresh, with little evidence of alteration or secondary minerals in thin sections.

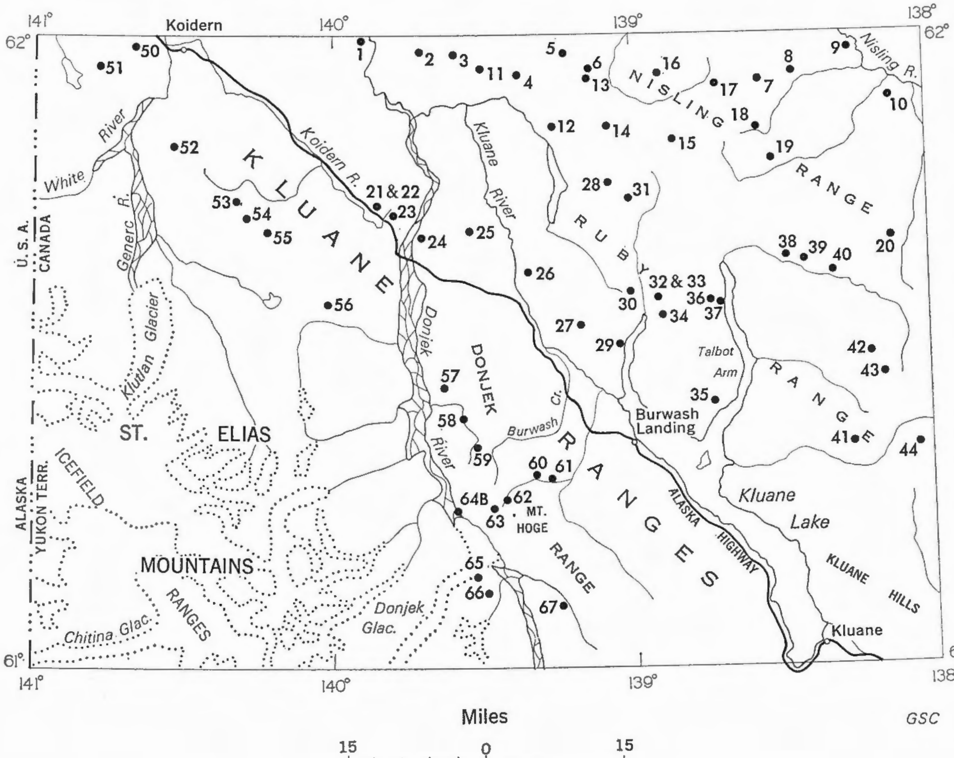


FIGURE 1 Location of samples of granitic rocks used for modal analyses.

Plagioclase crystals are 2 mm or more long, larger than the other components of the rock, although small crystals may be included in potash feldspar grains. Most have a well-developed crystal form, exhibit albite twinning, and many show zonal structure. The composition of the plagioclase is about An_{30}. Smaller anhedral quartz and potash feldspar grains and subhedral biotite and hornblende grains may occur in the interstices between plagioclase crystals. Thus early initial crystallization of plagioclase is indicated, but the jagged boundaries with other minerals suggest that crystallization continued until final consolidation of the rock.

Quartz and orthoclase are everywhere anhedral; the former commonly in mosaics, perhaps with sutured grain boundaries, the latter in optically continuous, non-perthitic shapeless masses that may include plagioclase. Myrmekite commonly occurs along plagioclase–orthoclase contacts.

Biotite predominates over hornblende in all granodiorites. Both are subhedral, and have light to dark brown and light to dark green pleochroism. They are clustered together and impart the foliation to gneissic rocks. Apatite and sphene are more common than iron ores and zircon, and together these accessory minerals constitute less than one per cent of the rock.

The hornblende–biotite quartz diorite is generally finer grained than the granodiorite, and, owing to a mafic content, between 15 and 30 per cent is darker. Plagioclase, biotite, hornblende, and quartz are similar to those of the granodiorites,

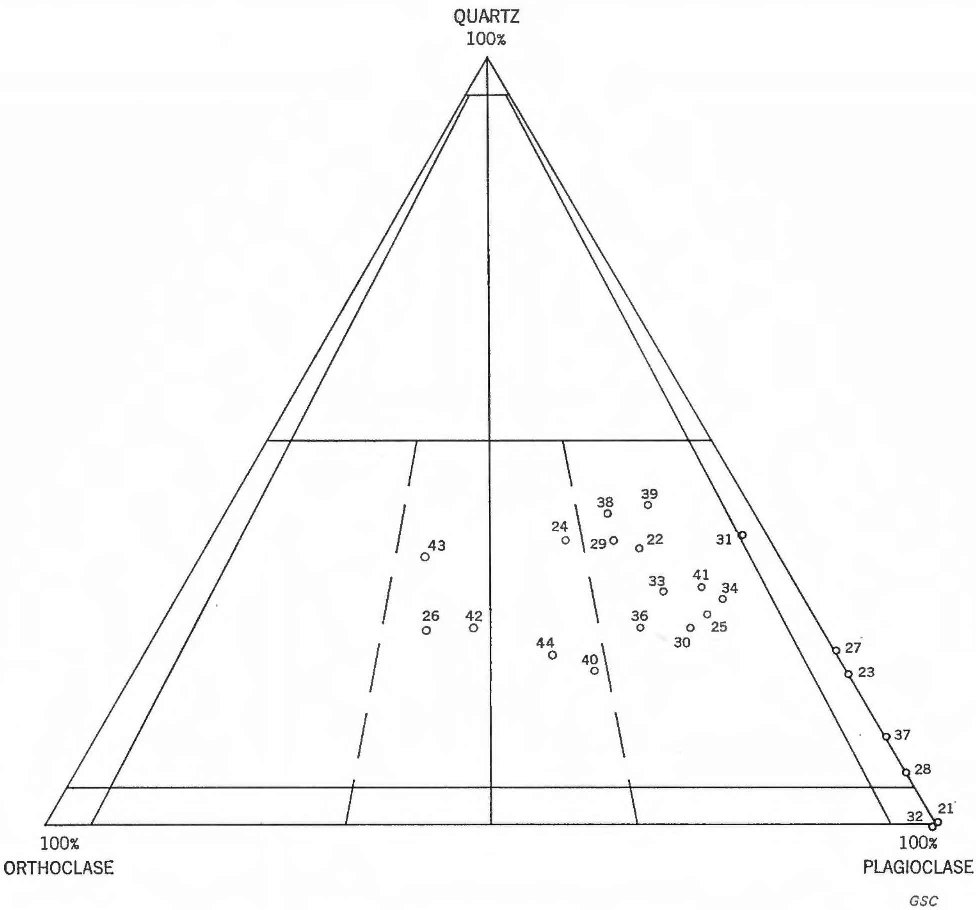


FIGURE 2 Per cent by volume of quartz, orthoclase, and plagioclase in samples of Ruby Range granitic rocks.

but the former is a more calcic andesine, with more abundant albite-carlsbad twins. Orthoclase is a minor component, occurring with quartz in the interstices between plagioclase. Augite may be present as a core surrounded by hornblende. Accessory minerals are the same as those of the granodiorites, and not more abundant.

Diorite, quartz gabbro, and gabbro are dark greenish grey rocks with a mafic content of 25 to more than 50 per cent (melagabbro). These basic rocks commonly occur in contact and transition zones, and are clearly recrystallized and partly granitized wall-rock material. Some have a metamorphic granoblastic texture, where constituents form an interlocking structure and feldspar-quartz aggregates form irregularly shaped eyes. In others, the dark minerals are merely clustered and the texture is more nearly granitic. In these rocks andesine or labradorite occur also in subhedral, relatively large crystals, up to 1 mm in size. Quartz and minor orthoclase are interstitial and in places in granophyric aggregates. The amounts of apatite, sphene, and iron ores are like those of the more granitic rocks but in addition several specimens contain some carbonate.

Alaskite and quartz monzonite occur in a stock in the highest part of Ruby Range, at the east border of the map-area. These rocks are related to and described with similar rocks of Nisling Range. Modal analyses revealed only few other rocks that may be classed as quartz monzonite. These are probably end-members of a series with increasing potash feldspar from gabbro and diorite to granodiorite.

Roof Pendants of Ruby Range

Roof pendants, partly of carbonate metamorphic rocks in various stages of migmatization, are common on both sides of Talbot Arm. West of Brooks Valley, these roof pendants increase in size to form a continuous area of schist and limestone (described with the Yukon Complex). As elsewhere, clastic rocks have been metamorphosed to a quartz-feldspar-biotite assemblage, ranging in texture from laminated hornfels, through schist to gneiss, and basic rocks are converted to amphibolite. The carbonate rocks, however, are relatively unaffected and may occur as lenses in the granitic rock.

The granitic rocks near contacts with limestone are light coloured, and where examined in thin section, reveal predominant perthitic feldspar. One section shows a cataclastic epidote-quartz monzonite with over 20 per cent epidote scattered throughout in small and larger grains, together with quartz, microcline, and oligoclase. Another specimen contains only 5 per cent each of quartz, augite, and albite, the remainder being microperthite.

Lithology of Nisling Range "Granodiorite"

The intrusions of Nisling Range are on a smaller scale than those of Ruby Range and are of two distinct types, Nisling Range "granodiorite" and Nisling Range "alaskite".

Along the entire north border of the map-area and probably occupying much of Nisling Range to the north are intrusions of granodiorite and quartz monzonite.

Table I

Modes of Some Granitic Rocks of Ruby Range Batholith

Specimen No.	21	22	23	24	25	26	27	28	29	30	31	32	33	34	36	37	38	39	40	41	42	43	44
Field No.	62I	62J	57B	56A	208A	121F	120I	112H	102B	107E	308I	306A	306B	304B	378A	378D	354A	353A	360C	426I	433D	436B	430C
Quartz + myrmekite		38.5	14.2	35.5	27.5	24.2	17.6	3.7	34.9	21.4	30.9		23.5	25.0	23.2	9.8	38.2	38.4	17.1	26.5	25.3	35.6	21.4
Orthoclase		14.6		21.0	11.7	42.0			16.5	11.5	3.0		11.7	7.6	19.4		15.3	10.6	23.0	10.2	64.8	37.8	30.2
Microcline																							
Plagioclase	74.0	46.8	57.7	37.6	52.8	29.2	57.6	46.0	42.1	49.4	49.8	60.5	44.0	53.4	49.1	69.5	39.2	41.4	43.3	49.5	9.0	24.1	41.8
Composition of plagioclase	lab.	olig.	and.	olig.	and.	and.	and.	lab.	and.	and.	and.	and.	and.	and.	olig.	and.	olig.	and.	olig.	and.	alb.	alb.	olig.
Amphibole	10.4	0.1	3.7		0.4	0.4	1.0	38.4		6.5	5.6	28.2	7.9	4.0	1.9	9.2	0.4	4.1	1.5	0.2	0.3		0.6
Pyroxene	10.5						3.4																
Biotite	2.8		24.0	5.9	7.5	4.2	20.2	10.7	6.5	10.9	10.1		11.4	10.0	6.2	8.1	6.1	4.7	5.1	13.3	0.3	2.3	6.0
Chlorite												8.7				3.2							
Epidote											0.1		0.1										
Apatite	0.3		0.1		0.1	x	0.2	x				0.2	0.3		0.1		0.2	0.4	x	0.1			
Magnetite, pyrite	2.0		0.1					0.2			0.1		0.4				0.4	0.3	x		0.3		
Sericite, muscovite																							
Sphene										0.2		1.3	0.2		0.1	0.2	0.2		x				
Fluorite																						0.2	
Zircon										0.1			0.5					0.1		0.2			
Calcite			0.3					1.0				1.1											
	Enstatite-hornblende-gabbro	Leuco-granodiorite	Hornblende-biotite quartz diorite	Biotite quartz monzonite (slightly gneissic)	Biotite granodiorite	Biotite quartz monzonite	Augite-biotite quartz diorite	Biotite-hornblende meta-quartz gabbro	Biotite granodiorite (gneissic)	Hornblende-biotite granodiorite	Hornblende-biotite quartz diorite	Hornblende diorite	Hornblende-biotite granodiorite	Hornblende-biotite granodiorite	Hornblende-biotite granodiorite	Hornblende-biotite-quartz diorite	Biotite granodiorite	Hornblende-biotite granodiorite	Hornblende-biotite granodiorite	Biotite granodiorite	Alaskite	Leuco-quartz monzonite	Biotite quartz monzonite

Modal analyses of these intrusions are given in Table II and Figure 3. They are essentially biotite–hornblende granodiorite, granogabbro, and quartz monzonite. The granodiorites are medium to coarse grained and darker coloured than equivalent rocks of Ruby Range. This is partly due to a darker tone of the feldspars. The plagioclase is in many samples light green, and the orthoclase is dark grey or distinctly reddish. The amount of dark minerals varies between 15 and 20 per cent.

Many Nisling Range granodiorites differ from those of Ruby Range by carrying conspicuous hexagonal biotite flakes up to a quarter of an inch diameter. Some of the rocks are visibly heterogeneous, and contain megascopic green patches of hornblende, biotite, chlorite, and plagioclase within the pinkish assemblage of plagioclase, orthoclase, quartz, and minor hornblende and biotite.

Under the microscope granodiorite and some granogabbro show subhedral plagioclase from 2 to 8 mm maximum length as the largest mineral. It is commonly sericitized, the indicated composition being near 50 per cent anorthite. The clotting of dark minerals, observed megascopically, is also evident in thin sections. Horn-

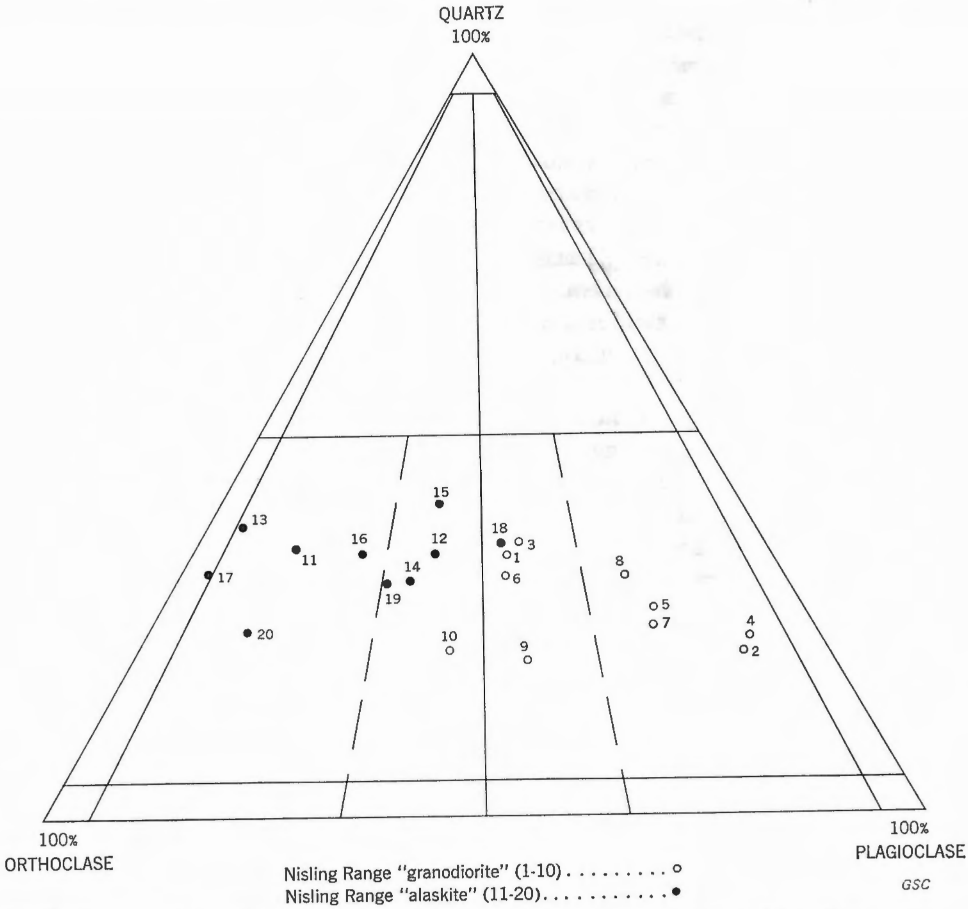


FIGURE 3 **Per cent by volume of quartz, orthoclase, and plagioclase in samples of Nisling Range "granodiorite" and "alaskite" intrusions.**

Table II

Modes of Some Granitic Rocks of Nisling Range

	Nisling Range "granodiorite"										Nisling Range "alaskite"									
Specimen No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Field No.	69B	129F	132B	133E	135D	136G	336G	335C	339C	346I	131A	149B	136E	144M	312E	317E	320B	334A	349C	374D
Quartz + myrmekite	25.1	17.5	28.2	18.4	21.5	31.4	20.2	27.9	21.5	19.8	34.6	33.8	37.8	28.8	40.2	32.6	32.2	34.7	29.7	24.2
Orthoclase + perthite	28.2	8.2	22.2	7.2	14.2	29.0	15.7	14.1	26.8	39.5	52.3	37.5	57.4	42.6	33.6	44.5	62.9	27.6	45.4	65.0
Plagioclase	31.3	56.7	27.0	54.5	45.1	34.0	46.6	42.7	40.5	31.8	11.8	25.1	4.2	23.0	23.0	19.0	2.4	32.8	22.8	10.1
Composition of plagioclase	and.	and.	and.	lab.	and. lab.	and.	and.	and.	and.	olig.	olig.	alb.	alb.	alb.	alb.	alb.	alb.	alb.	alb.	alb.
Amphibole	9.2	6.9	12.0	7.4	9.0	3.7	8.5	10.2	2.6	0.5										
Pyroxene		0.5	2.8	0.1	0.4		0.6													
Biotite	6.2	9.9	4.2	11.7	9.0	1.9	8.4	5.0	8.5	0.4	0.9	3.6		5.6	3.2		1.9	4.5	2.1	0.5
Chlorite			1.6	3.0												3.7				
Epidote				0.1				0.1												
Apatite				0.1	x															
Magnetite, pyrite		0.3	1.8	0.1	0.8				0.1		0.5		0.6			0.1	0.5			
Fluorite			0.2														0.1	0.4	0.1	0.2
Zircon																0.1				
Based on 500 point-counts	Biotite-hornblende quartz monzonite	Augite-hornblende-biotite granodiorite	Biotite-hornblende quartz monzonite	Hornblende-biotite granogabbro	Biotite-hornblende granogabbro	Biotite-hornblende quartz monzonite	Hornblende-biotite granodiorite	Biotite-hornblende granodiorite	Biotite quartz monzonite	Porphyritic biotite-hornblende quartz monzonite	Leucogranite	Alaskite	Alaskite	Alaskite	Alaskite	Alaskite	Alaskite	Alaskite	Alaskite	Alaskite

blende, in many places with augite nuclei, occurs in clusters with biotite, chlorite, magnetite, and minor apatite. Either hornblende or biotite may predominate, or these minerals may occur in equal amounts.

Anhedral orthoclase and quartz, in places as granophyre, fill the spaces between plagioclase and dark minerals. Embayments of quartz and to a lesser extent orthoclase penetrate plagioclase or appear to have replaced that mineral entirely, leaving odd-shaped fragments of plagioclase in a field of quartz.

Quartz monzonite is similar to granodiorite and may have been derived from it by addition of quartz–potash feldspar material. Hand specimens are generally lighter coloured and the dark mineral content varies more widely; it is between 5 and 20 per cent. Potash feldspars are pink or dull grey and quartz may also be the dark and smoky variety. Orthoclase may occur as megascopic phenocrysts, up to a quarter of an inch in size. In thin sections the rock also resembles granodiorite and shows subhedral andesine and clots of dark minerals, commonly in an anhedral matrix of quartz and orthoclase. The last two minerals commonly occur in irregular masses of a size equal to or greater than the plagioclase and mafic minerals.

Lithology of Nisling Range 'Alaskite'

Several bodies of light coloured granitic rocks, elongated in an east–west direction, occur in Nisling Range and one was mapped in Ruby Range. For convenience they are termed Nisling Range 'alaskite' although other rock types are also present.

Most of these rocks are alaskite, but some with a higher percentage of albite may be classed as leucogranite or leuco-quartz monzonite. Most of the schists and also the granodiorites of Nisling Range are riddled with rhyolitic dykes and sills that are probably closely related to these granitic plutons.

In hand specimens, especially those of granophyric character, the alaskite is distinct from the granodiorite. In the alaskite, the mineral grains vary from fine to coarse but, as they are less firmly bonded than those in the granodiorite, the rocks are commonly porous and have a crumbly weathered surface and noticeably rusty colour. In outcrops they may look like coarse clastic sediments, with rough pinnacles and gravelly talus slopes on the valley walls in contrast to the smooth, grey-white mountain sides of granodiorite.

Dark, smoky, quartz grains are conspicuous in most specimens, as well as light rusty or pink potash feldspar. The low percentage of biotite and the absence of hornblende are also distinct field characteristics.

Thin sections show a xenomorphic–granular assemblage of mainly clear quartz and perthitic potash feldspar with rare microcline twinning, commonly altered and cloudy. Irregularly rounded and corroded quartz grains in places enclose feldspar, but the reverse relationship also occurs. Micrographic intergrowths of quartz and potash feldspar may occur in patches. Plagioclase, mainly albite, is present as small subhedral individuals, commonly enclosed in the potash feldspar. Biotite occurs in small amounts, partly altered to chlorite, and small flakes of muscovite may be enclosed in feldspars, especially plagioclase. A common and diagnostic accessory is fluorite, in colourless irregular aggregates or veinlets. Microscopic light green veinlets of this mineral were seen south of the head of Rockslide Creek. Wolframite has been found in these rocks west of the head of Alaskite Creek.

Dykes

In many parts of Nisling Range rhyolitic rocks appear to be the dominant rock type. In some places they are dykes, commonly vertical and trending about due north, that cut schist, granodiorite, and volcanic rock. In Nisling Range, where outcrops are scarcer than elsewhere in the map-area and bare rocks resulting from glacial scouring are absent, they occur largely as loose blocks and "felsenmeer" on the flat plateau tops. Even in areas apparently consisting mainly of rhyolite, scattered outcrops of schist, granodiorite, or volcanic rock commonly indicate that the rhyolite occurs as dykes or dyke swarms within these rocks. Thus on the accompanying geological map sub-units (1a) and (6a) of the Yukon Complex map-units (1) and (6) indicate the presence of numerous rhyolitic dykes.

Areas of rhyolite rock slides are recognizable at a distance by their light orange to yellow colours. Rock fragments are sharp and angular, and thinner slabs have a metallic ring when struck.

In hand specimens the rocks are medium grey to light rusty brown, and may contain small vugs. Most are porphyritic with smoky quartz and white feldspar phenocrysts up to one eighth of an inch in size. Thin sections of most rocks show a matrix of quartz and potash feldspar, partly with granular and partly with granophyric texture. The quartz and potash feldspar grains may be as small as 0.2 mm and have irregular interlocking shapes; drop- and dendrite-shaped growths also occur.

Most samples have phenocrysts of quartz and potash feldspar. The quartz is commonly rounded and may show canals and embayments as indications of remelting, it may also occur in fragments of quartz mosaics similar to those of metamorphic quartzites. Potash feldspar phenocrysts are commonly several millimetres in size, perthitic, and with a dirty brownish, hardly transparent colour. In contrast to potash feldspars of the 'granodiorites', they are subhedral and have some carlsbad twins. Subhedral plagioclase is present in some sections and is mainly a cloudy, semitransparent albite, but clear or sericitized oligoclase also occurs. Other minerals present in minor amounts in some samples are biotite, hornblende, magnetite, and fluorite.

Though rhyolitic dykes are a major constituent of the rocks of Nisling Range, they are not prominent in Ruby Range. There, darker porphyritic rocks are more common and are, in contrast to the rhyolites, readily recognizable as dykes intruded into the Yukon Complex schists and granodiorites.

Samples of such dykes, taken from the ridge west of Donjek River and from west of Grafe Creek, are dense black rocks with a dark purple tinge, and with white feldspar phenocrysts up to about 2 mm in size. The thin section shows the feldspar, both as phenocrysts and in the matrix, to be labradorite or bytownite remarkably fresh in appearance. Phenocrysts of diopside are for the most part altered into an aggregate of sericite and serpentine. In addition to plagioclase, the matrix contains chlorite and sericite.

These basaltic dykes are lithologically similar to volcanic rocks of Tertiary age and may have been feeders for them. On the other hand, some dykes or small intrusive bodies of dioritic and gabbroic composition, occurring in various localities in Ruby and Nisling Ranges, are petrographically similar to older rocks. A small canyon north of the valley connecting the north end of Tincup Lake with Onion Creek cuts a composite dyke intruding highly folded quartzite. A light coloured, medium-grained phase is most abundant. The thin section shows labradorite up to about 1 mm size, brown hornblende, minor diopside with reaction rims of hornblende, interstitial quartz, and iron ore. The plagioclase is fresh zoned andesine and the rock is therefore a quartz diorite. The dark coloured, medium-grained phase is of diabasic texture, with albitized plagioclase up to about 3 mm long, containing scattered chloritic material. Diopside is partly altered to serpentine and the matrix consists of iron ore, serpentine, and calcite. The general petrographic character and the degree of alteration of these rocks is like that of the Triassic Mush Lake Group and suggests a relationship with Mesozoic volcanic rocks.

Mode of Origin of the Granitic Rocks

In the last decades much detailed and fundamental research has been done on the origin of granitic stocks and batholiths. The concept of granitization has gained much support and is applicable for many granitic areas, although a magmatic origin still seems more likely for other intrusions. The reconnaissance geological mapping of the area suggests that both processes occurred in Yukon Plateau granitic rocks.

Ruby Range appears to be a good example of the formation of granitic rocks as the final stage of regional metamorphism of a stratified rock sequence. The gradual change of the rocks may actually be observed when proceeding towards the batholith from low grade Yukon Complex schist through quartz-feldspar-biotite schist and gneiss, into granodiorite. Transitions from greenstone through amphibolite into hornblende diorite and quartz diorite also occur. It is highly probable that during the formation of the batholith the rocks went through these transitions. In Ruby Range batholith the islands of carbonate rocks within the granitic mass are remnants that by their composition could not readily be converted.

The rocks along the north border probably had a similar origin by granitization, but there basic rocks may have predominated originally. The transition was from basaltic augite-labradorite rocks through hornblende-plagioclase gneiss to diorite, granodiorite and quartz monzonite (*see* Table II and Figure 3). Quartz and potash feldspar were introduced to affect this change, and outcrops and hand specimens actually show the incomplete mixing of mafic and felsic material. Thin sections suggest that quartz and potash feldspar were the latest minerals, introduced interstitially between plagioclase and mafic minerals.

On the other hand, only mobile magma of alaskite to granite composition could have produced the numerous rhyolite dykes in Nisling Range and evidently also produced the related coarse-grained rock by slow cooling of larger plutons. It seems likely, however, that such granitic magmas were produced by the ultimate melting of the gneissic rocks. This is suggested by the appearance of quartz phenocrysts in the rhyolites. These are not only commonly corroded, but also exhibit in places microscopic mosaic texture such as occurs in gneissic rocks. They are, therefore, more probably the residual parts of an otherwise molten gneissic rock than a first generation of newly formed crystals in the cooling magma.

Age of the Granitic Rocks of Yukon Plateau

The age of granitic rocks of the Yukon Complex cannot be determined directly by their relationship to fossiliferous beds. Field evidence gives only indirect indications from conglomerates of the late Jurassic to early Cretaceous Dezadeash Group and the early Tertiary Amphitheatre Formation, carrying clasts of granitic rocks. It is probable that the granitic and metamorphic debris, deposited with these formations into the St. Elias geosyncline, were partly or entirely derived from Yukon Plateau rocks.

A few potassium-argon datings of Yukon Plateau granitic rocks have been made. In the section on the Yukon Complex, potassium-argon datings of 140 and 147 m.y. (Middle Jurassic) have been quoted for quartz–biotite schist surrounding the batholith. A sample of granitic rock gave the following result (Lowdon, 1960):

GSC 59-12. Biotite from biotite quartz monzonite, south of Gladstone Lakes, 61°21′N, 138°03′W; 176 m.y.; Lower Jurassic according to the 1960 Kulp and Holmes time-scales.

No explanation can be offered why the metamorphic rock should show a younger age than the granitic rock, but generally the older age is probably more accurate.

Several age determinations on massive and gneissic granitic rocks have yielded early Tertiary ages (Lowdon, 1960, 1961).

GSC 59-13. Biotite from gneissic biotite granodiorite, west of Talbot Arm, 61°25′N, 138°45′W; 58 m.y.; Paleocene.

GSC 60-32. Biotite from coarse-grained, slightly gneissic, biotite granodiorite, southeast of Christmas Creek, 61°01′N, 138°08′W; 58 m.y.; Paleocene.

GSC 60-31. Biotite from fine-grained biotite quartz monzonite, rapids south of Canyon Lake, Aishihik map-area, 61°05′N, 136°59′W (eastward continuation of Ruby Range); 65 m.y.; Paleocene.

Thus granitic rocks of at least two distinct ages may occur in Ruby Range batholith, some very early Jurassic, and some very early Tertiary or late Cretaceous. Unfortunately no difference between various parts of Ruby Range was noted in the field.

No dates are available for the alaskite intrusions of Nisling and Ruby Ranges. They are difficult to obtain, as the intrusions contain little biotite and are commonly much weathered. As they are related to rhyolite dykes that cut the Nisling Range granodiorite, they are younger than some granodiorite bodies. Perhaps they are also of early Tertiary age. The few dates available seem to suggest that in early Jurassic and again in early Tertiary times the granitic and metamorphic rocks were recrystallized and, at almost the same time, were uplifted, eroded, and incorporated in conglomerates. This may seem improbable and could be attributed to incorrect, too young, K-Ar ages. On the other hand, fairly close coincidence of these events may be envisaged, final recrystallization occurring as a result of decreasing temperature and pressure brought about by uplift of the complex and ensuing erosion of the overlying rocks.

Granitic Rocks of St. Elias Mountains

The granitic rocks of St. Elias Mountains may be separated into two divisions on the basis of area, lithology, and mode of occurrence. The 'Kluane Ranges intrusions' occur mainly in that range, are chiefly hornblende granodiorite and quartz diorite, and were probably intruded at medium depth. The 'Donjek Range intrusions' occur in Donjek Range and also in Icefield Ranges and form some small stocks in Kluane Ranges. They are quartz monzonite, alaskite, and rhyolite, and were probably emplaced at shallower depth.

'Kluane Ranges Intrusions'

A complex of granitic rocks with attendant contact metamorphic rocks underlies a large part of Kluane Ranges northwest of Donjek River. Smaller bodies occur between Donjek and Duke Rivers, and on Slims River mainly south of the map-area.

Lithology

The Kluane Ranges granitic rocks are mainly medium-grained, medium-coloured, equigranular granodiorite and quartz diorite, with quartz, feldspar, hornblende, and biotite commonly distinct in hand specimens.

Thin sections of most samples reveal hypidiomorphic, equigranular assemblages of fresh or only slightly altered minerals. The order of crystallization, indicated by mineral relationships, appears to be apatite and iron ores first, then plagioclase and hornblende, with biotite somewhat later, and quartz and potash feldspar as the latest minerals.

Table III gives modal analyses of twelve specimens, named with slight modifications according to Johannsen's system. They are mainly hornblende granodiorite and quartz diorite with minor biotite. Diorite and gabbro occur in marginal areas and smaller bodies. Rocks rich in hornblende, grading into hornblendite, are also common at the contacts.

Plagioclase is the main constituent and occurs in subhedral crystals, 1 to 2 mm in size, with albite twinning in many instances combined with carlsbad and pericline twins. The composition is mainly oligoclase and andesine. In some samples these minerals are sericitized and more rarely saussuritized. Hornblende is the main dark mineral, in dark rather stubby green to brown pleochroic crystals up to 1 or 2 mm long. Quartz is an important constituent in most rocks, and is in anhedral embayed grains up to 1 mm in size, with variable extinction, or in mosaics of interlocking grains, commonly interstitial, between plagioclase and hornblende. Myrmekite and mortared quartz also occur along the edges of feldspars. Anhedral orthoclase crystals, though minor in volume, are commonly as large as plagioclase, or larger. They are embayed into them or the two feldspars are separated by myrmekite borders. Minor amounts of biotite, commonly altered to chlorite, occur in most samples. Iron ores, sphene, and apatite are minor accessories and epidote is in some samples an abundant product of replacement.

Metamorphic and Metasomatic Rocks of the Contact Zone

Various types of metamorphic and migmatitic rocks are present in the contact zones of the batholitic intrusions. Some of these have been discussed as metamorphic variants of the formations involved. Other metamorphic rocks of unknown age, that are closely related to the intrusions, are discussed in this section.

Ultrabasic and Basic Rocks

Basic rocks are mostly amphibolized near contacts with granitic intrusions. Duke River, just below the mouth of Granite Creek, reveals a good section of the contact between hornblende granodiorite and peridotite. The marginal rock is light coloured and fine grained with few inclusions of dioritic rock, but at the contact it contains abundant hornblende crystals several inches long lying perpendicular to the wall-rock. A thin section of the amphibolized rock at the contact reveals a granoblastic assemblage of brown-green pleochroic stubby hornblende, only 0.2 mm in size, with some magnetite and very fine interstitial epidote and zoisite. Some fresh labradorite crystals occur near the contact with the younger intrusion. The same section shows medium-grained gabbro across a sharp contact, carrying bytownite and augite with hornblende rims and magnetite in granular xenomorphic textures. Another section of the marginal rock shows fine-grained granoblastic areas of labradorite, augite, hornblende, and magnetite, as well as less completely recrystallized areas with hornblende, epidote, zoisite, and quartz–albite–sericite veinlets.

Volcanic Rocks

Pre-batholitic volcanic rocks are in many places in contact with granitic intrusions. Such contacts are well exposed along and south of the canyon of Wade Creek, in the mountains southwest of Edith Creek, and in those southwest of Miles Creek. Metamorphism to the albite–epidote facies and to the hornblende–hornfels facies is most common.

Epidotization is clearly visible in outcrops near contacts; the rocks have a yellowish green cast with veinlets and amygdules of epidote. The rocks are mostly converted into epidote-albite greenstone. Microscopically the albitized plagioclase still exhibits a diabasic texture. Epidote is the most prominent mineral in the matrix, within the plagioclase, and in the amygdules. Chlorite, magnetite, carbonate, and quartz occur in varying quantity.

The volcanic rocks southwest of Edith and Lynx Creeks and those south of Wade Creek are pervaded by granitic dykes and sills, or have been hydridized by the introduction of pegmatitic material to such an extent that volcanic and intrusive rocks are difficult to separate. Volcanic rock in close contact with sills of albite

Table III

Modes of Some Granitic Rocks of the St. Elias Mountains

	Kluane Ranges Intrusions												Donjek Range Intrusions							
Specimen No.	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64A	64B	64C	65	66	67
Field No.	562A	$555C_2$	$574D_2$	534J	$513C_3$	$514A_3$	518C	182A	42F	41A	29A	22A	$28F_3$	170F	$164B_1$	$164B_2$	$164B_4$	256J	$251E_2$	168I
Quartz and myrmekite	3.8	27.0	26.0	24.0	35.6	31.6	27.2		0.6	20.2	21.6	15.5	30.0	38.6	30.8	33.0	1.6	3.2	33.6	31.0
Orthoclase	3.4	3.2	5.4	14.4	20.4	14.0	6.6			15.2	7.6	3.3	33.4	59.2	44.0		0.4	0.8	4.6	19.2
Microcline																		0.4	26.6	9.8
Perthite															17.4	63.2		0.2	12.2	
Plagioclase	66.6	61.0	63.4	47.8	40.0	43.6	48.8	69.8	64.4	43.8	57.2	66.5	33.4		5.2	2.4	62.0	79.4	9.6	34.0
Composition of plagioclase	and. lab.	olig.	olig.	and.	olig.	alb.	mainly saussurite	byt.	and.	alb.	and.	and.	alb.		alb.	alb.	lab.	olig.	alb.	olig.
Amphibole	14.2		0.2	9.8	1.2	6.2	4.6	0.6	27.6	1.0	4.5	8.7			2.6		22.8	2.0	13.0	2.0
Pyroxene								22.8				2.7					6.4			
Biotite	3.2	2.8	3.8	2.8	1.2	2.2		1.2	1.6		7.5		0.2				4.8	12.8		3.0
Chlorite	7.2	4.2			0.2	0.2	1.0	3.2	2.2	14.4			2.8				0.8	0.2		
Epidote	0.8	1.8			0.4	0.8	11.8			0.8								1.0		x
Apatite	0.8		0.2	0.4				0.4	0.6	x		x							0.4	x
Magnetite, pyrite			1.0	0.8	1.0			2.0	2.8	2.4	1.3	2.1	0.2	0.6		0.2	0.8		x	0.6
Sericite, muscovite						1.4														0.4
Sphene										2.2	0.4	1.2								
Fluorite														1.6	x					
Zircon																				x
Based on 500 point-counts	Biotite-hornblende quartz diorite	Biotite quartz diorite	Hornblende-biotite granodiorite	Biotite-hornblende granodiorite	Hornblende-biotite leucogranodiorite	Albite granodiorite	Epidotized hornblende-biotite granodiorite	Augite gabbro	Hornblende diorite	Albite granodiorite	Hornblende-biotite granodiorite	Hornblende quartz diorite	Alaskite	Alaskite	Alaskite	Alaskite	Hornblende-biotite gabbro	Hornblende-biotite diorite	Hornblende-albite granite	Hornblende-biotite quartz monzonite

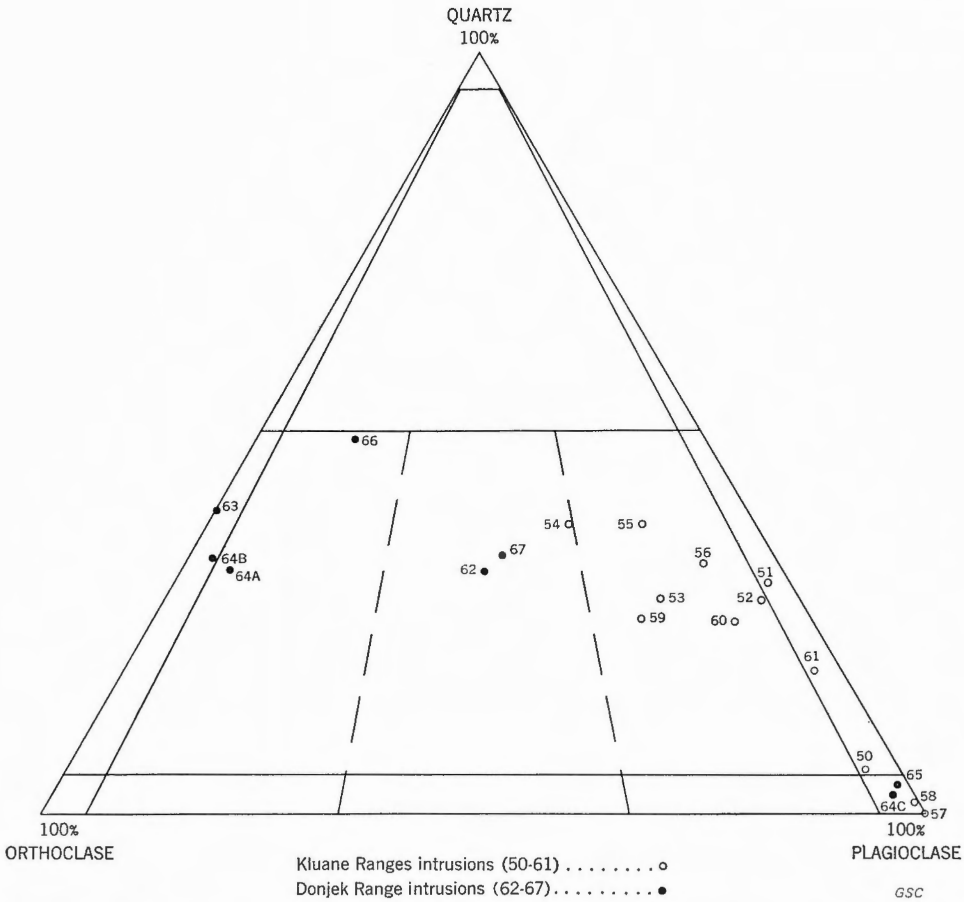


FIGURE 4 **Per cent by volume of quartz, orthoclase, and plagioclase in samples of Kluane and Donjek Ranges intrusions.**

granodiorite is in many places a dense black rock with white or light green specks of feldspar phenocrysts. A thin section shows little change in the original hyalopiliitic texture. The plagioclase phenocrysts are partly saussuritized but the labradorite microlites, up to about 0.3 mm long, are unaltered. Smaller grains of clear augite also occur throughout. Between these there is a profusion of minute, cloudy yellowish grains of epidote, and some aggregates and veinlets of actinolite.

Higher degree of recrystallization to hornblende–plagioclase assemblages has produced gabbroic rocks, which in hand specimens show massive black hornblende penetrating as irregular veinlets and tongues into white weathering feldspathic material, and appear to be partly fine-grained hornblendite. The latter reveals in a thin section 43.5 per cent labradorite, 17.5 per cent augite, 23 per cent hornblende, 1 per cent olivine, 9 per cent magnetite, and 6 per cent sericite. Brown, only slightly pleochroic hornblende pervades the rock with a poikiloblastic texture. It includes patches of augite crystals and plagioclase, but also rims augite with narrow bands.

It also appears as a filling of microscopic linear cracks. Plagioclase is much sericitized, except where included in hornblende, where it is fresh. Magnetite occurs as irregular knotted stringers throughout the rocks.

Hybrid Rocks

Granitic sills and small bodies, occurring in the volcanic rocks of the contact zone, may be hybrid rocks. The intimate mixing of the original green volcanic material with introduced pink or grey pegmatitic material may be observed in many hand specimens. Granitic rock, occurring together with epidotized volcanic rock as described above, is albite granodiorite (Table III, No. 55). A hand specimen from the Edith Creek area is greenish grey, medium grained, and contains abundant specks and spots of dark material. The thin section shows a granitic to micropegmatitic assemblage of quartz, albite and perthitic orthoclase, the feldspars are sericitic. The dark parts are aggregates of very small flakes of biotite, hornblende, chlorite, magnetite, and epidote. It is rather remarkable that the associated dark volcanic rock described in the foregoing section, contains unalbitized labradorite and augite together with much fine-grained epidote.

Another hybrid rock, from the area south of Wade Creek, is shown in Table III, No. 59. The rock is fine grained with a very striking colour mixture of medium yellow-green and pink to blood red. The pink spots apparently represent pegmatitic material that has been introduced into the rock. The thin section shows mainly elongated subhedral plagioclase up to 1 mm long, albitized and with much chlorite, sericite, and epidote. Slightly perthitic orthoclase is also euhedral in part, and appears to envelop albite in places. Interstices are largely filled with quartz–orthoclase micropegmatite. Chlorite has replaced biotite and there are a few grains and needles of hornblende. Also present are large crystals of sphene, scattered magnetite, and some apatite.

Sedimentary Rocks

Sedimentary rocks of the Dezadeash Group, metamorphosed into banded hornfels, have been described with that group. Limestone of Permian or Triassic age is mainly altered into medium- to coarse-grained marble.

Skarn has also developed locally, as on Wade Creek, with medium- to coarse-grained, andradite–epidote–calcite, or andradite–diopside assemblages.

'Donjek Range Intrusions'

In Donjek Range one stock of granitic rocks underlies the glacier-capped peaks at the head of Granite Creek and continues westward to the foot of Donjek Glacier. Another body occurs between the upper part of Donjek River and Bighorn Creek. Larger bodies occur west of Donjek River, between Steele Creek and Spring Creek glaciers, and on both sides of Donjek Glacier. There an intimate mixture of granitic, hybrid, and metamorphic rocks, similar to that south of Edith and south of Wade Creek, occurs, and prohibits an accurate definition of the contact. Judging from aerial photographs and from morainal material, much of the unexplored Icefield Ranges, including Mount Walsh, Mount Steele, and Mount Wood, consists also of granitic rocks.

Lithology

The Donjek Range intrusions are petrographically distinct from those of the Kluane Range (*see* Table III). Their grain size ranges from fine to coarse, and they are commonly light pink or reddish, due to the large amount of potash feldspars and scarcity of dark minerals. Most of the latter occur in unidentifiable aggregates rather than recognizable individual crystals.

Modal analyses show these rocks to be alaskite, granite, and quartz monzonite, but the preponderance of alaskite in the samples tested may not be representative of the bulk of the intrusions.

Alaskite is a fine- to medium-grained, light grey or salmon pink rock with an xenomorphic granular texture, and consists mainly of quartz and potash feldspar (orthoclase, microperthite, and microcline) and in one case considerable albite. Albite, if present, is subhedral and earlier than potash feldspar which may enclose and partly replace it. Potash feldspar occurs largely as perthite, in irregular patchy, or finely lamellar intergrowth with albite. Borders between quartz and potash feldspar are scalloped, with either mineral sending embayments into the other, and the two minerals apparently crystallized together. Some rocks are porphyritic, with euhedral potash feldspar and rounded quartz in a fine quartz–feldspar matrix. There is only a few per cent of dark minerals. Hornblende is dark green and pleochroic, and is probably the arfvedsonite variety. Fluorite is a distinctive component in several slides.

Albite granite (66) is a medium-grained, darkish rock, with recognizable quartz, feldspar, and hornblende crystals. The thin section shows phenocrysts of microcline up to 5 mm across in a matrix of mainly potash feldspar, quartz, and albite, together with considerable hornblende.

Quartz monzonite (67) is a light coloured and apparently fine-grained rock. The thin section shows phenocrysts up to 4 mm in size of microcline and oligoclase. There is much interstitial myrmekite and little hornblende and biotite.

Hornblende-biotite diorite (65) slightly resembles Kluane Ranges rocks and is fine grained, with recognizable biotite, hornblende, and feldspar. The thin section shows oligoclase, mainly untwinned, or finely twinned, with irregular inclusions of microcline, a little microcline and quartz, considerable biotite, and some hornblende.

Contact Metamorphic and Hybrid Rocks

The contact between intrusive and metamorphic rocks of Donjek and Icefield Ranges is indistinct. Granitic dykes and sills are intimately mixed with hornfelsic rock and in many places the two occur in about equal amounts. This relationship is well exhibited on the walls of the Donjek Glacier valley. Several types of contact metamorphic rocks not changed into hybrid granitic rocks, have been described in the section on the schist–greenstone complex of the Donjek and Icefield Ranges.

East of the snout of Donjek Glacier, medium-grained, light pink alaskite (Table III, 64A, B) contains rounded inclusions, 1 inch to 1 foot in diameter, of basaltic rock (64C), in part porphyritic and in various stages of assimilation. The dark parts constitute half or more of the total rock and, where little changed, resemble Tertiary volcanic rocks. The partly assimilated rock, recrystallized into medium-grained gabbro (64C), shows on the hand specimen clusters of hornblende interspaced with light coloured feldspathic material. The thin section shows the light mineral to be mainly subhedral calcic plagioclase, with a few per cent of interstitial quartz and orthoclase. Hornblende, commonly with a nucleus of augite, and in clusters together with biotite form more than 30 per cent of the entire mineral content.

Another specimen of what appears to be assimilated or granitized country rock from the same area of intrusions is a dark, fine-grained rock with feldspar phenocrysts about $\frac{1}{8}$ inch in size. The thin section shows granulitic assemblages with $\frac{1}{2}$ mm grain-size of granodioritic composition, with oligoclase (50%±), quartz (20%±), orthoclase (20%±), and hornblende and biotite (10%±). The phenocrysts are oligoclase.

A recrystallized rock from the area west of upper Donjek River contains pink feldspar porphyroblasts up to an inch across in a fine-grained, dark, slightly gneissic matrix. These are potash feldspar, mainly microcline, in a cataclastic base of quartz, oligoclase, and microcline, all with signs of strain, and many fragments of hornblende, biotite, epidote, sphene, and apatite.

Grey, fine-grained, granite-granulite from the west wall of Donjek Glacier, at the 6,000-foot contour, appears to be intrusive into hornfels. It consists of a granulitic assemblage of quartz, microcline, and oligoclase, with fine biotite, muscovite, epidote, and zircon. Anhedral, porphyroblastic masses of microcline up to 2 mm in size also occur.

Structural Relationships

The granitic rocks of Kluane Ranges show intrusive relationships with Permian and Triassic volcanic and sedimentary rocks, with the basic and ultrabasic sills that invaded these rocks earlier, and with the Jurassic-Cretaceous greywacke sequence. For the smaller bodies the contacts are sharp though highly irregular, with numerous dykes and apophyses traversing the invaded and recrystallized country rocks. Only the larger, originally probably deeper, intrusions between Donjek and White Rivers exhibit in places a diffuse contact zone with mica schist and gneiss, showing metamorphism similar to the regional metamorphism of the Yukon Complex. Tertiary sediments unconformably overlie contact metamorphic and hybrid granitic rocks associated with the 'Kluane Ranges intrusions' in the area south of Wade Creek. But the only direct contact between a granitic body and these sediments, on the north of Granite Creek, is a northeast-dipping fault (Pl. VIII A). At least part of the Kluane Ranges intrusions were therefore emplaced in the period between early Cretaceous and early Tertiary time, when the rocks of Kluane Ranges were also subject to severe folding. After this period of "syntectonic" intrusion the rocks were passively involved in thrust faulting that superimposed them in places on lower Tertiary sediments.

'Donjek Range intrusions' were only seen to invade Palaeozoic rocks. Their contacts are in places poorly defined, due to intimate mixing of granite and country rock, either in dyke swarms or in intrusive breccias. The granitic mass surrounding the foot of Donjek Glacier interrupts an otherwise continuous belt of Kaskawulsh Group and 'greenschist complex' rocks. Furthermore, the forces inducing low grade dynamic metamorphism in these rocks did not affect the intrusions. On the other hand, contact metamorphism induced by the intrusions is superimposed on low grade dynamic metamorphism. Thus the intrusions probably followed the first late-Palaeozoic folding phase affecting Kaskawulsh and greenschist complex rocks.

South of Donjek Glacier contact metamorphic rocks are in fault contact with Tertiary sand and gravel, and at higher elevation Tertiary lava overlies granitic rocks.

South of Granite Creek the Donjek Range granitic rocks form the upper plate of the Duke River thrust, and have been superimposed on Permian to Tertiary beds. Like the Kluane Ranges intrusions, they were therefore involved in Tertiary faulting.

Age of the Granitic Rocks of St. Elias Mountains

The structural data available for defining the age of St. Elias granitic rocks have been summarized in the foregoing section. The Kluane Ranges intrusions intrude Permian to Cretaceous beds, and a contact zone is unconformably overlain by Paleocene or Eocene sediments. The Donjek Range intrusions have invaded pre-Permian rocks, and are overlain by Tertiary lavas. Both types of intrusions were involved in post-Paleocene faulting. Furthermore, fragments in Cretaceous and early Tertiary conglomerates indicate the existence of granitic terranes, subjected to erosion, during those periods. However, these fragments may have come from either the Yukon Complex or the St. Elias Mountains granites. Thus the available evidence shows Kluane Ranges intrusions to be Cretaceous, but possibly in part of older Mesozoic age, whereas Donjek Range granitic rocks are more widely bracketed between the Permian and Tertiary.

As noted, however, the Kluane Ranges intrusions are mainly plagioclase feldspar rocks (granodiorite, quartz diorite, diorite) whereas the Donjek Range intrusions are largely potash feldspar rocks (granite, alaskite, quartz monzonite). Examples of smaller bodies of potash feldspar rocks showing intrusive relations to the major batholiths of plagioclase rocks are common throughout the Cordillera. Some examples are the granitic intrusions of Whitehorse map-area (Wheeler, 1961), Atlin map-area (Aitken, 1959), Fort St. James map-area (Armstrong, 1949), and Nelson map-area (Little, 1960). In each area the potash feldspar-rich rocks are at least slightly younger than the Cretaceous or older main batholith. Only for the Coryell granite is a Tertiary age indicated with some degree of certainty, and for some intrusions in the Atlin area a provisional Tertiary age is assumed. By analogy it may be suggested that the Donjek Range intrusions are younger than the Kluane Ranges intrusions and possibly of late Cretaceous or earliest Tertiary age.

Perhaps the granitic rocks developed concurrently in Yukon Plateau and St. Elias Mountains. If so, the granodiorite and quartz diorite of Ruby and Kluane Ranges developed in Cretaceous, and perhaps also earlier time, and the granite and alaskite of Nisling and Donjek Ranges were emplaced slightly later.

Amphitheatre Formation

Name and Definition

Tertiary sedimentary deposits are widespread in the map-area, though they are small in aerial extent and thickness. Similar beds have been mapped in adjacent regions but have never been named. The name Amphitheatre Formation is here proposed for these beds, after prominent exposures in the badlands on the south side of Amphitheatre Mountain (Pl. VIII A). It is to designate continental, clastic sediments of early Tertiary age. Some late Tertiary deposits may have been included in the mapping, but they are not included in the Amphitheatre Formation.

Distribution

The Amphitheatre Formation occurs in scattered areas in the Duke Depression, west of the Kluane Ranges, from Sheep Creek in the southeast to Rabbit Creek in the northwest. The relative lowness of this belt is partly due to low resistance to erosion of the sediments. The formation occurs also in the continuation of the Duke Depression to the south in the Dezadeash area.

Lithology and Thickness

The formation consists of sandstone and sand, conglomerate and gravel, shale, coaly shale, coal and clay, and tuff, probably in that order of abundance.

Sandstone, pebbly sandstone, and conglomerate, although resistant to erosion, and cliff-forming, merge in places laterally and vertically with their unconsolidated equivalents. Selective and localized bonding of the clastic material is also apparent from concretions, occurring in layers or separately. These do not show any apparent difference in components or bedding from the surrounding unconsolidated material. Boulders generally separate easily from the enclosing matrix and conglomerate faces therefore have a rough surface, following the shapes and imprints of the component clasts. Boulders are everywhere well rounded and commonly have a smooth polished surface. The arenaceous and rudaceous sediments are all light coloured. The harder beds are light yellow, orange, and brown; the softer beds appear to be leached, nearly white. The sandy material is generally arkosic. The coarse components are volcanic, intrusive, and minor sedimentary rocks in various proportions derived from older formations of the Kluane and Donjek Ranges, and metamorphic rocks, probably derived from the Yukon Plateau to the east.

Field identification of 100 boulders from a ridge at the head of Congdon Creek gave the following distribution:

Quartz-feldspar pegmatite	2
Coarse-grained granite (pink feldspars)	1
Fine-grained quartz monzonite	6
Quartz monzonite	3
Biotite granodiorite	12
Hornblende granodiorite or quartz diorite	5
Hornblende diorite	2
Gabbro (medium and coarse grained)	3
Peridotite	1
Rhyolite	4
Porphyritic dacite	12
Porphyritic basalt or andesite	4
Basalt or andesite	3
Cherty tuff	1
Quartzite	5
Dark banded quartzite	2
Vein quartz	7
Fine-grained gneiss	17
Quartz-feldspar-biotite gneiss	10
	100

This rock assemblage suggests derivation from the Yukon Complex. Typical St. Elias sediments are missing, and the minor amount of volcanic rocks might equally well have its source in dykes of the Yukon Complex as in volcanic formations of St. Elias Mountains.

Light brown and grey shale, laminated to poorly bedded, occurs in minor amounts and locally carries fossil leaves. Some beds of tuffaceous shale and sandstone also contain such imprints. Coal, coaly shale, and soft grey underclay are found in most areas of exposure, but generally contain only a few inches to 2 feet of clean coal. These deposits are discussed more fully under *Economic Geology*. The sedimentary succession appears to be cyclic, with conglomerate at the bottom, ranging through pebbly sandstone and sandstone, to shale with clay and coal at the top. The total thickness of the formation varies greatly. On the south slope of Amphitheatre Mountain roughly 1,500 feet is exposed, and the measured section on the Wolverine escarpment totals about 1,900 feet. On the other hand, in the area west of upper Donjek River, beds assigned to the Amphitheatre Formation are generally less than 200 feet thick, and in many places Tertiary volcanic rocks directly overlie pre-Tertiary formations.

Structural and Contact Relations

So far as can be established, the Tertiary sediments are gently folded in a shallow syncline along the northeast side of their discontinuous belt of exposures, but are thrown in steep open folds on the southwest side. Flat-lying beds and gentle folds are well exhibited west of Ptarmigan Creek, on Amphitheatre Mountain (Pl. VIII A), and south of Wade Creek; steep folding is best demonstrated in the Cement Creek area. This creek derives its name from steep, concrete-like walls of Tertiary conglomerate. Though the Amphitheatre beds have been folded, they obviously only participated in the last phases of orogeny, and the major compression occurred before their deposition. The most intense tectonic movement involving these beds is exhibited on Sheep Creek, where Permian and Triassic gabbro and volcanic rocks overlie the sediments on a flat overthrust (Pl. IX A).

The unconformity at the base of the formation may be observed in several places and in some the angularity is visible. Thus flat-lying Tertiary sediments between Bullion and Sheep Creeks overlie steeply dipping Dezadeash beds. A slight distance to the north, the contact with the Mush Lake limestone is steep to overturned but apparently not a fault. Between the heads of Congdon and Nines Creeks, Tertiary gravels lie with angular unconformity on Cretaceous as well as Triassic sediments. An east tributary of Ptarmigan Creek, heading near point 6800, exposes Triassic or older gabbro overlain by Tertiary gravels. The gabbro has a weathered zone, at least 4 feet thick, the lower part of which consists of fragments of crumbly gabbro in rusty 'sand', the upper part is mainly 'sand', but exhibits on close inspection the texture of the original rock. On a south tributary of Granite Creek, Mush Lake volcanic rocks are similarly weathered to a depth of about 10 feet below the contact with Tertiary gravels. Between Burwash Creek and Donjek River the formation lies unconformably on gabbro and Triassic volcanic and sedimentary rocks, and on an area of contact metamorphic rocks. West of Donjek River the angular unconformity is well displayed in an anticline of Amphitheatre beds, with more complexly folded Mush Lake sediments in the axial part.

The occurrence in Tertiary conglomerate of boulders, derived largely from Mesozoic volcanic and intrusive rocks, confirms this unconformable relationship.

Origin

There can be little doubt that the Amphitheatre beds were deposited in fresh-water lakes and rivers, and most writers, considering similar Cordilleran early Tertiary sediments, have suggested intermontane basins. Bostock (1952) pointed out that Tertiary sedimentary rocks occur along the Duke Depression in small scattered areas, commonly exhibiting relatively thick, horizontal successions of strata, only tilted and faulted along the southwest side. He concluded that they were deposited in the hollows of an old land surface of marked topographic relief and that local warping and faulting occurred later.

It should be borne in mind, however, that Tertiary sediments may have been deposited over a wide belt west of the present Shakwak Trench. Present exposures, mainly at relatively high elevations, are but small erosional remnants and some tracts of these sediments may be concealed by flat overthrusts in Kluane Ranges. The sedimentary facies demonstrates the momentous change that occurred between the deposition of the Dezadeash Group and the Amphitheatre Formation. The former accumulated in the marine deep waters of the eugeosyncline, the latter in continental basins on the folded, intruded, uplifted, and partly levelled geosynclinal deposits.

And whereas the Dezadeash Group may be compared to "preparoxismal" flysch deposits, the Amphitheatre Formation finds its counterpart in the Alpine Molasse, with a slight difference in relative ages. Both are at least partly continental sediments, containing many conglomerates with boulders of older igneous and sedimentary rocks. And both accumulated after the main folding, in basins near or within the newly elevated mountains, but were affected by late phases of folding and overthrusting.

Age

One collection of fossil leaves from the Amphitheatre Formation was identified and commented on by W. L. Fry, previously of the Geological Survey.

GSC plant locality 4874. Badlands Creek below Amphitheatre Mountain, lat. 61°18′25″, long. 139°22′15″:

Metasequoia occidentalis (Newberry) Chaney
Alnus kenaiana Hollick
Alnus alaskana Newberry
Alnus cf. *A. alnifolia* (Goeppert) Hollick
Corylus evidens Hollick
Ulmus borealis Heer
Uιmus cf. *U. speciosa* Newberry
Salix sp.

Although this small flora does not yield altogether conclusive evidence as to its age, it does have several species identical with those found in Alaskan Tertiary floras. The Alaska floras are generally considered to be Paleocene or possibly in part early Eocene. This Yukon flora can be correlated with those in Alaska.

Later collections were determined and commented on by D. C. McGregor, of the Geological Survey.

GSC plant locality 4985. Headwaters of McLellan Creek, lat. 61°51′30″, long. 140°56′20″:

Corylites fosteri (Ward) Bell
Equisetum arcticum Heer
cf. *Sequoia concinna* Heer

GSC plant locality 4986. Creek south of Rabbit Creek, lat. 61°49′40″, long. 140°51′40″:

Several fragments of angiosperm leaves, including perhaps
Alnus or *Ulmus*

GSC plant locality 4987. West cutbank of St. Clare Creek, lat. 61°29′20″, long. 140°22′0″:

cf. *Alnus alnifolia*
Sapindus or *Salix*
cf. *Ulmus*
Several other fragments of angiosperm leaves, too fragmentary for identification. There was a meagre spore flora, in which the following genera were recognized:
Leiotriletes (= *Deltoidospora*)
Acanthotriletes
Calamospora

98818—7

None of the collections is sufficient to allow accurate age assessment. Lot 4985 suggests early Tertiary. Lots 4986 and 4987 suggest an early Tertiary age, but this is by no means definite. The spores found in 4987 are long ranging and of no use for dating these beds.

An earlier collection from about the same locality as plant locality 4874 on Amphitheatre Mountain was made by H. S. Bostock (1952) and examined by W. A. Bell:

Conifers
Sequoia langsdorfii (Brongniart) Heer
Angiosperms
Trochodendroides arctica (Heer)
Corylites hedridica Seward and Holtturn
Age indicated is Paleocene

A Paleocene to Eocene age is therefore most likely for the Amphitheatre Formation.

Correlation

In Alaska (Smith, 1939), Tertiary coal-bearing beds, similar to the Amphitheatre Formation and with plant fossils of probable Eocene age, occur in a broad band on the north side of Alaska Range. South of that range, the Kenai Formation of Cook Inlet, the Chickaloon Formation of the Matanuska Valley, have long been known as early Tertiary coal-bearing deposits. In southeastern Alaska scattered exposures of continental and interbedded marine Eocene beds have been found.

Beds of equal age and lithology were also mapped directly southeast of the map-area by Kindle (1952) and Watson (1948). The Sustut Group of northern British Columbia (Lord, 1948) is also a coarse clastic continental formation, unconformably overlying folded and intruded Mesozoic rocks, and is itself partly flat lying and partly gently folded. However, according to the evidence of fossil leaves, it may be Upper Cretaceous to Paleocene and thus slightly older.

St. Clare Group

Name and Distribution

The youngest group of bedded rocks in the map-area is a sequence of lavas and tuffs, overlying the Amphitheatre Formation and occurring partly as horizontal, partly as gently folded beds. The group has previously been designated as "Newer Volcanics" (Cairnes, 1915), or "Tertiary Volcanic Rocks" (Kindle, 1952), but the name St. Clare Group is here proposed because of the extensive exposures of these volcanic rocks in the drainage area of St. Clare Creek.

The group underlies the highest part of Kluane Ranges east of Duke River, where it forms peaks up to 8,500-foot elevation. It also underlies an area west of Duke River and some higher peaks of Donjek Range. A cap of volcanic rock overlying Tertiary sediments on Amphitheatre Mountain is conspicuous from the Alaska Highway. West of Donjek River small caps of volcanic rock are present south of Donjek Glacier, and north of Steele Creek (Pl. VIII B) to beyond Klutan Glacier is an impressive sequence many thousand feet thick of St. Clare volcanic rocks that covers a wide belt, which decreases in width towards the Alaska border. The group is divided into a lower formation consisting mainly of volcanic flows and pyroclastic rocks and an upper formation of mainly volcanic–boulder conglomerate.

Lithology and Thickness

The variations in lithology of the St. Clare Group are well expressed in the following stratigraphic section, measured on the escarpment south of Wolverine Creek; it includes also the Amphitheatre Formation.

	Thickness (feet) Unit	Total to base of section
ST. CLARE GROUP		
Upper Formation		
(aggregate thickness 655 feet ±)		
Overlying strata covered		
Flow breccia, appears more acidic than underlying breccias, light green rock fragments and yellowish glassy feldspar phenocrysts in light reddish grey matrix	60	3,975
Covered interval	50	3,915
Flow breccia, black, with lenticular blobs of black obsidian	20	3,865
Tuff breccia, basaltic	20	3,845
Covered interval	20	3,825
Basalt, amygdaloidal	130	3,805
Volcanic pebble conglomerate, well-bedded and fairly well sorted, mainly basalt pebbles; upper part contains layers of tuff with white, porous, lapilli and other beds with larger fragments of yellowish white, light red, dark red, and black-grey pumice in a yellowish grey matrix. Some beds appear to be water transported with well-sorted fragments, others contain unsorted fragments	110	3,675
Volcanic-boulder conglomerate, boulders to 3 feet in diameter and slightly rounded, some finer beds with fairly good bedding	80	3,565
Covered interval	20	3,485
Lapilli tuff, fairly well bedded, basaltic and white pumice fragments	20	3,465
Lapilli tuff, mainly white pumice fragments	25	3,445
Volcanic breccia and coarse tuff, mainly basalt blocks, up to a foot in diameter	100	3,420
Lower Formation		
(aggregate thickness 1,440 feet ±)		
Covered interval	20	3,320
Basalt, mainly amygdaloidal	90	3,300
Coarse tuff and tuff breccia	30	3,210
Basalt, bottom massive, top amygdaloidal	10	3,180
Covered interval	20	3,170
Basalt, mainly massive	20	3,150
Basalt, bottom is massive, top amygdaloidal, with a red 2-foot breccia layer on top	55	3,130
Volcanic breccia	10	3,075
Basalt, mostly amygdaloidal; falls over hard massive layers	160	3,065
Basalt, mostly amygdaloidal, partly covered	200	2,905
Basalt, mostly vesicular and in places porphyritic, basal part massive. A few feet of brick-red breccia at top	140	2,705

	Thickness (feet) Unit	Total to base of section
Lower Formation (cont'd)		
Basalt, mostly amygdaloidal	220	2,565
Tuff, thick-bedded, light purplish grey, fine- and coarse-grained; a few beds of lapilli tuff. Two feet of top layer baked brick-red by overlying flow	135	2,345
Basalt, massive, large amygdules at bottom, also vesicular in upper part	25	2,210
Basalt, vesicular and crumbly, partly covered	95	2,185
Ash and tuff, poorly exposed	10	2,090
Basalt, vesicular, feldspar phenocrysts	20	2,080
Basalt, massive, slightly porphyritic, rough columns about 4 feet in diameter	50	2,060
Sand with coaly streaks	2	2,010
Basalt, with rough columnar jointing. Roughly spheroidal, vesicular basalt in upper 20 feet	98	2,008
Basalt, massive, aphanitic, irregular spheroidal masses, about a foot in diameter, at base; smaller round masses at top	30	1,910
AMPHITHEATRE FORMATION (aggregate thickness 1,880 feet ±)		
Tuff, partly consolidated, white, fine- to coarse-grained, in places with current bedding; 3 inches of coal 2 feet above base, some plant fossils	30	1,880
Conglomerate, well consolidated, breaks across pebbles	15	1,850
Sand, fine- to coarse-grained, clayey, whitish, some interbedded ash; a few bands of coaly shale near top	70	1,835
Sand, shaly, fine-grained, with harder fine-grained tuff on top, contains imprints of ferns and deciduous leaves	10	1,765
Sand, locally argillaceous, medium- to coarse-grained, white-grey, some tuffaceous layers	85	1,755
Coal, clean, brittle, with dull lustre	6 in.	1,670
Clay, with white sandy layers	2	1,669½
Coal, as the above	6 in.	1,667½
Sand, fine-grained, clayey, and shale; some coaly layers with here and there a shaly coal bed about 2 inches thick, thinly fissile; in places directly on basalt	10	1,667
Basalt, dark grey, hard and massive, lower 2 feet crumbly, vesicular	20	1,657
Shale, silty, greenish grey, poorly bedded, with some sandy and coaly layers; upper part contains thin beds of tuffaceous and bentonitic material	250	1,637
Sand, and sandstone, feldspathic, white and yellow, medium-grained; a few inches of dark clay and coaly shale at bottom	3	1,387
Sand, shaly, medium- to coarse-grained, some pebbly layers	10	1,384
Pebble conglomerate, well consolidated	20	1,374
Sand, grey, argillaceous, medium-grained	20	1,354
Sandstone, very coarse, and granule to pebble conglomerate, only locally well consolidated; concretions; one foot of coaly shale near top	45	1,334
Sand, feldspathic, medium- to coarse-grained, a few thin layers of coaly shale	50	1,289
Shale, grey, with 2 inches shaly coal on top, lenticular	1	1,239
Sand, grey, medium-grained	3	1,238
Conglomerate, pebble- to cobble-size; falls over lower part	40	1,235
Gravel, granule- to pebble-size, poorly sorted	40	1,195
Shale, sandy, grey, soft, partly covered	30	1,155
Sand, coarse-grained, slightly consolidated	10	1,125
Conglomerate, pebble-size, fairly well consolidated, disc-shaped concretions on top	10	1,115
Shale, grey, sandy, poorly bedded, with three shaly coal seams, about 2 inches thick	25	1,105
Sandstone and pebble conglomerate, 1 inch of coal, all poorly exposed	60	1,080
Shale, sandy, grey, hard, poorly bedded	20	1,020
Sand and gravel, mostly poorly exposed, thickness approximate		1,000

Lower Formation

The Tertiary volcanic rocks are distinguished by their reddish to rusty brown colours and general freshness, as compared to the predominantly green, more altered aspect of Mesozoic extrusive rocks. The flows are mainly basaltic and, as the measured section shows, range in thickness from 10 to 200 feet. They are commonly massive; in places columnar in the lower part, and vesicular to amygdaloidal near the tops. Tops may be brecciated, and brick-red due to abundant hematite. Fillings of amygdules and cavities in breccia are calcite, chalcedony, and zeolites.

In thin section the basaltic matrix is seen to consist of an assemblage of clear, unaltered laths of labradorite about 0.2 mm long, soft-pink slightly pleochroic augite, and magnetite. The augite may be ophitic or granular, and both textures may occur within one thin section. Interstitial material and amygdules consist mainly of carbonate and chlorite. Minor constituents are apatite, hematite, and epidote. Many samples contain phenocrysts of labradorite with complex twinning, from 1 to 5 mm in size, and smaller olivine entirely altered to serpentine and carbonate.

In the Donjek region, south of Hoge Creek, andesite was seen with parallel arrangement of tabular andesine, up to an inch in size. The thin section reveals two generations of plagioclase, but no mafic minerals.

A specimen of fine-grained, maroon tuff reveals in thin section fragments of volcanic rock, less than 1 mm in size, and broken fragments of feldspar in a carbonate–hematite matrix. The fragments are mainly small laths of andesine, embedded in hematite.

The thickness of the measured section south of Wolverine Creek is 1,440 feet. A much thicker section, totalling 4,600 feet, and not including any part of the upper conglomerate formation, was described by Sharp (1943) from the flat-lying succession north of Steele Creek.

Conglomerate Formation

The upper 655 feet of the described section constitutes a separate unit of the group, which consists of conglomerates, containing mainly pebbles and boulders of Tertiary lavas, volcanic breccia, and tuff. Similar conglomerates are also widespread in the St. Clare and Bull Creeks area. Their dips conform to those of the underlying St. Clare volcanic rocks, from which the boulders are exclusively derived. They are angular to rounded, and up to 2 feet across. A section of over 500 feet, between St. Clare and Count Creeks, exhibits only coarse conglomerate at the bottom. Upwards the beds are finer grained, with more intercalations of brown sand and red-brown shale, also of volcanic origin and containing scattered pebbles. Towards the top some light coloured tuff and some coal and plant remains were seen.

The described section contains tuff and flow breccia overlying the conglomerate beds. A welded tuff contains grey angular fragments in a coaly black, glassy matrix. Under the microscope this rock shows fragments of basalt and andesite, consisting mainly of labradorite or andesine and minor augite and separate broken crystals of these minerals, in a dark reddish brown unaltered glass matrix. The uppermost breccia contains fragments of porphyritic latite, with phenocrysts of albite and aegirine–augite in a matrix of the same minerals and tourmaline. This breccia may well be related to the Tertiary intrusive rocks described in a later section.

Structural and Contact Relations

The St. Clare Group is folded to the same degree as the Amphitheatre Formation. It occurs as a shallow syncline, with dips up to 45 degrees, in the Kluane Ranges east of Duke River. West of Duke River and in the area between Steele Creek and Klutlan Glacier, several parallel folds, some with steeply northeast-dipping limbs occur (Pl. VIII B). The folding of the formation is confined to a northeastern margin of the outcrop area and is most pronounced along Duke River fault. Farther southwest the lavas are undisturbed.

From published reports it would appear that Tertiary lavas in adjacent areas are only locally folded. To the west of the map-area, Capps (1916a) mentions near-vertical lava beds in the White River basin, but his report and Moffit's work (1954) indicate that most of the Wrangell lavas in the eastern Alaska Range are essentially flat lying. Wheeler (1963) found that Tertiary volcanic rocks in Kaskawulsh map-area are undeformed, but Kindle (1952) stated that in Dezadeash area the beds, though flat lying in many places, show dips ranging up to 30 degrees. As in Kluane Lake area, folding of Tertiary lavas is therefore confined to certain belts of the St. Elias Mountains and Alaska Range geosyncline. However, in a more southwesterly tectonic element, the Yakataga geosyncline, Tertiary sediments were moderately to strongly compressed in latest Tertiary to Quaternary time (Miller, 1957). Local folding of Tertiary lavas in St. Elias Mountains may have occurred at the same late date, or earlier.

The contact between the Amphitheatre Formation and the St. Clare Group may be conformable and to some extent gradational, as indicated in the measured section. Although there is a definite break, with sandstone and conglomerate below, and lava and tuff above, one 20-foot lava flow occurs in the Amphitheatre Formation at 223 feet below the assumed contact, and some sand and coal occurs in the St. Clare Group at 128 feet above the contact.

The St. Clare Group overlaps the Amphitheatre Formation to the west. In Donjek Range and north of Steele Creek the volcanic sequence lies unconformably on Mesozoic and older rocks. West of upper Donjek River, however, some sediments again occur below the volcanic rocks.

Origin, Age, and Correlation

The volcanic rocks were poured out over a land surface established and elevated in late Cretaceous to early Tertiary time and in part covered by the Amphitheatre continental sediments. Unaltered basaltic dykes, found in these sediments as well as in some older rocks, indicate that the lavas welled up through fissures. Tuffs and breccias interbedded with the lavas suggest that volcanoes over these fissures acted as centres of eruption and explosion. These may now be marked by stocks of felsitic rock.

The age of the St. Clare Group can only be determined as Paleocene or younger, on the basis of the Paleocene or Eocene age of the Amphitheatre Formation.

The conglomerate beds in the upper part of the St. Clare Group are directly on trend with the "Older glacial beds", mapped by Capps (1916a) in Alaska, north of the origin of White River at Russell Glacier. These beds are steeply tilted and consist of beds of gravel, interbedded with eight layers of 'tillite', ranging from 4 to 200 feet in thickness. The boulders are "mostly basic extrusive rocks of brown, purple, and reddish colour, and the matrix has a slight purple tinge." Photographs of some of the boulders, presented in the above report, show distinct glacial striations.

Though striated boulders, and layers that have the appearance of till or tillite are missing, the description fits the deposits on St. Clare Creek. It is probable that the two similar formations are correlative, but nonetheless there is as yet insufficient evidence to assign a Pleistocene age to the upper St. Clare Creek beds. The Alaska and Yukon occurrences of folded gravels would merit detailed investigation to establish more clearly their age and correlation.

In the eastern Alaska Range, adjacent to Kluane Lake area, Moffit (1954) considered the Wrangell lavas, overlying Tertiary sediments, to be of Eocene to Recent age. They are slightly tilted but "do not appear to have taken part in the folding that affected the coal beds." Extrusion of the lavas has continued intermittently almost until recent time, and Mount Wrangell has emitted steam and ash in historic time. It seems that, with the information at hand, a similar age of Paleocene to Recent must be applied to the St. Clare Group.

Tertiary Intrusions

Sills, dykes, and small stocks of felsitic or basaltic composition occur widely in the Tertiary sedimentary and volcanic rocks, but only the larger ones are shown on the accompanying map. A porphyritic texture attests to the shallowness of these intrusions. The small stocks could be interpreted as former centres of eruption that were finally plugged with felsitic material. There is also some suggestion that a lake in the felsite cone north of Cement Creek is an explosion crater.

Latite, Rhyolite, and Trachyte

The more prominent felsitic bodies, about 2 miles in diameter and conspicuous in the landscape by their white colour, occur west of Count Creek, north of Cement Creek, and at the head of Halfbreed Creek. The rocks are creamy white, pink, light reddish brown, or light green and commonly have feldspar phenocrysts up to 2 mm in size. Thin sections reveal differences in composition. Latite is perhaps the most common rock type. The phenocrysts are andesine or oligoclase and, in some samples, light green augite. The feldspar of the matrix is mainly sodic plagioclase, up to 0.2 mm long. Hematite, epidote, and calcite also occur in various amounts. Kindle (1952) described similar but coarser grained Tertiary rocks from the adjacent Dezadeash area as soda syenite. Rhyolite contains phenocrysts of potash feldspar, in some samples together with biotite or aegirine-augite. The matrix consists of a trachytic mesh of sanidine laths, up to 0.2 mm long, and interstitial quartz. Fine hematite, aegirine–augite, and tourmaline may also occur.

Rocks classed as trachyte are similar, but lack detectable quartz in the matrix. A coarser variety of this rock exhibits a granular assemblage of potash feldspar up to 2 mm in size, less albite, and interstitial quartz and micro-pegmatite. Mafic constituents to a total of about 30 per cent are light coloured augite with grass-green rims, magnetite, tourmaline, and some apatite.

Olivine Gabbro

A steeply dipping body of gabbro, more than 500 feet wide, occurs within folded Tertiary volcanic rocks south of Cement Creek and strikes parallel with the beds. Similar gabbro also outcrops on a tributary north of Steele Creek (Pl. VIII B). The rock is medium grained, but a porphyritic phase, about 10 feet wide with feldspars up to one inch in size, was seen at the contact with Tertiary volcanic rocks north of Steele Creek.

In thin section the gabbro exhibits a diabasic assemblage of clear labradorite and deep pink, non-pleochroic augite, up to 2 mm in size, and smaller, remarkably fresh, olivine. Olivine may be enclosed in augite and exhibits only minor serpentine-filled cracks. Magnetite occurs abundantly as grains and rods. In the field these young gabbros cannot be distinguished with certainty from the older group of basic intrusions if not in contact with Tertiary formations. Under the microscope, however, they are readily distinguished by the general freshness, the characteristic pink augite, and the presence of unaltered olivine. With some doubt other gabbros, exposed on Steele Creek, which show extensive alteration into secondary hornblende, actinolite, and chlorite, have been assigned to the older group of rocks. They may however belong to the younger group and their alteration may be related to the proximity of the Duke River overthrust, which was active after their intrusion.

Besides these gabbroic bodies there are many smaller basaltic feeder dykes, which are lithologically like the lava flows that penetrate both Tertiary sedimentary and volcanic rock.

Sub-Recent Volcanic Ash

A layer of white volcanic ash occurs locally in all parts of the map-area, and is mainly preserved in low-lying areas under a thin cover of vegetation. This ash is widely distributed in Yukon Territory and Alaska and has been described fully by several writers, mainly Moffit and Knopf (1910), Capps (1916 a and b), and Bostock (1952). The present work has mainly led to confirmation of previous reports, and the following is largely based on them.

Distribution

Capps, and later Bostock, gave isopach maps of the ash layer showing greatest thickness south of White River, at the Alaska–Yukon border, where the explosion occurred. Greatest known extent of the ash is to the east where it occurs on the Mackenzie–Yukon Divide, 450 miles from the centre of dispersion. Capps suggested that, if observations had been made at the time of explosion, the ash fall might well have been perceptible to a distance of 1,200 to 1,500 miles, as in the Alaskan Katmai explosion of 1912. Within Kluane Lake map-area, the mainly easterly transport of ash by the then prevailing wind is readily seen in the field. Ash beds 6 inches to more than a foot thick occur in the west third of the area, whereas only a few inches is present in exposures farther to the east.

Centre of Dispersion

All previous reports agree that the explosion crater must have been near Mount Natazhat. The area west of the foot of Klutlan Glacier, on both sides of the International Border, is covered with dunes of ash, which from a distance and on photographs look like snow (Pl. V, middle distance). The dunes are up to several hundred feet high, and the original thickness of ash, though now perhaps multiplied in the dunes, could be about 100 feet. A suggestion by T. Riggs Jr., a surveyor of the International Boundary Commission, that the crater might lie in a glacial cirque 4 miles north-northeast of Mount Natazhat is quoted by Capps, but he was unable to visit the locality.

The writer believes that the crater probably lies at the foot of Natazhat Glacier, in a roughly circular area of ash dunes with knob-and-kettle topography (Pl. XI). During the field work, this area was considered as part of the Natazhat Glacier end moraine, as shown on the published topographic map on scale 1:250,000. However, in comparison with neighbouring glaciers this foot appears to be far too long and too wide. Furthermore, an actual end moraine of the glacier can be seen along the south side of the area of ash dunes. This moraine is marked on the aerial photograph (Pl. XI) by a band of white ash, that presumably fell on the glacier some 1,400 years ago and is now concentrated at the foot. If this area of ash dunes indeed represents the explosion centre, it was evidently filled up by ash falling back into the crater and by morainal material in the south part.

Lithology

The grain size of the ash no doubt varies with distance from the source. Within Kluane Lake area, the ash superficially resembles a coarse white sand, with grains up to several millimetres in size. Fragments of pumice up to 4 inches long are mentioned by Capps in the area of thickest ash, and were collected by the writer on the surface and in crevasses of dead ice of Klutlan Glacier, exposed where Generc River cuts through the wasting and forest-covered glacier terminus.

The glassy substance of the pumice is colourless and transparent under the microscope and contains many gas bubbles. Hornblende and feldspar crystals may be enclosed. A refraction index of about 1.495 indicates rhyolitic to dacitic composition. Grains of plagioclase and hornblende make up about one quarter of the ash. The plagioclase is zoned and twinned, and andesine to labradorite in composition. The hornblende is acicular, green, and faintly pleochroic. Biotite, noticed by Knopf, was not seen in ash examined by the writer.

Time of Eruption

Hayes noted in 1892 that nearly all the ash that fell on Klutlan Glacier is now concentrated in the terminal moraines. Thus the ice moved from snowfield to glacier foot since the explosion. To cover that distance, several hundred years would certainly be required.

The time of the ash-fall was roughly calculated by Capps (1916b) from an exposure on White River where a 2-foot layer of ash is covered by 7 feet of peat. From various sets of horizontal tree-roots that grew successively from tree-stems, keeping pace with rising permafrost, and from correlative tree-ring counts, he calculated a growth of peat of one foot in 200 years. This led to a rough estimate of 1,400 years for the age of the peat directly overlying the ash. Most recently this estimate has been substantiated by radiocarbon dates of peat, above the ash, which were between 1,750 and 1,520 years (Fernald, 1962).

Genetic Relationships

The explosion is perhaps related to the felsitic rocks intruding Tertiary sedimentary and volcanic rocks as sills and plugs. These, and the recent vent, are aligned north of Duke River fault. In the rhyolite cone north of Cement Creek there is also a suggestion of an explosion vent. Perhaps acidic magma, differentiated from the basaltic magma of Tertiary and Quaternary volcanism, could rise to the surface along this fault zone or fissures near it to form shallow intrusions and occasional volcanic explosions.

Chapter IV

STRUCTURAL GEOLOGY

Kluane Lake map-area occupies parts of two distinct major tectonic belts that may be traced far into Alaska and British Columbia. The northeastern belt is part of a positive zone, underlain by crystalline rocks of the Yukon Complex, and may be called Yukon geanticline. To the northwest, in Alaska, it continues as the Tanana geanticline (Miller, Payne, and Gryc, 1959). To the south it splits in the eastern and western crystalline belts of Gabrielse and Wheeler (1961). The western belt has also been called Coast geanticline. The structure of the Yukon Complex has been discussed briefly in the appropriate section earlier in this report.

The southwestern belt is underlain by folded eugeosynclinal rocks of St. Elias Mountains and may be called St. Elias geosyncline. To the northwest it continues in the Alaska Range geosyncline, to the south in the Seymour geosyncline of the Alaskan Alexander Archipelago (Miller, Payne, and Gryc, 1959).

The two regions are separated by the lineament of Shakwak Trench, generally regarded as an important structural feature (Pl. I).

Shakwak Lineament

Shakwak Trench is mentioned in foregoing chapters as the major trunk valley separating St. Elias Mountains and Yukon Plateau. Earlier explorers like Brooks (1900) and McConnell (1905) regarded it as a major physiographic feature but did not recognize its structural significance. More recently Bostock (1948) compared the valley to the Rocky Mountain Trench and Tintina Valley, and later (1952) suggested that the straight, steep front of Kluane Ranges on the southwest side (Pls. I, V) and the marked difference in the geology on each side of the valley were evidence of a great fault zone, extending at least from White River to Dezadeash Lake. He also drew attention to a lineament, locally visible in airphotos (Pl. IV) and crossing glacial features such as drumlinoid ridges, that may reflect a post-glacial fault. From the alignment of the mounds he inferred possible lateral movement.

Later, St. Amand (1957) and Twenhofel and Sainsbury (1958) boldly traced a Denali fault or lineament, running in a wide arc for 1,600 miles from Bering Sea, north of and through Alaska Range, to Shakwak Trench and thence to the Lynn Canal–Chatham Strait lineament or alternatively to the Coast lineament along the southwest edge of the Coast Mountains 'batholith'. St. Amand speculated further that the Denali fault might be continuous with the Californian San Andreas fault-system, and considered the possibility of a right-lateral transcurrent movement of 150 miles along the Denali fault. Twenhofel and Sainsbury (1958) pointed out that the geological data neither support nor deny this hypothesis, and Gabrielse and Wheeler (1961) also have misgivings when considering the implications of movement of such extent. The writer earlier (1958) suggested that the Shakwak lineament is an old hinge line between the Yukon–Tanana geanticline and St. Elias geosyncline, along which from time to time considerable vertical movement occurred between these two geological regions.

General Features

Along the 200 miles of Shakwak Trench the Kluane Ranges front is steep and remarkably straight, contrasting with the lower, indistinct border of Yukon Plateau. Thus the Kluane front may well be a fault scarp. The position of the fault on the geological map is tentatively based on linears visible on airphotos along the southwest edge of the valley deposits.

The components of the Yukon Complex are no doubt older than most of the St. Elias formations, and the regional metamorphism and granitization of the complex probably occurred at considerable depth. Thus a total rise of the northeast side of the lineament of many thousands of feet is indicated. Yet the Kluane scarp and the much greater height of the St. Elias block strongly suggest a rise of several thousand feet on the southwest side in Tertiary and Pleistocene time.

A notable feature, also observed along the Rocky Mountain Trench, is the divergence (up to 30 degrees) of the direction of the lineament and the trend of formations abutting it. Rocks exposed at the edge of Kluane Ranges are largely highly sheared and disturbed volcanic rocks, partly changed to chlorite schist, with minor argillite and limestone. Bedding and schistosity, if more or less uniform, commonly strike northwest, with a vertical or steep southwest dip. Steep northeast dips and moderate southwest dips occur also, mainly of bedding planes. Minor faults may be seen in some places, most with steep or vertical fault planes. No exposures are known of the principal fault, presumably separating Yukon Complex rocks from those of the St. Elias Mountains.

Possible Extensions of the Lineament

To the south in Dezadeash map-area (Kindle, 1952), the wide Shakwak Trench terminates in Dezadeash Lake, or may be considered to bifurcate into two much less distinct lineaments along minor valleys. One branch continues in the direction of the main valley along Frederick Lake and the middle part of Kusawa Lake, between granitic rocks of the Yukon Complex, and is not evident farther southeast. Another branch may continue with a deflection of 40 degrees along the Klukshu Valley, separating Dezadeash Group and Yukon Complex rocks, partly with indicated fault contact. South of there, Watson's mapping (1948) did not bring out a prominent lineament of either physiographic or geological importance. However, St. Amand (1957) projected his Denali fault through Lynn Canal and Chatham Inlet, and Twenhofel and Sainsbury (1958) suggested a split, with one lineament following the southwest edge of the Coast Mountains. To the north, the lineament follows the front of the Nutzotin Range and Mentasta Mountains, consisting mainly of Jura-Cretaceous sediments. The extension between Little Tok and Slana Rivers is doubtful, as no clear topographic or geological expression of the lineament exists. It may follow a small range mapped as Devonian and Carboniferous by Moffit (1954), thereby separating Devonian fossil localities to the northwest from Permian localities to the southwest, as listed in Moffit's bulletin. Thence the lineament may be traced into the "great fault", mapped first by Mendenhall (1905), that separates for some 50 miles the metamorphic complex to the northeast from Permian and younger rocks to the southwest. Geologically, the contrast of rocks on either side of the fault is just like that along Shakwak Trench, morphologically the difference is reversed, as the metamorphic rocks form the crest of the Alaska Range whereas the younger rocks to the south occupy a low-lying area on the northern margin of the Copper River basin.

To Delta River, the course of the lineament is the same as that of the Denali fault proposed by St. Amand (1957). Farther west the Denali is considered to follow Anderson Pass fault in the Alaska Railroad area (Capps, 1940), and the Farewell and Holitna faults in the Kuskokwim region (Cady, *et al.*, 1955). These faults do not separate major geological or physiographic provinces and each of the opposing blocks contains Permian, Triassic, Cretaceous, and granitic rocks. If the Shakwak lineament continues in its character of hinge line between Tanana–Yukon geanticline and Alaska Range–St. Elias geosyncline, its course would be farther north through McKinley Park, along the contact between the Birch Creek schist and Permian to Cretaceous rocks. Thus, in the present discussion, the Shakwak lineament is limited to the course from Dezadeash Lake to Tok River, where it clearly separates the two major structural units and also has a prominent topographic expression. Tentatively it may be continued to Delta River and perhaps to beyond Nenana River. But a note of caution should be sounded regarding the continuity of the 1,600-mile fault zone, of which the Shakwak lineament would be a part. Although St. Amand and other authors after him have stated that the fault can be traced from Bering Sea to Dezadeash Lake, and possibly on to Lynn Canal, they also appear to admit that the continuity of the fault is conjectural.

Character of Displacement

The nature of the structure producing the Shakwak lineament, like that of the better known Rocky Mountain Trench, has not been established definitely. The straightness of the lineament over great distance indicates a steep fault or sharp flexure. The apparent discordance of structures on either side suggests that the feature is a major one, perhaps involving the deeper parts of the continental crust. A vertical component of movement along the structure is indicated by both topographic and geological contrast, but whereas the physiography shows the recent rise of the southwest—St. Elias block—the geology implies the elevation of the northeast Yukon Complex block.

St. Amand (1957) has suggested right-lateral strike-slip movement of about 150 miles for his proposed Denali fault, which joins Shakwak lineament and many other faults into one "gigantic fault". Gabrielse and Wheeler (1961) speculated that if a 150-mile right-lateral movement occurred along this fault extending through Lynn Canal and Chatham Strait, formations of the St. Elias Mountains would formerly have been opposite similar formations in the Alexander Archipelago. However, this reconstruction would still leave Yukon Complex rocks of the Kluane Lake area opposite Cretaceous rocks of the Nutzotin Range, and vertical movement would still be necessary. Twenhofel and Sainsbury (1958) emphasized that the only known movement is vertical.

So far as the writer can discover, no compelling geological or geophysical data have as yet been put forward supporting strike-slip movement along Shakwak lineament[1]. The mechanics of transcurrent movement are also difficult to envisage where the lineament stops, bends sharply, or splits as for instance at Dezadeash Lake. Admittedly, similar complications have been found in the San Andreas system, and have been explained by movement along secondary thrust faults.

On the other hand, as Twenhofel and Sainsbury (1958) observed, the geological and topographic contrast across the lineament are definite indications of a vertical component of movement. Thus, in the absence of proof of major lateral movement, this writer would rather consider Shakwak lineament as the hinge line between two crustal blocks along which occurred differential vertical movement of many thousand feet, possibly coupled with a horizontal component of the same order of magnitude.

During Mesozoic time the northeastern block, the Tanana–Coast geanticline, rose in relation to the St. Elias geosyncline to the southwest. Reversal of the movement, with a rise of the St. Elias Mountains, probably occurred during and after the Tertiary and Cretaceous phases of compression of the geosyncline.

Duke River Fault

This most significant fault separates Permian to early Tertiary rocks, with Kluane Ranges intrusions, on the northeast, from Devonian and (?) Mississippian rocks, with Donjek Range intrusions, on the southwest (Pls. I, VIII B).

East of Bullion Creek the fault is marked by a zone of sheared and mashed rocks. Highly crumpled beds of calcareous and gypsiferous argillite, together with zones of gypsum and anhydrite 20 feet wide or more, occur east of this sheared zone and may have welled up diapirically along the fault. Steep to vertical schistosity and bedding suggest that this part of the fault zone is steeply inclined.

On and above Duke River and Dickson Creek a recumbent anticline of Kaskawulsh limestone apparently overrides Permian (or Triassic?) chert, gabbro, and peridotite, together with highly folded and disturbed Tertiary volcanic rocks. Farther northwest along Duke River, Tertiary volcanic rocks unconformably overlie pre-Permian schist and limestone of the upper plate, whereas in the lower

[1]Of twenty-one first motion data on earthquakes in the North Pacific, presented by St. Amand, most have vertical as well as horizontal components. Of the three with epicentres in Alaska, only one is less than 50 miles from the proposed major fault. It strikes at a 60-degree angle across it and has no horizontal component. One other has no determined movement, and the third has a *left*-lateral component.

plate Paleocene sediments overlie Triassic rocks and gabbro with peridotite. The absence of Tertiary sediments below volcanic rocks southwest of the fault suggests either non-deposition or erosion due to relative uplift of the southwest block. Such movement must have occurred before the extrusion of the volcanic rocks. Strong, though open folding of the volcanic rocks capping the upper plate indicates wrinkling of the overriding block during its northeastward advance, and must have occurred after the accumulation of volcanic rocks. Two stages of Tertiary movement are therefore indirectly indicated.

On ridges between the glaciers at the head of Granite Creek, Donjek Range intrusions overlie fossil-bearing Permian strata, gabbro, schist, and Tertiary volcanic rock. The contact is generally hidden by talus, but is evidently a fault.

On Hoge Creek, limestone and highly contorted argillite of the Kaskawulsh Group are in fault contact with steeply northeast-dipping Permian conglomerate. West of Donjek River, a north tributary of Steele Creek exhibits a fault between steeply northeast-dipping limestone and Tertiary lavas dipping 50°SW (Pl. VIII B). As the canyon follows the fault, its attitude is not readily apparent but must be steep.

Farther west, in the St. Clare Creek region, no pre-Tertiary rocks come to the surface, and the fault is assumed to follow a zone of relatively steep folds with dips in volcanic rocks up to 70 degrees. Thence the structure is tentatively connected to the presumably faulted contact of Tertiary lavas and pre-Permian rocks west of Klutlan Glacier.

The apparent alignment of Tertiary plugs and sills of felsitic rocks and also the presumed sub-recent explosion centre below Natazhat Glacier along the fault, and their possible genetic connection, were mentioned earlier.

Summing up, the fault is a structural contact between a block with pre-Permian rocks and a block with Permian to Tertiary rocks. It was active after eruption of the Tertiary lavas, but was probably also active at an earlier Tertiary or late Cretaceous date. The compression of Tertiary and other beds near the fault suggests thrust faulting with the direction of thrust northeast. Though in a few places exposures indicate a steep fault, the sinuous map pattern argues for a southwest inclination.

Generc–Tchawsahmon Fault Scarp

An escarpment west of Generc River that passes through the White River Canyon and forms the west wall of the valley of Tchawsahmon Creek is probably a fault. The raised west block contains Permian to Cretaceous strata; the lower east block is concealed. The extension of this fault along the north scarp of Wolverine Plateau (*see* Pl. IV), inferred previously (Muller, 1958), is no longer considered probable. The scarp is now believed to mark an unconformable contact between Tertiary rocks south of Wolverine Valley and possibly underlying most of it, and volcanic and granitic rocks to the north.

St. Elias Fault

A major fault is also believed to be responsible for the lineament separating the probably granitic crest of Icefield Ranges, with elevations of 8,000 to over

FORMATIONS OF THE ST. ELIAS MOUNTAINS

CENOZOIC

TERTIARY
PALEOCENE AND LATER
ST. CLARE GROUP

PALEOCENE OR EOCENE
AMPHITHEATRE FORMATION: Rhyolite

MESOZOIC

CRETACEOUS AND (?) EARLIER
Granitic intrusions

Hornfels, migmatite

JURASSIC AND CRETACEOUS
UPPER JURASSIC AND LOWER CRETACEOUS
DEZADEASH GROUP

TRIASSIC
UPPER TRIASSIC
MUSH LAKE GROUP

PERMIAN AND/OR TRIASSIC
Gabbro, peridotite

PALAEOZOIC

PERMIAN AND (?) EARLIER
LOWER PERMIAN AND (?) EARLIER
CACHE CREEK GROUP

DEVONIAN AND/OR MISSISSIPPIAN
KASKAWULSH GROUP and GREENSCHIST COMPLEX

FORMATIONS OF THE YUKON PLATEAU

MESOZOIC AND (?) CENOZOIC

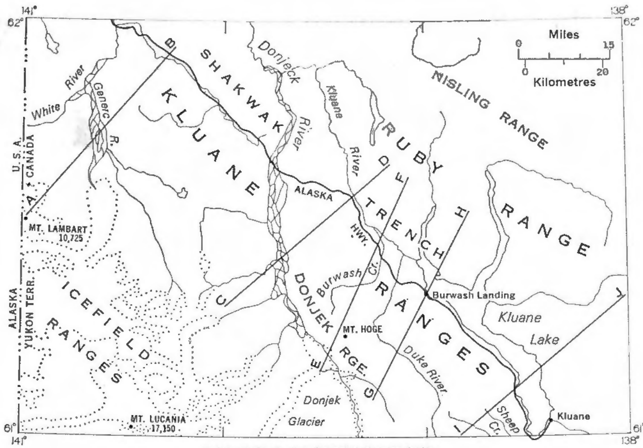
MESOZOIC AND (?) EARLY TERTIARY
Ruby Range batholith

PRE-MESOZOIC (MAINLY)

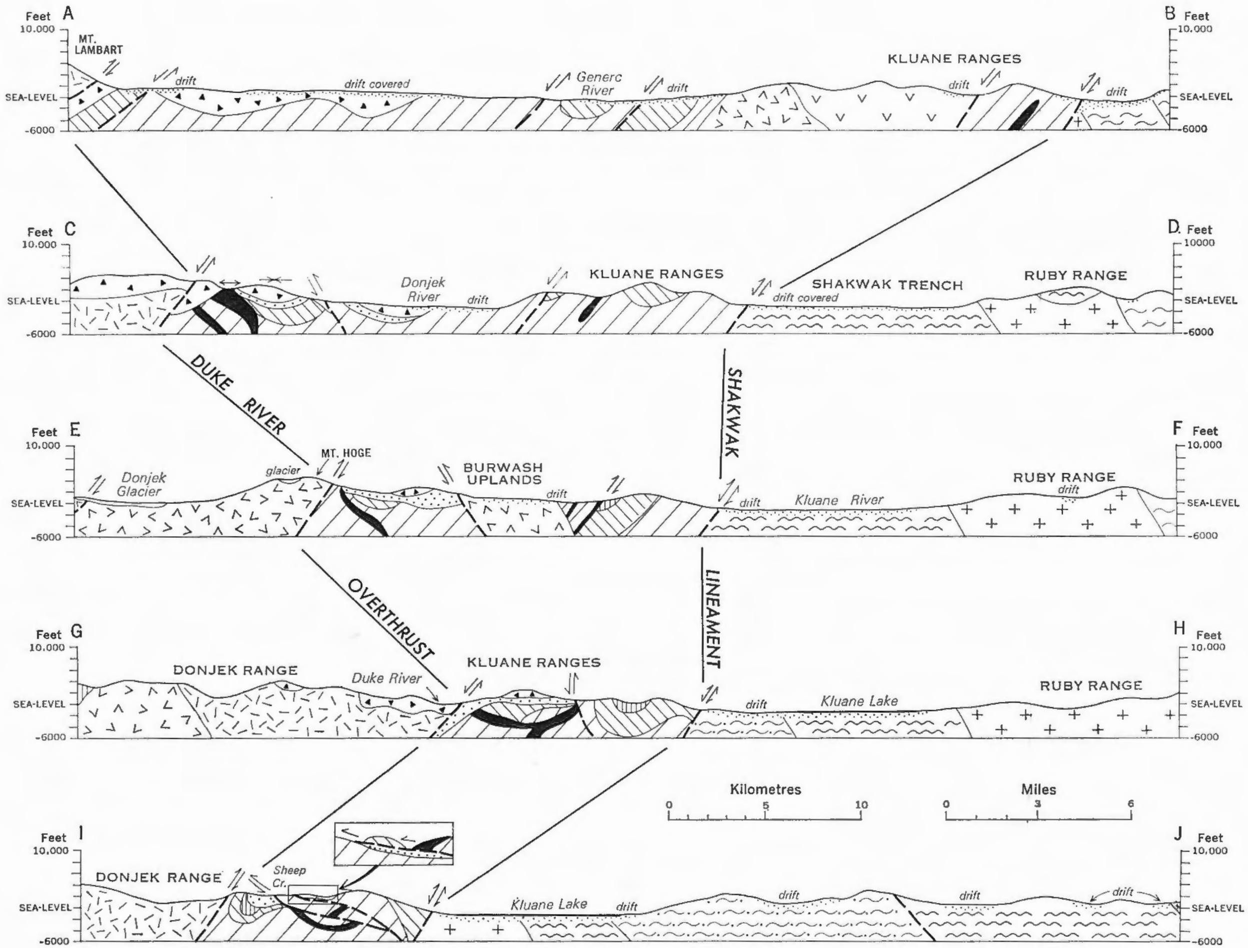
YUKON COMPLEX
Schist, marble, amphibolite

Quartz-sericite schist

Gneiss, quartz-biotite, schist, quartzite



LOCATIONS OF CROSS-SECTIONS



SECTIONS ALONG LINES A-B, C-D, E-F, G-H, AND I-J

FIGURE 5 Schematic structural sections across Ruby Range, Shakwak Trench, and Donjek Range.

16,000 feet, from the lower Icefield Ranges, containing Palaeozoic schist and marble overlain by Tertiary volcanic rocks. According to information received by the author, the fault is marked by a zone of strongly mylonitized granitic rock.

Structure of Kluane Ranges

Kluane Ranges lend themselves better to stratigraphic and structural analyses than do other parts of the area, thanks to a lesser degree of metamorphism and the occurrence of some fossil-bearing formations. These possibilities were only partly exploited and more detailed work in these ranges may be rewarding. The general structure is one of several tight synclines involving Triassic and Cretaceous rocks, separated by anticlines or faults where Permian and (?) older volcanic rocks come to the surface. The folds are arranged *en échelon* along Shakwak lineament.

Along Shakwak Trench the ranges reach a structural high between White and Donjek Rivers, where Permian and older rocks face Shakwak Trench and are backed by granitic and metamorphosed volcanic rocks. A lower structural level is apparent to the southeast, from Donjek to Slims Rivers, by the increasing extent of Triassic and Cretaceous rocks until, in Dezadeash map-area, mainly Cretaceous rocks are exposed. A similar decrease in structural level occurs northwestward from White River towards the mainly Cretaceous Nutzotin Range of Alaska.

Of particular interest is a flat overthrust exposed at the head of Sheep Creek (Pls. I, IX A). There, soft, gently dipping Tertiary sediments exposed on both forks are overlain by a cap of gabbro with minor disturbed Permian or Triassic sediments. To the west, the Tertiary deposits are in steep, apparently unconformable but unfaulted, contact with Triassic and Cretaceous rocks. To the east, they are in fault contact with Permian and (?) older sedimentary and volcanic rocks. A flat thrust fault, dipping towards Shakwak Trench under the front range, appears to be the most likely interpretation. The thrust may be continuous with a fault bringing older rocks in contact with Tertiary sediments between Halfbreed and Ptarmigan Creeks. A wide zone of light purple and green clay with mashed schist, gabbro, and peridotote occurs along this fault. A further possible extension of the fault brings granitic rocks over Tertiary sediments in the area of Granite and Badlands Creeks. This fault may continue still farther into a zone of crushed granodiorite overlying Tertiary sediments southwest of the cap of volcanic rock (Pl. VIII A). Such a fault would separate the younger volcanic rocks from the older but underlying sedimentary rocks. It would be somewhat similar to detachment thrusts, as mapped in Tertiary volcanic rocks in Wyoming (Pierce, 1957). As more detailed mapping would be required to establish these relationships, the fault is not shown on the accompanying geological map but is suggested on Plate VIII A.

Outline of Geological History

There is no positive evidence that any rocks exposed in the map-area were formed in pre-Devonian time. However, quartz–mica schists of the Yukon Complex may represent Cambrian or Precambrian clastic sedimentary rocks, and a group comprising chlorite schist, greenstone, and carbonate rocks may have been derived from Ordovician rocks. Though the Yukon Complex may have undergone low-grade metamorphism in Palaeozoic time, final metamorphism and granitization occurred in Jurassic to Cretaceous and perhaps even early Tertiary times.

In the St. Elias geosyncline region of the map-area, Middle Devonian marine carbonate and slate are the oldest rocks known. Across Shakwak lineament the Yukon–Tanana region in Alaska also contains Devonian rocks; the establishment of the Tanana–Yukon geanticline therefore did not occur until later.

The deposition of a greywacke–greenstone sequence of probable Devonian to Mississippian age apparently followed. The eugeosynclinal succession may be related to a similar, better known, Devono–Mississippian sequence in the Pelly–Cassiar Mountain belt (Gabrielse and Wheeler, 1961). These authors infer that the crystalline belts separating these basins were already established at that time. On the other hand, present data do not contradict a possible continuity of the two eugeosynclines and the activation of the geanticlinal regions between them at a later date.

No unconformity has definitely been demonstrated between Devono–Mississippian rocks and the Permian sequence. However, a pre-Permian disturbance is suggested by differences in structure and degree of metamorphism, the aerial separation of the two rock groups, and the coarse clastic nature of some lower Permian rocks.

Conditions in the St. Elias region remained eugeosynclinal during Permian and Triassic time. Deposition of the Permian Cache Creek Group started with volcanic conglomerates, breccias and tuffs, continued with greywacke and argillite, and terminated with limestone, chert, and cherty tuff. Sills and dykes of basic and ultrabasic rocks, were probably emplaced in the Cache Creek Group in Permian or early Triassic time.

An apparent hiatus between Lower Permian and Upper Triassic rocks suggests a temporary uplift of the geosyncline, but in the Kluane Lake map-area no angular discordance has been found, demonstrating a folding phase for this time interval.

Volcanism was intense during Triassic, Karnian, and earlier time, when many thousand feet of basaltic lava of the Mush Lake Group accumulated, together with minor sediments. In the succeeding Norian stage, sedimentation of several hundred feet of limestone and calcareous shale occurred. Centres of eruption may have existed in Nisling Range, shedding volcanic material into the Whitehorse trough.

The Tanana–Coast geanticline may have come into being during Jurassic time. A few potassium-argon age determinations on Yukon Complex rocks indicate crystallization during that period. If this date can be accepted, elevation and subsequent erosion was immediate, as granitic boulders occur in the Lower Jurassic Laberge Formation of the Whitehorse Basin. Miller, Payne, and Gryc (1959) also inferred that in adjacent Alaskan areas differentiation into geanticlinal and geosynclinal belts occurred in Middle Jurassic time. Subsidence in Jurassic time of the St. Elias geosyncline in respect to the rising Tanana–Coast geanticline seems likely, with the Shakwak lineament as hinge line. It is not substantiated by known Jurassic deposits, except those of the latest Jurassic and early Cretaceous Dezadeash Group, in or near the map-area, but Jurassic strata are known in the Alaskan continuation of the geosyncline. The uppermost Jurassic to Lower Cretaceous greywacke–

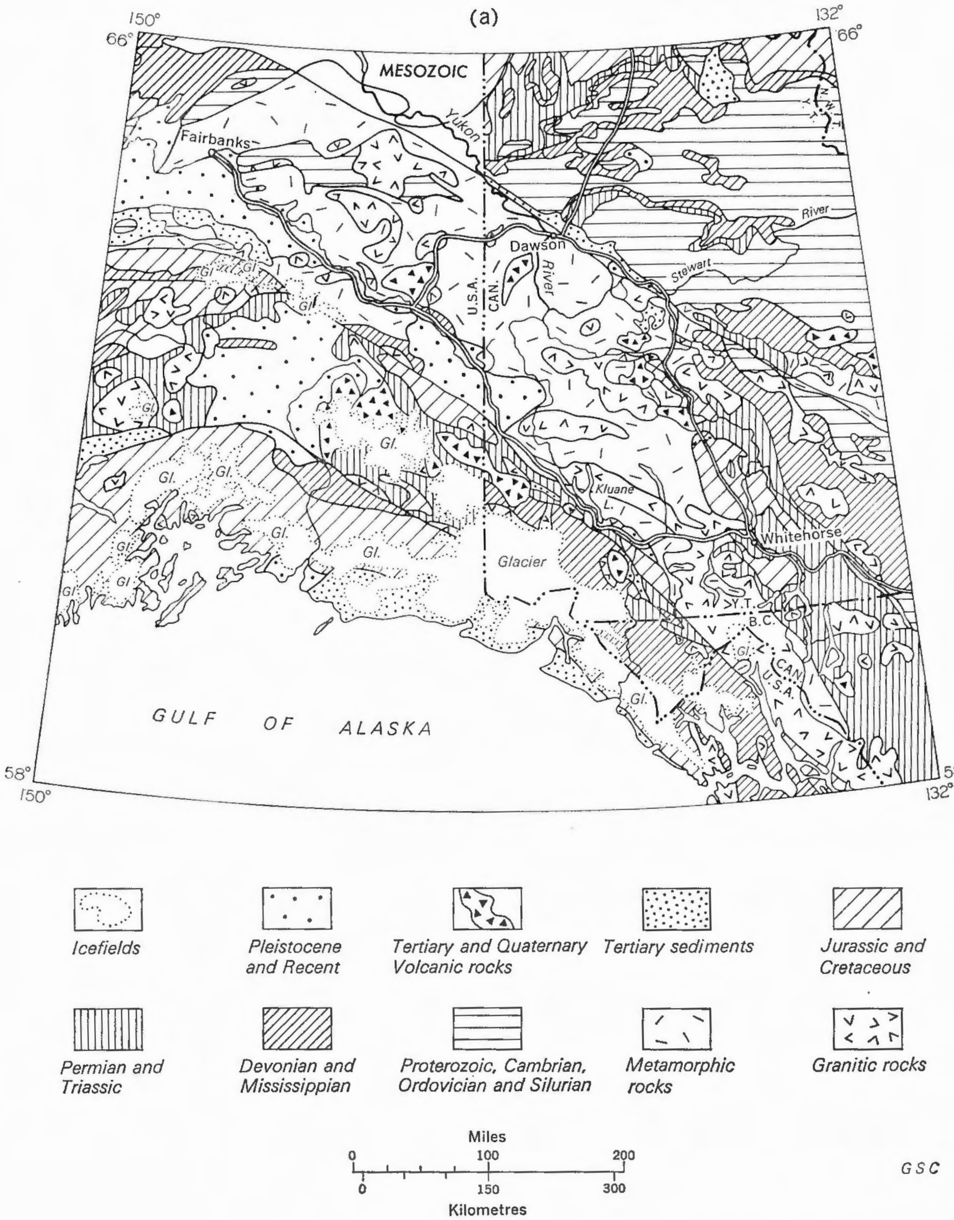


FIGURE 6 (a) Geologic setting of Kluane Lake map-area

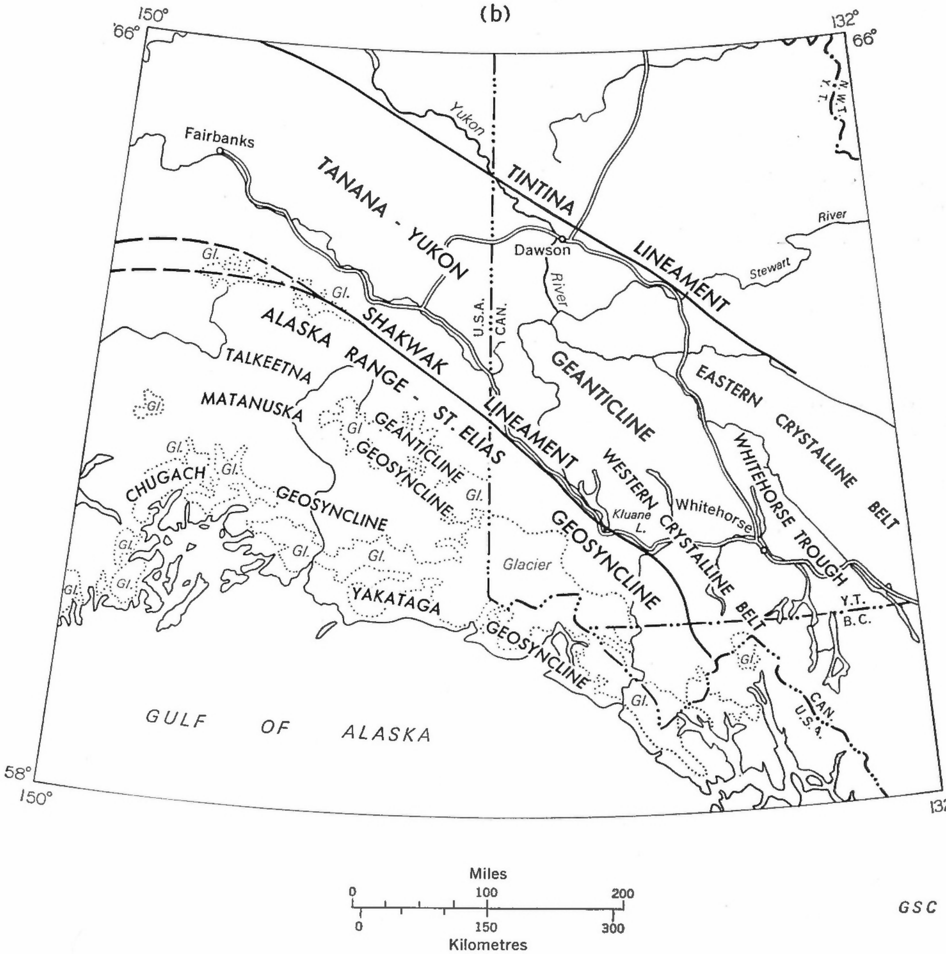


FIGURE 6 (b) Major structural features of the region.

argillite sequence of the Dezadeash Group represents the final stage of deposition, probably by turbidity currents, in the deeps of the St. Elias geosyncline. Conglomerates with granitic and volcanic rocks may have been derived from the Yukon geanticline to the east, which perhaps separated the geosyncline from continental deposition in the Whitehorse Basin of the Lower Cretaceous Tantalus Formation.

After deposition of the Dezadeash Group, the strata of the St. Elias geosyncline were severely folded and invaded by granitic intrusions. Though the Kluane Ranges intrusions were emplaced into Dezadeash sediments in Cretaceous time, part of them may be of Jurassic age. The alaskites of Donjek Range may be slightly younger than the Kluane Ranges intrusions. Although supporting evidence is lacking, it seems probable that intrusion of granitic rocks in the Yukon Complex also continued in Cretaceous time. The Nisling Range alaskite probably succeeded the Ruby Range and Nisling Range granodiorite intrusions. The Cretaceous orogeny probably also brought about northeastward reversed faulting along Shakwak lineament, reversing the hinge movement during geosynclinal subsidence. Severe folding and granitic intrusions also occurred during early Cretaceous (late Neocomian to Aptian) time in the Alaska Range and Seymour geosyncline, northern and southern continuations of the St. Elias geosyncline and in the Tanana–Coast (= Yukon) geanticline (Miller, Payne, and Gryc, 1959). The Whitehorse trough was, according to Wheeler (1961), also deformed in mid-Cretaceous time.

Judging by a few potassium-argon ages for the Yukon Complex granitic and gneissic rocks, its final crystallization occurred in latest Cretaceous to earliest Tertiary time.

Erosion of the newly formed mountains preceded and accompanied deposition of early Tertiary continental coal-bearing clastic sediments in the remaining basins of the St. Elias geosyncline. These beds were succeeded by outpourings of several thousand feet of basic lavas and associated pyroclastic rocks.

In the latest orogenic phase, Kluane Ranges were compressed between the buttresses of Icefield Ranges to the southwest and Yukon Complex to the northeast. Northeastward thrusting along the Duke River fault, as well as flat southwestward overthrusts, superimposed pre-Tertiary volcanic and intrusive rock on Tertiary sediments and the Tertiary strata were thrown into open folds.

In late Tertiary and perhaps Quaternary time, Tertiary and older formations were intruded by felsitic plugs and sills. These intrusions, and also the sub-recent volcanic explosion near Mount Natazhat, may have been due to acidic residual magma rising along the Duke River fault zone.

During Pleistocene time the area was repeatedly covered with ice-sheets, terminating in valley glaciers. Three glaciations of decreasing extent, successively reaching Nisling and Ruby Ranges, and St. Elias Mountains, are provisionally recognized. Preserved glacial features suggest decrease in height and extent, and deeper entrenchment into the valleys, for each successive glaciation. Thus much of the morphology of the area was carved out in Quaternary time.

A sub-recent volcanic ash deposit, occurring throughout southwest Yukon and parts of Alaska, probably originated from an explosion crater at the foot of Natazhat Glacier, now covered with ash and glacial debris.

Chapter V

ECONOMIC GEOLOGY

Geological conditions in Kluane Lake area, especially St. Elias Mountains with eugeosynclinal volcanic and sedimentary rocks intruded by small basic and ultrabasic and large granitic bodies, would seem to be promising for economic deposits. Mineral deposits known so far include placer gold, copper-nickel-platinum sulphides associated with ultrabasic intrusions, native copper in Mezosoic volcanic rock, scheelite and molybdenite in granitic rocks, gypsum in Triassic and older sediments, and coal in Tertiary sediments. Only placer gold has been produced; the total production up to 1960 is estimated to have been in the neighbourhood of 30,000 ounces.

Much of the following is compiled from earlier reports by McConnell (1905), Cairnes (1915 a, b), Bostock (1952), Skinner (1961), the annual reports of the Hudson Bay Mining and Smelting Co. Ltd., the administration of the Emergency Gold Mining Assistance Act; and some items in the *Northern Miner*. It includes activities to the end of 1960.

Placer Deposits

Placer gold is the only mineral that has been produced from the area, although expectations were high at various times for economic deposits of other minerals.

Small placer operations have continued intermittently since Dawson Charlie from Carcross staked his discovery claim on July 4, 1903, on a stream in Ruby Range, since named Fourth of July Creek. In the autumn of that year four miners staked claims in Kluane Ranges on Bullion Creek and Sheep Creek. Burwash and Arch Creeks were staked in May 1904. Gladstone Creek was also staked in that year as well as several other creeks just south of the map-area.

Bullion Creek

Bullion Creek is mostly a deep canyon excavated in Palaeozoic limestone and schist, overlain by Pleistocene boulder clay and lake deposits. The original stakers recovered some 40 ounces of very coarse gold at the foot of the canyon, but the gravels were found to be irregular, with an average yield of $3.00 to $5.00 per shovel per day. The Bullion Hydraulic Company built a flume to provide water-pressure for hydraulic mining but an estimated expenditure of some $300,000 in buildings and equipment resulted in the recovery of $1,000 worth of gold between

1904 and 1906. In 1914 a total of some $5,000 was believed to have been extracted from the entire creek. Small amounts of gold have been taken out by various miners in later years. J. Coglan was active there in 1945 and H. Thorsen worked the creek in the 1950's, averaging some 30 ounces a year to a total of 220 ounces, using shovel, flume, and sluice-box.

Action Mining Co., owned by J. P. La Cross and J. Kelly of Fairbanks, Alaska, purchased Thorsen's claims in 1959 and staked others. Using mechanical equipment they produced 5,240 ounces in 1959 and 1960. They reported the gold to be coarse grained with 10 cent-sized grains and larger, of 65 per cent fineness. Their largest nugget weighed 3 ounces, but a 7½ ounce nugget had been found previously. An assay of gold sold to the Royal Canadian Mint by H. Thorsen in 1949 gave 83 per cent gold and 11 per cent silver.

Sheep Creek

On Sheep Creek, as on Bullion Creek, gravels have mainly been worked in the narrow rocky canyon. In the wide basin at the head, mainly underlain by Tertiary sediments, little evidence of placer mining exists. In 1914 Cairnes estimated that $10,000 worth of gold had been extracted, and it is doubtful if that amount was equalled in years since. In past years the stream was intermittently worked by C. Strandberg and H. Fourner; R. Chaykowsky produced 120 ounces from this stream in 1960.

Burwash Creek

Burwash Creek (Pl. III) has also been mined in a relatively narrow rock canyon flowing between a section of Kluane Ranges in the north and Burwash Uplands in the south. Only the middle section of the stream flows through Tertiary and Pleistocene deposits, the head in Donjek Range and the long lower canyon are in Permian, Triassic, and granitic and basic intrusive rocks.

In 1904 coarse gold was found from the foot of the lower canyon upstream for a distance of 8 miles or more, but no very rich ground was discovered. The gold in this creek is flatter than in Bullion Creek, and is worn into smooth, thin plates. At that time a nugget of 5 ounces, including less than one ounce of quartz and rock, had been found, and nuggets of $25.00 to $30.00 (at $20.07 per ounce) were obtained frequently. The gold was very fine, assaying $18.00 to $18.10 an ounce (87 per cent). The creek was then the best producer in the area and has retained that position ever since.

So far as can be established, little placer mining occurred from then until 1945, when Burwash Mining Co. Ltd., managed by Henry Besner, started operating a sluicing plant, fed by D8 bulldozers and a ¾ cubic yard power shovel, using a 4-man crew. Total production from 1948 to 1960 inclusive, taken from the report on Emergency Gold Mining Assistance, was nearly 10,700 ounces of gold, or an average of 823 ounces per year. The gold is coarse, and the concentrates also contain some platinum, native silver, and native copper.

Also active on the lower part of this creek from 1948 to 1951 was Kluane Dredging Co. This company operated a floating separation plant using a 10x10-foot hopper with a grizzly, fed by a dragline with $2\frac{1}{2}$-yard bucket. The gravel was sized by a 4-foot diameter trommel screen with overall length of 33 feet and screen sizes $\frac{3}{4}$, $\frac{5}{8}$, $\frac{1}{2}$, and $\frac{3}{8}$ inch. The fines went through sluice boxes with riffles and coco matting, and mercury was used for catching the finest gold. The report on Emergency Gold Mining Assistance gives a production of nearly 3,095 ounces for the years 1948, 1949 and 1951; in the following winter the plant was taken over the ice on Kluane Lake to Gladstone Creek.

Arch Creek

This creek flows in a canyon through pre-Tertiary rocks overlain by glacial deposits, in a longitudinal valley of Kluane Ranges. No mention was made of this stream by McConnell (1905), but Cairnes (1915) reported intermittent activity since 1904, most of the gold being obtained from the lower canyon. Before 1950 the stream was worked for several years by C. Bryden and partners. Later P and G Placers Limited, managed by R. O. Davis, mined the creek by bulldozing and sluicing and produced, according to Skinner (1961), 205 ounces of gold in 1959 and 105 ounces in 1960.

White River Area

Cairnes (1915 a, b) mentioned the occurrence of placer gold on Pan, Bowen, and Hidden Creeks, east tributaries of Tchawsahmon Creek near the lake, and on Koidern River. So far as can be established not much gold was produced from these creeks at any time.

Fourth of July Creek

Besides various creeks in Kluane Ranges, gold has also been found in some of the streams of Ruby Range. Placer gold was first discovered within the map-area in 1904 on Fourth of July Creek. This valley, in Yukon Complex schist, is floored with boulder till, in which, as Cairnes (1915a) reported, shafts were sunk to a depth of 70 feet without encountering bedrock. Placer mining has actually only been carried out in recent stream gravels overlying the "clay bedrock" and the gold, as Cairnes stated, was concentrated from the till. Granitic boulders, up to 10 feet in diameter, attest the foreign provenance of that drift. Cairnes estimated a production between $6,000 and $10,000 until 1914. Though some prospecting was done in later years no record of any significant later production exists.

Gladstone Creek

This other Ruby Range stream with minor placer production also flows in a drift-covered valley in Yukon Complex schist. Gold was found there just below the mouth of Cyr Creek, and Cairnes estimated in 1914 a recovery of $2,000 to $3,000, from recent stream-gravels concentrated from the boulder till.

Between 1952 and 1955 the same part of the creek was worked by Kluane Dredging Company with the equipment previously used on Burwash Creek. The report on Emergency Gold Mining Assistance gives a production in these years totalling 5,770 ounces. Apparently the company fell into financial difficulty and stopped operations in 1956.

Origin of Placers

The placer gold production of the area has been mainly from Recent, and probably also some Pleistocene, stream-gravels. In one instance placer gold was found in Tertiary gravels cut by a small stream north of Hoge Creek, but little mining was done due to shortage of water and difficulty of access.

There is little reason to believe that the placers were directly derived from lode gold in the immediate vicinity. The drainage basins of the gold-bearing creeks have no intrusive or metamorphic rocks in common that would be the source of gold. Common features of the placers are rather the occurrence in relatively narrow canyons, cut in bedrock underlying thick glacial valley deposits. The canyons thus apparently acted as large natural sluice-boxes, through which great quantities of glacial material (in some instances augmented by Tertiary deposits) were washed down, with the elimination of sand and clay and the concentration of coarser components and placer minerals. Boulder till of the Ruby ice-sheet overlies the areas drained by the placer creeks, but may well have been enriched by residual material of the Nisling ice-sheet. This drift entered the map-area mainly with the Shakwak ice-stream. It is interesting to note that, though the entire area has no doubt been prospected, no placers have been found in canyons cut below valleys occupied by the St. Elias glacial advance. The apparent barrenness of streams incised below the younger glacial deposits may be due partly to the shorter time available to concentrate placers from the overlying drift, and partly to the smaller, localized bedrock area available as a source for the St. Elias drift, against the large area, including part of Yukon Complex and Coast Mountains crystalline rocks, available as source rocks for the older drift deposits. A wider selection of source rocks would be more likely to give valuable placer concentrates.

Native Copper

Occurrences

Native copper has been known in the region before the advent of the white man. It was actively traded by the Indians and used to make axe heads, arrow heads, knives, and cooking utensils. Its occurrence was first recorded by Hayes (1892) in the account of his trip with Lieutenant Schwatka from Yukon to Copper River. Though in Selkirk he was told about masses of copper the size of a log cabin, he found only small copper nuggets, a few ounces in weight, on Kletsan Creek. In the following years the occurrence of copper attracted many prospectors to the White River-Nabesna region.

The Kletsan Creek occurrence has to this day remained a placer deposit, and copper nuggets may still be taken from the creek bed. There is no doubt that the copper is derived from the amygdaloidal volcanic rocks of the Mush Lake Group at the head of that stream, but no mineable deposit has been found. Veins of native copper in amygdaloidal andesite were discovered and staked in 1905 on the east side of the upper White River canyon, about 1½ miles above Canyon City on the edge of the valley of Tchawsahmon Creek, by Solomon Albert, J. R. Slaggard, and M. C. Harris. The occurrence was investigated by Capps (1916a) and later by Cairnes (1915b), who described it as follows.

> On Discovery property three adits have been driven distances respectively of 30, 20, and 20 feet; in addition a certain amount of surface work has been performed, mainly in the shape of open-cuts and trenches. This development has shown that the volcanic country rock is traversed by numerous irregular fractures, some of which exhibit pronounced slickensiding. These seams in places contain native copper, a number of slabs of which have either weathered out or have been dug up that weigh as much as several hundred pounds each, and one particularly large tabular mass was measured by the writer that is about 8 feet long, 3 feet 6 inches wide, and 4½ inches thick, and is estimated to weigh about 6,000 pounds. Narrow calcite veins, containing chalcocite as well as stringers of cuprite and disseminated native copper, also traverse these rocks in places. In addition, in one of the adits the dark green volcanic country rock contains occasional veinlets of chalcocite, which mineral is also disseminated through the rock in places. In the bottoms of the cuts, chalcocite also begins to appear, and in places specimens were obtained showing the chalcocite partly oxidized to the native state. It is thus perfectly evident that the native copper is a surface oxidization product and is derived directly from the chalcocite. Further, as occasional particles of chalcopyrite occur in places disseminated through the amygdaloids, it would seem probable that with greater depth this will prove to be the primary copper mineral.

At the time of the writer's visit in 1957 the large slab was still present but the old cuts were mostly overgrown. The slab, actually weighing 2,590 pounds, was, in the following winter, transported to Whitehorse on the instigation of the Yukon Historical Society and erected in front of the museum. A little stockpile of smaller slabs and nuggets was seen near the White River bank at former Canyon City. One slab, taken by the writer, still retains parts of the enclosing amygdaloidal andesite.

Several occurrences of copper have been staked since 1908 in Mush Lake amygdaloidal lavas northeast of Tatamagouche Creek and the head of Quill Creek. Most of these claims have lapsed; the best known is the one until recently belonging to the Jacquot Brothers, situated near the head of a tributary to Tatamagouche Creek and some 1,000 feet north of the cairn at elevation 6,370. It is a one-foot zone striking N70°E and dipping 40°NW, in dark green and purple amygdaloidal lavas impregnated with bornite and malachite, with quartz, epidote, and calcite as accessory minerals. An average sample, taken across the vein by Cairnes (1915a) yielded 33.12 per cent copper but no gold or silver. Copper nuggets, found in Burwash Creek placers, are probably derived from these occurrences in the Mush Lake volcanic rocks.

Native copper has also been found in several parts of Chitina Valley, Alaska, in amygdaloidal lavas of the Nicolai greenstone, probably correlative to the Mush Lake rocks.

Origin

It seems probable that copper was originally present as a minor component of the volcanic rock and was later concentrated by supergene enrichment. Lindgren (1933) cites many other examples of native copper in basic flows, noting the association with minor chalcocite and bornite, as well as epidote, calcite, prehnite, chlorite, and other minerals, indicating deposition at temperatures below 250°C. As Lindgren said "... the suggestion that the whole or a part of the copper in the deposits was extracted by waters from the rock itself almost forces itself on the observer, and, although a number of investigators uphold the idea of ascending deep-seated waters of magmatic origin as a carrier of the copper, the suggestion noted above can not as yet be discarded."

We may also note that the rich Kennecott Copper deposits in Alaska occurred in the Triassic Chitistone limestone, overlying the Nicolai greenstone, the Alaskan equivalent of the Mush Lake volcanic rocks. Bateman and McLaughlin (1920) concluded that heated meteoric waters extracted copper from the greenstone and redeposited this in the limestone. Although this viewpoint was apparently accepted by Lindgren, it was omitted later in Bateman's text-book (1950). It would seem that economic copper deposits may yet be found elsewhere in limestone overlying Triassic volcanic rocks. Unfortunately such limestones are poorly developed within the map-area.

Nickel—Copper—Platinum Deposits

Hudson Bay Mining and Smelting Co., Wellgreen Property

Much general interest was attracted to the Kluane Lake area in June 1952 when nickel was identified in samples of sulphide occurrences in Kluane Ranges. The discovery was on a gully, tributary to a stream subsequently called Nickel Creek. The claims, staked by W. Green and associates and originally owned by a syndicate of Whitehorse businessmen, were acquired by Hudson Bay Mining and Smelting Co. of Flin Flon, Manitoba, and became known as the Wellgreen property. The first published report on the property, based on diamond drilling, gave 67,000 tons of proved ore averaging 1.96 per cent nickel, 1.33 per cent copper, and values in platinum, cobalt, and gold.

After initial surface geological work and drilling, underground work was started with an adit at the 4,250-foot level. This adit was extended for several thousand feet and by raises and shafts other levels were established and driven at the 4,470- and 4,050-foot levels.

On January 1, 1956, the total estimated tonnage was 728,000 tons of ore containing 2.05 per cent nickel, 1.42 per cent copper, 0.073 per cent cobalt, 0.005 ounce of gold, 0.038 ounce of platinum, and 0.027 ounce of palladium a ton. Exploration work was suspended in that year but the claims, now registered in the name of the Hudson Yukon Mining Co. Ltd., are being held in good standing.

The geology of the deposit is complex and, as the results of the underground work are mostly confidential, only a very brief sketch can be given. The ridge of

Kluane Ranges between Nickel Creek and Shakwak Trench consists of a syncline in amygdaloidal basic lavas of the Mush Lake Group. These lavas are underlain by a sequence of argillite, limestone, cherty tuffaceous greywacke with graded bedding, and minor chert-pebble conglomerate of Permian and/or Triassic age. These are in turn underlain by volcanic conglomerate. This sequence appears to form a northeastward overturned anticline with an axial zone roughly following Nickel and Arch Creeks. It is intruded by an obliquely crosscutting sill of medium-grained peridotite and gabbro. This sill is up to several hundred feet thick, follows the bedding only roughly, and bifurcates into two plates. The ore minerals occur as solid bodies of sulphide at the contact of the basic rocks and the siliceous tuffs, as well as disseminated sulphides near the contact. It appears that no mineralization took place at the contact of intrusion and limestone.

According to a statement by Hudson Bay President Canning (*Northern Miner*, January 7, 1955) the ore was explored along the adit level for a distance of 1,600 feet. It occurs in a series of shoots, up to 200 feet long and 20 to 30 feet wide.

Canalask Nickel Mines, White River Property

This property, on the east bank of White River, was originally staked by Prospectors Airways Ltd. It was optioned by Canalask Nickel Mines Ltd. in 1954 and subsequently explored by diamond drilling and underground work. Several sections of core with up to 3.5 per cent nickel were recovered, and in 1956 the company announced that an orebody 380 feet long, 50 feet wide, and with average depth of 290 feet had been outlined. This orebody contained 550,000 tons of ore with an average grade of 1.68 per cent nickel.

Expectations to mine and mill the ore for sale to Japanese smelters have apparently not materialized.

The geology of the deposit is not well known. It occurs in basic tuffs and lavas assigned to the Cache Creek Group, in contrast to the Hudson Bay deposit which occurs mainly in sedimentary rocks of that group. The deposit is 200 feet to the north of the contact of peridotite and volcanic rock, rather than directly along the contact as in Quill Creek. The deposit also differs in carrying a higher proportion of nickel. One drill-hole reported on gave 50 feet averaging 1.97 per cent Ni and 0.05 per cent Cu, and 4 feet with 3.24 per cent Ni and 1.07 per cent Cu.

Other Explorations for Nickel

After the staking of the Wellgreen property on Quill Creek, many more claims were staked throughout Kluane Ranges, on Arch Creek, Edith Creek, and Duke River, on and adjacent to bodies of peridotite. Besides Hudson Bay Mining and Smelting Company, other companies in the field were Prospectors Airways, Conwest Exploration, Teck Exploration, Brikon Explorations, and Barymin Mines. Diamond drilling as well as magnetometer, electro-magnetic, and resistivity surveys were carried out on these claims, but no orebodies were discovered. Some sulphides carrying up to 5 per cent Ni were however found near the mouth of Dickson Creek.

Origin of the Nickel–Copper–Sulphides

The sulphide deposits that accompany basic and ultrabasic intrusions of Quill Creek and White River were studied in some detail by F. A. Campbell (1960). The sulphide minerals are pyrrhotite mainly, with pentlandite, chalcopyrite and sphalerite, in that order of crystallization. Pyritization preceded the main mineralization at White River but could not be detected at Quill Creek. The ore occurs in shears and fractures in gabbro, peridotite, and country rock, and mineralization therefore took place after emplacement of the intrusions. The peridotite contains spectroscopically determined values of nickel, ranging from 0.2 to 0.8 per cent, and cobalt about 0.004 per cent; copper was not determined. Campbell however did not believe that the ores originated by leaching of the peridotite, since the peridotite is relatively unaltered. Although recognizing the spatial relationship of ultrabasic and basic rocks with the sulphides, he considered that the sulphide fraction was separated at depth from the parent magma and intruded as an ore fluid after consolidation and fracturing of gabbro and peridotite. Whether ore segregation happened at depth or *in situ* during crystallization of the ultrabasic rocks may be difficult to establish. But certainly the occurrence is analogous to a great number of known sulphide deposits carrying copper, nickel, and related metals associated with ultrabasic rocks and considered as typical magmatic ores.

Molybdenite, Wolframite, and Fluorite

Molybdenite, wolframite, and fluorite have been found in veinlets and nests in granitic rocks, mainly light coloured quartz monzonite, granite, and alaskite of Donjek and Nisling intrusions, but not in commercial quantity.

Small quantities of molybdenite were reported by R. P. Sharp (1943) from the granitic intrusions southeast of the bend of Steele Glacier. Apparently a few flakes of molybdenite and chalcopyrite occur in a 200- to 300-foot border zone of highly silicified, pyritized porphyritic biotite granite. Boulders of quartz monzonite with veinlets containing chalcopyrite, pyrite, specular hematite, and considerable molybdenite are abundant on the Steele Glacier medial moraine.

Another small showing of molybdenite was found west of Steele Glacier by a mining geologist, and boulders of a distinctive fine-grained granitic rock containing thin sheets of molybdenite have been traced along moraines up to a small glacier on the north side of Mount Steele. Molybdenite has also been noted in hornfels boulders on Spring Creek Glacier and leucogranite boulders on Donjek Glacier. The statement by Skinner (1960) that the source of molybdenite float on Steele Glacier was located by Southwest Potash Corporation should, according to this writer's information, be modified to read that the source region was established, but is covered by ice.

Small quantities of molybdenite have also been reported from the head of Mineral Creek, east of Brooks Valley.

Wolframite, together with fluorite and chalcopyrite, was found by J. Meloy west of the head of Alaskite Creek. Fluorite, a common minor microscopic constituent of Donjek Range and Nisling Range intrusions, occurs in nests of light green crystals south of the head of Rockslide Creek. The light coloured granitic and pegmatitic rocks of these intrusions could conceivably carry a deposit of economic size of this group of minerals.

Coal

Lignite seams, in places more than 4 feet thick, were discovered by early placer miners in Tertiary sediments on upper Sheep Creek (Pls. I, II). According to McConnell (1905), the coal was found to be of excellent quality, burning freely in an ordinary Yukon box stove. Cairnes (1915) mentioned, besides the occurrence on Sheep Creek, an occurrence in the amphitheatre in the Duke River area (Amphitheatre Mountain). There in a section of 1,200 to 1,500 feet of sediments twelve seams of lignite of good quality, more than 12 inches thick and with aggregate thickness of 30 to 50 feet, were said to be exposed. This estimate appears to be too optimistic, as much of the coal is shaly and of poor quality.

In 1950 a group of Whitehorse businessmen took a coal mining lease on a strip of land straddling Granite Creek. No development was done, as efforts to obtain government assistance to build a road into the area failed. A coal seam, several feet thick, was also noted in the Tertiary deposits south of Cement Creek. The following are measured sections of some seams:

1. *Middle one of three seams, outcropping a few hundred feet below the cap of lava and agglomerate on Amphitheatre Mountain*

Roof: Shale, grey, fissile, soft, about 2 feet, overlain by sand

Shale, coaly, with streak of coal	0′4″
Coal, fairly clean, bright and dull bands of about ⅛ inch	0′5″
Shale, soft, black	0′1″
Coal, fairly clean, bright	0′7″
Coal, slightly shaly, dull, with specks of pyrite	0′9″

No seams better than the above were seen in the amphitheatre.

2. *Coal at head of south tributary of Granite Creek*

Roof: Loose sand and gravel, pebbles well rounded and up to about 6 inches diameter

Coal, well-bedded and with a few thin shale partings. Cracks in the lower 2 feet are filled with ice. *Sample No. 1* of upper 3 feet	5′0″
Shale, brownish grey, blocky, fairly well bedded, with layers of coaly shale	5′8″
Coal, seems more regular and cleaner than No. 1. A few thin shale partings. No ice. *Sample No. 2* taken from full thickness	4′2″
Clay, soft, brown, with some grey shale at bottom	0′8″
Coal, interbedded with coaly shale and brown shale. Ice in lower part. *Sample No. 3* from upper 2½ feet	3′0″
Clay, brown	0′8″
Shale, coaly	0′9″

3. *Coal on east tributary of Ptarmigan Creek*

Roof: Soft coaly shale

Coal, soft and slightly shaly, lower part is hard and brittle	3′0″
Shale, blocky, soft, dark brown	2′6″
Coal, hard and brittle, with good cleat	1′0″
Shale, brown, and light brown fireclay	2′0″
Sand, light brown, slightly shaly	6′6″
Siltstone, brown, with coaly fragments	0′6″
Shale, brown, chunky	1′0″
Coal, fairly hard, clean, and brittle	6′0″

Complete analyses were carried out by the Fuels Division of the Mines Branch, Department of Mines and Technical Surveys, on the three channel samples taken in 1950 from Section 2, south of Granite Creek, and are given in Table IV. The samples were shipped in air-tight containers.

Table IV

Analyses of Coal Samples, taken south of Granite Creek

Laboratory No. Moisture condition	Sample 1 32618		Sample 2 32619		Sample 3 32620	
	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry
Proximate Analyses						
Moisture %	22.6	0.0	22.3	0.0	20.6	0.0
Ash %	10.1	13.0	13.7	17.7	27.6	34.7
Volatile matter %	35.9	46.4	32.3	41.6	27.7	34.9
Fixed carbon (by difference)	31.4	40.6	31.7	40.7	24.1	30.4
Ultimate Analyses						
Sulphur %	0.1	0.1	Trace	Trace	Trace	Trace
Calorific Value						
B.T.U. per lb. gross	8065	10415	7485	9635	5750	7245
Ash Fusibility						
Initial °F	—	2120	—	2330	—	2700
Softening temp. °F	—	2240	—	2430	—	2750+
Fluid temp. °F	—	2270	—	2490	—	2750+
Caking properties (residue at 950°C)	Non-agglomerate					
B.T.U. moist, mineral-matter free	9416		9287		9300	
Classification	Sub-bituminous C					

Three other, less complete, samples are given. No. 4 was taken by the writer from a 6-foot seam, west of the west fork of Sheep Creek; Nos. 5 and 6 are quoted from the report by D. D. Cairnes (1915a) and are respectively from a 4½-foot seam at the head of the left fork of Burwash Creek, and a 4½-foot seam from the upper part of the "amphitheatre" north of Granite Creek.

These samples may not be as representative as those given above.

	Sample 4 (1956)	Sample 5 (1914)	Sample 6 (1914)
Moisture %	21.8	10.2	11.2
Ash %	7.8	9.1	5.4
Volatile matter %	36.7	42.0	40.9
Fixed carbon % (by difference)	33.7	38.7	42.5

It is doubtful if these deposits could be of more than local use. The occurrence in folded strata, in high areas with much relief makes strip-mining unlikely. On the other hand, underground mining in the soft, partly frozen enclosing sands and gravels, does not appear to be feasible on any extensive scale.

Serpentine and Asbestos

Hard, non-flexible fibrous serpentine has been found in veins in many peridotite occurrences in the Kluane Ranges, but no chrysotile asbestos is known from there. However, a group of claims were staked in 1954 by A. Rosen for Northwestern Explorations Ltd. on a small occurrence of chrysotile veins in the ultrabasic rocks in the Yukon Complex. The showing is on a small tributary of Kluane River, northwest of two lakes draining into Tincup Lake. The occurrence was found to be small and the claims were dropped.

Gypsum and Anhydrite

A good-sized deposit of gypsum and anhydrite is exposed in a mountain and canyon east of Bullion Creek (Pls. II, X B). Although at one time a lease had been taken out on this deposit, no development work was done. The gypsum appears to occur at the base of the Duke River thrust and may well have risen diapirically. It is of interest to note that a large deposit of high quality gypsum was located in 1959 by Frobisher Limited near the head of the O'Connor River, west of the Haines Road. Both deposits occur with the Kaskawulsh group, and may well be derived from the same evaporite sequence.

Smaller occurrences of gypsum were found at the headwaters of Bock's Creek, Burwash Creek, and at the junction of Wade and Maple Creeks. There the gypsum may be related to Upper Triassic sediments.

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PLATES II to XI

PLATE II. View southwest from south end of Kluane Lake across Sheep Creek and Bullion Creek towards St. Elias Mountains. (RCAF, T6–124L)

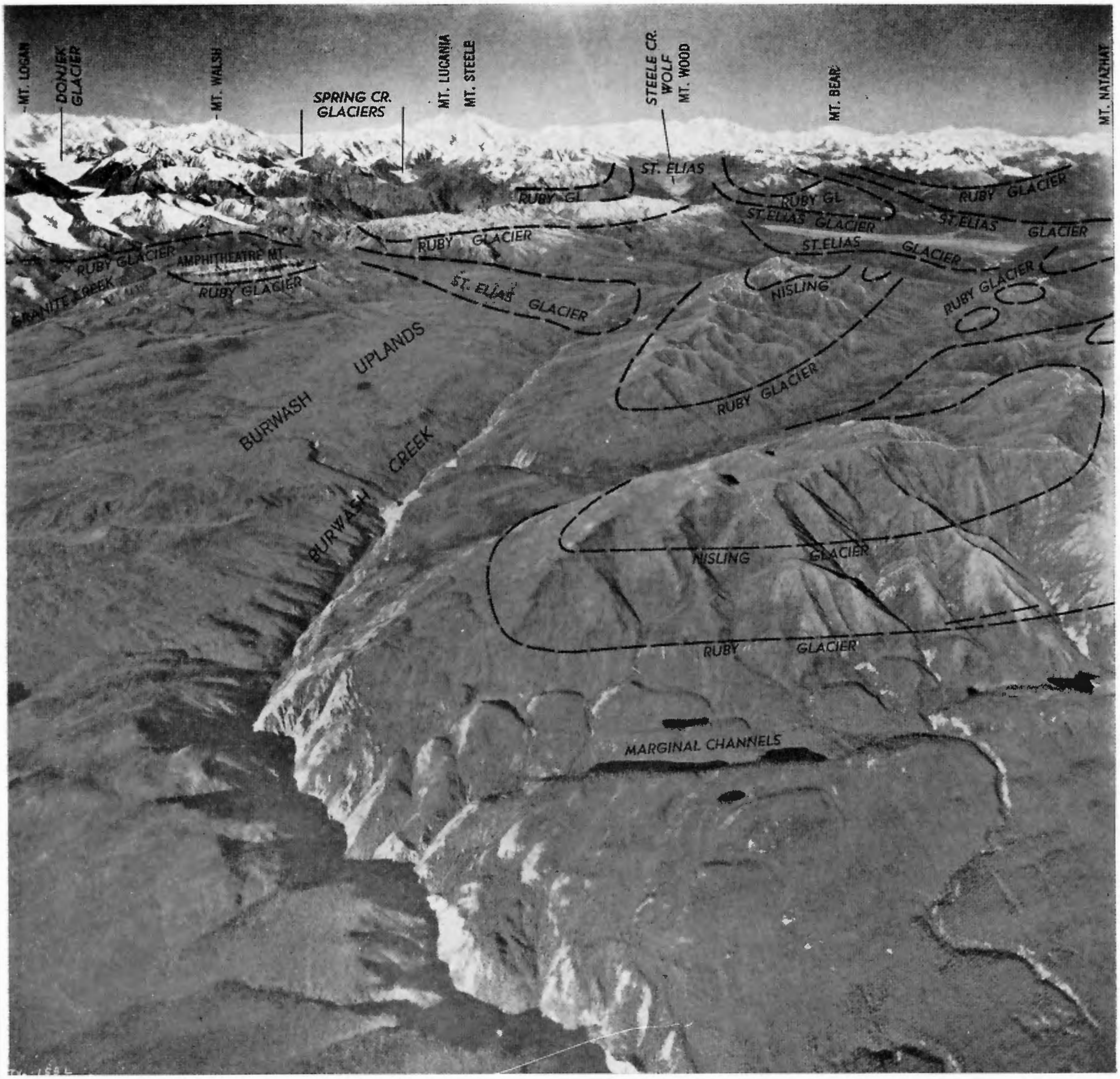


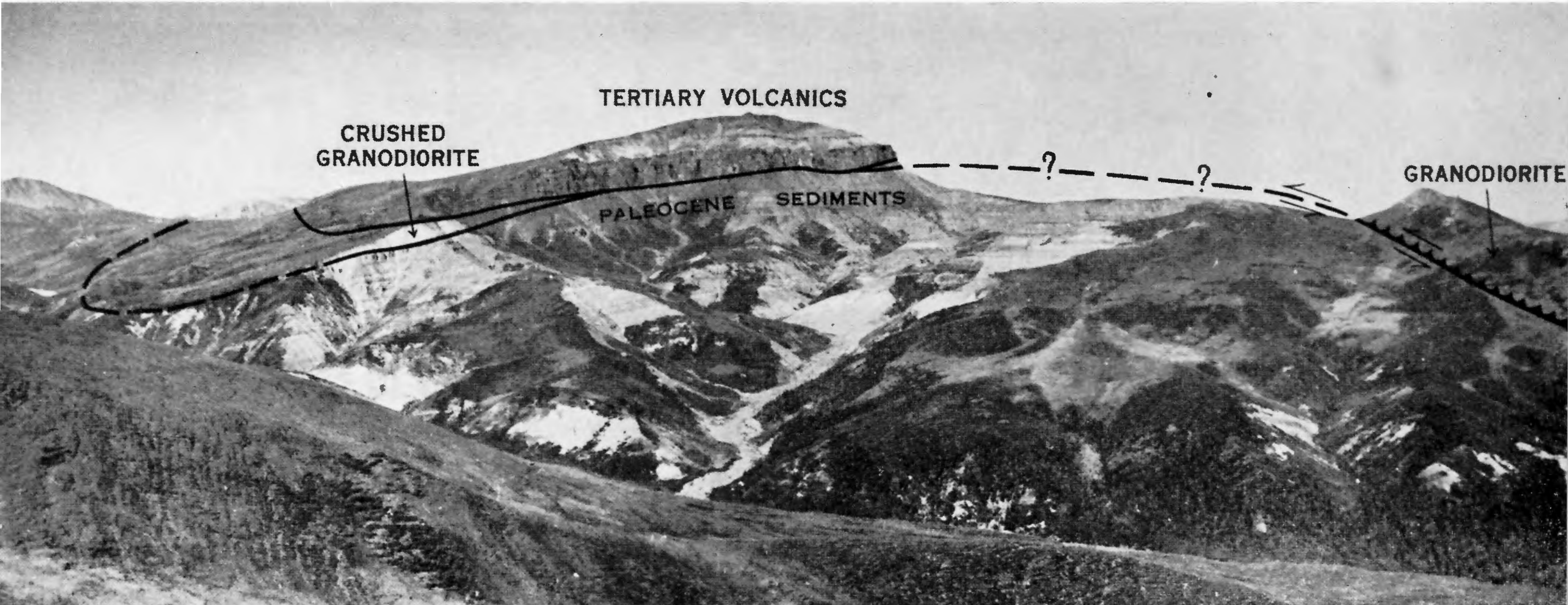
PLATE III. View southwest across Burwash Creek. Note marginal channels and indicated levels of glaciation. (RCAF, T6–155L)

PLATE IV. View southwest along Donjek River. Note assumed fault trace in drift. The valleys in Kluane Ranges, except for the more recent high cirques at left, were probably glaciated in an early glaciation and modified by later subareal and fluvial erosion. (RCAF, T7–10L)

PLATE V. View southwest from north end of Shakwak Trench. Note relatively smooth, low-slope surface of Ruby ice-sheet in contrast to steep, gullied sidewall, and notched, flat spurs of Nisling ice-sheet, in turn in contrast to steeper, unglaciated peaks. Moraines in some cirques may be of St. Elias glacial advance. Lake levels suggested by faint bench and aligned delta cones. Ash dunes near Mount Natazhat. (RCAF, T7–36L)

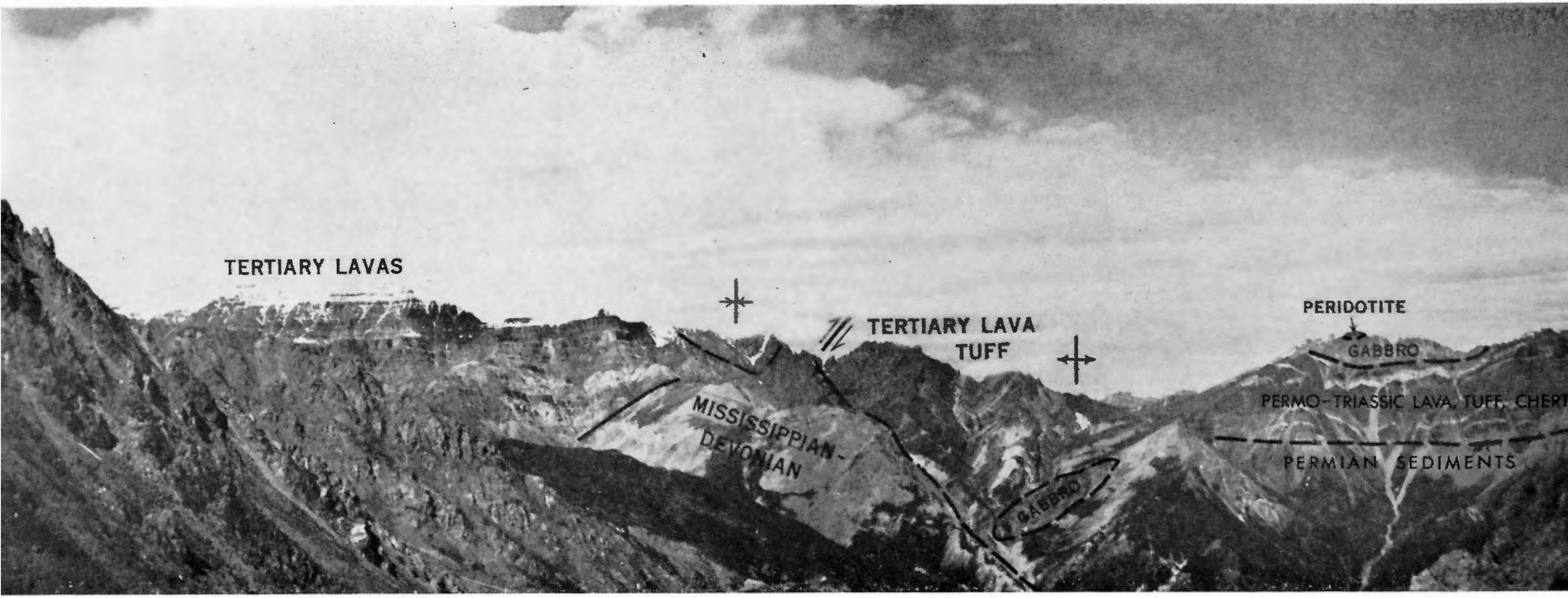
PLATE VI. View northeast across Gladstone Creek. Note *roches moutonnées*, stoss-and-lee topography showing ice-movement to left, notched spurs and cutbanks in till and lake silt on Gladstone Creek. (RCAF, T6–135R)

PLATE VII. View northeast across junction of Donjek and Kluane Rivers. Note well-defined moraines of Ruby ice-sheet. (RCAF, T7–24R)



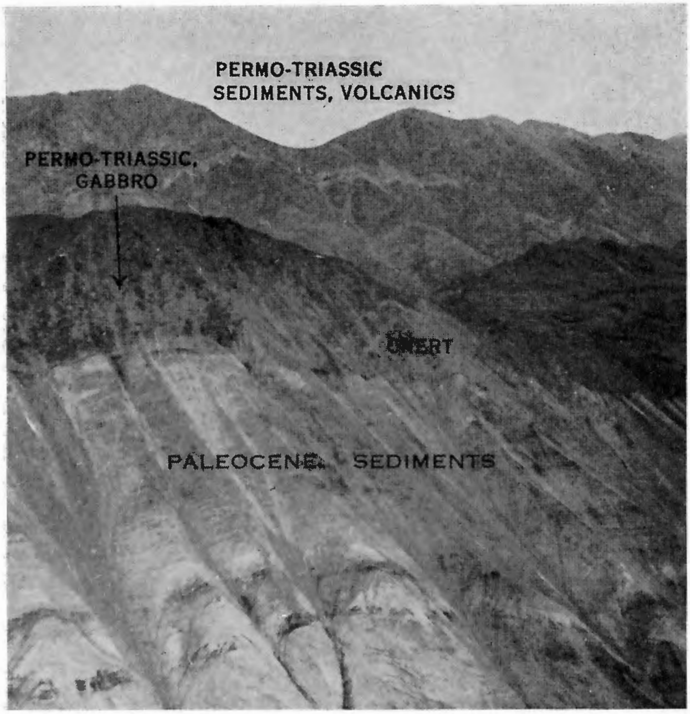
JEM, 8–2, 3–56

PLATE VIII. A. Amphitheatre Mountain from south. Tertiary sediments, overlain by volcanic rocks. Fault brings granodiorite over sediments and may continue as indicated.



JEM, 7–1, 2–52

PLATE VIII. B. North side of Steele Creek. Tertiary lavas are generally flat-lying (at left), but folded along fault zone and in fault contact with Kaskawulsh Group.



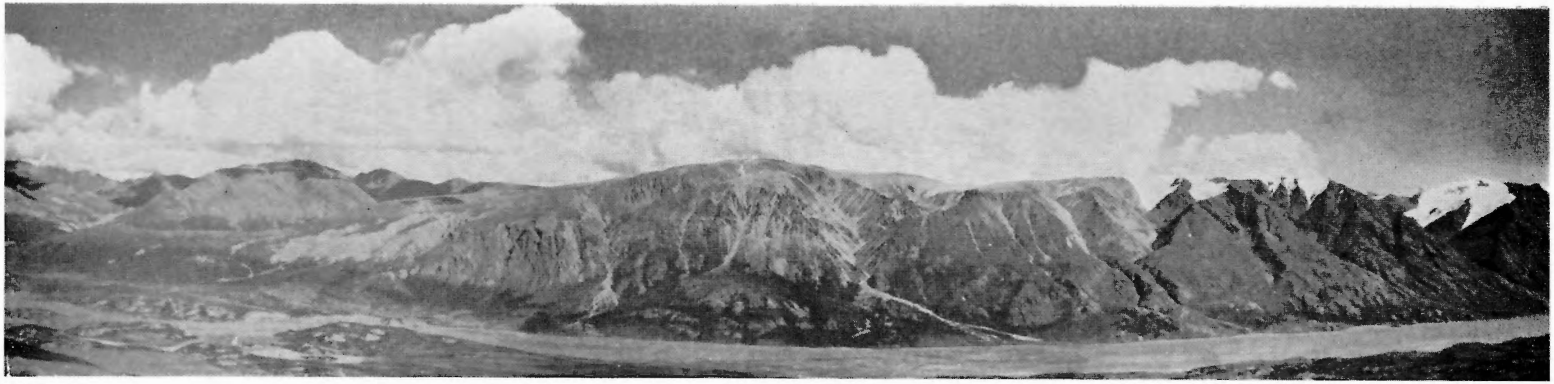
A. Northeast wall of west fork of Sheep Creek; Permian or Triassic gabbro and chert overlie Tertiary sediments on flat thrust.

JEM, 6-6-56

PLATE IX

B. East side of Donjek Valley, east of Donjek Glacier. Three glacial terraces: upper level is Ruby ice-sheet; middle level is St. Elias glacial advance; lower, valley level is sub-recent glaciation.

JEM, 5-4-51



JEM, 10–4, 5, 6, 7–52

PLATE X. A. East side of Donjek Valley south of glaciers. Three glacial levels: Ruby ice-sheet over top; St. Elias glacial advance on bench at middle level; sub-recent glaciation on valley bottom. Donjek intrusions surrounded by schist near centre.

JEM, 10–8, 11–1, 2 ,3–56

PLATE X. B. View northeast across Bullion Creek. Deeply incised till and lake silts. Gypsum-anhydrite mountain at right.

PLATE XI. Vertical airphoto of assumed explosion centre at foot of Natazhat Glacier. Circular wall is only faintly expressed. Most white on photo is ash. Ash that fell some 1,400 years ago has been concentrated at foot of glacier. (RCAF, A13134–78)

INDEX