MR-049-05

GEOLOGY OF THE FOSSIL CREEK AREA
WHITE MOUNTAINS, ALASKA

A THESIS

SUBMITTED TO THE DEPARTMENT OF GEOLOGY

AND THE COUNCIL ON GRADUATE STUDY

OF THE UNIVERSITY OF ALASKA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

MASTER OF SCIENCE

IN GEOLOGY

by

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and

M. Charles Durfee

May 1, 1961

We certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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PREFACE

This thesis presents the research of two graduate student investigators. Approval for the integration of their findings into one thesis, as granted by the Graduate Council of the University, was based on the special circumstances surrounding this work.

R.E. Church and M.C. Durfee conducted field research in adjacent field areas in the White Mountains. Although each student made independent field and laboratory investigations and preliminary manuscript preparation, the contributions of both workers were strengthened by a final combined presentation. In addition, a format was obtained which would ease the publication of these findings as a joint report.

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ABSTRACT

The Fossil Creek area is on the west flank of the White Mountains, approximately 50 miles north of Fairbanks, in the highlands between Beaver Creek and Cache Mountain. This area offers the best opportunity in the region for research on the structural and stratigraphic relationships between the Lower Paleozoic and pre-Middle Ordovician and Precambrian rocks. Previous studies of the are were reconnaissance investigations by the U. S. Geological Survey, the results of which were summarized by Mertie in U. S. Geological Survey Bulletin 872.

The oldest units mapped in the area are pre-Middle Ordovician metamorphic rocks. The sequence includes micaceous quartzites, quartz mica schists, metavolcanics, marbles, impure quartzites, cherts, phyllites, slates, and hornfelsed rocks in the eastern part of the area, and quartzites, slates, and metavolcanic rocks along the west margin. The slates are dated as Early Ordovician or Late Cambrian on the basis of a faunal assemblage collected by Blackwelder of the U. S. Geological Survey in 1915 to the northeast of the mapped area.

The Ordovician Fossil Creek volcanics overlie the pre-Middle Ordovician metamorphic rocks. The unit includes altered pyroxene andesites, altered tuffaceous conglomerates, altered tuffaceous agglomerates, and a quartzose sandstone. The Fossil Creek volcanics were previously dated as Middle Ordovician on

the basis of fossils collected by Blackwelder.

The Silurian Tolovana limestone is generally in fault contact with the Fossil Creek volcanics. It is a dark gray to blue-black, hard, dense limestone. Laboratory analyses show that the sequence contains oolitic, and dolomitized zones. Measured stratigraphic thicknesses range from 3200 feet to 4600 feet. Fossils collected from several localities re-affirm that the Tolovana limestone is of Silurian age.

Post-Silurian intrusives also occur in the area. These include gabbro, quartz monzonite, and tourmaline granodiorite dikes emplaced in the Tolovana limestone and pre-Middle Ordovician metamorphic rocks. The Cache Mountain quartz monzonite pluton intrudes the pre-Middle Ordovician metamorphic rocks and locally superimposed static metamorphism.

The major structural elements of the Fossil Creek area include a series of northeast trending thrust and reverse faults along which yielding has been to the northwest and by a high angle fault which is upthrown on the east side. Seven faults are recognized. The attitude of Tolovana limestone beds generally strikes northeast and steep dips prevail. Fold axes in the limestone also strike to the northeast and axial planes appear to dip steeply to the southeast.

INTRODUCTION

Location

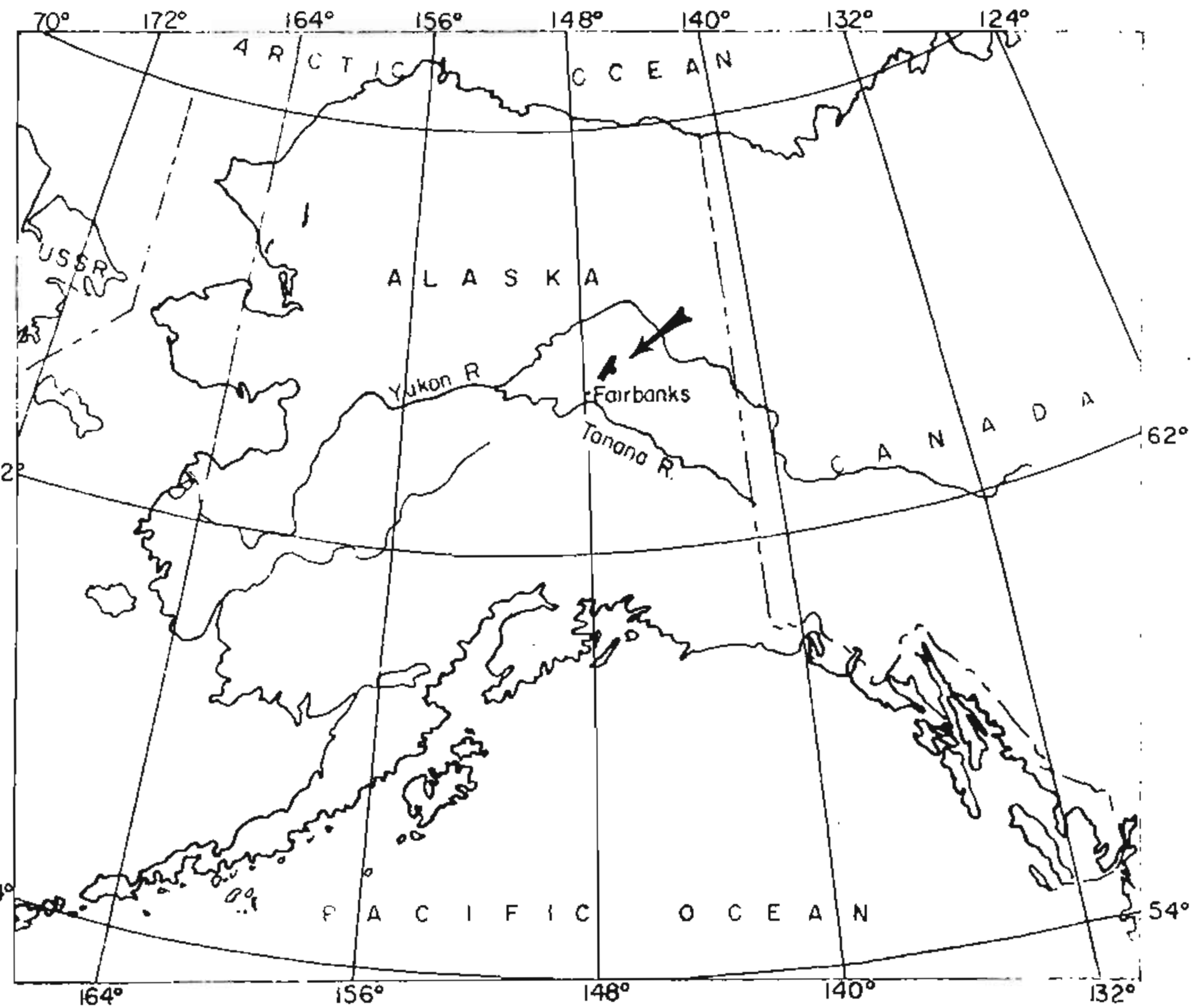
The Fossil Creek area is in the northwestern part of the White Mountains approximately 45 miles north of Fairbanks. The White Mountains form part of the uplands between the Yukon and Tanana Rivers in the highlands physiographic province of Interior Alaska.

The irregularly shaped study area includes the part of the White Mountains located within a rectangle defined by 65°25' and 65°40' north latitude, and 147°15' and 147°40' west longitude (fig. 1).

Roads, trails, and transportation

Travel in the White Mountains is slow and somewhat difficult due to the lack of roads or man-made trails. The nearest road is the Elliot Highway which is 25 miles to the south.

Forty years ago supplies were freighted over a winter trail from Olnes northward to Beaver on the Yukon River near the mouth of Beaver Creek. This trail passed over the drainage divide between the Tanana and Yukon Rivers to the big bend of Beaver Creek, and followed Beaver Creek northward. During the summer, prospectors used to raft down Beaver Creek. The trail has recently been used in summer to reach the big bend of Beaver Creek, but is



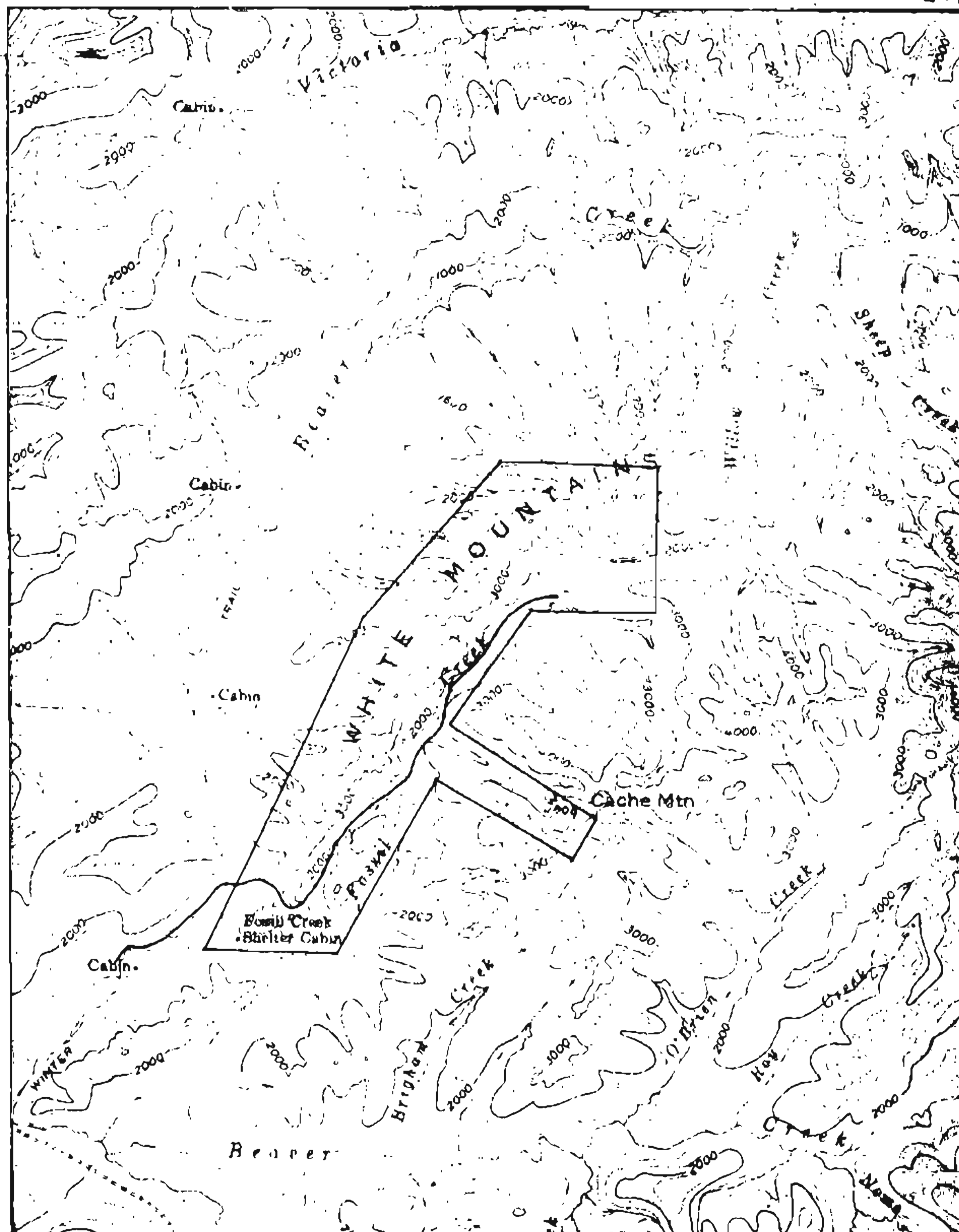
INDEX MAP SHOWING LOCATION OF THE FOSSIL CREEK AREA, ALASKA
Figure 1

accesible only to tracked vehicles or those equipped to traverse swamps.

Small boats powered by outboard motors are occasionally used on Beaver Creek, but numerous bars and the low water level encountered during most of the summer months makes this type of transportation difficult.

Easiest access to the area is provided by light aircraft, and this was the method used by the writers while studying the Fossil Creek area. Two landing areas suitable for light aircraft are located along Beaver Creek. The best field is an improved meander bar of Beaver Creek near the Bucholtz cabin site about 5 miles southwest of the southern limit of the Fossil Creek area. It is used extensively by hunters and fishermen, and was utilized several times by the writers. Another landing area is located on a gravel bar of Beaver Creek near the Shebal hunting cabin about 3 1/2 miles downstream from Bucholtz's airstrip. It is a short strip, however, and it is often flooded at high water.

Access to the actual study area and transportation within it were by foot. The access route followed Beaver Creek from the airstrip to a point one mile north of the confluence of Fossil and Beaver Creeks, and then east across Beaver Creek into the study area (fig. 2). Back packing was difficult in some areas because of dense alder



TOPOGRAPHIC MAP OF FOSSIL CREEK AREA,
WHITE MOUNTAINS, ALASKA

Access route

Contour Interval 200 ft

0 5 10 MILES

Scale

North

Compiled from U. S.
Geological Survey base

Figure 2

and willow stands. Whenever possible, game trails were utilized which greatly facilitated travel.

Supplies were received at the base camp sites three times during the season by means of pre-arranged free fall air drops from light aircraft.

Recently helicopters have been used within the area by petroleum companies and would seem to be the ideal method of transportation.

Previous exploration and study of the area

The first white men to enter the Yukon-Tanana region were traders of the Hudson's Bay Company who established Fort Yukon in 1847, but who did not explore the area west of it. The region was known to the Russions through the reports of natives who visited the trading posts on the Yukon, but they did little to explore the area either, although Ivan Lukeen of the Russian American Company was the first trader to reach Fort Yukon (in 1863) from the lower Yukon (Mertie, 1937, p. 3). After the purchase of the territory by the United States, numerous traders and prospectors penetrated the Yukon-Tanana region, but little factual information concerning the geology resulted.

The first geologic expedition to penetrate the Yukon-Tanana region was a United States Geological Survey party headed by J. E. Spurr in 1896. Spurr, assisted by H. B. Goodrich and F. C. Schrader, crossed Chilkoot Pass to the headwaters of the Yukon and descended it to Nulato. On this trip they visited the mining camps at Fortymile, Circle, and Rampart (Spurr, 1898). The party mapped these mining districts and attempted to systematically classify the rocks exposed along the Yukon River.

In 1898, A. H. Brooks and W. J. Peters ascended the White River to its headwaters, portaged to the Tanana River and traveled down it to its mouth (Brooks, 1900). Thus, although neither of these geologic reconnaissance parties penetrated the area under study, a general knowledge of the geology of the areas north and south of it had been gained prior to 1900.

Prospectors had undoubtedly passed through the Fossil Creek area previously, but it was not until the inception of a systematic geologic survey of the Yukon-Tanana region in 1903 under the direction of A. H. Brooks that the Fossil Creek area was penetrated by a geological party. This task was undertaken by L. M. Prindle, in co-operation with other United States Geological Survey geologists, and continued by him until 1911 (Mertie, 1937, p. 6). During the summer of 1904, Prindle, assisted by F. L. Hess, made a reconnaissance traverse from Cleary Creek across the White Mountains to the southern limit of the Yukon flats, then southwest to the main divide between the Yukon and Tanana drainage systems, and finally west along this divide to the Rampart region (Prindle and Hess, 1906, p. 9). During this traverse they mapped the geology of the Fossil Creek areas on a reconnaissance scale.

In 1905, a topographic party under D. C. Witherspoon, accompanied by R. D. Stone as the geologist, conducted a topographic reconnaissance from Fort Hamlin to Circle. They carried their topographic and geologic investigations south into the Fossil Creek area of the White Mountains (Stone, 1906, p. 128).

The Fossil Creek area was again visited by Prindle, accompanied by B. L. Johnson, in 1909.

From 1911 until 1931, study of the Yukon-Tanana region was carried on by J. B. Mertie, Jr. He worked in the Fossil Creek area in 1921. His work culminated in the publication of U. S. Geological Survey Bulletin 872, "The Yukon-Tanana Region, Alaska", in 1937. Incorporated in this work is the otherwise unpublished stratigraphic and paleontologic information obtained by Eliot Blackwelder in the Fossil Creek area during 1915.

In addition to the topographic and reconnaissance geologic studies made by the U. S. Geological Survey, the surface waters of the area were very briefly studied as part of the program of surface water studies conducted from 1907 to 1912 in the Yukon-Tanana region.

Since 1937 no published work has appeared concerning the geology of the Fossil Creek area. However, several oil exploration parties are known to have examined the region during the past several years.

Present investigation

Scope of the report

The purpose of this study was to gain understanding of the detailed geology of a relatively small area which would yield regionally significant information on the structure and stratigraphy of the Ordovician and Silurian rock units and their relationships to the pre-Middle Ordovician metamorphic rocks. The Fossil Creek area was selected because of excellent vertical and areal exposure.

This report presents the results of an integrated field and laboratory study of the Fossil Creek area, including a 1:20,000 scale geological map and structure sections.

The report includes an analysis of the geologic history of the area in respect to the regional tectonic setting.

Field and laboratory methods

During the first week of the field season, which lasted from June 3, 1960 until September 2, 1960, Dr. Robert Forbes, thesis advisor to the writers, and the latter made a 7 day reconnaissance of the Fossil Creek area. This was done in order to obtain a better appreciation of the geological and geographical problems to be encountered in the area. As a result of this reconnaissance it was decided that Church should study the northern Fossil Creek ridge area and that Durfee would be responsible for an adjacent area to the southwest. In addition, possible access routes, base camp sites, and airdrop locations were investigated. From the information gained on this traverse a field schedule was established and arrangements were made for aerial resupply at the base camp sites on specified days.

Aerial photographs at an approximate scale of 1:40,000 were used in the field for mapping. The location of each geologic station was recorded on the photos at the same time that the information was recorded in the notebook. In addition, structural attitudes, formational contacts, fault traces, and other geologic information were recorded on a photo. This information was transferred to U. S. Geological Survey 1:63,360 scale maps, and from this a final map was prepared on a 1:20,000 scale base. The notes were supplemented by kodachrome and black and white photographs.

Field work was accomplished from four base camps. The areas within one day's range of each camp were mapped first, and then 5 or 6 day pack trips were made to the more remote parts of each area.

Two measured sections of limestone were made in the northern and central Fossil Creek areas utilizing the brunton and tape method.

About 250 rock specimens were collected, and from these approximately 200 thin sections were made. From thin section analysis, the mineralogical composition, textural relationships, and petrogenesis of the volcanic and plutonic rocks was determined. In addition, rock chips were selectively stained for K-feldspar using the sodium cobaltinitrite method.

The metamorphic rocks received special study to determine their mineralogical composition, metamorphic grade, and metamorphic history. In addition to thin sections, polished sections, stained chips and acetic acid etches were prepared on carbonate specimens as an aid in determining the characteristics and petrogenesis of the Tolovanna limestone.

Collections of fossils were made from several new localities during the summer. These fauna were sent to the Alaskan Geology Branch of the U. S. Geological Survey for identification.

Climate, vegetation, and wildlife

Climate

The Fossil Creek area has the continental climate typical of interior Alaska. The climate is characterized by long, cold winters with few daylight hours in midwinter, and short, warm summers with almost continuous daylight.

There are no weather data for the Fossil Creek area, but conditions probably differ little from Fairbanks. Fairbanks has a mean annual temperature of 26.1°F, and absolute minimum recorded temperature of -66°F. Freezing temperatures have been recorded every month except July (U. S. Weather Bureau, 1943). The mean summer temperature is 57.8°F at Fairbanks.

The mean annual precipitation is 11.7 inches, but more than 60 percent of this falls during the field season, from May through September. Thunderstorms are common in the region.

The writers observed that wind is more common in the White Mountains than at Fairbanks and that the velocities seemed higher, although no measurements were taken.

Permafrost occurs discontinuously in the Fossil Creek area, but no study of its extent or distribution was attempted.

Vegetation

The vegetation of the Fossil Creek area consists of spruce forest, alders, willows, dwarf birch, moss, lichens and sedge tussocks. The valley of Fossil Creek and the south facing slopes support dense growths of white spruce and occasional cottonwood trees. White spruce up to 24 inches in diameter in the stream valleys, but decreases rapidly in size and frequency toward timberline. Timberline elevations are quite variable and depend on the degree of southern exposure and the rock type. On south facing slopes where the bedrock is limestone, spruce trees occur up to elevations of 3000 feet. On north facing slopes, where the bedrock is volcanic material, the timberline may be only 2000 feet above sea level. Timber does not occur on north facing slopes where the bedrock is limestone.

Above timberline the vegetation changes from spruce trees to dwarf birch. Above this occur lichens, moss, and small flowering plants. The upper slopes of the limestone ridges generally support plant communities of the heath type according to Gjaerevoll (1953, p. 161).

Dense alder and willow thickets occur along the banks of Fossil Creek and in poorly drained areas in the creek bottom. These thickets also occur in draws on the south facing slopes and are particularly abundant on the northwest facing volcanic slopes.

Poorly drained areas on the interfluves and in creek bottoms support a muskeg vegetation of scrub spruce, sedge tussocks, Sphagnum mosses, alders, and willows.

Flowering plants occur at all elevations, and, in addition, high and low bush cranberries and blueberries are plentiful.

Wildlife

A number of varieties of animals occur in the Fossil

Creek area. Dall sheep are the most numerous of the big game animals, and are frequently seen on the upper slopes of Fossil Creek ridge. Black bears are very common also, particularly in Fossil Creek Valley. The bears may be very bothersome and care should be taken to keep all food stored at least 10 feet off of the ground. Moose are also present in the valleys, and caribou were seen to the east of the mapped area near the head of Fossil Creek. Grizzly bear have been reported in the area, but none were encountered.

Small animals such as rabbits, squirrels, marmots, weasels, and mice were observed, and other fur-bearing animals undoubtedly also occur.

The only game birds observed were grouse and ducks. Hawks, falcons, eagles, ravens, owls, Alaska jays, and many varieties of songbirds are also present.

Grayling are found in Fossil Creek and are the only fish present in the area.

Acknowledgments

The writers wish to gratefully acknowledge the Ohio Oil Company for the generous grant which they awarded to the Geology Department of the University of Alaska which made this project possible.

We wish to express our appreciation to Dr. Robert B. Forbes, our thesis advisor, for his invaluable guidance in the classroom and field, and for the many hours of his time granted to us for discussion of our project.

Appreciation is expressed to Dr. Marvin Andreson, Dr. Troy L. Péwé, and Mrs. Florence Weber for critically reviewing our manuscript for their assistance during preparation of the thesis. In addition, the writers are greatly indebted to Mr. Donal M. Ragan for invaluable discussions which greatly aided the solution of many of our problems.

Gratitude is extended to W. C. Fackler and D. Wallington of American Stratigraphic Company for many valuable discussions which greatly aided the writers in working with the stratigraphy of the limestone.

Tom Olson and Hawley Evans of Fairbanks Air Service are thanked for expertly flying the writers to and from the Fossil Creek area, and for delivering our supplies on time in what was often poor flying weather.

We want to thank Leroy Shebal for his assistance in arranging for new supplies after ours had been eaten by bears.

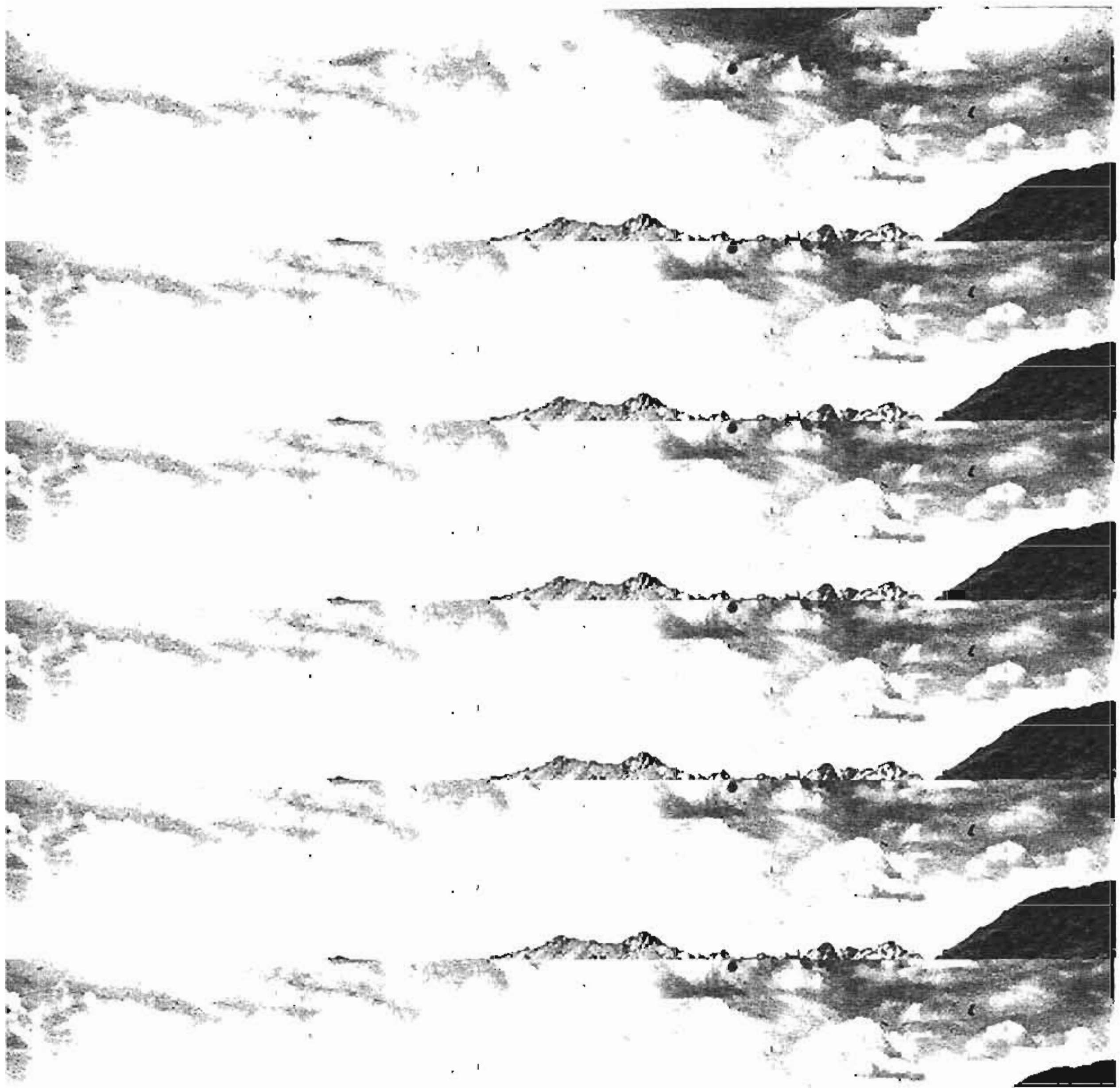
We especially express our appreciation to our wives, Janet Church and Alice Durfee for encouragement throughout the field season, and while the manuscript was in preparation. We are additionally grateful to them for typing the final manuscript.

PHYSIOGRAPHY

Topography

The major topographic features of the Fossil Creek area include a prominent northeast trending ridge system of the White Mountains, segments of Beaver Creek and Fossil Creek valleys, and a narrow, eastward extending ridge rising towards, and including Cache Mountain (fig.2).

Fossil Creek ridge is the major topographic feature of the region. It is a northeast trending, barren rock ridge of limestone and volcanic rock which actually consists of three segments: a southern section south of the mapped area and separated from it by the water gap of Fossil Creek, a central section; and a northern section which is separated from the central section by a wind gap (fig. 2). The altitude of the ridge crest is generally more than 3000 feet in the central section, and in the northern section it is generally more than 3500 feet in elevation. Several peaks along the ridge are more than 4000 feet above sea level. The crest of the ridge is very rugged and serate, particularly in the portion formed by vertical limestone beds. In the extreme southern part of the mapped area Fossil Creek ridge bifurcates and two ridges occur, separated by Bear and Windy Valleys (fig. 3). The eastern ridge is only 5 miles long and trends northeast into the valley of Fossil Creek.



In the northern Fossil Creek area a smaller ridge of volcanic rocks and limestone beds lies to the west of the main ridge. The small ridge is dissected by a number of deeply incised valleys (fig. 2).

A series of spur ridges descend to the northwest from Fossil Creek ridge to the valley of Beaver Creek. The east flank of Fossil Creek ridge slopes steeply towards the narrow valley floor of Fossil Creek.

Several gently sloping ridges descend westward from Cache Mountain to Fossil Creek valley and present a sharp contrast to the abrupt rise to Fossil Creek ridge on the west. A series of altiplanation terraces is present on the ridges which descend from Cache Mountain.

Cache Mountain, elevation 4772 feet, is the highest peak in the Fossil Creek area. The minimum elevation, approximately 1220 feet, occurs in the valley of Beaver Creek where the creek flows westward out of the mapped area. The maximum relief is over 3500 feet, but the average relief is about 2000 feet.

Drainage

The runoff within the mapped area flows either into Fossil Creek or Willow Creek, which are tributaries of Beaver Creek, or directly into Beaver Creek from numerous short tributary streams which drain the west slopes of

Fossil Creek ridge (fig. 2). Beaver Creek flows northward into the Yukon River.

All of the streams, including Beaver Creek, are clearwater streams. None of the streams in the actual study area are navigable except Beaver Creek, which can be navigated in a small boat.

Much of the drainage of the area underlain by limestone is internal. During rainstorms the water rapidly disappears into talus slopes and reappears at the base of the slopes as springs. Most of the small tributaries of Fossil Creek are intermittent and flow only for a few hours after a heavy rain.

Fossil Creek, which heads on the north side of Cache Mountain, flows southward, parallel to Fossil Creek ridge, until it cuts through the ridge at the southern limit of mapping (fig. 2). It receives the run-off from the east slope of Fossil Creek ridge, as well as from the northern and western slopes of Cache Mountain.

Both Beaver and Fossil Creeks have had long and complex histories (Mertie, 1937, p. 27). Fossil Creek probably previously flowed through the wind gap that now separates the central Fossil Creek ridge area from the northern Fossil Creek ridge area. Later it was captured by a stream flowing southward to Beaver Creek, without crossing Fossil Creek ridge. Still later, a small tributary of Beaver Creek, by working headwardly across Fossil

Creek ridge, captured Fossil Creek and formed its present course. At one time, the channel of Fossil Creek might have been incised farther west than at present, along a course now marked by possible valley floor remnants, Windy Pass and Bear Pass (fig. 2).

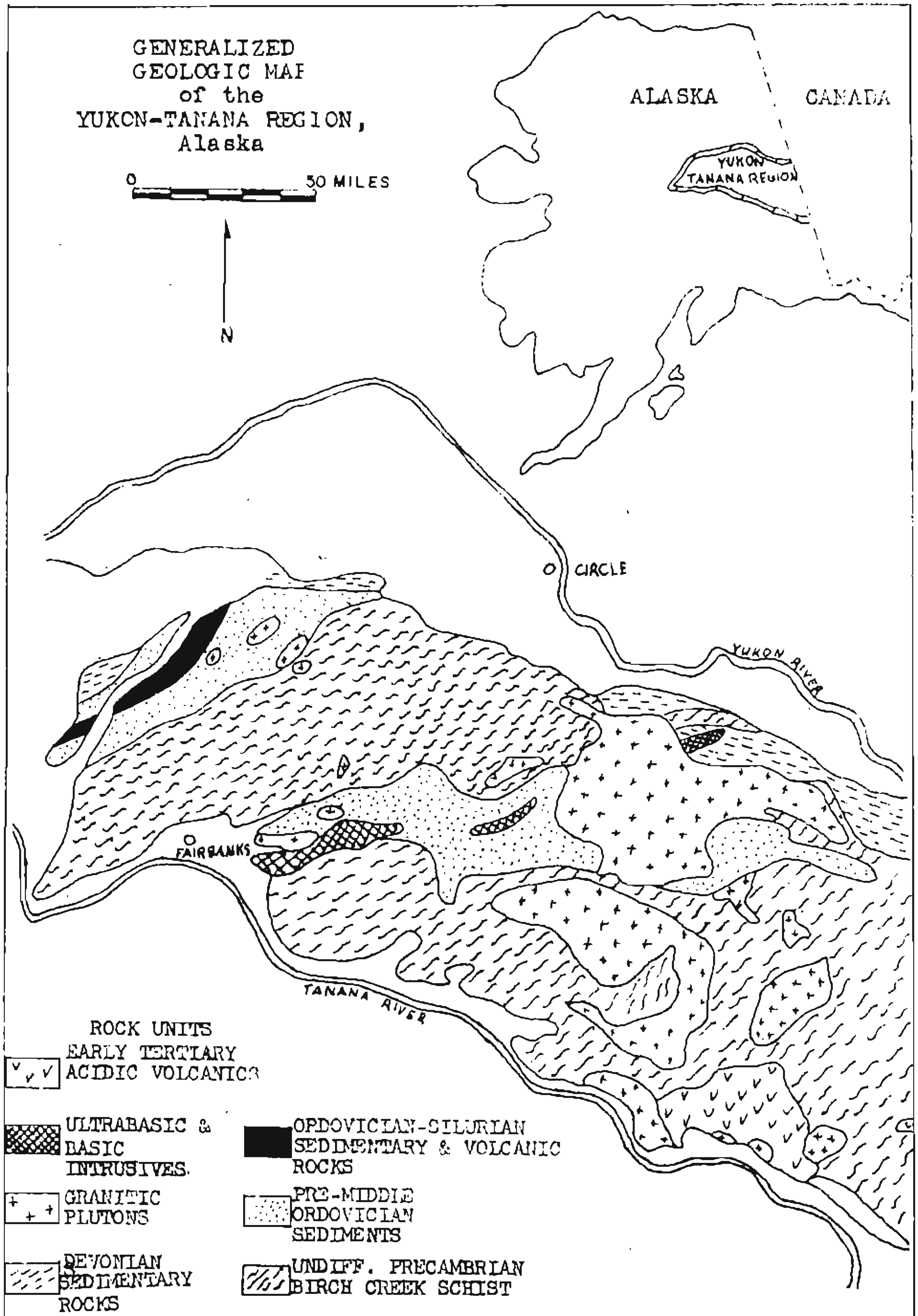


Figure 4

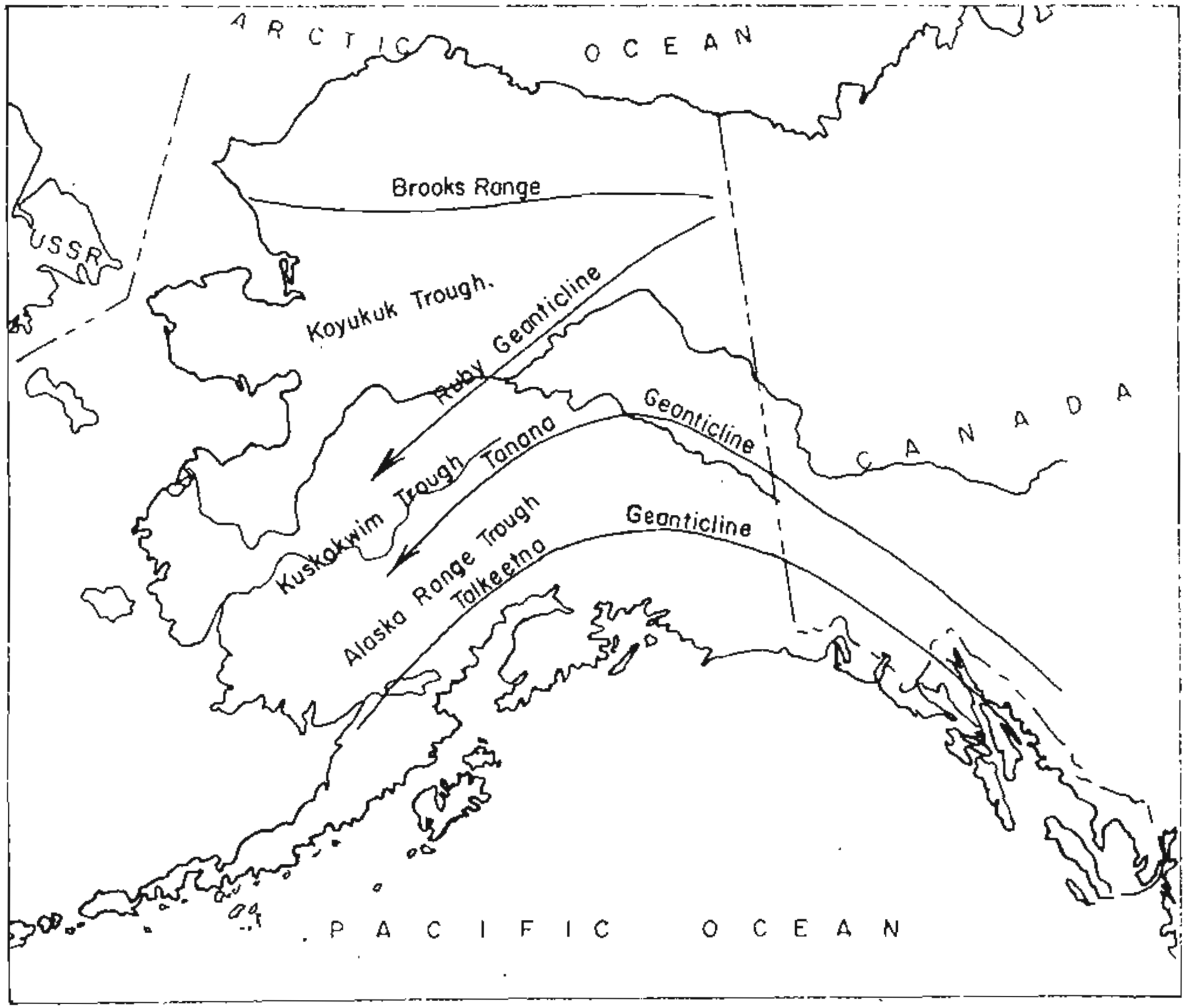
(From Geologic Map of Alaska, 1957)

GEOLOGIC SETTING

The rocks that crop out in the Yukon-Tanana region range in age from Precambrian through Quaternary. Every system except the Jurassic is represented by sedimentary or metamorphosed sedimentary rock units, including metasediments and metavolcanics; unaltered volcanic rocks; marine shales, limestones, cherts, sandstones, and conglomerates; and continental sandstones, shales, conglomerates, and coal measures. Devonian, Cretaceous-Jurassic and Tertiary intusives also occur and range in composition from ultrabasic to acidic, and in size from small dikes to batholiths (fig. 4).

The Yukon-Tanana uplands region is to a large extent located on the Tanana geanticline (Payne, 1955), the broadest of three major geanticlines created during the Early Cretaceous orogeny, and to a lesser extent in the area of the Kuskokwin geosyncline created during the same orogeny. The Tanana geanticline has been traced from the eastern part of the Kuskokwim region northeastward to central Alaska and thence eastward into Canada (fig. 5).

The Kuskokwim geosyncline is north of the Tanana geanticline and roughly parallels it. The Fossil Creek area is between the axes of these two major Mesozoic structural features, but is closer to the axis of the Kuskokwim geosyncline.



LATE CRETACEOUS STRUCTURAL FEATURES
(modified from Payne, 1955)
Figure no. 5

During the late Cretaceous and Tertiary orogenies local arches were developed along the axis of the Kuskokwim geosyncline resulting in removal of much of the Mesozoic and Paleozoic sedimentary cover from local areas. The presence of one of these arches in the Fossil Creek area would explain the lack of upper Paleozoic, Mesozoic, or Tertiary sediments in the area. Within the Fossil Creek area only pre-Middle Ordovician metamorphic rocks, Ordovician volcanic rocks, Silurian carbonate rocks, unconsolidated Quaternary sediments, and acidic and basic intrusives have been recognized.

Figure 6. Cache Mountain and adjacent peaks as seen from central Fossil Creek ridge. The broad, well rounded ridges of the lower slopes are underlain by pre-Middle Ordovician rocks.

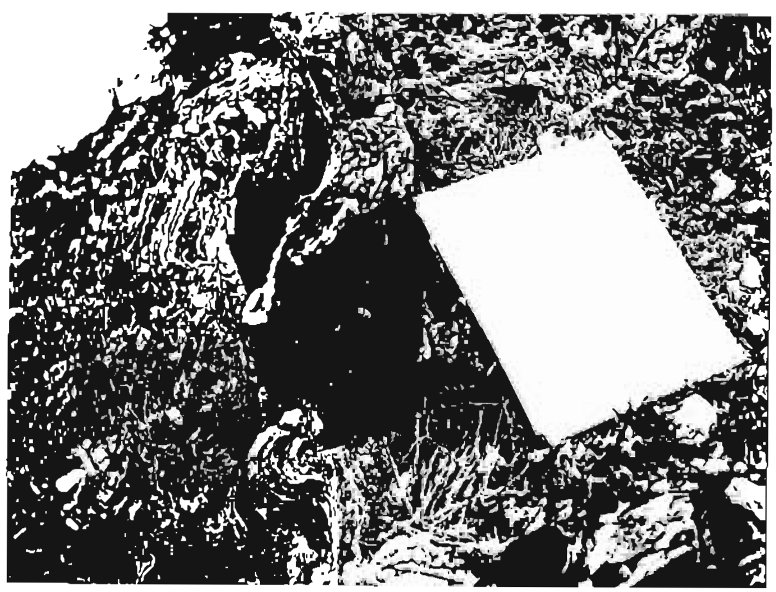


Figure 7. A small overturned fold in pre-Middle Ordovician sequence which crops out at south end of Fossil Creek ridge between Windy Valley and Fossil Creek. The fold axis plunges 40°, N 65° E.

THE PRE-MIDDLE ORDOVICIAN SEQUENCE

Mertie (1937, p. 66) has subdivided the pre-Middle Ordovician rocks into five lithologic units which are exposed along a zone from the north end of the White Mountains southeastward to Champion Creek. These units are generalized by Mertie as follows:

A. Slate and quartzite (top of section).

B. Black argillite, slate, and chert.

C. Red and green slates, quartzose sandstone, and a little limestone.

D. Quartzose sandstone and grit, in part feldspathic arkose and greywacke, all interbedded with slate.

E. Phyllite and quartzite, overlain by somewhat less altered quartzitic rocks.

According to Mertie, the Fossil Creek area is bordered on the northwest by Unit A, and on the southeast by Unit B. Units C, D, and E occur successively to the southeast.

Regional distribution

Pre-Middle Ordovician rocks occur in a northeast trending belt extending from the Tatalina River to the north fork of Preacher Creek (Mertie, 1937, p. 65). Rocks representing a continuation of this belt crop out further to the southwest in the area between the Tolovana and Tanana Rivers. The main portion of this belt is over 90 miles long and the maximum width is approximately 20 miles (Mertie, 1937, plate 1). The White Mountains occur within this northeast trending belt.

Another belt of pre-Middle Ordovician rocks extends eastward from the lower valley of the Chena River for approximately 160 miles into the Forty Mile region. This belt is approximately 30 miles wide.

Local distribution

The Fossil Creek area is bounded on both the northwest and southeast sides by pre-Middle Ordovician rocks. Along the northwest margin of the area these units form the low rounded spurs rising from the valley of Beaver Creek towards Fossil Creek ridge. Along the southeast margin of the area, the pre-Middle Ordovician rocks occur in a belt which extends generally east of, and parallel to Fossil Creek (pl. 1.).

Three isolated exposures of the pre-Middle Ordovician rocks also occur in the area. The largest of these occurs to the northwest of Fossil Creek ridge and appears to be the core of a small anticline. Another exposure occurs in a structurally complex portion of northern Fossil Creek ridge. A very small slice of pre-Middle Ordovician rocks has apparently been brought up by a thrust fault in the southern part of the area (pl. 1.).

In order to facilitate the petrologic description of the pre-Middle Ordovician rocks they have been divided into four units based on either their structure or geographic position. These units are as follows:

1. Cache Mountain units
2. Southern Fossil Creek units
3. Beaver Creek units
4. Central Fossil Creek-Southern Willow Creek units

Generally, the areas underlain by pre-Middle Ordovician rocks are topographically expressed as low, rounded ridges which are almost completely covered by vegetation (fig. 6); good exposures are rare. Rubble can be picked up in frost scars and stone nets, however. Outcrops are almost entirely restricted to small stream valleys and to the steep edges of altiplanation terraces.

Stratigraphic thickness

No reliable estimate of the thickness of the pre-Middle Ordovician rocks can be made. Basal units have not been recognized in the area, and the nature of the upper contact with the Ordovician Fossil Creek volcanic rocks is obscure. The structure of the pre-Middle Ordovician units is also very complex, which makes thickness estimation additionally difficult.

Structure

The foliation in the pre-Middle Ordovician metamorphic rocks strikes approximately N 60° E, and generally dips to the southeast. Occasional dips to the northwest were recorded, however. The trend ranges between N 35° E and N 85° E. The rocks generally appear, however, to be isoclinally folded, with axial planes dipping to the southeast.

Very few folds were found, and where they occur, the plunge varies considerably (fig. 7).

Petrology

Cache Mountain units

The pre-Middle Ordovician rocks which crop out between Fossil Creek and Cache Mountain are chiefly low grade and lowest medium grade synkinematically metamorphosed, slightly argillaceous, quartz rich sediments. Near the contact zone of the Cache Mountain intrusive, late recrystallization caused by static thermal metamorphism tends to obscure the earlier schistose fabric in favor of a hornfelsic texture. Minor metasiltstone and metavolcanic intercalations are also present.

Because of lithologic similarity, the small slice of pre-Middle Ordovician rocks brought up along a thrust plane in the limestone in the southern part of the area is discussed here with the Cache Mountain units (fig. 8).

The Cache Mountain units include the following rock types:

Metasiltstones
Phyllites and phyllitic schists
Polymetamorphosed quartz rich pelitic rocks
Biotite-bearing actinolitic hornblende hornfels

Figure 8. An outcrop showing a small slice of pre-Middle Ordovician rocks which have been brought up along fault "G". The outcrop is located on the east side of Fossil Creek ridge in the southeastern portion of the area.

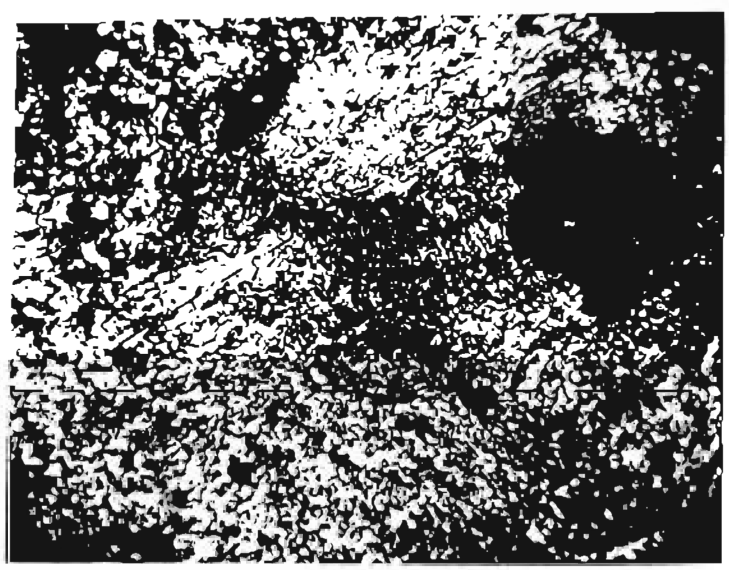


Figure 9. Photomicrograph showing s_1 and s_2 transecting relationships in polymetamorphosed quartz rich peletic rock (specimen no. 4: pl. 5). Crossed nicols, X 80.

Metasiltstones.-- (Specimen no. 1; pl. 5) An extremely fine grained, massive, dark green metasiltstone occurring on the low end of the mapped ridge rising towards Cache Mountain is chiefly composed of very fine grained clastic quartz and plagioclase; the accessory minerals are zircon, tourmaline, magnetite, and apatite. Some of the clastic plagioclase grains show relict polysynthetic albite twinning, with extinction angles indicating an approximate composition of sodic andesine. A slight amount of recrystallization of the quartz has occurred, indicating that the rock has undergone low grade synkinematic metamorphism.

Phyllites and phyllitic schists.-- (Specimen nos. 2 and 3; pl. 5) The majority of the rocks in the Cache Mountain units are quartz rich metamorphic rocks with varying amounts of argillaceous material. These rocks are typically fine to medium grained and weather to a dark green to tan color. A foliation is observable in the more argillaceous types. Typical mineralogy includes clastic quartz and a few grains of clastic oligoclase-andesine, recrystallized albite, well developed muscovite, chlorite, and incipient biotite. Common accessory minerals include zoned tourmaline, apatite, and magnetite. Zircon and rutile occur less commonly as accessories.

The clastic grains range from less than 1 mm to approximately 3 mm in diameter and are generally well rounded. Occasionally, twinning is preserved in the plagioclase; more commonly it has been obliterated by recrystallization. Sericite, chlorite, some muscovite, and incipient biotite occur interstitially; the parallel alignment of these minerals defines a well developed crystallization foliation. Recrystallized and sheared clastic quartz also shows a fair degree of preferred orientation, with the c axes normal to the direction of foliation.

These rocks represent the recrystallized equivalents of impure quartz rich sediments containing varying amounts of argillaceous material. The schistose fabric and the presence of the mineral assemblage, muscovite, chlorite, and incipient biotite indicates that these rocks have been subjected to synkinematic metamorphism, of a grade transitional between upper-low and lowermost medium grade (fig. 10).

Polymetamorphosed quartz rich pelitic rocks.-- (Specimen no. 4; pl. 5) The polymetamorphosed quartz rich pelitic rocks have essentially the same megascopic characteristics and mineralogy as the dynamically recrystallized quartz rich argillaceous rocks. They are fine to medium grained and weather a dark green to tan color. They contain clastic quartz, some clastic plagioclase, recrystallized albite, chlorite, muscovite, and incipient biotite. Tourmaline, apatite, magnetite, and rutile occur as accessories.

In addition to an earlier crystallization foliation defined by parallel oriented muscovite, chlorite, and incipient biotite, some of these rocks show a latent transecting schistosity (s_2) defined by incipient sericite. This s_2 transects the original foliation at an angle of approximately 35°.

Superimposed on these two s planes are the effects of a still later hornfelsing, as evidenced by randomly oriented muscovite and sericite (fig. 9).

These pelitic rocks have a polymetamorphic history. The original quartz rich argillaceous sediments have been subjected to two periods of synkinematic metamorphism as well as a later static thermal metamorphism. The record of the earliest dynamic metamorphism is defined by the parallel alignment of the muscovite, chlorite, and incipient biotite. The later stage of dynamic metamorphism is indicated by transecting s_2 defined by late sericite. Directionless muscovite and sericite are related to the static thermal metamorphism produced by intrusion of the Cache Mountain pluton.

It is probable that all of the Cache Mountain pre-Middle Ordovician metamorphic rocks have a polymetamorphic history, but the evidence of the earliest synkinematic metamorphism is seldom preserved.

Biotite bearing actinolitic hornblende hornfels.--(Specimen no. 5; pl. 5) A dark gray, fine grained, massive metavolcanic unit occurs near the contact of the Cache Mountain intrusive. The rocks in this unit are composed of actinolite, plagioclase, quartz, biotite, and accessory amounts of apatite, magnetite and rutile. Some of the amphibole is compositionally closer to actinolitic hornblende than actinolite.

No relict volcanic textures are preserved. The acicular fine grained actinolite has formed matted, directionless aggregates. Biotite crystals are also randomly oriented (fig. 11).

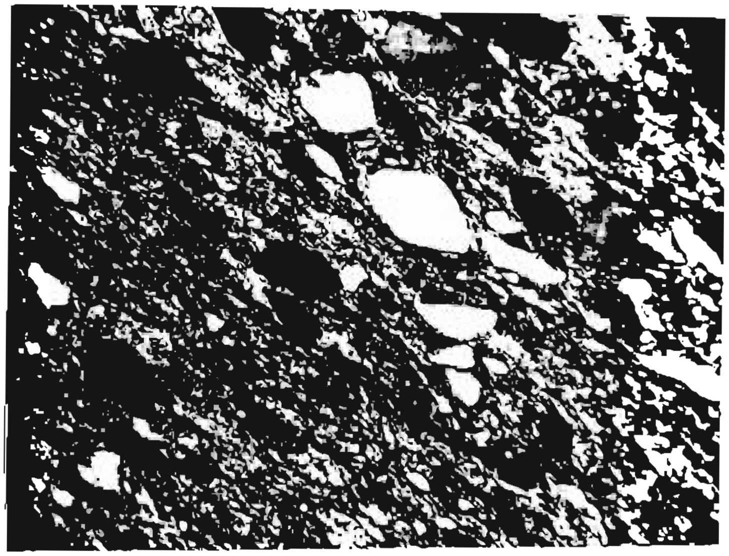


Figure 10. Photomicrograph of phyllitic schist transitional between upper-low and lower medium grade from the pre-Middle Ordovician of Cache Mountain (specimen no. 3; pl. 5). Crossed nicols, X 80.

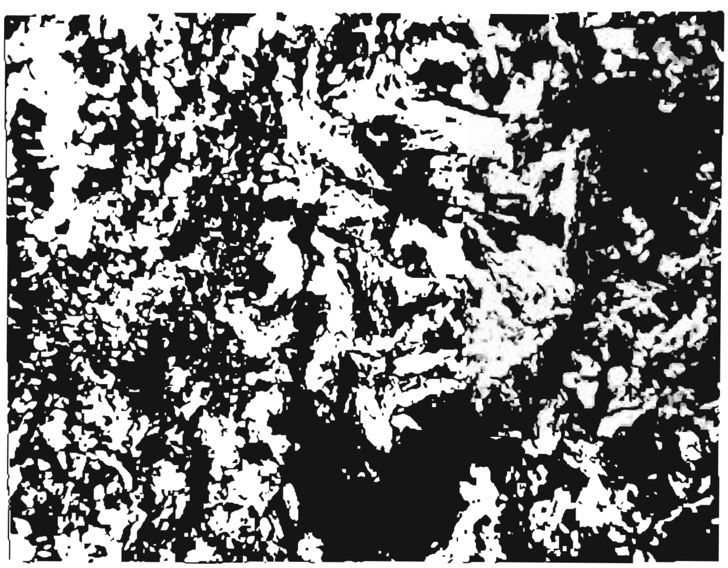


Figure 11. Photomicrograph of biotite bearing actinolitic-hornblende hornfels (specimen no. 5; pl. 5) showing randomly oriented, matted actinolite aggregates. From the pre-Middle Ordovician of Cache Mountain. Crossed nicols, X 80.

Although no relict igneous texture remains, the mineralogical assemblage suggests that this rock was originally a basic volcanic. Subsequent static thermal metamorphism associated with the emplacement of the Cache Mountain intrusive has hornfelsed the rock.

Southern Fossil Creek units

Two specimens were studied from the valley of Fossil Creek south of the Cache Mountain units. Both of these were picked up as rubble as the area is almost completely covered. Both are low grade dynamically metamorphosed rocks. The southern Fossil Creek units consist of the following rock types:

Greenschists
Impure marbles

Greenschist.-- (Specimen no. 6; pl. 5) The fine grained, dark green, greenschist shows a definite foliation in the hand specimen. Carbonate, chlorite (both pennine and clinaclore), plagioclase, quartz along with diopsidic augite, magnetite and stilpnomelane make up the rock. Accessories include leucoxene and apatite.

The rock is generally fine grained, except for a few medium grained relict diopsidic augite and magnetite phenoclasts which have been sheared and stretched parallel to the foliation. Chlorite and stilpnomelane have grown around these phenoclasts parallel to the foliation. A crystallization foliation is fairly well developed. The carbonate comprises over 40 per cent of the rock, while the pyroxene and chlorite each comprise approximately 15 per cent. The plagioclase, quartz, magnetite, and stilpnomelane are minor minerals, and together comprise approximately 25 per cent. The accessories make up the rest of the rock.

The rock was originally a basic volcanic, as indicated by the relict mineral assemblage. Later low grade synkinematic metamorphism has produced the foliation which is defined by the chlorite and stilpnomelane, and has also sheared and deformed the relict pyroxene and magnetite. Much of the carbonate has probably been added later by hydrothermal solutions.

Impure marbles.-- (Specimen no. 7; pl. 5) The impure marbles are very fine grained, weather to a light gray color, and show a distinct foliation. They are dominantly composed of carbonate, with minor quartz, tremolite, and opaque carbonaceous matter.

Closely spaced shear planes and the preferred orientation of the tremolite and carbonaceous matter occurring within and parallel to these closely spaced shear planes define the foliation. The calcite has been recrystallized and shows well developed glide twinning.

The assemblage carbonate, quartz, and tremolite indicate that recrystallization occurred under the conditions of low grade synkinematic metamorphism, and that the parent rock was an impure dolomitic limestone.

Beaver Creek units

Pre-Middle Ordovician metamorphic rocks are very poorly exposed along the west margin of the mapped area. The rock units that do crop out include the following:

Quartzites
Greenschists
Black slates

Quartzites.-- (Specimen no. 8; pl. 5) The light gray, fine grained, massive quartzites (fig. 12) that occur in the Beaver Creek units are extremely pure, containing 98 to 99 per cent quartz, minor sericite, chlorite (pennine), and incipient biotite. Sphene, zircon, rutile, and opaques occur as accessory minerals.

The quartzites are directionless. The quartz grains are embayed and fractured, however, and show undulatory extinction so that the rock no longer appears to have a sedimentary texture. Because of their monomineralic character, these quartzites do not provide reliable assemblages for an accurate determination of metamorphic grade, but the presence of sericite, chlorite, and incipient biotite suggests that metamorphism was due to temperatures associated with the upper part of the low grade zone.

Greenschists.-- (Specimen no. 9; pl. 5) The light green, dense, fine grained greenschists (fig. 13) are composed of relict anhedral diopsidic pyroxene phenoclasts in a very fine grained matrix of untwinned plagioclase (albite?), epidote, and chlorite; in some samples, small quantities of very fine

Figure 12. Pre-Middle Ordovician quartzites which crop out in one of the Beaver Creek units (specimen no. 8; pl. 5).

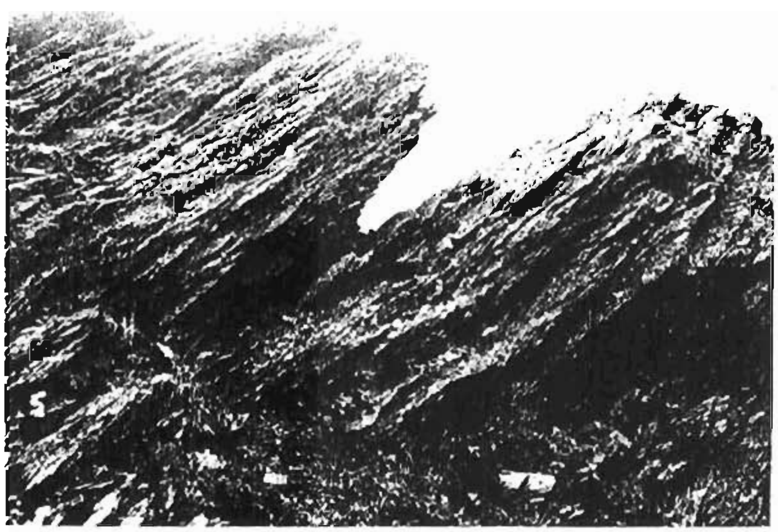


Figure 13. Pre-Middle Ordovician greenschists which crop out at specimen locality 9; pl. 5.

grained sericite, quartz, sphene, incipient biotite, and incipient amphibole.

These greenschists display a strong foliation which is chiefly produced by the subparallel alignment of chlorite and, when it is present, incipient biotite.

The mineral assemblage albite-epidote-chlorite is definitive of the greenschist facies. These rocks have been formed by upper low grade synkinematic metamorphism of basic (andesitic or basaltic) volcanic rocks which may have been in part tuffaceous.

Slates.-- (Specimen no.10; pl. 5) The slates in the Beaver Creek units are very fine grained, thinly bedded, black in color, and foliated (fig. 14). No mica was detected. The outcrop was intensely foliated and contorted.

The original sediment probably was a fine grained shale. Later low grade synkinematic metamorphism produced the present rock.

The slates are anomalously of lower metamorphic grade than the quartzites and greenschists in the Beaver Creek units.

Central Fossil Creek - southern Willow Creek units

This unit includes the pre-Middle Ordovician rocks which crop out along the central part of Fossil Creek, on the interfluve between Fossil and Willow Creeks, and in the core of the anticlinal structure northwest of Fossil Creek ridge (pl. 1).

The units which occur in this area compose a petrologic and compositionally heterogeneous sequence. Rock types present include synkinematically metamorphosed metasediments of lower most and upper low grade, and polymetamorphic rocks which display hornfelsic textures superimposed by static thermal metamorphism on the pre-existing synkinematic foliation. Rock types include:

Carbonate rocks
Impure chert
Quartzite
Slate
Phyllite
Hornfels

Carbonate rocks.-- (Specimen nos. 11 and 12; pl. 5) These rocks vary in composition from almost pure carbonate rocks to quartzose and highly argillaceous carbonate types. The carbonate-quartzose carbonate compositional range is most common, however. The carbonate rich members are typically dark gray and some specimens display a well developed foliation. The quartz rich members are dark to medium gray, poorly bedded very fine grained, and are not foliated. Representative types are composed of fine grained calcite and 0 to 40 per cent fine to medium grained, rounded to subrounded quartz and quartzite fragments. Chlorite (pennine?) is common, and clastic plagioclase, opaque minerals, incipient biotite, organic material, and sericite occur as minor constituents. Epidote, sphene, amphibole, tourmaline, and rutile occur as accessory minerals.

The textures of the carbonate rocks are quite variable.

Typically sedimentary quartzose carbonate members have only questionable, very weakly developed shear zones and display no effects of recrystallization. Some units display well developed shear zones although the clastic grains do not appear to be recrystallized. Other units are intensely sheared marbles displaying closely spaced shear planes and elliptically trimmed quartz grains, and in some cases, recrystallized quartz grains. Generally the foliation is produced by closely spaced shear planes with chlorite often developed in the shear zones. In the marbles, however, sericite or incipient biotite has also developed along the shear planes, and in some of these the foliation may actually be a crystallization foliation rather than a mechanical foliation. Much of the calcite shows well developed glide twinning.

These rocks represent impure carbonates which were probably deposited in a marine environment and later subjected to penetrative deformation which produced shearing and possibly some low grade synkinematic metamorphism, as indicated by the foliation and the mineral assemblage. The varying degrees of deformation and metamorphism seen in these sediments may be due to the difference in competence of the various parent rock types of the central Fossil Creek-southern Willow Creek units.

Impure chert.-- (Specimen no. 13; pl. 5) The dark gray to black, slightly calcareous, banded cherts (fig. 15) which appear scattered throughout the unit are composed primarily of quartz and chalcedony, and often contain abundant organic

Figure 14. Fine grained, thinly bedded, black slate (specimen no. 10; pl. 5) from the pre-Middle Ordovician of the Beaver Creek area.

Figure 15. Layered impure chert in the pre-Middle Ordovician central Fossil Creek - southern Willow Creek unit, which crops out at specimen locality 12.

material. Calcite, sericite, and chlorite also occur in minor amounts.

The cherts are extremely fine grained and often display compositional layering due to differences in carbonaceous content. Some of the cherts show no effects of deformation, but others display a poorly developed foliation as a result of sub-parallel alignment of very fine grained sericite and chlorite.

Due to poor exposures of the chert units it is difficult to determine their origin. At some time after they were deposited some units were slightly recrystallized.

Impure quartzite.-- (Specimen no. 14; pl. 5) These dark greenish gray, fine-grained micaceous quartzites are typically composed of very fine grained, subrounded quartz grains and variable amounts of clastic plagioclase (calcic oligoclase), muscovite, organic matter, and incipient secondary biotite. Opaque minerals and tourmaline are common accessory minerals.

Relict bedding is present in some of these quartzites and the quartz grains often do not appear to have been much recrystallized. The foliation of some of the quartzites is defined by poorly developed shear zones which appear to be the result of shearing without recrystallization; other units display well developed crystallization foliation defined by the parallel alignment of sericite and incipient biotite.

The mineral assemblage and textures of these rocks indicate that they were originally deposited in a marine environment as argillaceous quartzose sandstones and subarkoses. Later they were subjected to low grade synkinematic metamorphism.

Phyllitic slate.-- (Specimen no. 15; pl. 5) The black, dark gray, and green slates which occur at this locality are generally siliceous (fig. 16). They are composed of extremely fine grained quartz, plagioclase (albite), sericite, chlorite, and organic matter. Incipient biotite (?) is also occasionally present.

The directional fabric of some of these rocks is produced by closely spaced shear planes, and very little recrystallization appears to have taken place. Other specimens display well developed crystallization foliations produced by subparallel alignment of chlorite, sericite, and incipient biotite. Late veinlets of quartz crosscut the foliation. Often a mylonitic zone has developed along the contacts between these late quartz veinlets and the surrounding slate.

The rocks included in this unit underwent deformation which produced shearing without recrystallization as well as low grade synkinematic metamorphism. The mechanically sheared rocks, might better be referred to as sheared argillaceous rocks rather than slates, but have been included in this unit as there seems to be a complete gradation between the two end members.

Phyllite.-- (Specimen no. 16; pl. 5) The gray green phyllitic members of the sequence are composed of very fine

Figure 16. Phyllitic slate in the pre-Middle Ordovician central Fossil Creek - southern Willow Creek unit, which crops out at specimen locality 14.

grained plagioclase, sericite, epidote, and incipient biotite (possibly stilpnomelane), which is confined to the shear planes. Magnetite and graphitic material are also present in accessory quantities.

The phyllites display a well developed crystallization foliation produced by parallel alignment of sericite and the development of incipient biotite (?) in the shear zones. Sub-isoclinal shear folds are also present.

These rocks were formed by upper low grade synkinematic metamorphism of argillaceous rocks.

Hornfelsed sediments.-- (Specimen no. 17; pl. 5) A number of small basic dikes intrude the metamorphic units of the central Fossil Creek - southern Willow Creek units. These intrusives have superimposed static thermal metamorphic effects on the pre-existing synkinematic foliation. The mineralogy of these gray, massive hornfelsed rocks is very similar to that of the dynamically metamorphosed argillaceous rocks which the dike intrude. They are dominantly composed of plagioclase (albite), sericite, and graphitic materials, and traces of epidote, amphibole, and zircon. In addition to the hornfelsed argillaceous rocks observed near the contact of basic dikes, at least one micaceous quartzite appears to have developed late static muscovite and biotite.

Hornfelsic textures are defined by randomly oriented sericite, muscovite, and biotite. The micaceous quartzites still retain their crystallization foliation which is outlined by oriented sericite and incipient biotite. The late static recrystallization is indicated by randomly oriented muscovite and biotite which tend to obliterate the earlier schistosity.

The polymetamorphic history of the rocks is due to late contact metamorphism related to the intrusion of the small basic dikes as superimposed on an earlier synkinematic foliation.

Age and correlation

The only fossils found in the pre-Middle Ordovician sequence were collected by Blackwelder in 1915. These were found in the upper portion of unit B, along Willow Creek, and have been dated as either Early Ordovician or Late Cambrian in age (Mertie, 1937, p. 73). Mertie suggested that unit B was Lower Ordovician, and that the overlying unit A was either Lower Ordovician, or lower Middle Ordovician. He also suggested the presence of an unconformity between units B and C, and that units C, D, and E were Precambrian and correlative with the lower portion of the Tindir group (Mertie, 1937, p. 75).

Because units A, B, C, D, and E were not described in detail by Mertie, the writers were unable to correlate these units with the pre-Middle Ordovician rocks in the Fossil Creek area.

Dutro (1959) dates these same pre-Middle Ordovician units as possibly being Early Ordovician and Late and Middle Cambrian. These are then possibly underlain by Upper Precambrian rocks.

Metamorphic anomalies

The metamorphic grade of some pre-Middle Ordovician rock types is anomalously low when compared to the somewhat higher metamorphic grade of other types in the sequence. The metasiltstone (page 25) on the flank of Cache Mountain and the slate (page 31) in the Beaver Creek area are of lower grade than the adjacent phyllites, phyllitic schists and greenschists. Field relationships are concealed by extensive cover and the cause of these anomalies is uncertain. Possible explanations include infolding, faulting, local up grading due to migmatization or local highs in the isothermal pattern during metamorphism.

ORDOVICIAN FOSSIL CREEK VOLCANICS

The name "Fossil Creek Volcanics" was applied to this unit by Mertie (1937, p. 81) for exposures in the vicinity of Fossil Creek. Prindle (1913, p. 37) previously grouped this unit with the pre-Middle Ordovician rocks, and called the entire group the Tatalina group, questionably dated as Ordovician in age.

No attempt has been made here to stratigraphically subdivide the unit. Layering is obscure and therefore the structural relationships within the sequence are not well understood. While the unit is largely volcanic, rare conglomeratic and quartzitic sandstone units do occur.

Regional distribution

The Fossil Creek Volcanics appear to be restricted to the White Mountains. They occur in a narrow belt, within and parallel to the regional trend of the pre-Middle Ordovician rocks. The major portion of this belt stretches approximately 25 miles southwestward from Willow Creek to Beaver Creek, near the big bend of Beaver Creek. This belt is never more than 5 miles wide. A few discontinuous occurrences of the Fossil Creek Volcanics crop out southwest of this main belt (Mertie, 1937, pl. 1) (fig. 4).

Local distribution

The Fossil Creek Volcanics crop out in two main belts in the White Mountains: the west marginal belt, and the central belt (pl. 1). The west marginal belt lies adjacent to the western limestone ridge. The central volcanic belt nearly everywhere separates the two main limestone ridges. Towards the south, the central belt thins and disappears, and then reappears in the extreme southern portion of the area. To the north, the outcrop pattern of the volcanics widens, joining the western marginal belt and extends around the northern end of the eastern limestone ridge (pl. 1).

Stratigraphic thickness

Due to the massive character of the volcanics, attitudes were not obtained, and the true thickness must be estimated. Mertie (1937, p. 84) estimates 2000 feet as a minimum thickness for the volcanic unit. Generalized structure sections in this report (pl. 1) indicates that this is probably the correct order of magnitude. Fault contacts, however, make estimation difficult.

Petrology

The Fossil Creek Volcanics include a variety of sedimentary, pyroclastic, and flow rocks. Altered pyroxene andesites predominate, although altered tuffaceous conglomerates are nearly as abundant in the north half of the area. Locally, altered tuffaceous agglomerates occur and a quartzose sandstone unit was also mapped at two locations. Near fault contacts, the volcanics are often highly sheared and distinctly foliated. The volcanic units are commonly severely altered by hydrothermal action. The Fossil Creek Volcanic sequence contains the following rock types:

Altered pyroxene andesites
Quartzose sandstone
Altered tuffaceous conglomerates
Altered tuffaceous agglomerates

Flow rocks

Altered pyroxene andesites.-- (Specimen no. 18; pl. 5) The altered pyroxene andesites typically display a fine grained ground mass containing subhedral phenocrysts. In outcrop the rocks are dark green, dense and massive (fig. 17 and 18).

The altered pyroxene andesites are composed of subhedral phenocrysts of augitic pyroxene and oligoclase-andesine, inbedded in a very fine grained matrix of euhedral oligoclase-andesine microlites and anhedral pyroxene grains. Calcite, chlorite, quartz, clinozosite, pistacite, and altered volcanic glass also occur as minor constituents. Accessory amounts of sericite, prehnite, leucoxene, magnetite, zircon, pyrite and iddingsite also occur. Spherulitic aggregates of pumpellyite and vesicles filled with plagioclase (albite?), calcite, chlorite and zeolites also occur.

All of the pyroxene andesites display the effects of hydrothermal alteration to some extent. The degree of alteration

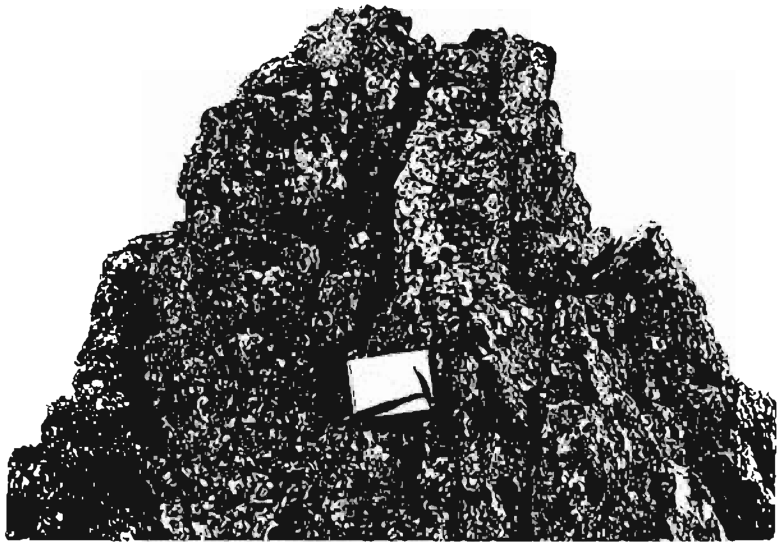


Figure 17. Altered pyroxene andesites which crop out in the central volcanic belt in the south central portion of the area, west of Fossil Creek.

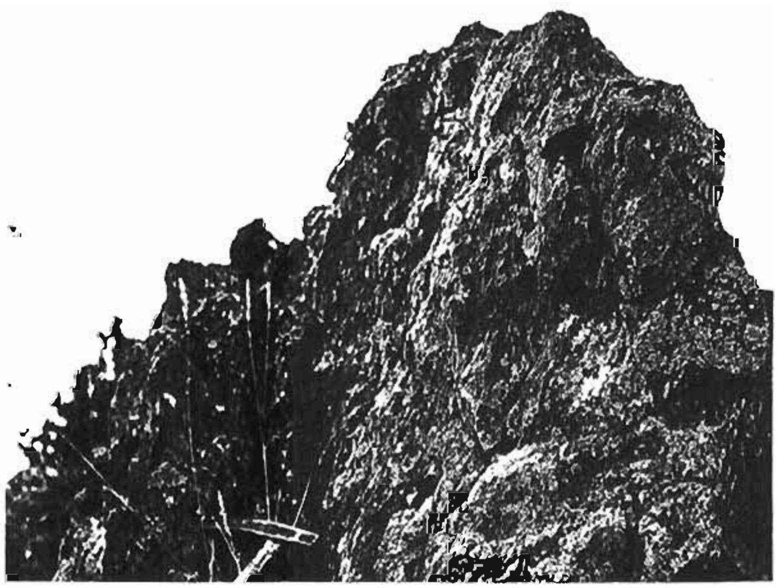


Figure 18. Altered pyroxene andesites which crop out in the west marginal belt in the southwestern portion of the mapped area, between Beaver Creek and Fossil Creek ridge.

varies from minor amounts of sericite and incipient chlorite along the twin planes of plagioclase to rare examples of wholesale saussuritization of plagioclase by prehnite and/or calcite.

Alteration of the plagioclase has produced free calcite, prehnite, and clinozosite. Commonly more calcite is present than that which could have been derived from the decalcification of plagioclase. Carbonate is commonly present in the matrix as well as in and around plagioclase phenocrysts. Occasionally phenocrysts and microlites have been completely replaced by pseudomorphous aggregates of calcite. Prehnite is less common than calcite although occasionally it may be more abundant. Clinozosite also occurs as a plagioclase decalcification byproduct, although pistacite is the more common epidote mineral.

Sericitization of plagioclase grains is largely incipient, and is commonly restricted to the compositional planes of polysynthetic twins of both phenocrysts and microlites.

A considerable amount of chlorite has also formed from the mutual alteration of pyroxene and plagioclase. Evidently, magnesium has been contributed to the reaction by adjacent pyroxene. Fine grained acicular aggregates of chlorite commonly occur as vesicle fillings although such aggregates are also distributed randomly throughout the matrix.

Volcanic glass is often present, and it has been altered to a semi-opaque, turbid, dark brown mineraloid. Some of this material appears to be palagonitic.

The pyroxene seems to have been more resistant to hydrothermal alteration. The phenocrysts as well as smaller grains in the matrix are relatively unaltered.

The altered pyroxene andesites are typically porphyritic, with medium grained pyroxene and plagioclase phenocrysts imbedded in a very fine grained ground mass. The phenocrysts generally range up to 4 or 5 mm in diameter and are usually subhedral. Euhedral phenocrysts do occur however. Filled vesicles are also common. The matrix is often so fine grained that individual grains are indistinguishable even under the microscope. Volcanic glass and mineraloidal material are common in the matrix. Fine grained euhedral plagioclase microlites and anhedral pyroxene grains comprise most of the matrix. In many specimens the microlitic ground mass shows flow structure.

Shearing along fault contacts has locally produced greenschists from the altered pyroxene andesites. An incipient foliation and accompanying effects of recrystallization which disappear away from the contact are present at a number of localities. Some albite has retrogressively recrystallized from the plagioclase phenocrysts. Pyroxene phenoclasts have been sheared, fractured and stretched out parallel to the foliation. The foliation is often visible in the outcrop as well as in thin section. Similar structures are present in other Fossil Creek Volcanic units near fault contacts.

The presence of vesicles and the trachytic textures clearly indicate that these rocks originated as volcanic flows. The original basic melt began to cool slowly, as indicated by the plagioclase and pyroxene phenocrysts. Upon extrusion, however, the cooling was much more rapid as indicated by the extremely fine grained glassy matrix.

After consolidation, these volcanic rocks have undergone a period of hydrothermal alteration which has altered the plagioclase phenocrysts and more rarely the minerals composing the matrix. Glass has been somewhat altered and devitrified. In some cases considerable calcite has been deposited by hydrothermal solutions. Pyroxene grains, however, are relatively unaltered.

The evidence is inconclusive as to whether these flows were marine or continental. No pillow structures were seen in the field. The volcanic conglomerates contain pebbles which are definitely water rounded. This rounding could represent a fluvial as well as marine environment.

Sedimentary rocks

Quartzose sandstone.-- (Specimen nos. 19 and 20; pl. 5) One quartzose sandstone interbed was found within the Fossil Creek volcanic rocks. This was found in both the northern and southern portions of the area. No estimates of thickness could be made.

These rocks are dark green in outcrop, medium grained, and very dense and hard. They consist chiefly of clastic quartz and minor plagioclase grains cemented by interstitial calcite. Infrequent clastic quartzite fragments are also present. Considerable chlorite also occurs interstitially. Accessory amounts of sericite, epidote, zircon, apatite, leucoxene and magnetite are also present.

The size distribution of clastic quartz grains is bimodal. The larger quartz grains are well rounded and coarse grained, ranging from approximately 1 to 2 mm in diameter. The smaller quartz grains are sub-rounded to rounded and are medium grained, averaging approximately .5 mm in diameter. The clastic plagioclase shows polysynthetic albite twinning and has a composition of approximately An_{10}. The plagioclase grains seem to be associated with the finer grained quartz. The grains seem to be fairly well sorted.

Pyroclastic rocks

Altered tuffaceous conglomerates.-- (Specimen no. 21; pl. 5) The altered tuffaceous conglomerates are composed predominantly of altered pyroxene andesite clastic fragments and, lesser quantities of quartz grains and quartzite fragments surrounded by an altered fine grained tuffaceous pyroxene andesite groundmass. The altered pyroxene andesite fragments and the groundmass have approximately the same composition. They are composed of subhedral augitic pyroxene and plagioclase phenocrysts in a very fine grained matrix of plagioclase (calcic oligóclase) microlites, anhedral augitic pyroxene grains, chlorite, and variable quantities of calcite, epidote, quartz, and palagonite. Prehnite, sericite, leucoxene, sphene, opaque minerals, and traces of amphibole occur as alteration products and accessories.

The hydrothermal alteration of these rocks is the same as that described under altered pyroxene andesites.

The clastic fragments are generally subrounded to sub-angular and range in size from twelve inch boulders to very fine grained sand. The average grain size varies considerably from one locality to the next. Generally, the matrix of the conglomerates is a mixture of tuffaceous and sand sized clastic material. Partly, however, subrounded clastic fragments occur in what is primarily a flow rock which displays a well develop-ed trachytic texture.

Although the fragmental material in this unit appears to be water worn, it is difficult to conclude whether deposition took place in a marine or continental environment.

Altered tuffaceous agglomerates.-- (Specimen no. 22; pl. 5) The altered tuffaceous agglomerates are composed of sub-angular volcanic fragments surrounded by a tuffaceous matrix. The fragments have an average diameter of 3 cm and a mineralogi-cal composition which is grossly similar to that described for the altered pyroxene andesites. Pyroxene and altered plagio-clase phenocrysts are imbedded in a very fine grained matrix of plagioclase microlites, pyroxene grains and altered glass. Accessory amounts of epidote, sphene, sericite, magnetite and amphibole also occur. The plagioclase has been altered to sericite and chlorite, and considerable chlorite occurs in the matrix.

The tuffaceous groundmass surrounding these fragments consists largely of plagioclase microlites and chlorite. Distinct crystals are rare. Smaller fragments, broken off from the larger ones, occur in the matrix and appear to be partly absorbed by the matrix. Alteration has been considerably more intense in the matrix than in the fragments.

The fragments are evidently pyroclastic, and have been surrounded by the tuffaceous material. Later hydrothermal action has produced the alteration.

Age and correlation

The Fossil Creek Volcanics have been dated as Middle Ordovician on the basis of faunal assemblages collected by Stone, Prindle, Johnson and Blackwelder (Mertie, 1937, p. 84). Edwin Kirk, who identified the fossils, originally considered them to be upper Ordovician (Richmond) in age (Mertie, 1937, p. 85). Upon later study, however, he decided that they were best assigned to the Middle Ordovician (Mohawhian) and correlative with similar assemblages found by Kindle along the Porcupine River and by Mertie near the international boundary (Mertie, 1937, p. 85).

The fossil localities listed by Mertie (1937, p. 84) could not be relocated by the writers. The assemblage collected from the Fossil Creek Volcanics came from the uppermost unit, which has been described as a reddish, tuffaceous limestone (Mertie, 1937, p. 82). This unit was not knowingly encountered by the writers, nor were any fossils found within the Fossil Creek Volcanics.

No other Ordovician volcanics have been recognized in interior Alaska. Dutro (1959) correlates the Fossil Creek Volcanics with Middle Ordovician limestone and slate in the Alaska Range, limestone from the Porcupine River, and a slate-chert and carbonate sequence from the Eagle-Circle area.

SILURIAN TOLOVANA LIMESTONE

The name "Tolovanna limestone" was applied by Mertie (1937, p. 86) to the exposure of Middle Silurian (Niagaran) limestone which crops out in the Tolovana valley about 50 miles south of the Fossil Creek area.

Regional distribution

The Tolovana limestone crops out intermittantly along a northeast trending belt 90 miles long and 2 to 5 miles wide; the belt extends from near the Tanana River northeastward to the northern Fossil Creek area (fig. 4), but according to Mertie (1937, p. 86) it is best exposed in the White Mountains. It is present farther southwest between the Tatalina and Tolovana Rivers and still farther southwest it reappears in the low hills west of the Tolovana embayment.

Local distribution

The Tolovana limestone is best exposed along the highest ridges in the Fossil Creek area. It is the most resistant unit to weathering in the area, and consequently produces the rugged crestlines (fig. 2) of the two main northeast trending ridges which form the major topographic features of the Fossil Creek area.

The irregular and discontinuous outcrop pattern of the limestone is chiefly due to extensive faulting. In the southern part of the Fossil Creek area the Tolovana limestone crops out in a broad belt which includes the two main ridges and the saddle between them. This belt bifurcates to the northeast and the outcrop pattern parallels the trend of each ridge. The west limestone ridge dies out to the north, and north of the wind gap which cuts across the central part of the Fossil Creek area the outcrop pattern of the limestone is discontinuous. The limestone crops out only as fault slices on the tops of three small knobs in this area.

The limestone belt which crops out as the east ridge disappears into Fossil Creek valley in the central part of the area. Field evidence indicates that the Ordovician metamorphic rocks have been thrust-faulted over it. It appears farther north, and north of the wind gap it is topographically expressed as another prominant northeast-trending ridge. Along the northeast side of this ridge a smaller spur ridge of limestone trends northeastward away from the main ridge. A number of small limestone blocks occur northeast of this spur on the same trend. Mertie explains this spur of limestone as the result of infolding with the Ordovician volcanic beds (1937, p. 87-88). The writers, however, believe that this outcrop pattern is the result of thrust faulting and that the limestone blocks are klippen.

Stratigraphy

The base of the Tolovana limestone is not exposed in the Fossil Creek area. The lower contact, that between the limestone and the Fossil Creek volcanics, is in every case a fault contact. These faulted contacts are rarely exposed as they are generally covered with talus and/or frost rived rubble.

The limestone is vegetation free and generally well exposed, particularly along ridge crests. Sizeable rubble-covered intervals do occur, however.

The color of the Tolovana limestone normally ranges from tan to blue-black on a freshly fractured surface. Weathering and accompanying leaching weather the limestone to an off-white color. Occassional pink horizons pigmented by iron oxide also occur. Megascopically, the limestone appears to be very fine grained crystalline, dense, and very pure. Rare zones contain vuggy or cavernous porosity, but it is believed that these are chiefly surface phenomena resulting from recent groundwater solution. Beds in the limestone generally range from 2 to 20 feet in thickness (fig. 19), but some beds are more massive. Because this formation is chiefly composed of carbonates which are very similar to one another in outcrop, it has not yet been possible to differentiate the Tolovana limestone into smaller units in the field. The occasional pink horizons do not have enough lateral continuity to be used as marker beds.

Microscopically, the Tolovana limestone shows a number of textural details. The lower part of the limestone sequence is composed of very fine grained dusty looking carbonate that

Figure 19. Massive beds of Tolovana limestone which dip 70° to the SE. These beds crop out in the upper part of the measured section in the northern part of the area.

is cut by many veinlets of later clear calcite which generally shows well developed glide-twinning. Following Folk's terminology (1959), these rocks are <u>micrites</u>.

The upper part of the limestone section is dominantly [illegible] ppt allochemical rather than orthochemical. The allochemical material is primarily composed of rounded to subrounded, fine to medium grained intraclasts and oolites (fig. 20), possibly some very fine grained pellets (nomenclature after Folk, 1959). The allochems range in size from less than 1/16 mm to 2 mm, and are composed of extremely fine grained carbonate similar to the grains described in the lower part of the sequence. The allochems are cemented by very fine grained clear calcite. Small fossil fragments also occur occasionally. The limestone is cut by numerous veinlets of coarse-grained clear calcite. The textures of several specimens are quite obscure and possibly indicate recrystallization. Other than rare, very small grains of opaque minerals, these rocks are pure carbonate. This sequence of rocks falls within Folk's family of sparry allochemical rocks and includes intrasparites, oosparites, possibly pelsparites, and combinations of these rock types.

Staining of the limestone samples has failed to reveal the presence of any well defined dolomitic zones. The stains do seem to indicate, however, that some zones may have a higher magnesium content than others. Rare dolomite lenses are present.

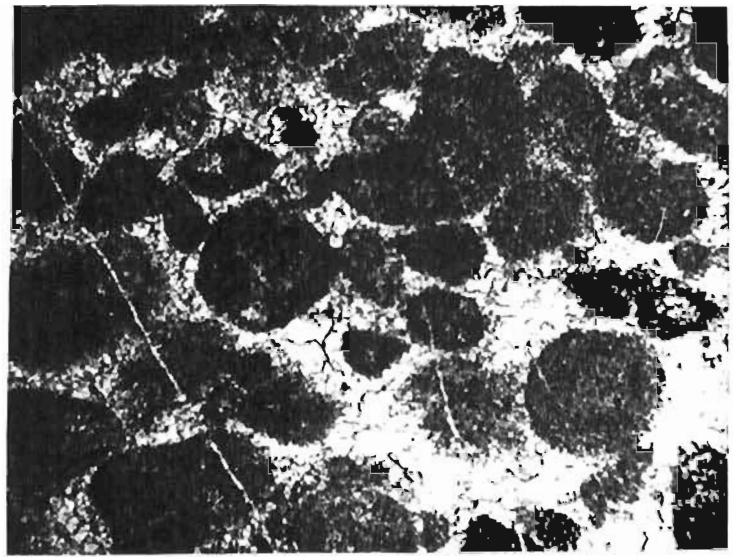


Figure 20. Photomicrograph of interclasts and oolites in Tolovana limestone (specimen no. 52; pl. 3). Plane light, X 80.

Two limestone sections were measured and described, one in the northern Fossil Creek area, and one in the southern Fossil Creek area (pl. 5). Because the limestone cannot be subdivided into distinct units in the field, these sections are not described in the text. The descriptions, based on microscopic as well as field observations, are presented on plates 2 and 3.

Thickness

The true thickness of the Tolovana limestone is not known. Mertie (1937, p. 88) suggests a possible thickness of as much as 3000 feet. The section of limestone measured by the writers in the northern Fossil Creek area is 3215 feet thick, and the section of limestone measured in the southeastern Fossil Creek area is 4225 feet thick. These thicknesses do not represent total thicknesses, however, as the bases of both sections are fault contacts, and the upper contacts have been removed by erosion.

Age and correlation

The Tolovana limestone has been dated as Middle Silurian (Niagaran) on the basis of a considerable fauna collected by Stone, Prindle, Johnson, Blackwelder, and Mertie. Mertie has tabulated the fossils from all of these collections (1937, p. 90) which were identified and dated by Edwin Kirk. Originally some of the assemblages were considered to be of Late

Silurian and even Devonian age (Prindle, 1913, p. 43) and it was thought that the Tolovana limestone might represent continous sedimentation from mid-Silurian to Middle Devonian time. More extensive faunal collections from the limestone and subsequent studies of Devonian fauna and stratigraphy showed that this is not true, however. Because the fossils collected from the Tolovana all occur near its base, it is also possible that the uppermost part may be late Silurian (Mertie, 1937, p. 91).

The writers experienced difficulty in relocating previous fossil localities due to the generalized nature of the location descriptions. During the course of the field work, however, fossils were collected from nine localities, some of which may be the same as those described by Mertie. The locations of the fossil collections are shown on plate 5, and are described as follows.

Station No.	Locality Description
F-1-REC	An assemblage of corals, brachiopod fragments, and crinoid columnals was recovered from the first western spur southwest of the northernmost extent of limestone outcrop. The fossils occur in rubble on the slope 20 to 50 feet above the limestone-volcanic contact.
F-2-REC	The limestone klippe which forms the top of the knob 0.4 miles north of the upper valley of Willow Creek contains fossils as float and in the outcrop

near the top of the knob, approximately 800 feet above Willow Creek.

F-3-REC Poorly preserved corals occur in rubble 200 to 300 feet above the limestone-volcanic contact on the northwestern side of the northwestern-most knob of limestone in the Fossil Creek area. The corals comprise as much as 50% of the float, but none were recovered in place.

F-4-REC Poorly preserved corals and brachiopod fragments occur in rubble near small east-west trending pass in the central part of the limestone knob described under F-3-REC.

F-1-MCD One half mile southwest of the wind gap in the central portion of the Fossil Creek area corals occur as float for approximately 200 feet up slope from the east limestone-volcanic contact on the western-most limestone ridge.

F-2-MCD This collection site is approximately one mile southwest of the wind gap in the central part of the Fossil Creek area. Corals occur as float and in outcrop in the limestone along the west contact of the western-most limestone ridge.

F-3-MCD Corals occur as float near the west limestone-volcanic contact on the fourth west trending spur south of the wind gap in the central Fossil Creek area.

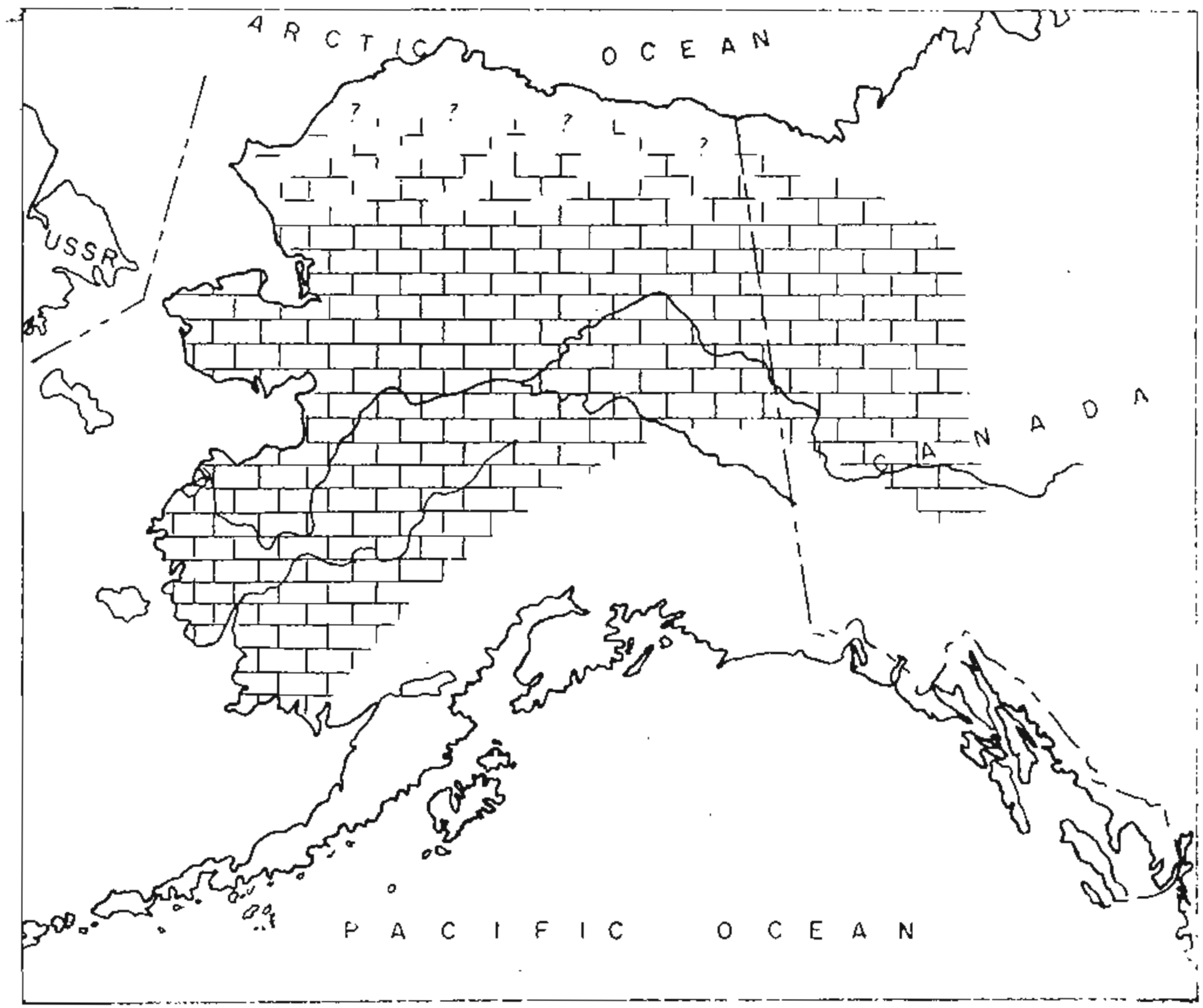
F-4-MCD Pentameroid brachiopods occur as float and in outcrop near the eastern contact of the limestone on the westernmost ridge of the fifth west trending spur south of the wind gap in the central Fossil Creek area.

F-5-MCD Approximately half way between Windy Pass and the top of the ridge to the west, pentameroid brachiopods occur as float and in outcrop. Corals occur as float from here to the top of the ridge, where they also occur in outcrop.

Preliminary identifications and age determinations have been made on selected fossils from these collections. These include pentameroid brachiopods and favositid corals of Silurian age.

The Tolovana limestone represents only one small area of limestone in a very broad belt of Silurian carbonate rocks which extends from Cape Krusenstern on the north side of Kotzebue sound eastward along the south side of the Brooks Range, across the Porcupine River area, and far eastward into the Mackenzie River region of northwestern Canada. This belt extends northward in Canada to the Arctic Ocean (Martin, 1959), and southwestward in Alaska into the Kuskokwim valley (Cady and others, 1955). Fig. 21 shows the probable extent of the Tolovana limestone and its time equivalents as the time of their deposition.

Dutro (1959) correlates the Tolovana limestone with the Skajit limestone which crops out sporadically along the southern side of the Brooks Range, the White limestone of the



AREA OF SILURIAN LIMESTONE DEPOSITION

Figure 21

Eagle-Circle area, and unnamed Middle Silurian limestones in the Porcupine River area, the Kuskokwim area, and on the Seward Peninsula. A graywacke-chert sequence in the Alaska Range is also believed to be the age equivalent of the Tolovana limestone.

Conditions of deposition

The Tolovana limestone that crops out in the Fossil Creek area appears to have been deposited in a shallow marine environment under locally very stable conditions. Deposition occurred in a widespread seaway which was probably in a miogeosynclinal tectotope.

The lower, very fine grained portion of the limestone was deposited by chemical or biochemical precipitation of calcium carbonate which formed a microcrystalline calcite ooze. The conditions under which the upper section of the limestone formed must have been somewhat different. The rounded intraclasts and presence of oolites indicate that there was wave or current action in the area. The intraclasts are interpreted as having been derived from erosion of previously deposited, weakly consolidated carbonate sediment from adjoining parts of the sea bottom and then redeposited (Folk, 1959, p. 4). Small intraclasts probably form the nuclei of the oolites.

The presence of fossils of reef building organisms indicates that at least part of the Tolovana limestone had an organic origin. Because fossils of these organisms occur only at widely separated localities, the writers do not believe that the organic contribution was great. It is postulated that these fossil accumulations represent small, widely scattered biohermal structures that grew on a shallow sea bottom during deposition of the limestone.

The presence of the intraclasts and oolites is presented as evidence for a shallow marine environment. The area must have been above wave base in order for these to form. In addition, the presence of reef building organisms is further evidence for shallow water conditions. The almost complete lack of material other than calcareous constituents points to a very stable tectotope during deposition of the Tolovana limestone and: (1) lack of a source area from which terrigenous sediments were being derived; or (2) the Fossil Creek area was a local high and the terrigenous material bypassed the area.

QUATERNARY DEPOSITS

The Quaternary deposits in the Fossil Creek area consist of residual deposits covering much of the bedrock, and alluvial deposits in the larger valley floors. No morainal deposits have been recognized even though small poorly formed cirques are present above an elevation of 3500 feet on the northwest side of Cache Mountain and on the northwest side of the extreme northern end of Fossil Creek ridge. These cirques are considered to be Illinoian in age as they occur at an elevation too low to be of Wisconsin age. Wisconsin snowline occurred at an elevation of about 4500 feet above sea level in this region (Péwé and Burbank, 1960, p. 2088). The drift that formerly existed in the cirques has been removed by erosion.

Residual deposits

A poorly developed rocky soil covers most of the area underlain by metamorphic and volcanic rock types. On the steep upper slopes of volcanic ridges the soil grades to coarse, angular rubble particles which range up to several feet in diameter. The crests of some of the low ridges underlain by metamorphic rocks are covered with a mantle of frost rived material, the particles of which average less than 2 inches in diameter.

The sloping ridge which extends from Cache Mountain to Fossil Creek valley displays characteristic patterned ground features. Frost scars occur, and above an elevation of 3500 feet, well developed stone rings are found on the altiplanation terraces. The stone rings are 10 to 15 feet in diameter and are composed of fine material surrounded by coarse rubble up to 2 feet in diameter.

Little or no soil mantle has formed on the summit of Cache Mountain. Almost all of the surface is covered with large frost-rived blocks which range up to 10 feet in diameter. The blocks are probably still forming, and form vast talus piles of very coarse material along the headwalls of the cirques on Cache Mountain.

Extensive active talus slopes occur on the lower and middle slopes of the limestone ridges. The frost rived material which mantles these slopes is commonly less than 1 foot in diameter, although occasional large blocks occur. In some places intermittent streams have moved this material farther down slope during heavy rains to form talus fans in the valley floors.

Stream deposits

Coarse gravel deposits occur on the flood plains of Beaver, Fossil and Willow Creeks and in the lower portions of a number of tributaries to these streams. In addition, gravel deposits occur in low terraces along Fossil Creek.

In the northern part of the Fossil Creek area the gravel is very coarse and chiefly subangular. Boulder sized material is prevalent. The gravels become less coarse and better rounded in the southern portions of the area and contain a higher percent of sand. Locally, near metamorphic source areas the gravels become much finer.

INTRUSIVE ROCKS

Both plutonic and dike rocks discordantly intrude the older sediments of the area. Plutonic rock types include quartz monzonites and gabbros, and both tourmaline granodiorite and basic dikes occur in the area.

Plutonic rocks

Cache Mountain quartz monzonite

The higher elevations of Cache Mountain, in the extreme eastern portion of the mapped area are composed of quartz monzonite of a plutonic mass which appears to be of stock dimensions. The high, resistant quartz monzonite spires which form the summit mass of Cache Mountain are the highest topographic feature in the Fossil Creek area.

Petrology.-- (Specimen no. 23; pl. 5) The Cache Mountain quartz monzonite is a medium to coarse grained, light gray granitic rock. In outcrop, weathered exposures display a reddish buff or tan color. Subhedral potassium feldspar and quartz grains occur up to 10 mm in diameter; average size is approximately 4 mm. Subhedral to euhedral plagioclase crystals are generally smaller, averaging approximately 2 mm in diameter.

The Cache Mountain quartz monzonites display a typical hypidiomorphic-granular texture formed by roughly equigranular, interlocking grains of quartz, plagioclase, and microperthitic sanadine. Biotite grains often occur in clusters. Poikilitic biotite displays an unusual number of zircon inclusions.

The plagioclase composition ranges between calcic oligoclase and sodic andesine (An_{28} to An_{32}). Plagioclase grains are commonly normally zoned. Secondary sericite is often developed along compositional planes of albite twins and in the calcic cores of zoned crystals.

The potassium feldspar appears to be sanadine (often microperthitic). It is characterized by a 2V which varies between 5 and 35 degrees. The biotite shows very deep absorption (x= pale tan, y= medium brown, z= very dark brown). A green component is often present in the z direction. Zircon inclusions showing well developed pleochroic halos in the host biotite grains are abundant (fig. 22). Some of the biotite is altered to chlorite. Minor muscovite also occurs.

Tourmaline occurs as an accessory mineral in most specimens, and one occurence of topaz was recorded. Apatite and magnetite are also common accessories.

Fine and medium grained border facies types occur adjacent to the contact on the west ridge of Cache Mountain. These may be either apophyses of the main body, or cupolas of the main body separated by roof pendants. The mineralogy of these rocks is identical to that of the main intrusive body and they differ only in grain size.

The contact between the pluton and the pre-Middle

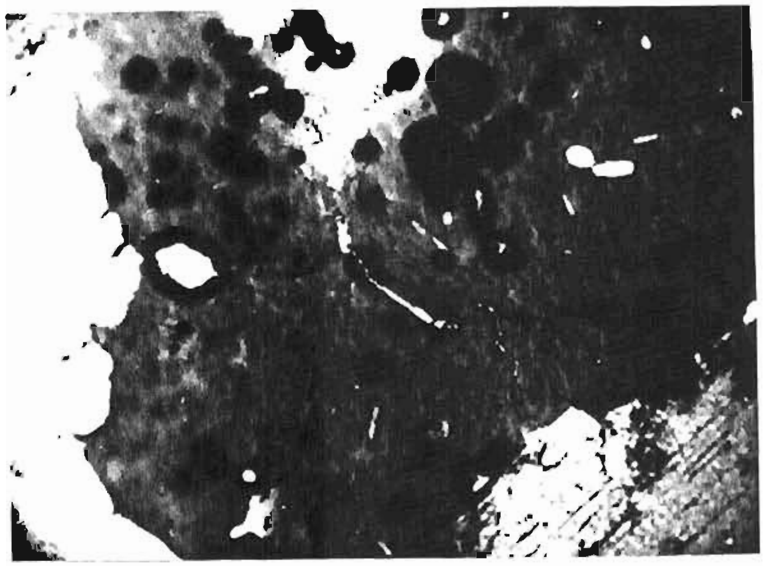


Figure 22. Photomicrograph of Cache Mountain quartz monzonite (specimen no. 23; pl. 5) showing poikilitic biotite containing many zircon inclusions. Crossed nicols, X 80.

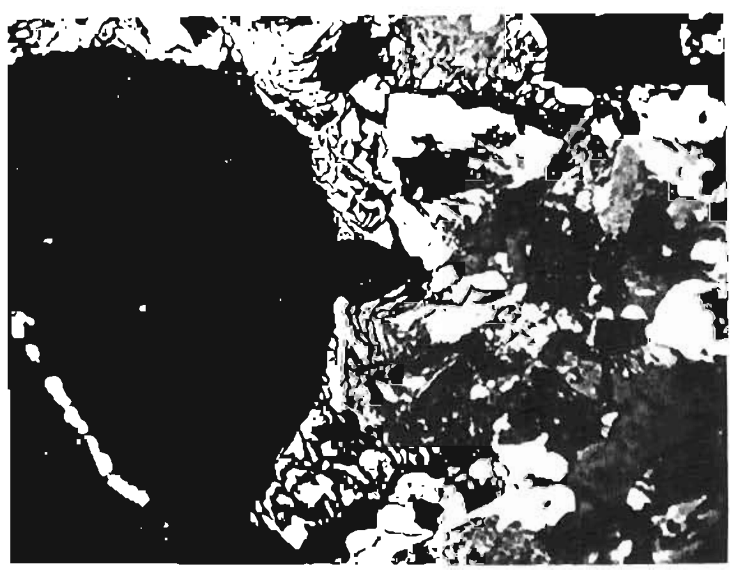


Figure 23. Photomicrograph of Beaver Creek quartz monzonite porphyry (specimen no. 24; pl. 5) showing micrographic intergrowth of quartz and feldspar in the matrix. Crossed nicols, X 80.

Ordovician country rock appears to be very sharp. The precise trace of the contact could not be seen, but it could be located within a few feet by the change in the composition of the rubble. A distinct thermal metamorphic aureole extends into the country rock for a considerable distance away from the contact.

The plagioclase constitutes from 20 percent to 25 percent of the rock, while sanadine constitutes from 25 percent to 30 percent. Quartz comprises from 20 percent to 30 percent and the minor minerals and accessories constitute the rest of the rock.

The presence of the sanadine and the dark brown biotite seem to indicate a high temperature origin, and conditions of emplacement transitional between the hypabyssal and plutonic zones.

Beaver Creek quartz monzonite porphyry

A small quartz monzonite porphyry body is exposed where a west trending spur of Fossil Creek ridge is truncated by the channel of Beaver Creek (pl. 1). Because of a limited exposure, an accurate estimate of the size of the intrusive cannot be made. The outcrop itself is small, however. Much of the actual outcrop is covered by vegetation and rubble (fig. 24).

Petrology.-- (Specimen no. 24; pl. 5) The Beaver Creek quartz monzonite porphyry is composed of large (average length 12 mm) perthitic orthoclase phenocrysts, euhedral to subhedral plagioclase phenocrysts (average length 4 mm) and subhedral to anhedral quartz phenocrysts (average diameter 3 mm), surrounded by a fine to medium grained matrix composed of plagioclase (approximate composition An_{24}), interstitial quartz, orthoclase, biotite, and accessories, calcite, zircon, sericite, and apatite.

The rock is porphyritic with a seriate fabric. The ground mass is typified by a micrographic intergrowth of quartz and feldspar (fig. 23). Much of the orthoclase shows a well developed perthitic texture. The biotite has been slightly altered to muscovite.

The Beaver Creek quartz monzonite is discordantly emplaced in the Tolovana limestone; this probably accounts for the free calcite which is present in the ground mass. No contact metamorphic effects were seen.

Orthoclase constitutes approximately 36 percent of the rock, while plagioclase comprises 34 percent, quartz 20 percent, and the biotite, calcite, and accessories constitute 10 percent.

Gabbros

A number of poorly exposed outcrops of dark greenish-black gabbroic rocks were discovered near Fossil Creek in the northeastern part of the Fossil Creek area, and on the interfluve between Fossil and Willow Creeks. These rocks occur in a narrow zone about 2 1/2 miles long paralleling an important fault zone in this area (plate 1). Because of poor exposures it was not determined whether these outcrops represent one or a number of small intrusive bodies. The similarity in composition of the rocks, however, indicates that if they are not part of the same body, they were probably derived from the same magma. Actual contacts were not found, and contact relationships between the gabbroic and metamorphic rocks which they intrude are not known.

Petrology.-- (Specimen no. 25; pl.5) On a fresh surface the gabbroic rocks display mottled dark green and light gray colors, but they weather to a dark greenish or black color. The gabbros generally are medium grained, but the grain size ranges from coarse to fine. Major mineral constituents include euhedral to subhedral plagioclase (An_{35}), subhedral pyroxene, small grains of anhedral chlorite, prehnite, and rare olivine. Biotite, potassium feldspar, pistacite, and actinolitic-hornblende also occur as minor constituents. Accessory minerals include zircon, apatite, sphene, iddingsite, magnetite, and perovskite.

Plagioclase constitutes from 45 to 75 modal percent of these rocks, and it is severly altered to aggregates of prehnite, sericite and epidote minerals. Plagioclase grains are often zoned, and in one sample showed a linear type of intergrowth as a result of apparent unmixing of the albite molecule.

Modal pyroxene ranges from 5 to 40 percent and it is often highly altered to chlorite, and in some cases, actinolitic-hornblende. Two, and possibly three chlorite minerals occur: pennine, clinochlore and/or prochlorite.

The biotite appears to be a high temperature variety. In plane polarized light it displays deep absorption (x= pale tan, y= medium brown, z= very dark brown). Some of it is bleached and partly altered to chlorite.

The gabbroic rocks generally have a hypidiomorphic granular texture. The plagioclase and pyroxene grains are equigranular and occassionally exhibit micrographic intergrowth. At one cite the gabbro has been sheared and displays mylonitic structure.

Even though the plagioclase composition is An_{35}, rather sodic for a gabbro, these rocks appear to have been originally crystallized as gabbros rather than diorites. The plagioclase appears to have been decalcified, as shown by the alteration aggregates of prehnite and pistacite, and was originally more calcic. Pyroxene, which is characteristic of the gabbro clan, is the dominant mafic mineral, while amphibole occurs only as an alteration product. Biotite, which is quite common in diorites is a minor constituent in these rocks. The presence of olivine seems to confirm the gabbroic classification.

Dike rocks

Tourmaline granodiorite

A discordant tourmaline granodiorite dike intrudes the

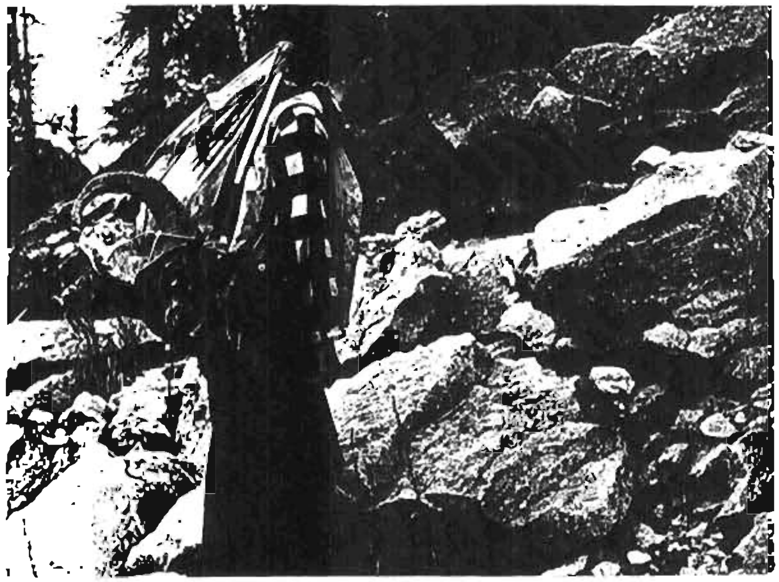


Figure 24. Outcrop of the Beaver Creek quartz monzonite porphyry on the east bank of Beaver Creek in the southwest part of the Fossil Creek area.

Figure 25. An outcrop of tourmaline granodiorite which occurs as a small dike in the southern portion of the area, on the east bifurcation of Fossil Creek ridge.

Tolovana limestone in the southern portion of the area on the east bifurcation of Fossil Creek ridge (pl. 1).

The exposure is very small and obscured by vegetation and frost rived rubble (fig. 25).

Petrology.-- (Sample no. 26; pl. 5) The rock is fine grained and predominately leucocratic. Fine grained bluish-black tourmaline occurs in clusters which average approximately 15 mm in diameter, giving the rock a porphyritic appearance.

The matrix is composed of fine grained equigranular plagioclase, sanadine and quartz. The plagioclase composition tends to average sodic oligoclase (An_{11}), and constitutes approximately 40 percent of the rock. The sanadine constitutes approximately 20 percent, while the quartz composes 25 percent, and the tourmaline, 15 percent of the rock. The tourmaline clusters consist of xenomorphic tourmaline grains occuring interstitially between the larger plagioclase, sanadine, and quartz grains, in concentrated area (fig. 26). The tourmaline dominantly shows blue pleochroism (o= blue, e= very pale blue), but near the periphery of many of the clusters the color grades to tan (o= tan, e= colorless). This shift in pleochroism is apparently due to a compositional change. Phlogopite and topaz occur in minor amounts. Apatite and zircon are accessories.

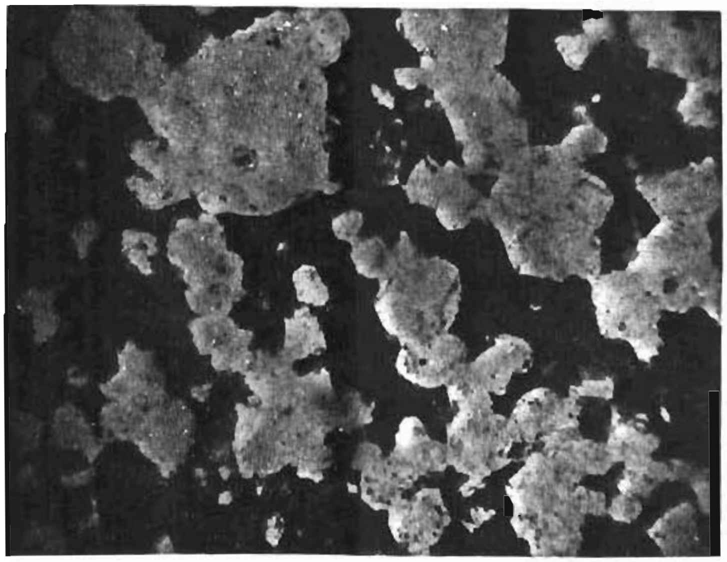


Figure 26. Photomicrograph of tourmaline granodiorite showing a portion of a tourmaline cluster. Plane light, X 80.

Altered basic dike rocks

A number of small altered basic dikes intrude the pre-Middle Ordovician metamorphic sequence in the northeastern part of the Fossil Creek area (fig. 27 and 28). These dikes vary from 10 to 20 feet in width, strike northeast, and parallel the regional trend (pl. 1).

One small basic dike intrudes the Tolovana limestone along the main ridge crest in the central part of the area. Scattered float indicates that other similar dikes may be present, but no more were seen by the writers.

Petrology.-- (Specimen no. 27; pl. 5) The mineralogy of the dikes which intrude the metamorphic sequence is very similar to that of the gabbroic rocks. They are dominantly composed of fine-grained euhedral to subhedral plagioclase laths, subhedral pigeonitic pyroxene, and minor prehnite, chlorite, opaque minerals, and leucoxene. Accessory biotite is sometimes present.

The plagioclase is calcic oligoclase (An_{29}), which is generally much altered to prehnite and chlorite.

The texture of these dike rocks varies from porphyritic to intersertal. Plagioclase phenocrysts 4 to 5 cm. in length occur in a fine grained groundmass in some of the dikes; in others the interstices between plagioclase laths are filled with very fine grained chlorite, opaque minerals and leucoxene.

Because the composition of these dike rocks is very similar to the composition of the gabbroic rocks, and since they occur in close proximity, they are considered to be genetically related.

The basic dike which intrudes the Tolovana limestone is extremely altered and hence difficult to relate to the other dikes. The dike rock is composed of fine grained euhedral to subhedral plagioclase laths, and extremely fine grained chlorite, calcite, leucoxene, and epidote. It is not possible to tell whether this dike is genetically related to the other altered basic dikes.

Age and correlation

Sanadine, tourmaline, and topaz are present in the tourmaline granodiorite dike and in the Cache Mountain intrusive, and therefore they are believed to be genetically related. The plagioclase is more sodic in the dike rock, and quartz, plagioclase, and sanadine occur in different proportions, but the gross mineralogy is strikingly similar.

The Beaver Creek quartz monzonite and the tourmaline granodiorite bodies intrude the Tolovana limestone. Because the tourmaline granodiorite is genetically related to the Cache Mountain intrusion, the acidic intrusions can be dated as post-Silurian. No more definite date can be placed on these acidic intrusions on the basis of the present work. Mertie, however, correlates the Cache Mountain intrusion and the tourmaline granodiorite dike with other similar intrusions throughout the Yukon-Tanana upland (Mertie, 1937, p. 215-216). He has proposed that they are of post-Paleozoic and pre-Tertiary age on the basis of a conglomerate found in the Charley River area composed of granitic boulders, and dated as either Late Cretaceous or early Tertiary in age (Mertie, 1937, p. 215-216). He further suggests that these granitic rocks are of Jurassic age, because no Jurassic rocks have been found in the area, which seemingly indicates that the missing interval was due to extensive uplift and mountain building (Mertie, 1937, p. 216). A lead-alpha date from radioactive zircon from a granitic rock in Granite Mountain near Big Delta has been dated as Cretaceous (Holmes and Péwé in press).

While Mertie does not mention basic igneous rocks in this vicinity, he has proposed a Late Devonian age for the ultrabasic intrusions south of Livengood, and a Mississippian age for basic intrusions in the northern part of the Fairbanks quadrangle on the basis of the strata which they intrude (Mertie, 1937, p. 205). On the basis of this present work, however, the basic intrusions in the northern Fossil Creek area can be dated only as Middle Ordovician or later, and in one case, post-Silurian.

STRUCTURAL GEOLOGY

The structure of the Fossil Creek area was interpreted by Mertie (1937, p. 83) as southwest plunging, closely appressed folds, with axial planes dipping steeply to the southeast. The two limestone belts were interpreted as synclines, separated by an anticline of volcanic rocks. Thrust faulting was recognized in the valley of Fossil Creek where complex structure, including a recumbent limestone fold wrapped around a volcanic core, was seen.

The writers could not locate the recumbent limestone fold wrapped around a volcanic core mentioned by Mertie (1937, p. 83). Fault "A", where it follows the valley of Fossil Creek, and possibly parts of fault "C" were probably recognized by Mertie (1937, p. 88). Mertie also suggests faulting in the vicinity of the small limestone klippen in the northeast corner of the mapped area (1937, p. 88).

The writers have reinterpreted the structure of the Fossil Creek area and feel that thrust faulting is much more important than previously realized.

A marked discordance in the structural trend of the limestone and the trend of the outcrop pattern occurs in the extreme southern end of the east limestone belt (pl. 1). This is anomalous since, except in very local areas, the structural trend of the limestone generally parallels the outcrop pattern. This discordance suggests that the outcrop pattern here is not controlled by the structure within the limestone.

Folds

Three major folds have been observed in the area.

A synclinal axis can be traced northeastward in the western limestone belt throughout the entire study area. Most of the wersten limb of this fold has been removed by faulting. The syncline, which trends N 45° E, is inclined and the axial plane dips steeply to the southeast (pl. 4). (See also structure section E-E'; pl. 1).

A second syncline occurs in the northern half of the eastern limestone belt. The axis of this syncline trends approximately N 60° E, and the axial plane dips steeply to the southeast (pl. 4). (See also structure section C-C').

An outcrop of pre-Middle Ordovician metamorpnic rocks in the extreme northern protion of the area is thought to be an anticlinal core (pl. 4). (See also structure section A-A'). This appears to be a southwest plunging anticline, however no satisfactory attitudes could by found, and the precise geometry of the fold is not known.

Several minor fold axes are suggested in the limestone beds along the southwestern side of the northern Fossil Creek ridge, and in the large limestone klippe east of fault "A" (pl. 4). These axes are the result of slight reversals of dips in beds that are nearly vertical. Because the beds are nearly vertical, the reversals slight, and the axes continuous for only short distances, it could not be determined whether these are the axes of folds or the result of irregularities in bedding.

Several reversals in dip are also found along the southern crest of the east limestone belt (pl. 1). While these are apparently minor folds, they do not seem to be consistent along the ridge crest, nor along the flanks of the ridge. These apparent folds are probably minor wrinkles caused by the thrusting of the limestone mass.

Faults

Seven major reverse and/or thrust faults are present. These all strike to the northeast and dip to the southeast.

While the existence of most of the faults is thought to be well documented, evidence for some is less conclusive.

The traces of these faults are outlined in detail on the tectonic map presented as Plate 4. The location, field relationships and evidence relating to each of these faults are discussed below.

Fault "A"

Description and location.-- Fault "A" is a high angle reverse fault which extends the full length of the mapped area, and parallels the northeastward structural trend. The trace of fault "A" follows the valley of Fossil Creek in the south, until, near the center of the mapped area it is offset slightly to the west by a small tear fault. From there the fault follows the eastern side of Fossil Creek ridge and finally becomes obscured in the extreme northern portion of the area (pl. 4).

Evidence.-- The evidence supporting fault "A" is as follows:

The pre-Middle Ordovician rocks are in direct contact with the Silurian Tolovana limestone along the lower portion of Fossil Creek, and the Fossil Creek volcanics are missing from their usual stratigraphic position.

Near the central portion of the mapped area, the pre-Middle Ordovician contact is offset sharply across the volcanics to the base of the limestone ridge (pl. 1). This sharp offset indicates the tear fault which has offset fault "A". North of the tear fault, the pre-Middle Ordovician metamorphic rocks are again in contact with the Tolovana limestone, with the Ordovician volcanics missing (pl. 1).

The trace of the fault is expressed topographically in limestone as transecting topographic depressions across spur ridges (fig. 29). The trends in the limestone on oppossite sides of the fault are sharply discordant. A discordancy of approximately 35° occurs in the strike of the limestone on the northwest, as opposed to the southeast

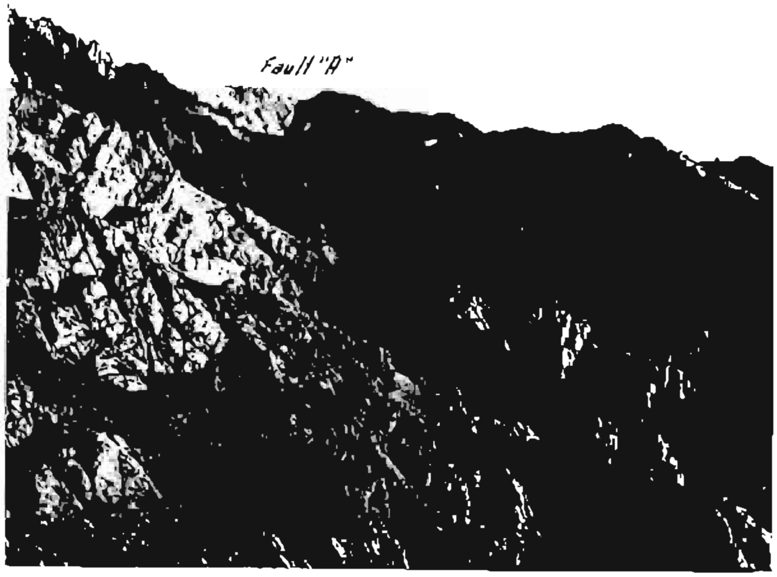


Figure 29. The trace of fault "A" as viewed to the NE from the southern end of northern Fossil Creek ridge. Note the divergent trends on either side of the fault.

Figure 30. Limestone slices in Ordovician volcanic rocks adjacent to the trace of fault "A" as seen looking N 60° E from near the window of metamorphic rocks on the east side of the northern Fossil Creek ridge.

side of the fault.

Farther to the northeast the fault forms the nearly straight contact between the volcanic rocks and the limestone. A few smaller slices of limestone have been imbricated with the volcanics (fig. 30).

The high angle character of the fault is denoted by the straightness of the trace as it crops out in rough topography in the northern part of the area between the limestone and volcanics, as well as through the limestone.

Fault "B"

Description and location.-- Fault "B" is a low angle thrust fault which has superimposed the Tolovana limestone over pre-Middle Ordovician and Ordovician rock units in the northeastern part of the mapped region (pl. 4). The trace of this thrust fault defines the exposed contact between the northeastern limestone spur and the volcanic rocks which almost surround it. Farther to the northeast, discontinuous remnants of the upper plate occur as limestone klippen resting on metamorphic and volcanic rocks.

Fault "A" cuts off this thrust to the west as shown in structural section C-C' (pl. 1).

Because of vegetation and rubble cover, the actual thrust contact is not exposed, but its existence can be deduced from strong structural evicence.

Evidence.-- Evidence for the existence of thrust fault "B" follows:

The discordant position of overlying Tolovana limestone on the pre-Middle Ordovician metamorphic sequence (pl. 1) and the absence of the intervening volcanic sequence is difficult to explain by any other means than faulting. In addition, the limestone beds dip steeply into the underlying contact with the metamorphic rocks. (See structure section A-A', pl. 1).

The isolated blocks of limestone which overlie both Ordovician volcanic rocks and pre-Middle Ordovician metamorphic rocks appear to be klippen (structure section A-A', pl. 1).

The strike of the steeply dipping limestone beds is discordant with the trace of the contact with the volcanics on the northeastern limestone spur of northern Fossil Creek ridge.

Several isolated slices of limestone occur in the volcanics near the volcanic-limestone contact. It is very difficult to account for these slices by any other means than faulting.

Fault "C"

Description and location.-- Fault "C" is a thrust, or possibly a high angle reverse fault that brings the pre-Middle Ordovician metamorphic rocks into discordant contact with the Fossil Creek volcanic units east of the northern part of Fossil Creek ridge (pl. 4 and structure sections A-A', B-B', and C-C'). Part of the fault trace lies in the valley of Fossil Creek where there is very little outcrop and the precise location of the fault is unknown.

The sinuosity of the fault contact near its northern extremity (pl. 1 and 4) may be the result of tearing as a result of differential yielding of the fault to the northwest or it could by the result of post-fault folding.

Evidence.-- The evidence for the presence of fault "C" is the weakest of any used in the Fossil Creek area to postulate the presence of faults. Its presence is not considered to be fully proved, but it is postulated, based on the following lines of evidence:

Numerous highly crumpled zones occur in the scattered outcrops of metamorphic rocks along Fossil Creek near the trace of the proposed fault. Small scale high angle faults are associated with these intensly deformed outcrops so that they seem indicative of a larger fault zone.

The interpretation of this fault presents by far the best explanation of the outcrop pattern seen in the area adjacent to the southeastern end of the northern section of Fossil Creek ridge (pl. 1 and structure section C-C').

Fault "D"

Description and location.-- Fault "D" is a gently southeastward dipping thrust that extends northeastward through Windy and Bear Valleys into Fossil Creek Valley, and forms the volcanic-limestone contact along the western side of northern Fossil Creek ridge. The upper limestone plate becomes discontinuous in the central portion of the area, where it has apparently been eroded. At the extreme northern end of Fossil Creek ridge the fault is transected by fault "A" (pl. 4).

Evidence.-- The following evidence is cited for the presence of fault "D":

There is a marked discordance in the strike of the limestone beds on Windy Pass as compared to the small spur ridge extending to the southeast. The strike of the limestone beds west of the fault line parallel the trend of the main ridge. East of the fault line, however, the strike abruptly shifts to the SSE, differing from the attitudes on Windy Pass by about 45° (fig. 31).

The contact between the limestone and the volcanics paralling Bear Valley is quite sinuous. The strike of the steeply dipping limestone beds however is quite uniform. The limestone in places strikes directly into the contact. The same discordance is even more apparent in the northern portion of the area, along the west flank of Fossil Creek ridge. At one locality in the north part of the area a sandstone interbed in the volcanics is truncated by the contact.

A limestone fault breccia occurs locally along the volcanic-limestone contact zone.

Isolated limestone blocks in the central portion of the mapped area (pl. 1) are small klippen, underlain by a gently dipping thrust fault (fig. 32).

Fault "E"

Description and location.-- Fault "E" is a high angle reverse fault that extends nearly the entire length of the mapped area, and is essentially parallel with the structural trend (pl. 4). Fault "E" follows very closely the trend, and in some cases is overlapped by fault "D" in the southern part of the area. At Bear Pass, however, it swings northward away from fault "D" and crosses the crest of Fossil Creek ridge (fig. 33). The trace then extends on slightly west of and parallel to the crest of the ridge. North of the wind gap, the fault divides into several splinters, and in the extreme northern portion of the area it becomes obscure (pl. 4).

Evidence.-- The following evidence supports the presence and location of fault "E":

The location and intersecting nature of faults "D" and "E" adequately explain the sporadic occurence of the central volcanic belt south of Bear Pass. The repeated appearance of the volcanics is apparently controlled by the divergence of faults "D" and "E". Where faults "D" and "E" overlap, the volcanics are not exposed.

North of Bear Pass, where the contact crosses Fossil Creek ridge, the limestone adjacent to the contact is severely mylonitized, indicating intense shear along the

Figure 31. Looking south towards Windy Pass from the eastern bifurcation of Fossil Creek ridge showing divergent trends on either side of fault "D". Beds on left (east) strike approximately N 80° E, while beds on right (west) strike approximately N 50° E.

Figure 32. A small limestone klippe in the central part of the area as viewed from the northern Fossil Creek ridge. The klippe is underlain by fault "D". The vertical beds strike approximately N 55° E.

contact. The mylonitic zone does not exceed approximately 30 feet in thickness.

North of the wind gap the fault appears to become a zone of imbricate thrust plates rather than a single fault, as indicated by several small fault slices of limestone with the volcanics, and discordancies in the attitudes of the beds within these blocks as compared to the attitudes of the contacts (fig.34).

Fault "F"

Description and location.-- Fault "F" forms the sinuous limestone-volcanic contact along the western margin of the area. The fault dips approximately 30 degrees to the southeast, and the trace parallels the structural trend (pl. 4).

Evidence.-- The evidence supporting fault "F" is as follows:

A synclinal axis parallels the northwest margin of the western limestone belt. The east limb of the syncline is everywhere at least five times thicker than the western limb (pl. 1, and structure sections D-D' and E-E'). The west limb of the syncline has been entirely eliminated by faulting in some localities (fig. 35 and 36).

The volcanic rocks along this contact display cataclastic textures, which disappear a short distance west of the contact. The sheared and recrystallized volcanics in the contact zone display a latent schistosity, and at

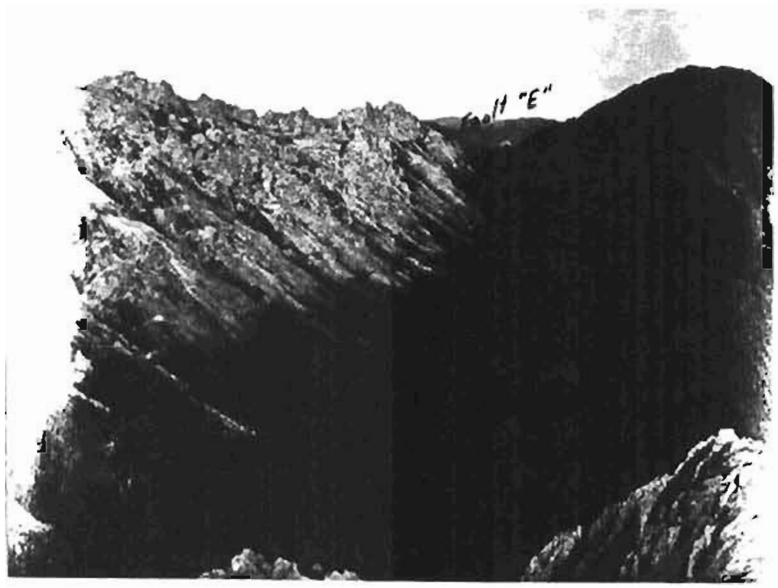


Figure 33. Looking north from theeastern bifurcation of Fossil Creek ridge toward the near vertical limestone-volcanic contact adjacent to peak 3973. The contact is formed by fault "E".

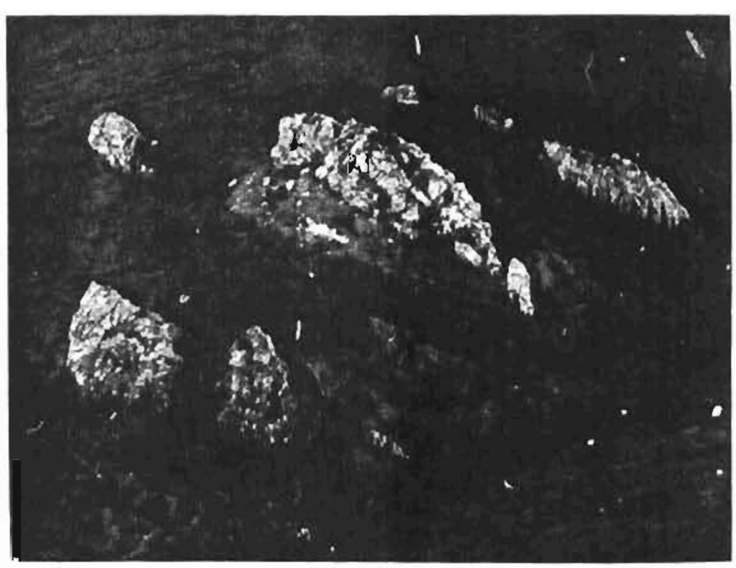


Figure 34. Limestone blocks surrounded by volcanics between the northern Fossil Creek ridge and the middle limestone outcrop of the western ridge.

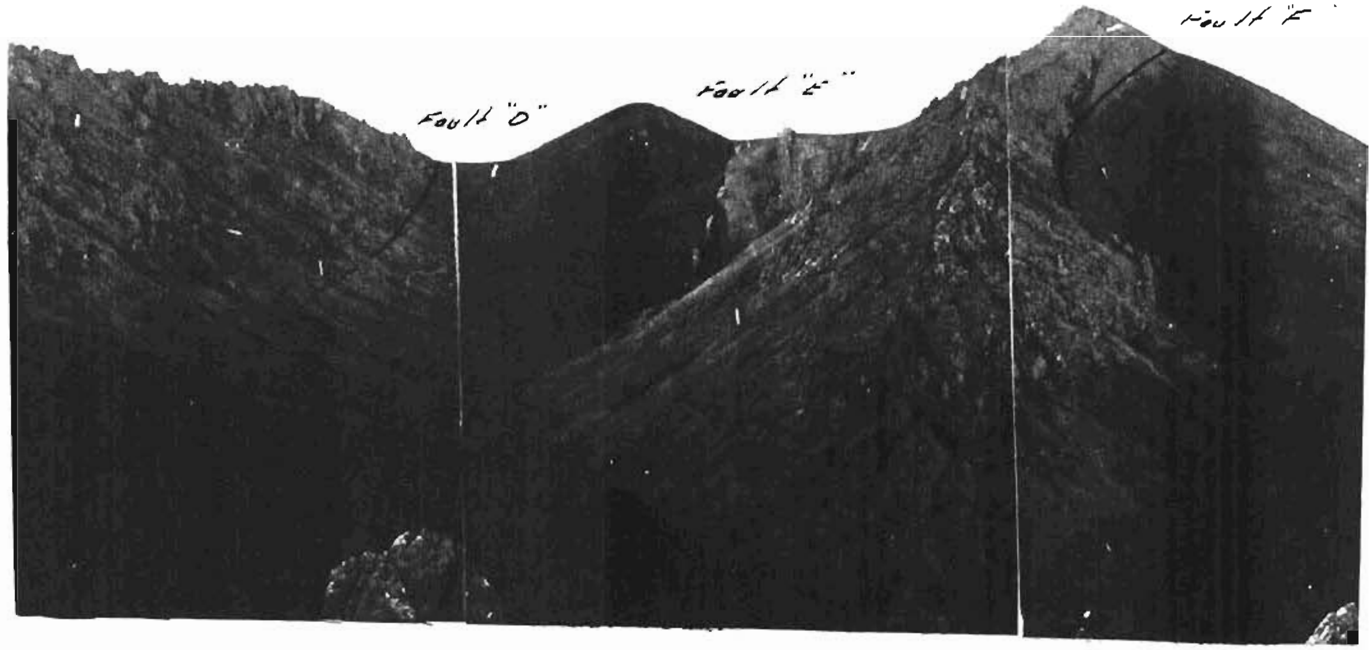


Figure 35. Panoramic view showing faults "D", "E", and "F" as viewed to the SW from the middle limestone outcrop of the west ridge in the northern Fossil Creek area. Note also the position of the isolated limestone blocks in the volcanic rocks.

Figure 36. The trace of faults "E" and "F" as viewed to the SW from near fossil locality F-4-RIC. Note the position of isolated limestone blocks surrounded by volcanic rocks.

some localities approach the greenschist facies in metamorphic grade. Sheared and brecciated limestones are also common along this contact.

Fault "G"

Description and location.-- In the southeastern part of the area, a high angle reverse fault is inferred along the southeastern side of the eastern limestone ridge, which is designated as fault "G". The fault apparently continues for only a short distance however, and the northern and southern extents are obscure (pl. 4).

Evidence.-- The fault is postulated on the basis of the following evidence:

Small topographic depressions mark the trace of the fault where it crosses two limestone spurs. A small outcrop of pre-Middle Ordovician metamorphic rocks occurs in one of these depressions. This small outcrop represents a small imbrication which was dragged up along the fault by the movement of the upper plate of limestone.

Interpretation

Based on the structure as interpretated (pl. 1), three relative periods of faulting are postulated:

Fault "C" occured before fault "B"; fault "B" occured between faults "C" and "A"; fault "A" was later than both faults "C" and "B". That "C" was the earliest fault is indicated by a small limestone klippe produced by fault

"B" that overlies the trace of fault "C" (structure section A-A'). That fault "B" was earlier than fault "A" is indicated in structure section C-C', where fault "A" can be seen to transect the largest of the limestone klippe produced by fault "B". Faults "B" and "D" may be the same fault, merely offset by fault "A" (structure section C-C'). Faults "E", "F", and "G" are impossible to date relative to the others.

The yielding in all of the faults has been to the northwest. The root zone of the thrust plates must have been to the east. Either the pre-Middle Ordovician has been thrust to the west over the root zone which is still present at depth, or the root zone has been entirely eroded away. Because the area to the east has probably been a positive geanticline since late Paleozoic time, the later explanation is favored.

The exact mechanism of faulting is difficult to postulate. It does not appear however to be the result of the shearing of overturned folds. It is possible that some movement occurred along the surface of the unconformity between the more resistant Fossil Creek Volcanics and the less resistant Tolovana limestone.

No definite age can be assigned to the faulting other than post-Middle Silurian. It is interesting to note, however, a marked difference in structural trend of the Devonian rocks to the north. Whereas the Silurian and older rocks in the Fossil Creek area trend N 60° E, the

Devonian rocks farther north trend approximately N 30° E. This discordance suggests the possibility that the folding and faulting are Late Silurian (Caledonian) in age. Payne (1955) however, indicates three Jurassic and two Cretaceous orogenies in Alaska. These may have had an effect on the structure of the Fossil Creek area, and thus is impossible to date precisely the age of these thrust faults.

GEOLOGIC HISTORY

The Fossil Creek area contains a very incomplete record; therefore most of the geologic history postulated below is based on a synthesis of the literature concerning the geology of central and northern Alaska. Particular use has been made of work by Mertie (1937), Cady, Wallace, Hoare, and Webber (1955), T. G. Payne and others (1952), and T. G. Payne (1955).

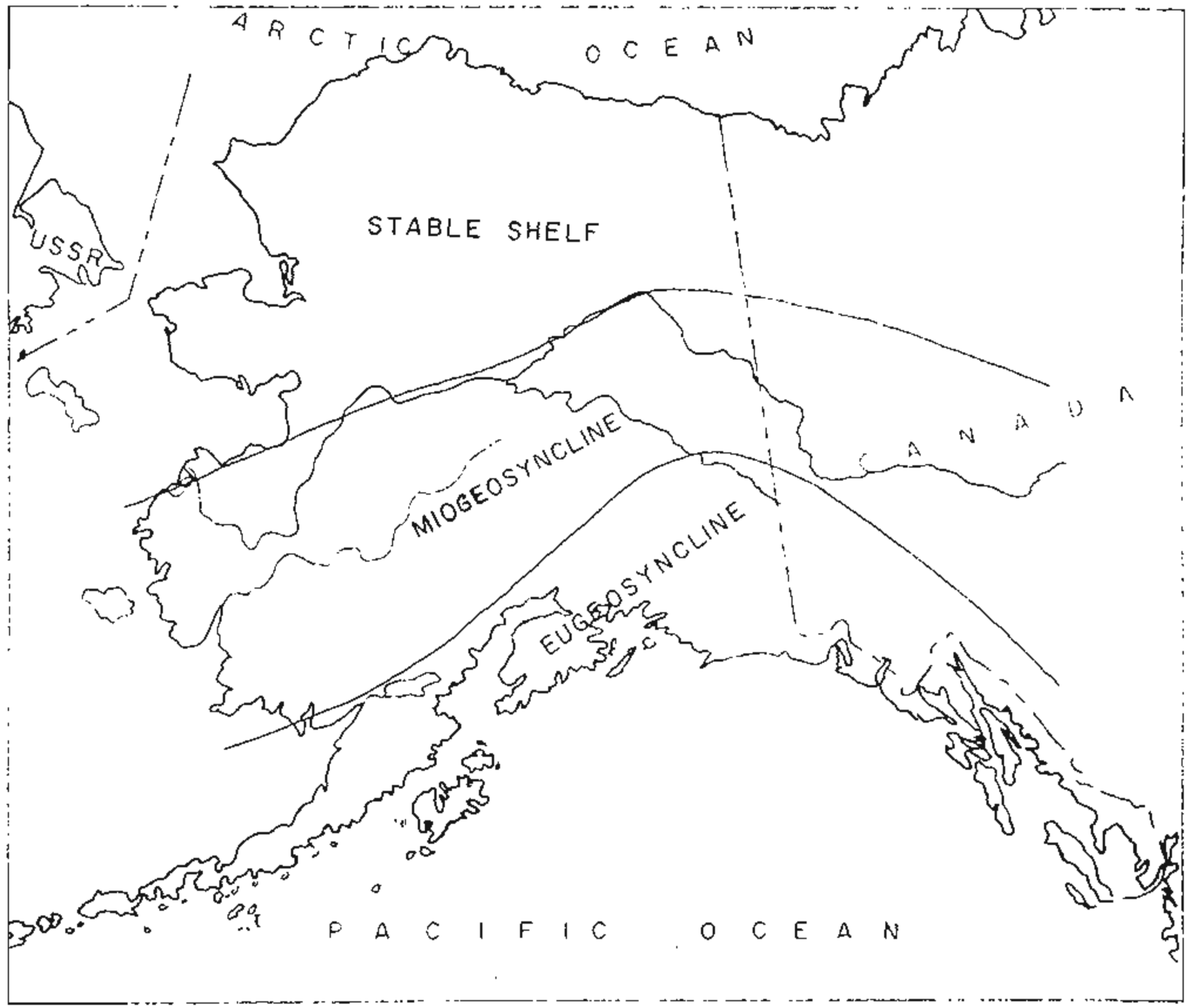
The oldest rocks known in Alaska are the quartzites, schists, gneisses, marbles, and amphibolites assigned to the Birch Creek schist sequence. These rocks are considered by Mertie (1937, p. 55) to be of early Precambrian age. The present rocks are the metamorphosed equivalents of materials which are probably of marine origin and include arenaceous, argillaceous, and calcareous sediments. Amphibolites are believed to be the metamorphic equivalent of intercalated basic volcanic sills or flows in the section. An orogeny which followed this initial period of sedimentation intensely deformed and synkinematically metamorphosed the sequence. Intrusion of granitic rocks possibly also occurred.

Little detailed work had been done on the structure and petrology of the Birch Creek schist until recently, but investigations by Forbes (1960, p. 2085) indicate that these rocks may have been subjected to the effects of at least two periods of orogeny. Following the final period of orogeny the sequence was probably uplifted and subjected to a long period of sub-aerial erosion (Mertie, 1937, p. 230).

In latest Precambrian or Early Cambrian time a mobile tectonic belt developed between the stable continental platform in northern Alaska and the Pacific Ocean floor. The carbonates, argillaceous sediments, quartzites, and altered volcanics of the Tindir group were the earliest units deposited in this belt. According to Mertie (1937, p. 64) between 20,000 and 25,000 feet of Tindir sediments were deposited in an apparently continuous sequence. Because rocks of the Tindir group are apparently unfossiliferous, and the oldest dated rocks in the region are Middle Cambrian in age, it is not possible to determine whether the Tindir group is late Precambrian, Early Cambrian, or both. Mertie (1937, p. 64) and Cady and others (1955, p. 101) favor a late Precambrian age.

A large portion of the clastic material of the Tindir group sediments was probably transported southward from the stable landmass in northern Alaska (Cady, 1955, p. 101). Volcanic activity occurred intermittently during deposition of the Tindir group, but apparently the group was not deformed, as marine Cambrian strata overlie it with structural conformity.

By early Paleozoic time northern Alaska was apparently a stable lowland area consisting of a shelf and perhaps part of the craton; interior and western Alaska was a miogeosyncline, and southern and southeastern Alaska were located in the eugeosyncline (fig. 37).



EARLY PALEOZOIC TECTOTOPES
(modified from Payne and others, 1951)
Figure 37

The Yukon-Tanana region was located in the miogeosynclinal tectotope during early Paleozoic time. According to Payne and others (1951, sheet 3), at least 20,000 feet of marine sediments of Cambrian, Ordovician, and Silurian ages were deposited. The Cambrian units are dominantly limestone with minor intercalations of black shale. The Ordovician rocks include limestone, black shale, cherts, quartzose sandstones, and, atypically for this belt, the basic volcanic rocks which occur in the Fossil Creek area. The Silurian rocks are entirely a carbonate sequence.

A period of deformation and metamorphism followed the deposition of the sediments which formed the pre-Middle Ordovician sequence. The extrusion of the Fossil Creek volcanic rocks occurred after the main pulse of this deformation and may represent a late stage in the orogeny. Mertie has suggested that the Fossil Creek volcanics are marine, but the writers found no evidence which proved this. There occurred a temporary break during the extrusion of the volcanics during which a calcareous sandstone member was deposited. This unit possibly represents a beach or near-shore bar in which the source material was nearby quartz rich rocks of the pre-Middle Ordovician sequence.

The source of the early Paleozoic sediments deposited in the miogeosyncline was probably the stable landmass which existed in northern Alaska. The early Paleozoic sediments thin northward onto the shelf where carbonates are the predominant type, and the total thickness of Cambrian, Ordovician, and Silurian sediments nowhere exceeds 5000 feet (Payne and others, 1951, sheet 3).

During deposition of the Silurian carbonates, the region must have been very stable. The Tolovana and equivalent units extend eastward from the Bering Sea across Alaska, into Canada, and probably into the Cordilleran area of the United States (fig. 18). The lack of quartz or other detrital material in this limestone shows that there was no clastic sedimentary transport from the northern stable area southward into this area of the miogeosyncline during Niagaran time. The lack of mechanically transported material may have been due to: (1) lack of currents strong enough to transport detrital material; (2) an extremely low lying source area on which almost no mechanical weathering was taking place so that there was practically no detrital material available; (3) there was no quartzose material available in the source area; or (4) the Fossil Creek area was on a local high and mechanically transported sediments bypassed it. This problem cannot be resolved without more detailed petrographic studies of Silurian rocks in other areas.

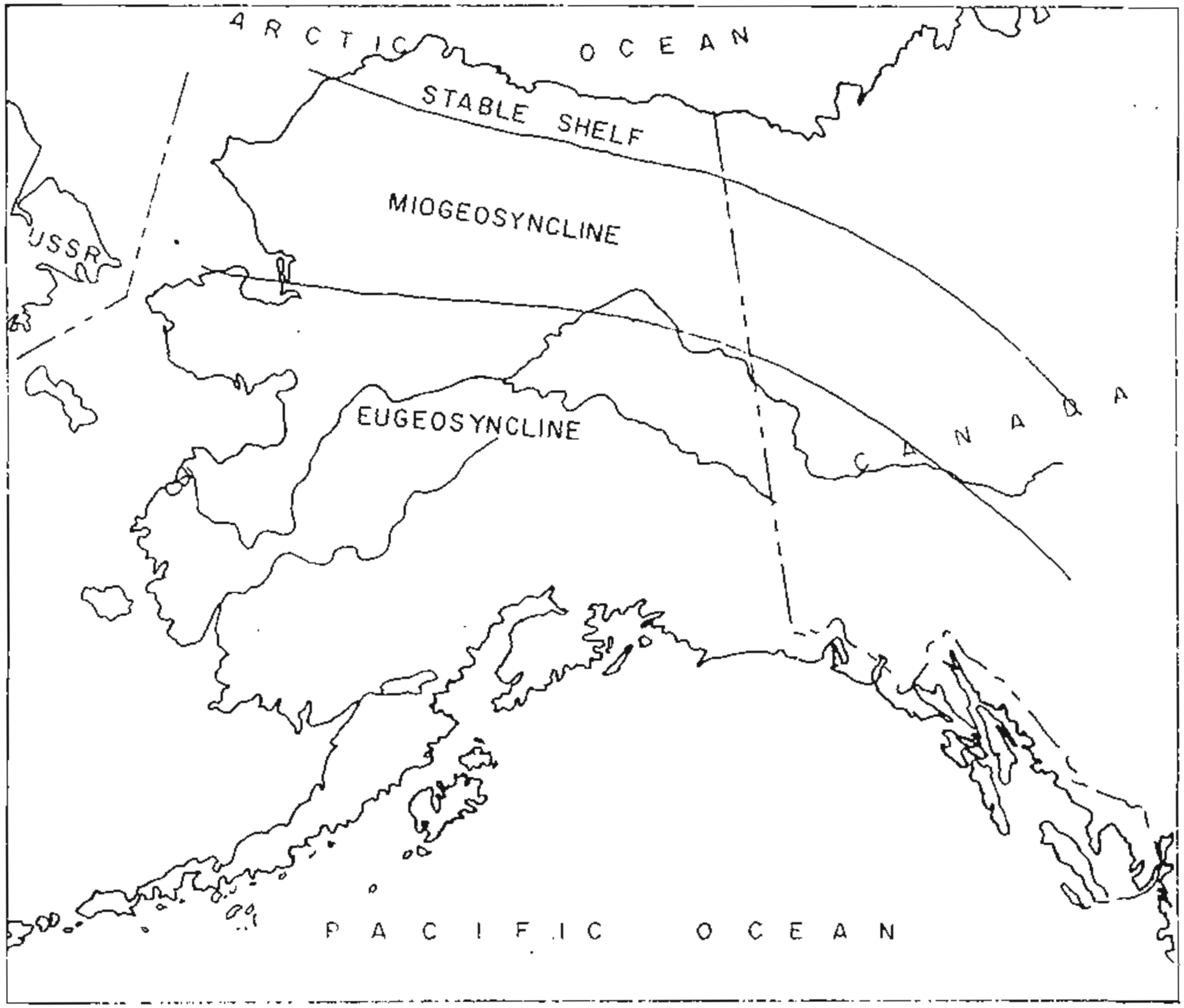
During Late Silurian or Early Devonian time the region was again deformed, and possibly uplifted, but apparently no plutons were emplaced at this time (Payne and others, 1952, sheet 3).

In late Paleozoic time the eugeosynclinal belt migrated northward until by the end of Paleozoic time it had reached the present position of the southern flank of the Brooks Range

(Payne and others, 1952, sheet 3). The miogeosyncline was restricted to the region now occupied by the Brooks Range and the Southern Arctic Foothills (fig. 38), and the shelf was restricted to the northern Arctic slope. As might be expected, a northward shift with time of basic intrusion and volcanism accompanied the migration of the eugeosyncline (Cady and others, 1955, p. 18).

During late Paleozoic time the Fossil Creek area was located in a eugeosynclinal tectotope. Deposition was marine except for local Pennsylvanian continental deposits. The Devonian, Mississippian, and Permian sediments include limestone, shale, chert, quartzose sandstones, conglomerate, and basaltic flows and tuff. Lack of sediments with the characteristic mineralogy of graywackes suggests generally weak tectonism during late Paleozoic time (Payne and others, 1951, sheet 3). An epeirogenic break is indicated, however, between Mississippian and Pennsylvanian or younger rocks by the local Pennsylvanian continental deposits.

During Mesozoic time linear troughs, which probably received sediments from adjoining island arcs, were developed in the eugeosyncline. Due to insufficient evidence, it is difficult to delineate the actual land and sea areas during Triassic, Jurassic, and Early Cretaceous time. However, graywacke sandstone, pyroclastics, submarine volcanics, and chert were widely deposited. It is possible that the Yukon-Tanana region was submerged during Triassic time, but Payne and others



LATE PALEOZOIC TECTOTOPES
Figure 38
(modified from Payne and others, 1951)

(1952, sheet 3) think that by Jurassic time most of the region between the Alaska and the Brooks Ranges was emergent. Payne (1955) indicates that three Jurassic orogenies occurred in Alaska and were during post-Bathonian, post Callovian, and post Portlandian time. The first phases of plutonism of batholithic dimensions, and mineralization of the Yukon-Tanana region possibly occurred during one or more of these orogenies.

In Early Cretaceous time considerable thicknesses of marine sediments and volcanics were deposited in the Yukon-Tanana region. This sedimentation was terminated in Albian time by an episode of intense orogeny accompanied by the emplacement of granitic bodies of batholithic scale.

During Albian time the eugeosyncline became differentiated into definable positive and negative areas (Payne and others, 1951). Three major anticlines were formed which plunged southward as finger-like projections into southwestern Alaska (fig. 5). The northernmost of these was the Ruby geanticline. It was separated from the Tanana geanticline by the Kuskokwim geosyncline. The Alaska Range geosyncline separated the Tanana and Talkeetna geanticlines.

During late Cretaceous time the Yukon-Tanana region was located for the most part on the Tanana geanticline, which may be traced from the eastern part of the Kuskokwim region northeastward to central Alaska, and thence eastward into Canada.

These positive and negative regions were maintained throughout late Cretaceous time and into the early Tertiary.

According to Cady and others (1955, p. 102), the Ruby geanticline was uplifted rapidly during the early part of Late Cretaceous time, but the rate of uplift reversed during later Cretaceous time. During Late Cretaceous time over 20,000 feet of clastic sediments were deposited in the Kuskokwim and Koyukuk troughs (fig. 5). The Kuskokwim geosynclinal sediments probably include the belt of Cretaceous rocks which now crop out in the Yukon-Tanana region from Manley Hot Springs east to the international boundary. Sources of the clastic sediments in the Kuskokwim and Koyukuk troughs were the early Brooks Range, the Ruby geanticline, and the Tanana geanticline which probably contributed material to the Alaska Range geosyncline.

The Yukon-Tanana region was further affected by Late Cretaceous orogenies which, although intrusion, local low grade metamorphism, and uplift occurred, were less intensive than the Early Cretaceous orogeny. Local arches were developed along the axis of the Kuskokwim geosyncline resulting in erosion of much of the Mesozoic and Paleozoic sedimentary cover from local areas. The Fossil Creek area is located on one of these arches, which probably explains the lack of upper Paleozoic, Mesozoic, and Cenozoic deposits.

By early Tertiary time most of interior Alaska was above sea level and nonmarine sedimentary rocks, including shale, sandstone, conglomerate, and coal were deposited in local basins in the interior. Volcanism occurred intermittently during Tertiary time and continued into the Recent. There is no evidence for either Tertiary sedimentation or volcanism in the Fossil Creek area.

Further uplift, faulting, and erosion have occurred during Quaternary time and glaciation occurred on the higher mountain peaks during the Pleistocene epoch. Evidence for pre-Wisconsin glaciation is present in the Fossil Creek area.

CONCLUSIONS

The pre-Middle Ordovician sequence of the Fossil Creek area includes slightly recrystallized to lower medium grade metamorphic rock derived of argillaceous, quartzose, carbonate, and volcanic parent rocks. Fragmentary evidence suggests that this sequence has been subjected to at least two periods of folding. Late Cambrian or Early Ordovician fossils were found by earlier workers in slates belonging to this sequence. These fossils and the overlying unmetamorphosed middle Ordovician volcanic rocks indicate that the latest orogeny which metamorphosed these rocks was probably Early Ordovician (Early Caledonian). Anomalies in metamorphic grade indicate that the sequence may include rocks of two different ages.

The Middle Ordovician Fossil Creek volcanics include pyroclastic, flow, and sedimentary rocks. This sequence unconformably overlies the pre-Middle Ordovician rocks.

The Middle Silurian (Niagaran) Tolovana carbonates were deposited in a shallow marine environment under tectonically stable conditions. The lower part is dominantly chemical or biochemical, but the upper, and predominantly allochemical portion, is believed to be the result of wave or current action in an area of weakly consolidated carbonate sediments. Scattered occurrences of fossil reef building organisms indicate that at least part of the Tolovana limestone is of organic origin.

Quaternary deposits include residual material and stream alluvium on which features indicative of a periglacial climate are developed. No morainal deposits are recognized, but small Illinoian (?) cirques are present.

Plutonic intrusives include quartz monzonites and gabbros. Granodiorite and altered basic dikes also occur within the area. The acidic intrusions are dated as post-Silurian, and the basic intrusions are dated as Middle or post-Middle Ordovician.

The writers have recognized three major folds in the Fossil Creek area: a syncline in the western limestone belt; a second syncline in the northern half of the eastern limestone belt; and a southwest plunging anticline in the extreme northern portion of the area.

Seven major reverse and/or thrust faults are believed to be present. Relative displacement along all faults is controlled by yielding to the northwest. The root zone of the thrust plates must have been located to the east. Such a root zone has not been found, however, and it is deduced that these rocks have been removed by uplift and subsequent erosion to the east.

A marked difference in trend of Devonian and Silurian rocks in the Yukon-Tanana upland suggests the presence of a regional unconformity. The folding and probably the faulting is Late Silurian (Caledonian). However, current tectonic trends and existing structures have undoubtedly been influenced by Jurassic and Cretaceous orogenies.

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