

**GEOLOGICAL
SURVEY
OF
CANADA**

**DEPARTMENT OF ENERGY,
MINES AND RESOURCES**

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BULLETIN 180

**STRATIGRAPHY AND STRUCTURE OF
THE "KENO HILL QUARTZITE" IN
TOMBSTONE RIVER – UPPER KLONDIKE RIVER
MAP-AREAS, YUKON TERRITORY**

(116 B/7, B/8)

D. J. Tempelman-Kluit

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D.J. T-K. 2-6-64

FRONTISPIECE. View of the south part of the Tombstone stock, looking southwest from near the Tombstone River — North Klondike River divide. Note the flat wide valley floor, the steep valley wall, and the well-developed alpine topography.

This rock is strongly jointed vertically and weathers into ruinous wedge-shaped ridges, surmounted by lines of sharp pinnacles and lofty tower-shaped peaks. The pillared character of the region is so remarkable that the prospectors have given it the name of the tombstone country. (McConnell, 1903, p. 63)



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By
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ENERGY, MINES AND RESOURCES
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Ottawa, 1970

PREFACE

The host rocks for the rich silver ores of the Keno Hill area, Yukon Territory, have long been regarded as Precambrian in age, but recent studies suggest that they are in part, at least, of Mesozoic age.

This report describes the geology of an area northwest of Keno Hill. The geological succession is similar to that at Keno Hill, but in addition two new formations were recognized by the author. The evidence for assigning a Mesozoic age to the greater part of the succession is presented and the structural geology of the area is examined in some detail.

Y.O. Fortier,
Director, Geological Survey of Canada

Ottawa, August 15, 1967

BULLETIN 180 — Stratigraphie und Tektonik des
Quartzites von Keno Hill im Tombstone Gebiet,
(Zentral-Yukon-Territorium).

Von D. J. Tempelman-Kluit

Ein mesozoisches Alter wird für einen Teil einer
früher für präkambrisch gehaltenen Schichtfolge gedeutet.
Der tektonische Stil des Gebietes ist dem der Rocky
Mountains in Alberta ähnlich.

БЮЛЛЕТЕНЬ 180 — Стратиграфия и структура
кварцита Кено-Хилл в районе Тумстоун цен-
тральной части Юконской Территории

Д. Я. Темпельман-Клюйт

Свиты ранее считавшиеся докембрийскими частично
оказались мезозойскими. Тектонический стиль района на-
поминает таковой Скалистых гор Альберты.

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STRATIGRAPHY AND STRUCTURE OF THE "KENO HILL QUARTZITE" IN TOMBSTONE RIVER – UPPER KLONDIKE RIVER MAP-AREAS, YUKON TERRITORY

Abstract

New stratigraphic evidence strongly suggests that the areally extensive "Lower Schist" and "Keno Hill Quartzite" (informal names), formerly included in the Precambrian Yukon Group, are, respectively, Jurassic and Lower Cretaceous. The two formations overlie Upper Triassic limestone and are intruded by probable mid-Cretaceous syenite stocks; Middle and Upper Jurassic fossils were found in structurally repeated, stratigraphic and lithologic equivalents of the "Lower Schist". Two new unnamed formations of slate and siltstone that are younger than the "Keno Hill Quartzite" and are probably of Lower Cretaceous age are described. The "Keno Hill Quartzite" and younger formations are homotaxial equivalents of the Lower Cretaceous Kandik Formation in east central Alaska.

The "Keno Hill Quartzite" is an 1,800-foot-thick succession of submaturation, massive, fine-grained orthoquartzite with interbedded black slate. A thin sandy limestone member occurs in its upper part and a single 600-foot-thick, continuous, vertically differentiated tholeiitic diabase and gabbro sill that intrudes the formation follows a slate member in the lower part of the formation. The "Keno Hill Quartzite" is a multicycle sandstone probably derived from late Paleozoic clastic rocks in the northern Yukon and deposited under shallow marine conditions; the upper part of the formation may be non-marine.

Lower and Middle Triassic siltstone and limestone occur in Tombstone area indicating that the central Yukon was tectonically quiet during the Early Triassic, in contrast to much of the western Canadian Cordillera in the southern Yukon and British Columbia. The lithology, relative thinness, and apparent completeness of the Mesozoic succession of Tombstone area and the lateral extent of the formations beyond the map-area indicate that miogeosynclinal conditions prevailed in much of central Yukon Territory during the Mesozoic; the central Yukon was formerly thought to have been a stable landmass throughout Mesozoic time.

Stratigraphic marker beds within the Lower Cretaceous rocks of Tombstone area outline large, concentric folds and define a number of late Early Cretaceous, southeast-dipping thrust faults that repeat the stratigraphic succession of the "Keno Hill Quartzite". The thrusts are imbricate structures between a surface of basal detachment or décollement and an overlying major thrust that brings Precambrian onto Mesozoic strata. The structures indicate a style of deformation that is similar to that found in the Rocky Mountains of Alberta and which has not previously been recognized in central Yukon Territory.

Résumé

De nouvelles données stratigraphiques laissent fortement supposer que les deux formations appelées (non officiellement) «Schiste inférieur» et «Quartzite de Keno Hill» et antérieurement comprises dans le groupe précambrien du Yukon appartiennent respectivement au Jurassique et au Crétacé inférieur. Les deux formations recouvrent du calcaire du Trias supérieur et comportent l'intrusion de stocks de syénite datant probablement du Crétacé moyen. On a trouvé des fossiles du Jurassique moyen et supérieur dans des équivalents stratigraphiques et lithologiques structurellement répétés de la formation «Schiste inférieur». L'auteur décrit deux nouvelles formations, non dénommées, de schiste et de grès plus récentes que celle de «Quartzite de Keno Hill» et datant probablement du Crétacé inférieur. La formation «Quartzite de Keno Hill» et celles plus récentes constituent des équivalents homotaxes de la formation de Kandik du Crétacé inférieur du centre-est de l'Alaska.

La formation «Quartzite de Keno Hill» constitue une épaisse succession de 1,800 pieds d'orthoquartzite sous-évolué à grain fin et massif, interstratifié de schiste noir. Un mince terme de calcaire sableux se trouve dans la partie supérieure et un sill simple de 600 pieds de gabbro et de diabase tholéitique continu, verticalement différencié, pénètre par intrusion dans la formation et vient à la suite d'un terme de schiste à la partie inférieure de la formation. La «Quartzite de Keno Hill» a une structure formée de grès polycyclique probablement originaire de roches clastiques du Paléozoïque supérieur du nord du Yukon et déposé en milieux marins peu profonds. La partie supérieure de la formation peut être d'origine non marine.

Les grès et calcaires du Trias inférieur et moyen de la région de Tombstone indiquent que le centre du Yukon était au cours du Trias inférieur une région à tectonique tranquille, contrairement à la majeure partie de la Cordillère au sud du Yukon et en Colombie-Britannique. La lithologie, la puissance relative et l'état complet apparent de la succession mésozoïque de la région de Tombstone et le prolongement latéral des formations au-delà de la région étudiée indiquent que des conditions miogéosynclinales ont existé dans la majeure partie du centre du Yukon au cours du Mésozoïque. Antérieurement, on émettait l'hypothèse que le centre du Yukon était demeuré une région tranquille au cours de cette ère.

Des couches caractéristiques au sein des roches du Crétacé inférieur de la région de Tombstone délimitent de larges plis concentriques et définissent un certain nombre de failles de poussée à pendage sud-est de la fin du Crétacé inférieur qui répètent la succession stratigraphique de la formation «Quartzite de Keno Hill». Les poussées ont donné une structure imbriquée entre un détachement ou un décollement de la partie inférieure et un vaste chevauchement des strates précambriennes sur celles du Mésozoïque. Les structures dénotent un type de déformation semblable à celui remarqué dans les montagnes Rocheuses de l'Alberta et non observé antérieurement dans le centre du Yukon.

INTRODUCTION¹

The "Lower Schist" and "Keno Hill Quartzite", host rocks for the rich silver ores of Keno Hill, have long been regarded as Precambrian but recent work by Green and Roddick (1962, pp. 10, 12), suggests they are younger. The present study was proposed by L.H. Green of the Geological Survey of Canada to follow up recently completed regional geologic investigations. The detailed study was designed to determine the age and stratigraphy of the "Lower Schist" and "Keno Hill Quartzite", and also to clarify the internal structure and structural relations of the two formations. The Tombstone area was chosen because of its good exposures.

The present work contains new stratigraphic evidence for the age of the "Keno Hill Quartzite" and "Lower Schist" and indicates probable correlatives of these two formations.

Part of the thick succession of rocks, formerly included with the Precambrian Yukon Group, is assigned to the Mesozoic.

A structural description, interpretation, and synthesis accounting for the marked thickening of the succession in Tombstone area by extensive, large-scale thrusting and folding within the "Keno Hill Quartzite" is included. Modifications in the geology of the central Yukon indicated by the stratigraphic and structural data from Tombstone area are investigated.

Location and Access

Tombstone area, 30 miles northeast of Dawson, lies between longitudes 138° and 139° and between latitudes 64°15' and 64°30' (Tombstone River, NTS 116 B/7, and Upper Klondike River, NTS 116 B/8) and includes about 400 square miles. The area, which is uninhabited, takes its name from a tributary of the Chandindu River and contains the upper reaches of the North Klondike River.

Tombstone area lies wholly within the southern part of the Ogilvie Mountains. It is just north of Tintina Trench, a straight, topographic depression that extends some 400 miles southeastward, from the Yukon-Alaska boundary. The area is at the western extremity of an east-trending, 120 mile-long belt of Mesozoic sedimentary rocks, the Keno Hill - Tombstone River belt.

The eastern part of the area is readily accessible. The only road in the area follows the west side of North Klondike River for most of its length through the area and joins the main Dawson - Whitehorse Highway 25 miles from Dawson. Most of the larger valleys provide natural routes of travel in which game trails are plentiful.

Original manuscript submitted by author 21 November, 1966.

Final version approved for publication 15 May, 1967.

¹This study was undertaken in partial fulfillment of the requirements for the degree of Doctor of Philosophy at McGill University, Montreal, Quebec.



D.J. T-K, 1-1-65

FIGURE 1. View looking west toward the headwaters of the North Klondike River and the divide with Tombstone River. The mountains are underlain by massive orthoquartzites (unit 13) and slates of unit 11 are exposed at their base just above valley level. Note the Fold Mountain anticline at the extreme left.

Topography

Long, branching, sharp-crested ridges that are typically serrate in those areas underlain by syenite (Fig. 2) dominate the topography. Three distinct groups of mountains, Tombstone Range in the south, Cloudy Range in the north, and Antimony Range in the east, rise to altitudes of more than 7,000 feet. Average relief is about 3,000 feet and maximum relief is 5,500 feet. The area lies on the divide between the Peel and Yukon Rivers drainage systems.

The mountain ranges are separated by the wide, flat-floored valley occupied by North Klondike and Tombstone Rivers. Drainage patterns in the area are typically dendritic and reflect little bedrock control. Stream gradients are generally high. Cirques, tarns, and hanging valleys occur at the heads of most tributary streams.

Tombstone area lies about 100 miles west of, and outside, the area of continental Pleistocene glaciation. The alpine glaciation that affected it was confined to high parts of the Ogilvie Mountains. Small receding glaciers occupy some north-facing cirques. Glacial drift mantles the hillsides to elevations of 3,500 feet. Till deposits in the North Klondike valley are locally as much as 50 feet thick and contain pebbles of local derivation. The treeline is at 3,500 feet or thereabouts and underbrush is generally light.



D.J. T-K. 10-7-65

FIGURE 2. View of the Tombstone stock looking west from near the headwaters of Grizzly Creek. Note the glacier beneath Mount Monolith in the centre foreground. Tombstone Mountain is in the centre distance.

Geological Investigations

A reconnaissance study of a previously unexplored region in the central Yukon, which includes the map-area, was made by Green and Roddick (1962) during Operation Ogilvie, and the regional geology of adjacent areas to the south was investigated earlier by Bostock (1943a, 1943b, 1947, 1948b). A large area in northern Yukon Territory was studied by the Geological Survey during Operation Porcupine (Norris, Price, and Mountjoy, 1963). Brabb and Churkin (1964, 1965) investigated the geology of the Charley River Quadrangle in east central Alaska.

The present study was begun in Tombstone River map-area in 1964 and was expanded eastward in 1965 to obtain additional structural and stratigraphic information from Upper Klondike River map-area. Traverses were made along the ridges and

valleys and plotting was done with the aid of barometer readings, compass resections, pace and compass traverses, and high-level photographs. Base maps enlarged to a scale of $\frac{1}{2}$ mile to 1 inch were used for plotting the field data.

Acknowledgments

The writer wishes to express his appreciation to Dr. L.H. Green, for selecting the area and for the numerous ways in which he assisted the progress of the work, both in the field and during the writing of the author's doctoral thesis. Dr. E.W. Mountjoy, of McGill University, under whose direction the thesis was written, made certain unpublished manuscripts and sections of Mesozoic strata available (Mountjoy, 1967a,b). For this assistance and other suggestions and for his critical reading of the manuscript the writer extends sincere thanks. Able assistance in the field was given in 1964 by M.B. Lambert, B.J. Lastiuka (deceased), and D.R. Harrison, and in 1965 by R. Forester, K.C. Stones, and D.W. Kushnir. The ability and willingness of these men to work under conditions that were at times adverse contributed much to the completion of the work. The generous co-operation and kindness of many of the residents of Dawson facilitated the work; particular thanks are due to Mr. C.C. Henderson, Mr. A. Innes-Taylor, and Mr. and Mrs. G. Walmsly. Members of the Yukon Territorial Government road maintenance crew assisted in many ways, especially Al Close, foreman.

STRATIGRAPHY

Tombstone area is underlain by a 10,000-foot succession of sedimentary and volcanic rock that is separated into two informally named parts, the Lower and Upper Divisions. The Lower Division (at least 5,000 feet thick) includes map-units 1 to 7. It comprises Precambrian and/or Cambrian quartz-pebble conglomerate, limestone, subarkosic sandstone, and maroon and green slate overlain by basic volcanic rocks. The youngest formation (Road River) of the Lower Division contains chert and slate of Ordovician and Silurian age.

The Upper Division overlies the Lower Division unconformably. Its oldest formation, the Tahkandit (map-unit 8), is overlain by a succession of Mesozoic rocks that includes map-units 9 to 15. The Mesozoic succession is 6,000 feet thick and is made up of Triassic shale and limestone, Jurassic slate, and Lower Cretaceous orthoquartzite, phyllitic slate, and siltstone.

The Jurassic slate (map-unit 11) and the Lower Cretaceous orthoquartzite (map-unit 13) have been traced as separate formations to Mayo district (Green and Roddick, 1962) where they are known informally as the "Lower Schist" and "Keno Hill Quartzite", respectively.

A diabase sill intrudes the Lower Cretaceous orthoquartzite, and two large mid-Cretaceous syenite stocks intrude the Mesozoic and older rocks. The present study is concerned mainly with the Upper Division and emphasizes the age and stratigraphic relations of the "Lower Schist" and "Keno Hill Quartzite".

Lower Division

The succession of the pre-Ordovician rocks of the Lower Division is not clear. On the west slopes of Chert Mountain the sequence is (from top down):

Maroon and green slate	— about 1,500 feet	— map-unit 4
Feldspathic sandstone	— about 1,500 feet	— map-unit 3
Limestone	— more than 50 feet	— map-unit 2

There is no evidence to indicate whether this sequence is overturned, structurally repeated, or an upright stratigraphic succession. Map-unit 1 probably underlies unit 2, but because it does not outcrop in the northwest part of the area, its relation to map-unit 2 was not determined.

Proterozoic and/or Cambrian

Map-unit 1

Unit 1 is in the southeastern part of Tombstone area and forms the hanging-wall of the North Fork thrust. As this thrust constitutes the southeastern limit of the map-area this unit was not studied in detail. Rocks of unit 1 are also present northwest of the map-area, where they are closely associated with those of unit 4 (Green and

"KENO HILL QUARTZITE", YUKON TERRITORY

TABLE I *Table of Formations*

Era	Period	Formation	Lithology	Thickness	
MESOZOIC	Middle Cretaceous	Unit 18	Coarse- to medium-grained syenite, monzonite, quartz monzonite and quartz diorite stocks.		
	Lower Cretaceous	Intrusive			
		Unit 17	Porphyritic hornblende diorite dykes.		
		Intrusive			
		Unit 16	Tholeiitic diabase and gabbro sill.		300-800 ft
		Intrusive			
		Unit 15	Buff-weathering, cross-laminated calcareous quartz siltstone with interbedded brownish grey shale.		+2,000 ft
	Unit 14	Green and red phyllitic and siliceous slate, minor chert.		500 ft	
	Unit 13	Massive, grey, fine-grained submature orthoquartzite; interbedded black slate; minor sandy limestone.		1,800 ft	
	Jurassic	Units 12 11	Black, graphitic slate and phyllitic slate, minor greywacke siltstone.		±1,500 ft
Disconformity					
Triassic	Units 10 9	Dark grey siltstone and fetid, shaly fossiliferous limestone.		0-200 ft	
Disconformity					
PALEOZOIC	Permian	Tahkandit Formation Unit 8	Crystalline crinoidal limestone, chert and chert pebble biosparite.	20-100 ft	
	Unconformity				
	Ordovician and Silurian	Road River Formation Unit 7	Black and grey chert and greenish grey argillite.	±500 ft	
	Cambrian?	Unit 6	Brownish weathering, calcareous siltstone, minor shale and chert.	0-500 ft	
	Cambrian? - Silurian?	Unit 5	Greyish green amygdaloidal augite basalt and volcanic breccia; calcite-filled vesicles and fractures.	0-2,000 ft	
PROTEROZOIC AND/OR CAMBRIAN	Cambrian?	Unit 4	Maroon and green shale, slate and argillite; minor chert.	±1,500 ft	
	Cambrian?	Unit 3	Feldspathic, lime-cemented submature orthoquartzite; oncolitic sandstone near base, minor shale and siltstone.	±1,500 ft	
	Cambrian?	Unit 2	Dark grey, massive oncolitic limestone; silicified and dolomitized.	+50 ft	
	Proterozoic?	Unit 1	Feldspathic sub-greywacke pebble-conglomerate with interbedded greenish shale.	10,000? ft	

Roddick, 1962). Neither the thickness nor the contact relations of unit 1 are known; the upper and lower contacts are not exposed in the map-area, and the unit is complexly deformed and outcrops poorly. Structural repetition within the unit precludes a reliable estimate of its thickness.

Unit 1 includes greywacke-like pebble-conglomerate (about 40 per cent) and olive-green slates, with lesser maroon and green slate and dark grey limestone. The pebble-conglomerate contains unsupported, rounded, ellipsoidal pebbles (about 5 mm across) of quartz and feldspar in a silty and micaceous groundmass. The pebbles constitute more than half the volume of the rock. Quartz pebbles are by far the most abundant and are generally composite, consisting of equant, interlocking grains with sharp, straight boundaries. Feldspar pebbles are only slightly altered; most consist of potash feldspar that may show microcline twins but other pebbles are composed of sodic plagioclase. The groundmass of the rock comprises silt-sized quartz grains, chlorite, muscovite, and limonite. The pebble-conglomerates are mature feldspathic subgreywackes (Folk, 1964) that appear to have been derived largely from a mixed metamorphic and igneous terrain.

A pre-Ordovician age for unit 1 (and units 2, 3, and 4) is indicated by fossils collected from the overlying Road River Formation. Unit 1 of Tombstone area is part of Green's and Roddick's (1962, p. 4), unit 3 to which they assigned a Proterozoic and/or Cambrian age. No refinement of this assignment can be given.

Map-unit 2

Several small outcrops of limestone (unit 2) occur near the mouth of Little Twelve Mile River and constitute the lowest exposed unit of the Lower Division in the northwest part of the area. Only 50 feet of unit 2 is exposed, and the total thickness of the formation is not known. The contact with the overlying rocks of unit 3 is not exposed and its nature is uncertain.

Massive, dark grey limestone constitutes the exposed part of unit 2. The limestone contains oncolites or pisolites as much as 2 mm across (30 per cent), rounded to angular micrite intraclasts as much as an inch long, and a few rounded, sand-sized grains of quartz; all components are set in a micrite matrix. Post-depositional changes include cavity in-filling by sparry calcite and subsequent partial replacement of this spar by dolomite; partial to complete recrystallization of micrite to a mosaic of sparry calcite; incomplete silicification of oncolites by chalcedonic quartz and veining by sparry calcite.

Limestones that may be equivalents of unit 2 were mapped as unit 3a by Green and Roddick (1962); they occur west of the area and extend to Alaska. About 1,000 feet of these limestones occur there and Brabb and Churkin (1965) considered these rocks as possibly Lower Cambrian. Unit 2 is here included in the Proterozoic and/or Cambrian?

Map-unit 3

Unit 3 occurs in the northwest part of Tombstone area on the west flank of Chert Mountain, where it weathers to a distinctive yellowish or buff colour and forms massive cliffs. Green and Roddick (1962) included it in their unit 3, which outcrops extensively northwest and east of the map-area. Unit 3 is estimated to be about 1,500 feet thick. The contact with the overlying strata (unit 4) may be conformable but is poorly exposed.

Thick-bedded (5 feet), massive sandstones with minor interbedded grey siltstone comprise unit 3. The basal 100 feet contains several 2-foot-thick beds of carbonate-cemented, oncolitic quartz sandstone. These have unsupported, well-rounded, spherical

quartz grains (between 0.2 and 2 mm in diameter), and ellipsoidal oncolites or pisolites set in a recrystallized sparry calcite cement. The oncolites are commonly multiple, have two or three nuclei, and reach diameters of 5 mm. They are recrystallized to a sparry mosaic that has preserved their internal structure in most specimens. Most of the quartz grains are monocrystalline, but a few composite grains consisting of several equant crystals are found. The upper part of unit 3 consists of submature, feldspathic calcite-cemented orthoquartzites that contain more than 70 per cent quartz, ranging in size from 0.1 to 1.5 mm with an estimated mode of about 0.35 mm. Minor amounts of microcline, muscovite, and chert occur in addition to zircon and tourmaline. The rock is cemented by sparry calcite and minor limonite; the cement commonly replaces quartz grains along their boundaries.

The presence of oncolites with rounded quartz grains in the basal part of unit 3 suggests active marine conditions and prolonged abrasion in a warm littoral or neritic environment. The textural inversion that combines moderate rounding and poor sorting suggests mixed sources as does the occurrence of "metamorphic" polycrystalline quartz with chert. Unit 3 is pre-Ordovician and may therefore be Cambrian or Precambrian. It contains no fossils.

Map-unit 4

Unit 4 occurs in the northwest part of Tombstone area and extends southward to Little Twelve Mile River. The unit is recessive and poorly exposed. The best outcrops are on the ridge west of Chandindu River and on the west flank of Chert Mountain. Unit 4 is estimated to be about 1,500 feet thick on Chert Mountain; internal repetition by folding has thickened the unit in most places. It is overlain by volcanic rocks of unit 5, and in its upper part is interbedded with them.

Massive to thin-bedded, deep maroon and light green slate and argillite constitute unit 4. The rocks are very fine grained aggregates of chlorite and sericite. They contain minor interbeds of greenish chert and thin beds of hematitic, crypto-crystalline, banded limestone. Lenses of pebble-conglomerate like that of unit 1 are found locally and thin beds of siltstones are interbedded with the slates in the upper part of unit 4.

Unit 4 is pre-Ordovician; its close association with overlying volcanic rocks (unit 5) and Road River strata indicates rough contemporaneity of these units and suggests a possible Cambrian age.

Equivalent rocks that outcrop extensively southeast and north of the map-area were included by Green and Roddick (1962) in their Precambrian and/or Cambrian unit 3. Lithologically similar strata that may also be equivalents occur in Tay River, Sheldon Lake, and Nahanni map-areas (Roddick and Green, 1961a, b; Green and Roddick, 1961), and in Flat River area (Gabrielse, Roddick, and Blusson, 1965), where they have been assigned to the Proterozoic. Bostock (1947) considered similar rocks (his unit 9) in Mayo area to be Early Paleozoic. Unit 4 may be Proterozoic and/or Cambrian; lithologic correlation with similar rocks elsewhere supports a Proterozoic age and data from the map-area suggest a possible Cambrian age.

Cambrian? – Silurian?

Map-unit 5

Unit 5 includes various types of volcanic rocks that occur in the west part of the map-area. The unit is resistant and forms good exposures at a number of places. It overlies slates of unit 4 with apparent conformity. Locally, as on Chert Mountain, thin flows are intertongued with maroon and green slates of unit 4. Lenses of unit 5 also occur within the overlying rocks of the Road River Formation. The exposed thickness of unit 5 changes from outcrop to outcrop; as much as 2,000 feet occurs near the southwest part of Tombstone area, but near the north margin of the map-area only a few hundred feet are present.

Unit 5 consists of greenish grey weathering, poorly layered, andesitic to basaltic, holocrystalline, pyroclastic, and hyaline volcanic rocks with minor interbedded greenish shale and grey crystalline limestone. Fine- to medium-grained holocrystalline varieties with intersertal textures are most common. They contain about 50 per cent plagioclase (An₄₀) that occurs as partly altered, subhedral laths as much as 5 mm long. Plagioclase is unzoned and commonly shows Carlsbad-Albite twinning. Purplish brown augite constitutes about 25 per cent and occurs as euhedral, long prismatic crystals as much as 5 mm long. Ilmenite is ubiquitous and forms about 5 per cent of the rocks occurring as skeletal crystals reaching 1 or 2 mm across. Brown oxyhornblende and biotite are found in some thin sections. As much as 25 per cent of the rock comprises chlorite, which forms aggregates of intergrown flakes that commonly contain relict grains of biotite and lamprobolite. Calcite occurs throughout as cavity and fracture fillings.

Lapilli tuffs and volcanic breccias constitute the pyroclastic varieties of unit 5. They contain angular fragments of altered hyaline and fine-grained basaltic rocks as well as other rock fragments (commonly chert), in a fine-grained groundmass of volcanic debris, which is generally partly altered to celadonite? and cemented by calcite and chalcedonic quartz. Volcanic fragments that contain tiny plagioclase laths and calcite-filled amygdules set in a dark, chloritized groundmass predominate. Chert fragments are purple and partly recrystallized; they contain small euhedral crystals of quartz. Lapilli and breccia fragments (commonly an inch across) constitute about 50 per cent of the rock. The glassy rocks are dark green, generally partly altered to chlorite and celadonite? and contain abundant ellipsoidal chalcedony and calcite-filled amygdules.

No fossils have been found in rocks of unit 5, but contemporaneity of the volcanic rocks with overlying strata of the Road River Formation is suggested by their contact relations and by the presence of chert fragments in the volcanic rocks. North of Fireweed Creek, where unit 5 is interbedded with Road River strata, Middle Silurian fossils (Appendix I-A) occur in a thin limestone about 20 feet below a 50-foot flow of volcanic rocks. On Chert Mountain, Ordovician fossils (Appendix I-A) in the Road River Formation occur about 100 feet above volcanic rocks of unit 5. On this basis unit 5 is tentatively assigned an Ordovician to Silurian age; parts may be as old as Cambrian. Lithological equivalents of unit 5 occur north and west of the map-area (Green and Roddick, 1962, map-unit 4, p. 5).

Map-unit 6

Unit 6 consists of brownish weathering, thin-bedded siltstones with minor interbedded greenish shale and chert. The siltstones contain 50 per cent angular silt to fine sand-sized quartz grains and about 10 per cent medium to coarse sand-sized monocrystalline quartz particles. The larger quartz grains are rounded and show quartz overgrowths of an earlier generation indicating that they were derived from a sedimentary source. The rocks contain about 15 per cent intergranular chlorite and limonite and are cemented by calcite that replaces grains along their boundaries.

No fossils were found in unit 6 and its age is not known. Its relation to Road River strata indicates a pre-Middle? Ordovician age and rough contemporaneity with unit 5 is suggested by its association with that unit. Unit 6 may therefore be Cambrian. Lithological equivalents of unit 6 may occur in Green's and Roddick's (1962) unit 3 of Precambrian and/or Cambrian age.

Road River Formation (map-unit 7)

Jackson and Lenz (1962, p. 32) applied the name Road River to a formation of Ordovician and Silurian shale and chert at a type locality in the Richardson Mountains in northern Yukon Territory. Lithologically similar rocks of the same age occur in the west part of Tombstone area. Good outcrops of the lower part of this formation are present on Chert Mountain and the upper part is best exposed north of Tombstone River; elsewhere in the map-area exposures of the formation are generally poor.

The Road River Formation is represented by about 500 feet of chert and argillaceous rocks in Tombstone area. The formation overlies unit 6 on Chert Mountain, but elsewhere units 4 and 5 occur immediately below it. The nature of the lower contact of the Road River Formation is unknown. Volcanic rocks of unit 5 are interbedded with the formation locally.

In Tombstone area the Road River Formation consists of a lower 200-foot member containing chert with interbedded black slate and an upper, 300-foot member made up largely of argillite. The chert is generally thick-bedded (six inches to several feet) and poorly laminated, ranging in colour from grey and black to pale green. It contains as much as 20 per cent ellipsoidal spherulites of chalcedonic quartz (about 0.15 mm across) that probably represent recrystallized radiolarian tests. The cherts of the formation are carbonaceous and argillaceous. Small rhombs of dolomite occur locally and pyrite is found throughout in aggregates of small anhedral grains. Regular veinlets of white chalcedonic quartz are common and are perpendicular to bedding in the chert. Chert breccias, consisting of angular fragments of chert several inches across are present locally.

The argillites in the upper part of the Road River Formation are greenish grey, fine-grained rocks that are locally calcareous and somewhat silty. They contain several thin interbeds of fetid, black, carbonaceous crystalline limestone that show a few relict skeletal structures.

Two fossil collections from the Road River Formation in Tombstone area were identified by D.H. Collins and B.S. Norford of the Geological Survey of Canada (Appendix I-A). One collection is probably Middle or Late Ordovician and the other may be Middle Silurian. On this evidence and from data for correlated rocks, the formation is assigned to the Ordovician and Silurian Systems.

The Road River Formation of Tombstone area is equivalent to Green's and Roddick's (1962) map-unit 9, which occurs north and south of the map-area. Its lithological and faunal characteristics allow correlation with Road River strata in the northern Yukon and east central Alaska, where the ages are established as Ordovician and Silurian. In the northern Yukon the Road River Formation has been investigated by Jackson and Lenz (1962), who established its faunal succession, and by Norford (1964), who studied its distribution and variations over a large area. The thickness of the formation varies between 500 and 2,000 feet in northern Ogilvie Mountains. Churkin and Brabb (1965) investigated the Road River Formation in east central Alaska. In Alaska and Ogilvie Mountains, as in Tombstone area, the Road River Formation is divisible into a lower cherty member and an upper argillaceous or shaly member.

Upper Division

Permian

Tahkandit Formation (map-unit 8)

The name Tahkandit Formation was first used by Mertie (1930b, pp. 122-123) who applied it to a 527-foot-thick succession of Permian conglomerates and limestones, at a locality in east central Alaska near the mouth of Nation River. Lithologically similar strata of the same age, herein correlated with the Tahkandit Formation and to which the same name is applied, occupy a narrow, northward-trending belt in the eastern part of Tombstone area. They are best exposed between Tombstone River and Fireweed Creek and are resistant to weathering, forming prominent bluffs. The maximum thickness of the Tahkandit Formation in Tombstone area is about 100 feet, but south of Tombstone River the formation is locally only 20 feet thick. The Tahkandit Formation overlies the Road River Formation unconformably. On the slope south of Fireweed Creek, where the unconformity is best exposed, the angle between the beds of the overlying and underlying rocks is one or two degrees. Lime-cemented chert-pebble conglomerates that constitute the basal part of the Tahkandit Formation immediately overlie the unconformity.

The Tahkandit Formation consists of crystalline limestone and interbedded chert and chert-pebble conglomerate. It is divided into three parts: a lower limestone with abundant detrital chert, a middle limestone with interbedded chert and an upper member of massive thick-bedded limestone.

The lower part of the formation weathers reddish brown, is about 20 feet thick, and contains several 6-inch beds of calcite-cemented chert-pebble conglomerate separated by thin beds of crystalline limestone with little detrital chert. Chert pebbles are rounded to angular and commonly half an inch across; some fragments are 6 inches long.

In the middle part of the formation (about 20 feet), interbeds and lenses of black chert less than a foot thick are prominent between beds of grey crystalline limestone. Chert beds constitute somewhat more than half of this part of the Tahkandit Formation, but detrital chert is lacking.

Massive, thick-bedded, crystalline limestone forms much of the upper 50 feet of the Tahkandit Formation. This weathers light grey to white and contains a few thin beds and lenses of black chert.

The limestones of the Tahkandit Formation are biosparrudites (Folk, 1964) containing fragments of crinoids, brachiopods, bryozoans, and possibly echinoderms. The fossil fragments are as much as 5 mm across; they are completely or partly recrystallized to sparry calcite and cemented by optically continuous, clear calcite overgrowths, but many grains retain relict skeletal structures. Locally abundant chert pebbles and rare sand-sized quartz grains make up the remaining detrital fragments. Pyrobitumen is a common minor constituent. The limestones are silicified, dolomitized, and veined by calcite. In general less than 5 per cent of the rock is replaced by dolomite, but in places the entire rock consists of an interlocking mosaic of dolomite rhombs. Chert pebbles and brachiopods are locally replaced by chalcedonic quartz.

The limestones of the Tahkandit Formation were evidently deposited under marine conditions in an active, warm, well-aerated, near-shore environment. Chert fragments that occur in the basal part of the formation were probably derived from the underlying Road River Formation.

Six fossil collections from the Tahkandit Formation at different localities in Tombstone area were identified by E.W. Bamber (Appendix I-B). On the basis of these fossils and others collected in the region north of the map-area, the Tahkandit Formation is dated as Middle Permian, probably Leonardian or Wordian.

The lithological and faunal similarities of the formation allow correlation with the Tahkandit Formation in Alaska (Mertie, 1930a) and northern Ogilvie Mountains (Douglas, Norris, Thorsteinsson, and Tozer, 1963). The Tahkandit Formation is also correlated with the upper part of Green's and Roddick's (1962, p. 11) map-unit 16. Poole (1965) reported Permian rocks in Mayo district in the same stratigraphic position as in Tombstone area, and it may be that a narrow, and perhaps discontinuous, belt of these rocks extends between these two areas.

Triassic

Map-units 9 and 10

Two units of Triassic rocks (9 and 10) outcrop in Tombstone area. Although they are almost certainly correlatives, unit 10 being the thrust-faulted repetition of unit 9, their equivalence is not proven. Unit 9 outcrops only in the vicinity of the divide between Tombstone and Little Twelve Mile Rivers, east of Chert Mountain. Unit 10 occurs in a narrow belt parallel with and close to the southeast margin of the map-area, and is best exposed on Mount Robert Service. Exposures of unit 9 are poor and its thickness could not be measured; it is estimated to be about 200 feet. Unit 9 overlies the Tahkandit Formation and although the contact is not exposed relations between the two formations are thought to be disconformable because only the lowest 20 feet of the Tahkandit Formation occurs beneath unit 9 on Chert Mountain. The upper contact of unit 9, with the overlying slates and shales of unit 11, may also be disconformable, because Triassic strata occur between the Tahkandit Formation and unit 11 at only one locality.

On Mount Robert Service, unit 10, about 100 feet thick, forms the hanging-wall of the Robert Service thrust. At no place are the strata that underlie unit 10 exposed above this thrust and the relations at the lower contact of unit 10 are therefore unknown. The fetid, shaly limestone of the formation is overlain by slate and shale of unit 12. The probable Upper Triassic age of unit 10 and the presence in unit 11 of Middle Jurassic fossils only 300 feet above unit 10 suggest that the contact between these two formations may be disconformable (Appendix I-C).

Unit 9 includes thin-bedded siltstone and shale and dark grey, impure limestone. The siltstone and shale, which occur in its lower part, account for somewhat less than half the formation's thickness. They are dark grey and brownish rocks that contain as much as 50 per cent angular, medium to coarse, silt-sized quartz, chert, and plagioclase grains, as well as a small proportion of altered mafic minerals in a carbonaceous and chloritic groundmass. The detrital constituents of these greywacke-like siltstones were probably derived from the underlying sedimentary and volcanic strata. Large, brown weathering, calcareous concretions occur locally in the siltstones. The limestones, which constitute the upper part of unit 9 are light grey weathering, impure, carbonaceous, fetid, partly recrystallized biomicritic rocks. They contain abundant pelecypods that locally constitute as much as half the rock. The fossil shells are closely compressed and give the rock a platy fracture. The limestones contain minor amounts of angular, silt-sized quartz grains.

Dark grey, fetid limestones like those that constitute the upper part of unit 9 also predominate in unit 10. They locally contain ellipsoidal intraclasts of sparry calcite, small pebbles of chert, and a few angular quartz grains, but generally they are platy, carbonaceous, partly recrystallized, micritic limestones that contain abundant pelecypod fragments. The lithology and faunal assemblages of units 9 and 10 reflect conditions of quiet marine sedimentation at moderate depth.

On the basis of three fossil collections identified by E.T. Tozer of the Geological Survey of Canada (Appendix I-C), unit 9 is confidently assigned to the Triassic. The fossils range in age from probable Smithian to Upper Norian (mid-Lower Triassic to uppermost Upper Triassic) and as there is no stratigraphic evidence of breaks in this succession, the unit could represent a fairly complete succession of the Triassic.

Unfortunately, well-preserved fossils were not discovered in unit 10 although pelecypod fragments are found at many places in this formation. Concerning these fragments, Tozer reported: "No determinable fossils are present. There are fragments of ribbed shells, possibly *Monotis*. The age cannot be determined but is possibly Upper Triassic." The fossil evidence, lithological similarity, and homotaxial stratigraphic relations of units 9 and 10 strongly suggest that they are equivalents.

Units 9 and 10 are probably equivalents of similar limestones, shales, and siltstones that occur in east central Alaska (Mertie, 1937, p. 154) and that range in age from Middle to Late Triassic (Brabb and Churkin, 1964). The Triassic rocks of Tombstone area are homotaxial with lithologically similar rocks that occur in a few isolated localities in northern Yukon Territory (Fig. 7). In most of these localities only Upper Triassic strata are recognized (Norris, Price, and Mountjoy, 1963; Mountjoy, 1967a).

Upper Triassic rocks in the vicinity of Kathleen Lake (Fig. 7) that are correlated with unit 9 have been briefly described by Green and Roddick (1962, p. 12).

"KENO HILL QUARTZITE", YUKON TERRITORY

Exposures there are not complete, but these rocks overlie "Keno Hill Quartzite", i.e., unit 13, and are reported to be 1,000 to 4,000 feet thick. Such relations are incompatible with the stratigraphic succession in Tombstone area and suggest that at Kathleen Lake the Triassic rocks may be thrust over the "Keno Hill Quartzite". The reported excessive thickness of strata at Kathleen Lake also suggests that the Triassic rocks there may be repeated by folding. Green and Roddick have also mapped Upper Triassic rocks (their map-unit 18) in the vicinity of Monster River (Fig. 7).

The occurrence of Triassic rocks with other Mesozoic strata at two widely separated localities along the Keno Hill - Tombstone River belt, i.e., Kathleen Lake and Tombstone area, implies that these rocks may occur elsewhere along the belt.

Jurassic

Map-units 11 and 12

The Jurassic rocks of Tombstone area have been assigned to two separate formations (units 11 and 12) that are herein considered structurally repeated correlatives, although their equivalence is not proven. Unit 11 extends in a belt from near the southwest corner of the map-area to its northern margin, and has been traced beyond the area to Keno and Galena Hills in Mayo district (Green and Roddick, 1962), where it is informally known as the "Lower Schist". The unit is best exposed north of Little Twelve Mile River and along the northern margin of the map-area. It weathers recessive and forms poor outcrops that are commonly covered by scree. Unit 11 is estimated to be 1,500 feet thick.

Unit 12, the probable equivalent of unit 11, occupies a narrow belt along the southeast margin of Tombstone area, where it is thrust, with unit 10, above younger strata. Unit 12 is truncated by the North Fork thrust in the northeast and southwest parts of Tombstone area. The best exposures of unit 12 are in the vicinity of Mount Robert Service, where its maximum thickness below the North Fork thrust is about 1,000 feet.

The contact between unit 11 and the overlying rocks (unit 13) is a surface of décollement and the stratigraphic relations at this contact are therefore obscure. This contact may have been conformable prior to structural modification, because the relations between presumable correlatives of units 11 and 13 in northern Yukon Territory and east central Alaska are conformable (Table II). The stratigraphic succession above unit 12 is not known.

Most of unit 11 consists of black slate and phyllitic slate with lesser amounts of interbedded, brownish, calcareous siltstone. The lower part of the formation locally contains several lenses of pebble-conglomerate as much as 15 feet thick, and thin beds of greywacke are interbedded with the slates in the middle part of the formation. Near the top of unit 11 the slates are brownish, and pale green siliceous phyllite occurs locally in thin beds. Near Tombstone and Brenner stocks the rocks of unit 11 are recrystallized to schists and hornfelses (*see* Contact Metamorphic Effects of units 16 and 18).

The black slates are carbonaceous, fissile, thin bedded, and commonly silty, and contain as much as 20 per cent quartz. Pyrite occurs throughout in tiny euhedral cubes. Conglomerates contain about 70 per cent rounded pebbles (0.5 to 2 mm across)

of chert, argillaceous chert, siltstone, and volcanic rock in a carbonaceous and chloritic groundmass that contains silt-sized quartz grains. The conglomerates are clearly of local derivation; their volcanic siltstone and chert pebbles probably came from units 5 and 6 and the Road River Formation (unit 7), respectively.

Immature feldspathic subgreywackes (Folk, 1964) form about 10 per cent of the thickness of unit 11. They contain quartz (30 per cent), chert (15 per cent), and plagioclase (10 per cent) grains as well as volcanic and shaly rock fragments (15 per cent) in a chloritic and carbonaceous groundmass. Glauconite is a trace constituent and calcite is a minor cementing agent that occurs throughout. The greywackes are poorly sorted; the grains are angular and range in size from coarse sand to silt.

Unit 12, like unit 11, consists mainly of thin-bedded, black, graphitic slate and phyllitic slate. The unit contains minor interbedded brown siltstone, but greywackes are almost absent and no pebble-conglomerates are found. The lowest 100 feet of unit 12 consists of greenish brown argillite and siliceous argillite. Dark grey, spherical ironstone concretions as much as 6 inches in diameter are common between 200 and 300 feet above the base of unit 11; they rarely contain fossils.

The lateral equivalent of unit 11 in Mayo district, i.e., "Lower Schist", has long been regarded as Precambrian and included in the Yukon Group. Only recently was it recognized that the formation is younger. Green and Roddick (1962, p. 10) first showed that the "Lower Schist" (their unit 14) does not belong to the Precambrian and they suggested a Devonian-Carboniferous age for the formation. Stratigraphic evidence from Tombstone area indicates a Jurassic age for the "Lower Schist".

Fossils that range in age from Bathonian to Oxfordian (Middle Jurassic to the lowest part of Upper Jurassic) were collected from unit 12 and identified by H. Frebold (Appendix I-D). Because the fossils occur about 300 feet above the base of unit 12, which is here about 1,000 feet thick, the unit may range through the Middle and Upper Jurassic Series.

No fossils have been found in unit 11, but the formation overlies Upper Triassic strata (unit 9) and is itself overlain by unit 13, of probable Lower Cretaceous age. Unit 11 is therefore also assigned to the Jurassic and because it occupies the same stratigraphic position and is lithologically similar to unit 12 the two are considered equivalents.

Rocks of units 11 and 12 probably correlate with the areally extensive Jurassic shales of east central Alaska and northern Yukon Territory. Unnamed Jurassic shales that occur in Charley River Quadrangle, Alaska (Brabb and Churkin, 1964), are lithologically similar to, and homotaxial with, strata of units 11 and 12 (Table II, Figs. 7 and 9). Jurassic strata in the northern Yukon (Jeletzky, 1960, 1961a, 1967; E.W. Mountjoy, personal communication, 1965) also show strong lithologic, stratigraphic, and faunal similarities to units 11 and 12 (Table II, Figs. 7 and 9).

Lower Cretaceous

Map-units 13, 14, and 15

Three formations of sedimentary rocks, herein assigned to the Lower Cretaceous, outcrop extensively in Tombstone area. The oldest of these, unit 13, forms the "backbone" of Keno Hill-Tombstone River belt and has been traced beyond the map-area to Keno and Galena Hills. The two younger formations, units 14 and 15,

extend eastward beyond Tombstone area some 20 miles, but are not known to occur in Mayo district. They were previously included by Green and Roddick (1962, pp. 12, 13), in their Jurassic unit 19. The present study reveals that Green's and Roddick's unit 19 contains probable Lower Cretaceous rocks (units 14 and 15) and "overthrust" Triassic and Jurassic strata (units 10 and 12). The three Lower Cretaceous units of Tombstone area have not been formally named, but unit 13 is known variously and informally as the "Keno Hill Quartzite" and the "Central Quartzite Formation" or simply the "Quartzite" in Mayo district.

Map-unit 13

Distribution, Thickness, and Contact Relations

Unit 13 underlies a large part of central and eastern Tombstone area, and is generally well exposed because it is resistant. Within the map-area the unit trends northeastward. Because marker horizons have not previously been recognized in unit 13 and because the unit is complexly deformed, its thickness has long been in doubt. The unit is repeated by thrust faults and folds and its resultant apparent thickness in the central part of Tombstone area is 50,000 feet. Recognition of marker horizons within the unit has provided an understanding of its internal structure and allows measurement of its thickness. The true thickness of unit 13, combined from two partial measured sections, is about 1,800 feet. The diabase sill (unit 16) that intrudes unit 13 throughout Tombstone area thickens the formation by between 400 and 800 feet. The thickness of unit 13 above unit 11 and below unit 13a (Fig. 5), and the thickness above unit 13a and below unit 14 are shown in the measured section (*see* Appendix III). The thickness of unit 13a was scaled from cross-sections; internal, small-scale repetition within that member does not allow accurate measurement. The structure where sections 3 and 4 were measured is shown in cross-sections QR and TU (*see* Map 1248A). Part of unit 13 may be missing immediately above the décollement contact with unit 11. Variations in the thickness of unit 13 have not been investigated.

The upper contact of unit 13 is sharp and may be conformable. Relations at this contact are obscured by shearing, and bedding in the overlying rocks of unit 14 has been destroyed by development of cleavage.

Stratigraphy and Lithology

Remarkably uniform, massive, grey, thick-bedded and fine-grained submature orthoquartzites constitute much of unit 13 (Fig. 5, Appendix III). The formation contains several horizons of black slate, the thickest of which, unit 13a, forms a useful marker horizon. Unit 13 also includes a 3-foot cherty slate member near its base and a 50-foot sandy limestone (unit 13b) in its upper part. An impure shaly limestone occurs locally about 100 feet below its upper contact.

The massive orthoquartzites of unit 13 range in colour from dark blue-grey through medium and brownish grey to pale green. Blue-grey orthoquartzites occur only in the lowest 500 feet of the formation and brownish types are found mainly in its middle and upper parts. Weathering produces no marked colour change, but exposed surfaces are commonly covered with green lichen.

Bedding thickness ranges from 6 inches to more than 20 feet; 5- to 10-foot beds are common (Fig. 3). Bedding surfaces are generally flat or gently warped and sole

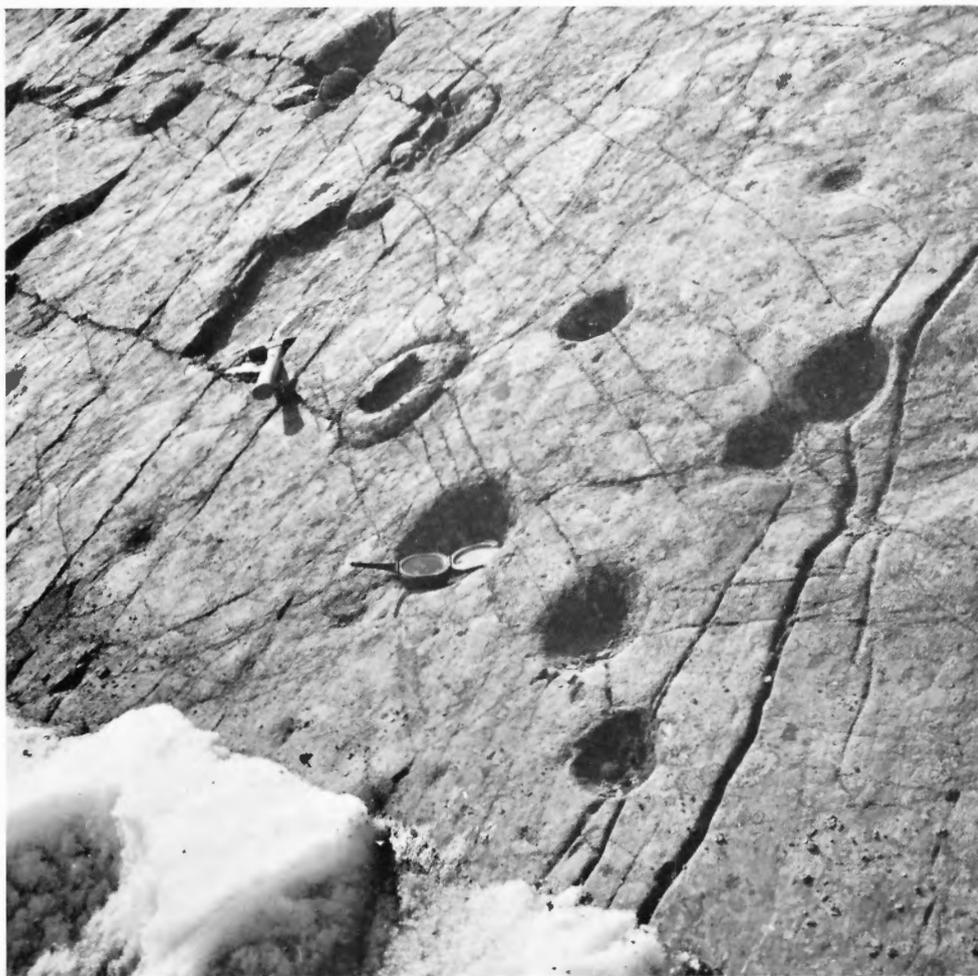
markings, other than burrows, are rare. Thick beds are separated by laminae of black slate that are less than half an inch thick. Lamination, crossbedding, slump structures, and ripple-marks are rare in the orthoquartzites. Ellipsoidal concretions as much as a foot across occur locally in the orthoquartzites (Fig. 4). They stand out only where they are weathered and except for a slightly higher limonite content they are identical to the host rocks. The massive orthoquartzites break into large angular blocks more than a foot across.

The orthoquartzites of unit 13 consist of moderately well sorted, unimodal fine sands, whose grain-size distribution is nearly symmetrical and leptokurtic. Grain-size ranges from coarse silt to coarse sand, but there is no evidence of systematic lateral or vertical grain-size changes. Conolly (1965) found that in any thin section of fine- to medium-grained orthoquartzite, the average of thirty to fifty random grain-size



D.J. T-K. 1-7-64

FIGURE 3. Vertical beds of blocky weathering massive orthoquartzite (unit 13) on Mount McIntyre. The bed in the centre is 5 feet thick.



D.J. T-K. 3-1-65

FIGURE 4. Flat bedding surface of massive orthoquartzite (unit 13) with round weathering holes left by limonite concretions in the south central part of Tombstone area. Concretions occur rarely in the orthoquartzite.

measurements gives a measure of the modal grain-size, accurate to ± 0.02 mm. Accordingly thirty grain diameters were measured and averaged in each of eighty-three thin sections of orthoquartzite of unit 13. The largest and smallest grain diameters in each thin section were also measured. In addition the 16 and 84 percentile grain-sizes were estimated in each thin section by measuring the grain-sizes that have one-sixth of the grains smaller and larger than themselves (Folk, 1964). The thin sections are of specimens from all parts of the map-area and represent all stratigraphic levels within unit 13.

The following ranges in values of the measurements were obtained:

smallest grain diameter range .03 to .05 mm (5.0 to 4.3ϕ)

84 percentile grain-size range	.08 to .11 mm (3.6 to 3.2 ϕ)
modal grain-size range	.12 to .18 mm (3.1 to 2.6 ϕ)
16 percentile grain-size range	.18 to .24 mm (2.6 to 2.1 ϕ)
largest grain diameter range	.55 to .80 mm (0.8 to 0.3 ϕ)

The small range of each value compared to the overall grain-size range indicates that the orthoquartzites of unit 13 are homogeneous, texturally uniform rocks, and because the range in each value is small, it is possible to give a meaningful average grain-size distribution for these rocks. Cumulative curves for the orthoquartzites based on the above measurements are plotted on Figure 6, and the approximate range in grain-size is shown by two heavy lines; an estimated average curve is shown between them. The approximate curves based on the data given above were tested by measuring 500 grain diameters in 5 of the 83 thin sections and constructing cumulative curves from these measurements. Figure 6 shows three of these cumulative curves superposed on the approximate curves; it is apparent that the fit is good and that the approximate values are reliable. The following distribution parameters are derived from the average curve of Figure 6 (Folk, 1964).

Graphic mean

$$\frac{\phi 16 + \phi 50 + \phi 84}{3} = 2.8\phi = .15 \text{ mm}$$

Graphic standard deviation

$$\frac{\phi 84 - \phi 16}{2} = .55\phi$$

Graphic skewness

$$\frac{\phi 16 + \phi 84 - 2\phi 50}{\phi 84 - \phi 16} = +.1$$

Graphic kurtosis

$$\frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)} = 1.3$$

Quartz constitutes 95 per cent or more of the orthoquartzites of unit 13 and forms monocrystalline grains that generally show weakly undulose or uniform extinction. The quartz contains a few vacuoles and rare microlites. The degree of rounding of quartz grains varies with particle size: grains larger than about 0.3 mm are subrounded to rounded, whereas smaller grains are angular to subangular. Sphericity is moderate for all grain-sizes, but there is a tendency to higher sphericity in larger grain-sizes. No preferred form orientation of quartz particles is apparent.

Chert grains form 1 to 2 per cent of most specimens of orthoquartzite; they are generally somewhat larger than the modal grain-size of quartz and are commonly rounded. Tourmaline (schorlite) and zircon are ubiquitous trace constituents that occur as small, well-rounded, nearly spherical grains. Muscovite is found as "ragged" flakes in a few thin sections of orthoquartzite.

Small fragments of black shale occur locally in the orthoquartzites of unit 13, in some places making up about 5 per cent by volume. The fragments are tabular and angular and commonly 1 or 2 mm long; they are thought to have been derived from the interbedded slates of unit 13 and probably represent products of penecontemporaneous subaqueous erosion.

The detrital grains of the orthoquartzites are cemented by optically continuous, thin quartz overgrowths that have generally preserved the original particle outline. Quartz overgrowths form along part of the grain boundaries of most grains, but completely enveloped grains are rare and overgrowths larger than grains were not seen. The volume of quartz overgrowths constitutes about 5 per cent of the rock. Quartz overgrowths merge with each other, and with surrounding grains along indistinct boundaries. Grains in direct contact have straight or broadly cusped, interpenetrating boundaries that are commonly outlined by thin films of carbonaceous material. Sutured grain contacts are rare.

Intergranular chlorite, graphite, and limonite occur in small proportions in many thin sections of orthoquartzite. Chlorite is found in knots, or aggregates, of tiny flakes and is apparently authigenic. There are small amounts of interstitial calcite in a few thin sections. Stylolites of slight relief and small lateral persistence are common; they are generally parallel with bedding and are outlined by thin films of carbonaceous and limonitic material.

The nature and proportion of intergranular material to a large extent determines the colour of the orthoquartzites. Where these rocks are dark grey the proportion of intergranular carbonaceous matter is higher than where they are light grey. The brownish colour of some orthoquartzites reflects a predominance of limonite in the interstitial material. The orthoquartzites are bleached white where they are in contact with intrusive rocks and in these bleached quartzites the amount of intergranular matter is negligible.

Narrow, regular, and irregular veinlets of white quartz cut the orthoquartzites of unit 13 virtually everywhere and form about 1 per cent of the volume of these rocks. Most are perpendicular to bedding planes, but veinlets parallel with bedding, or at intermediate angles to it, also occur. In many veinlets the quartz shows palisade texture of intergrown prismatic crystals perpendicular to veinlet walls. Other veinlets contain mosaics of equant intergrown crystals. The quartz of both types of veinlets generally shows undulose extinction like that of the orthoquartzites, indicating that they formed prior to deformation. Much of the vein quartz is therefore thought to represent remobilized and recrystallized quartz, produced perhaps by pressure solution of the detrital quartz in the orthoquartzites during diagenesis.

The siliceous slate member near the base of unit 13 (Fig. 5) is made up of interbedded carbonaceous black slate and argillaceous chert containing numerous ellipsoidal spherulites of chalcedonic quartz about 0.2 mm across, that probably represent recrystallized radiolarian tests. Sedimentary manganese-bearing beds as much as several inches thick are interbedded with the siliceous slate at one locality. The manganese beds contain spherical nodules of rhodochrosite (50 per cent), which are between 1 mm and 5 mm across, in a fine-grained groundmass of chlorite that is partly replaced by dolomite.

Black slates are interbedded with the orthoquartzites of unit 13 (Fig. 5) and account for about one quarter of the thickness of the formation. The slates are fissile, carbonaceous rocks that contain about 10 per cent silt-sized quartz. Brownish, thinly laminated, calcareous siltstones are locally interbedded with the slates. The main slate member, unit 13a, has been recognized in most parts of the map-area.

Unit 13b (Fig. 5) consists of thick-bedded, buff-weathering, sandy limestone and minor interbedded brownish slate. The limestone contains between 30 and 50 per cent quartz and 10 per cent chert grains that "float unsupported" in a sparry calcite cement. Most quartz grains are monocrystalline, but some granule-sized quartz particles are composite and show a "stretched metamorphic texture" (Krynine, 1946). Tourmaline and zircon are minor constituents. Fragments of black shale and crystalline limestone (the latter with relict skeletal structures) are rare. The detrital fraction in the limestone is predominantly a fine sand, but granules as much as 3 mm long are found. Particle sphericity is moderate and rounding shows the same relationship to grain-size as is found in the orthoquartzites. The calcite cement is recrystallized, carbonaceous, and limonitic; it retains scarce, relict, indeterminate organic structures and replaces chert and quartz particles along grain boundaries.

A black, fetid, shaly limestone that locally contains indeterminate gastropods is found in places near the top of unit 13 interbedded with black slates (Fig. 5). The limestone is highly carbonaceous and strongly recrystallized; it has a relict pelleted texture and is cut by numerous irregular veinlets of white sparry calcite.

Age and Correlation

Rocks that are equivalents of unit 13 (i.e., the "Keno Hill Quartzite") have been studied in detail at the eastern extremity of the Keno Hill - Tombstone River belt in Mayo district. There these rocks have long been regarded as probably Precambrian (Keele, 1904, p. 131; 1906, p. 167; 1910, p. 302; Cairnes, 1915, p. 383; 1916, p. 429; Cockfield, 1918a, p. 463; 1919a, p. 483; 1921a, p. 496; 1923, p. 510; 1924, p. 531; Stockwell, 1926, p. 546; Bostock, 1943a, 1947, 1948b; Kindle, 1955; McTaggart, 1950, 1960; Green, 1957, 1958). Cockfield (1918b, p. 478) studied rocks of unit 13 in Tombstone area and reported a probable Precambrian age for these strata, correlating them tentatively with the Tindir Group. Green and Roddick (1962, p. 12), first assigned the "Keno Hill Quartzite" (i.e., their map-unit 17) to the Mesozoic and implied an early Triassic age for the formation. Data from Tombstone area strongly suggest that the "Keno Hill Quartzite" (i.e., unit 13) is Lower Cretaceous.

The long-supported Precambrian assignment of the "Keno Hill Quartzite" appears to be the result of a number of factors. In Mayo district metamorphism and deformation have destroyed original texture, marker horizons (few in any event), and fossil evidence so that the interrelationships and age of the lithological units are entirely obscure. In addition exposures are poor. The gross similarity of the metamorphic strata of Mayo area to the presumably Precambrian rocks of Klondike district (south of Dawson) led to their correlation.

No diagnostic fossils have so far been found in unit 13 or in the two overlying formations (units 14 and 15), also assigned to the Lower Cretaceous. Green and Roddick (1962) reported two collections of poorly preserved plant fossils from unit 13 (one of these was from Tombstone area) that indicate a late Paleozoic or Mesozoic age. Poorly preserved plant microfossils from the upper part of unit 13 also indicate a post-Silurian age. Poorly preserved gastropods, of which no identification could be made, were collected from the unit during the present investigation. In addition to these, a number of trace fossils or "problematica" were found in quartzites and shales in the lower and middle parts of unit 13 (Appendix I-E). The limited fossil evidence does not allow an age assignment, but it indicates a late Paleozoic or Mesozoic age.

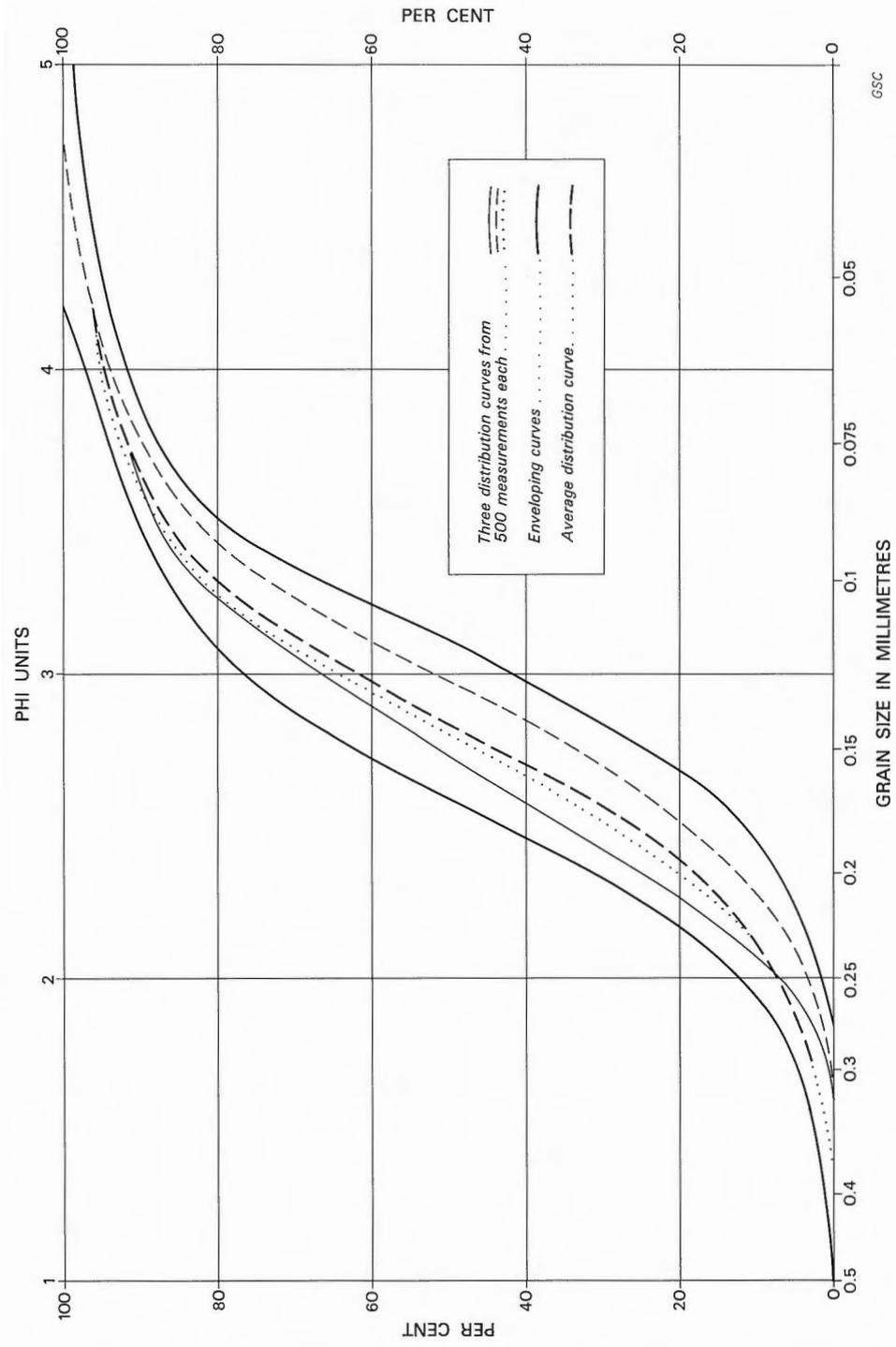


FIGURE 6. Grain-size distribution of orthoquartzites of unit 13.

Unit 13 overlies strata of unit 11 (Fig. 8) that are post-Triassic and probably Jurassic and is intruded by acid igneous rocks (unit 18) of probable mid-Cretaceous age. The unit is pre-late Cretaceous, because the lithology of Upper Cretaceous arkosic rocks, 60 miles northwest (Monster River), and 20 miles southwest of the area (Fig. 7) precludes their equivalence. An early Cretaceous age for unit 13 is therefore indicated and is supported by regional correlation with lithologically and stratigraphically similar strata of the same age (Figs. 7 and 9, Table II).

Unit 13 is probably the time equivalent of Member A of the Kandik Formation in east central Alaska (Brabb and Churkin, 1964) (Table II, Figs. 7 and 9). Member A is lithologically similar¹ to rocks of unit 13 and occupies the same stratigraphic position as unit 13. Member A of the Kandik Formation has been assigned to the Valanginian (early Lower Cretaceous) on paleontological evidence (it contains *Buchia sublaevis*; E.E. Brabb, personal communication, 1965). Unit 13 is probably also equivalent to the Lower Cretaceous orthoquartzites of Keele Range and Babbage River (E.W. Mountjoy, personal communication, 1965), and to the Valanginian and Hauterivian Lower Sandstone and Coal-Bearing (sandstone) Divisions of Richardson Mountains that have been investigated by Jeletzky (1958, 1960, 1961). A transition from marine to non-marine conditions between these two divisions may correspond to a similar transition in the upper part of unit 13 (Table II).

On stratigraphic data from Tombstone area, and from the age relationships of lithologically similar strata at the same stratigraphic position elsewhere, unit 13 is assigned to the Lower Cretaceous. The quartzites and sandstones of northern Yukon Territory and adjoining Alaska are Valanginian, but until better fossil evidence is available such close dating in Tombstone area is not justified.

Provenance and History

Regional data suggest that unit 13, and its probable equivalents in the northern Yukon, are multi-cycle reworked sandstones, derived from late Paleozoic sedimentary rocks in the Ogilvie and Richardson Mountains. The Lower Cretaceous orthoquartzites and sandstones of the Keno Hill - Tombstone River belt and the northern Yukon lie along two sides of a highland area that is thought to have existed throughout Mesozoic times (now the Ogilvie, Wernecke, and Richardson Mountains) (Fig. 7). Limits of deposition of the sandstones can be approximated from their present distribution. Figure 10, a generalized map, shows the southeastern border of deposition of the Lower Cretaceous sandstones in northern Yukon Territory and the northern depositional limit of the "Keno Hill Quartzite". The map is as accurate as the present regional data allow but it does not take into account the considerable structural readjustments that have occurred. The approximate depositional distribution (Fig. 10) of the two belts of Lower Cretaceous sandstones suggests they were derived from the highland, or positive, area between them (or perhaps from an area farther east).

The Upper Devonian Imperial Formation and unnamed Carboniferous and Permian sandstones are the only volumetrically important sandstone units that underlie the possible highland source area (Martin, 1959; Norris, Price, and Mountjoy, 1963; Douglas, Norris, Thorsteinsson, and Tozer, 1963), and if the Lower Cretaceous

¹The writer briefly studied the Kandik Formation in the field. Member A is made up of moderately sorted orthoquartzites that differ from those of unit 13 only in their somewhat larger overall grain-size (their mode lies between .15 and .20 mm as estimated from 5 thin sections).

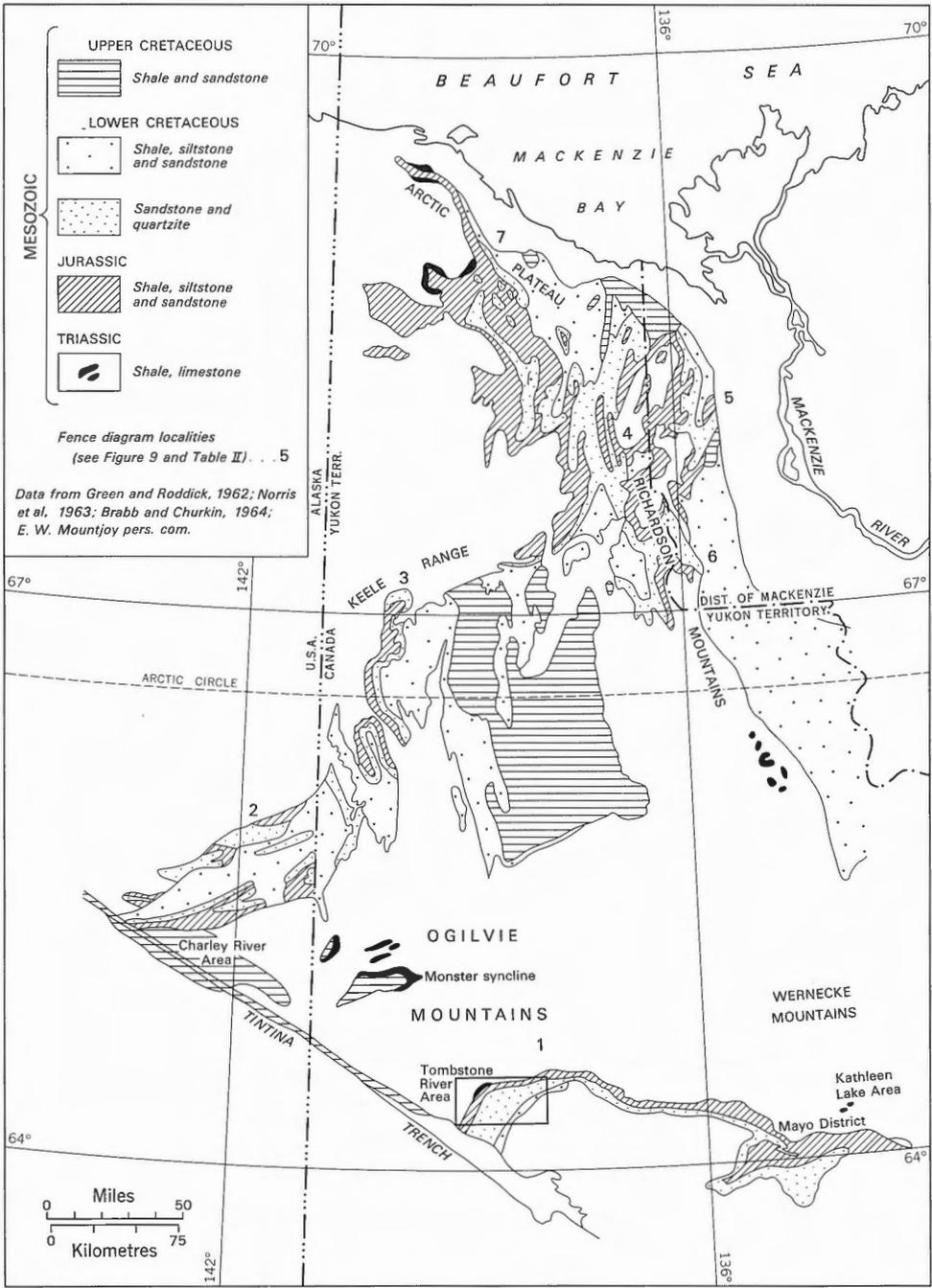


FIGURE 7. Distribution of Mesozoic rocks in northern Yukon Territory and east central Alaska.

TABLE II

Correlation Chart of Jurassic and Lower Cretaceous Formations in Northern Yukon and East Central Alaska (thicknesses in feet)

SERIES	Standard Stages	1		2		3				
		Tombstone Area (this report)		Charley River Alaska (Brabb and Churkin)		Keele Range (E.W. Mountjoy)		Porcupine River Area (Jeletzky, 1962)		
LOWER CRETACEOUS	NEOCOMIAN	Aptian		Member C Kandik Fm.						
		Barremian	† Unit 15		Member B Kandik Fm.		Mudstone with minor siltstone and sandstone			
				?	?					
		Hauterivian	?	+2000				?	4200	Erosional gap
				Unit 14	500		5000			
				?						
		Valanginian	*	† Unit 13	† Member A Kandik Fm.	±1000	†	Sandstone with lesser siltstone and shale		
				?	1700			3700		
		Berriasian								
	JURASSIC	UPPER	Portlandian			Unnamed		Shale and siltstone with minor sandstone		
Kimmeridgian			† Units 11 and 12		Shale and argillite, minor quartzite		3000	† Sandstone		
Oxfordian									2400	
MIDDLE		Callovian		±1500					†	
		Bathonian				5000			Sandy siltstone and silty sandstone	
		Bajocian							1500	
LOWER		Toarcian		Nondeposition and erosion?		Nondeposition and erosion?				
		Pliensbachian								
	Sinemurian									
	Hettangian									

See Figures 7 and 9.

*Non-marine.

†Marine.

TABLE II

4 Headwaters Bell River (Jeletzky, 1961)	5 Aklavik Range (Jeletzky, 1958)	6 East Flank Richardson Mountains (Jeletzky, 1960)	7 Babbage River Arctic Plateau (E.W. Mountjoy)
	Upper Sandstone Division † 400 †	Upper Sandstone Division 900	
----- ? ----- † Dark grey Siltstone Division +800	† Upper Shale Siltstone Division 1600	† Upper Shale Siltstone Division 3000 ?
* Coaly Quartzite 840 ----- - * White Quartzite 200	* Coal-Bearing Division 520	Overlap Erosional Gap	Sandstone ±500 ?
† Bluish grey Shale Division +400	* Lower Sandstone Division † ±500		Blue-grey shale 1500
† Lower Sandstone 300			† Sandstone and siltstone 500
	† Husky Formation (shale and siltstone) ±850		† Lower Shale
Lower Shale - Siltstone Division †	† Bug Creek Formation (siltstone and sandstone)	Lower Shale - Siltstone Division	
+1700	±600	1250 ? 2500
Sandstone 200			

“KENO HILL QUARTZITE”, YUKON TERRITORY

sandstones were derived from this source they must have been supplied by these Paleozoic sandstones. Additional material may have been derived from farther east, perhaps the Peel and Anderson Plains. Martin (1959, p. 2442) considered that the Upper Devonian clastic sediments of the northern Yukon were themselves derived, in part at least, from an area in the vicinity of the British and Barn Mountains. The Pennsylvanian and Permian clastic rocks were probably derived from a source east of them, perhaps the Precambrian Shield (Martin, 1959, p. 2445).

The uniform grain-size of the orthoquartzites of unit 13 and the absence of textural inversions in these rocks suggest strongly that they were derived from a single source and the presence of detrital chert in rocks of unit 13 shows that this single source was sedimentary. Tourmaline and zircon in the orthoquartzites do not conflict with this evidence; both these minerals commonly persist through several cycles of reworking



D.J. T-K, 5-7-65

FIGURE 8. Sharp contact between black slates of unit 11 (below) and massive orthoquartzites of unit 13 (above) near Fold Creek in the Northeastern Division. Note the numerous white quartz veinlets perpendicular to bedding in the orthoquartzite.

although they indicate initial derivation from an igneous or metamorphic source. The few polycrystalline "stretched metamorphic" quartz grains that are found in unit 13 also indicate that at least some of the material was derived initially from a metamorphic terrain. In addition the grain-size and monocrystallinity of the quartz in rocks of unit 13, which agrees well with that of particles derived from naturally disintegrated metamorphic rocks (Blatt, 1964), suggests an initial metamorphic provenance.

Petrographic data therefore corroborate the regional evidence and suggest that the orthoquartzites of unit 13 are reworked sandstones, derived from a single sedimentary source, whose original provenance was in part metamorphic. The Lower Cretaceous sandstones (unit 13 and probable equivalent strata in the northern Yukon and Alaska) were presumably derived from late Paleozoic clastic rocks (mainly the Upper Devonian Imperial Formation) in the northern Yukon that themselves may have originated from Precambrian metamorphic (and igneous?) rocks.

Depositional Environment and Conditions

Textural, lithological, and fossil evidence indicates that the orthoquartzites and interbedded slates of unit 13 were deposited in a shallow marine environment, but that non-marine conditions may have prevailed when the upper part of the unit was laid down. Trace fossils in the lower and middle parts of unit 13 (Fig. 5) belong in general to the Cruziana facies (Seilacher, 1964) indicating that the basal and middle parts of the unit were deposited in a well-aerated, shallow marine environment under conditions of moderate agitation such as prevail in neritic or littoral zones. The trace fossils signify that burrowing life flourished. No body fossils were found; however, strata that contain abundant trace fossils are generally otherwise unfossiliferous (Seilacher, 1964), and clean quartz sandstones are noted for their general lack of body fossils.

The grain-size of sandstones is a poor indicator of environment because the size of source material largely determines the grain-size of the sediment deposited. Nevertheless, fine-grained sandstones such as the orthoquartzites of unit 13 are generally found in the neritic or littoral zones some distance from shore (Folk, 1964). Although the environmental significance of sandstone grain parameters is not universally agreed on (Passega, 1957; Friedman, 1961), those of the orthoquartzites also fit the general requirements for a beach or near-shore setting. The moderate sorting of the orthoquartzites of unit 13 indicates that these rocks were not strongly reworked and that they were deposited rapidly (Folk, 1964) implying comparatively weak current activity. Shale fragments in the orthoquartzites reflect at least moderate local currents during deposition permitting some submarine, or possibly subaerial, erosion of the interbedded slates and incorporation of the products in the sandstones. Their uniform grain-size indicates that there was stability in the source and depositional areas while the orthoquartzites were being deposited. The slates interbedded with the orthoquartzites indicate intermittent rates of deposition. The homogeneity of the orthoquartzites and apparent lack of structures may be explained by the burrowing activity attested to by the trace fossils. This homogeneity may also reflect constant conditions of deposition and uniformly sized source material, and it could also reflect a very gently dipping paleoslope on which the sediments were laid down.

Curray and Moore (1964) have described a mechanism by which an extensive, regressive, littoral sand body is presently developing on the Costa de Nayarit in Mexico. Along a 150-mile stretch of the coast they describe a series of as many as 250 parallel

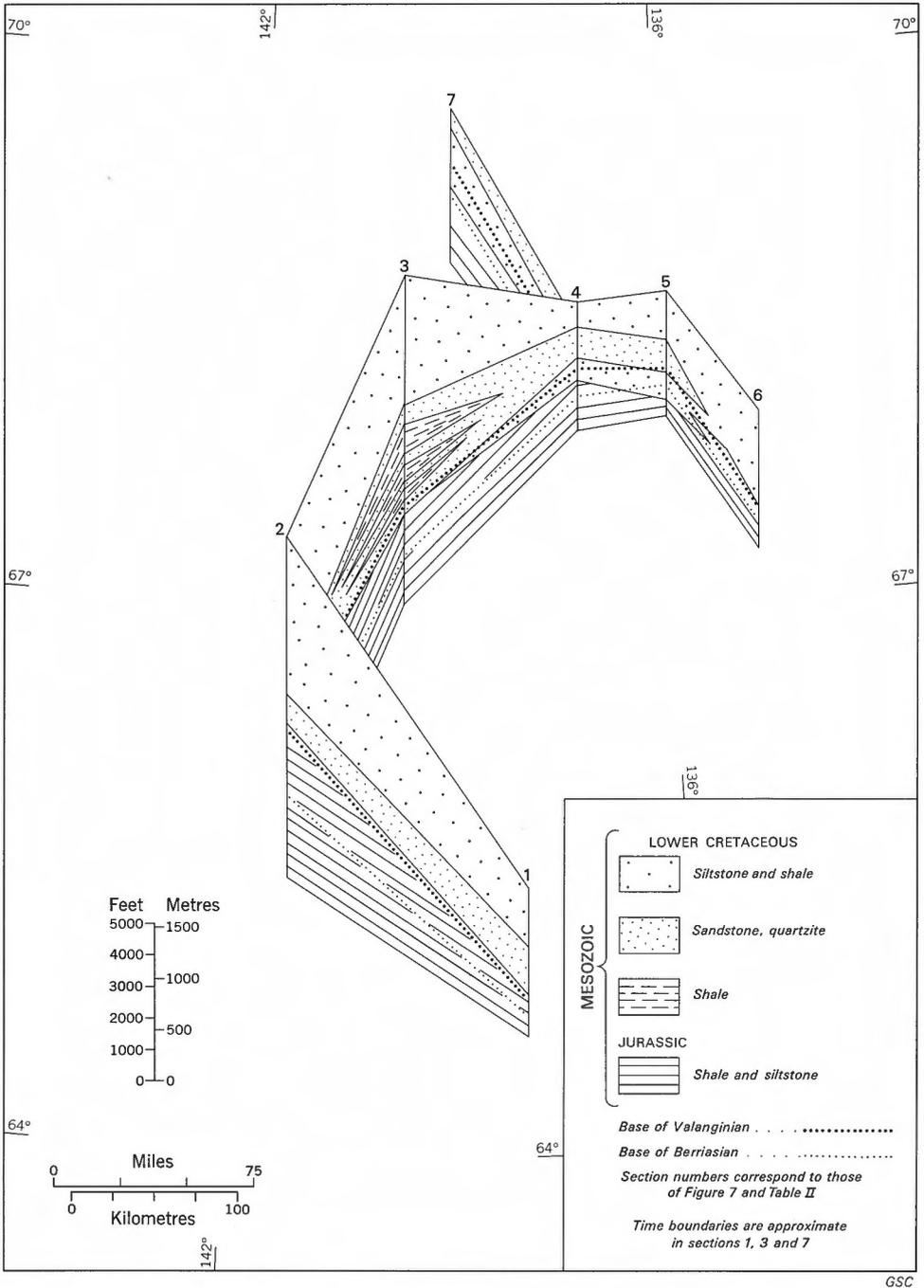


FIGURE 9. Fence diagram of Jurassic and Lower Cretaceous strata in northern Yukon Territory and east central Alaska.

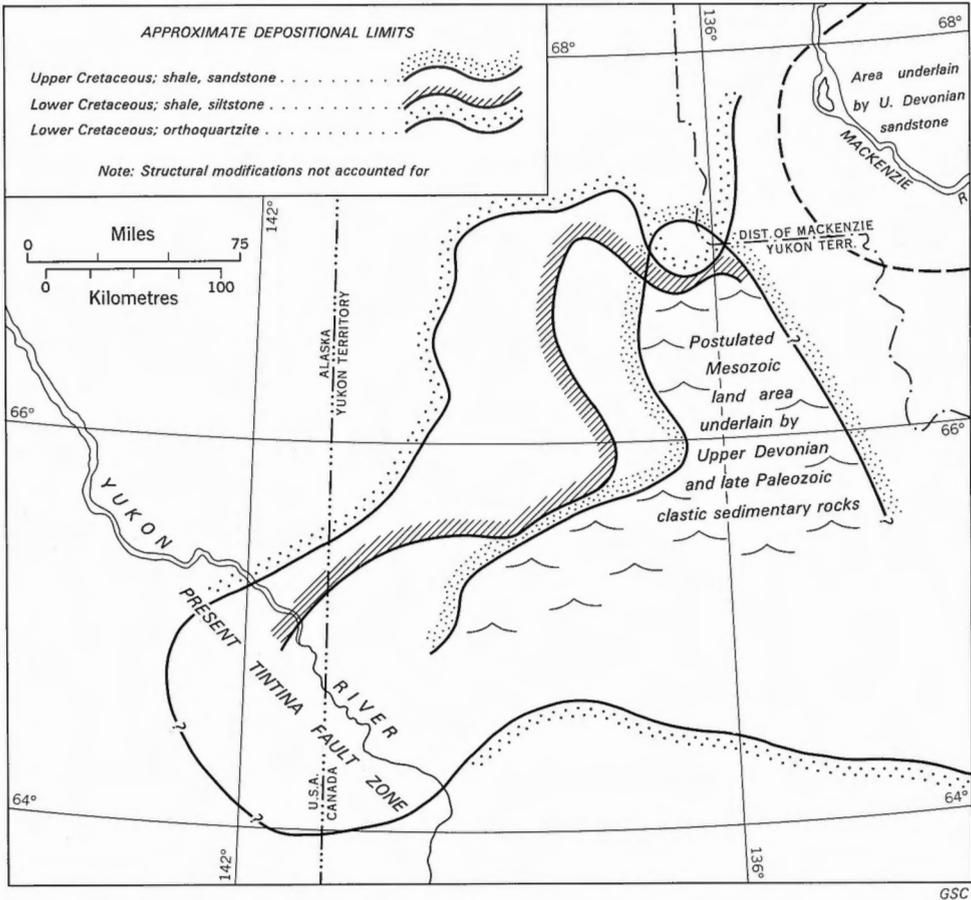


FIGURE 10. Approximate distribution limits of Cretaceous clastic rocks around probable Mesozoic land areas in northern Yukon Territory.

sand ridges forming a marshy strand plain, essentially at sea level, and as much as 7 or 8 miles wide. Each ridge is an abandoned longshore bar that was built up to sea level, at the plunge point of the waves, after the previously formed ridge had been completed. The mechanism by which the ridges form is a self regulating cyclic process, largely independent of fluctuation in the rate of longshore sediment supply. Extrapolation of the present dimensions of the sand body and the probable time it took to form (i.e., 3,000 to 5,000 years) suggests that a body of dimensions comparable to unit 13 might be formed in 1 or 2 million years. The depositional conditions deduced for unit 13 fit those that are operating on the Costa de Nayarit and a mechanism like that summarized above may have operated to produce unit 13.

Plant fossils that occur in slates near the top of unit 13 suggest that the upper part of the formation is non-marine. Lagoonal conditions may have prevailed to produce the shaly limestone found locally near the top of unit 13 (Fig. 5). A change from marine to

non-marine conditions in the upper part of unit 13 would imply regression that may have been the result of basin filling.

Folk (1964) has pointed out that although many orthoquartzites require long periods to form, those derived from an older sedimentary source need only brief periods of reworking and can be developed rapidly, because the source material is already enriched in quartz. The mineralogical maturity and textural submaturity of the orthoquartzites suggest that these rocks were deposited rapidly with little reworking, especially in view of their presumed sedimentary provenance. The Lower Cretaceous orthoquartzites in northern Yukon Territory, which are probably correlatives of unit 13, were also laid down in a relatively short time interval (they span only the Valanginian Stage of the Lower Cretaceous Series).

Map-unit 14

Unit 14 outcrops in several narrow, more or less continuous, belts immediately beneath thrust faults that repeat the Lower Cretaceous succession in the eastern part of the area. Exposures of unit 14 are generally good; the best outcrops are on the north side of Mount Robert Service.

Internal repetition by folding and destruction of bedding by cleavage precludes measurement of the thickness of unit 14, but it is estimated to be 500 feet. Its relative thinness, characteristic lithology, and position immediately above unit 13 make unit 14 a useful marker horizon. The upper contact of unit 14 with unit 15 is sharp and probably conformable.

Distinctive pale green and bright red, phyllitic and siliceous slates comprise most of unit 14. Thin beds of pale green argillaceous chert with minor black and white chert occur locally near the base. Beds are less than 6 inches thick and are locally emphasized by minute regular laminations. The slates weather white and are commonly stained bluish black by manganese oxides. On fresh surfaces the rock is pale greyish green or brownish green with irregularly shaped, bright carmine red spots, lenses, and blebs as large as several feet across. Both green and red colours occur in all outcrops, but green usually predominates except in stream exposures. The red colour occasionally follows cleavage or bedding.

The slates consist of a very fine grained groundmass of micas, mainly chlorite and muscovite, and contain a few grains of quartz (5 per cent) about 0.5 mm across. Small nodules of carbonate, about 0.2 mm in diameter, occur and tiny cubes of pyrite are scattered through the rock. In the more siliceous or cherty varieties, small ellipsoidal spherulites of chalcedonic quartz, with a uniform size of about 0.15 mm, occur abundantly, making up 20 per cent of the rock. These nodules probably represent slightly recrystallized radiolarian tests.

Evidence for the age of unit 14 is indirect as no fossils have been found in it. A lower limit for its age is provided by the underlying orthoquartzites of unit 13, which are probably early Cretaceous. The upper limit is given by the age of granitic stocks, which postdate the folding in which unit 14 was involved, and which are probably of mid-Cretaceous age. Unit 14 is therefore assigned to the Lower Cretaceous.

Rocks of unit 14 are probably correlatives of the lower part of Member B (interbedded siltstone and argillite) of the Kandik Formation (Brabb and Churkin, 1964) (Table II), but no green and red phyllitic slates occur in this member. The oxidation state of the iron in rocks of unit 14, which is thought to cause their distinctive colours, may be different elsewhere. This could result in a unit somewhat like the shales of the overlying unit 15, with which it might be included. Green and red slates have not been recognized in the Lower Cretaceous succession elsewhere in Yukon Territory.

It has been suggested to the writer that the green and red slates of unit 14 may represent strata of unit 4 (maroon and green slate), thrust above unit 13. Unit 14 cannot be the structurally repeated equivalent of unit 4 because:

- a) The maroon and green slates of unit 4 are much thicker and lithologically unlike those of unit 14.
- b) Volcanic rocks and quartz-pebble conglomerate associated with unit 4 do not occur with unit 14.
- c) If rocks of unit 14 were overthrust they would not everywhere occupy the same stratigraphic position above unit 13, and two superposed phases of folding, that are not found, should be evident in unit 14.

The slates of unit 14 appear to have been deposited in an oxygen deficient environment generally thought to exist in the deep stagnant parts of sedimentary basins where circulation is restricted or absent. Calvert (1964) has shown that sediments like those of unit 14 are presently being deposited on the slopes of the Gulf of California, where the basin floor intersects the oxygen minimum in the water column, at depths of 300 to 1,000 metres or more. The lithology of unit 14 reflects a transgressive event that followed deposition of the regressive orthoquartzites of unit 13.

Map-unit 15

Siltstones and shales of unit 15, the youngest formation in Tombstone area, overlie rocks of unit 14, and occur extensively near the eastern margin of the map-area. Unit 15 is generally poorly exposed, but good outcrops occur locally on Mount Robert Service.

The formation attains a maximum thickness of 1,000 feet, but its upper part is absent as older rocks have been thrust over it. East of the map-area about 2,000 feet occurs in the footwall of the Robert Service thrust.

Unit 15 contains yellowish brown weathering, thin-bedded and crosslaminated, lime-cemented quartz siltstone with interbedded brown shale. Bedding thickness ranges from half an inch to 6 inches. The proportion of interbedded shale is about half, but in the lower part of the unit siltstone predominates over shale. No extensive study has been made of the orientation of crosslamination in unit 15, but fourteen scattered observations suggest a southwestward direction of sediment transport.

The siltstones of unit 15 are uniform in grain-size and mineralogy; they contain about 60 per cent quartz and 10 per cent muscovite cemented by calcite and limonite. Fresh sodic plagioclase is a minor, but ubiquitous, constituent. Grain-size ranges from medium to very fine sand, with coarse silt sizes predominating (the estimated modal grain-size is 0.04 mm). The siltstone is moderately well sorted. Quartz grains are angular

and have low sphericity. Muscovite flakes are detrital and lie in the bedding plane. The cement replaces quartz along grain boundaries.

The muscovite content of the siltstones of unit 15 strongly suggests a metamorphic source area for these rocks. They were evidently deposited in a well-aerated, marine, and perhaps neritic environment. Unit 15 is a transgressive sequence, whose nature reflects no pronounced break in sedimentation between units 14 and 15.

Numerous trace fossils were found in rocks of unit 15 (Appendix I-F) but body fossils were not discovered. The age of the formation is inferred from its stratigraphic position and by lithological correlation with Mesozoic rocks to the north. The unit overlies rocks that are apparently Lower Cretaceous and cannot be younger than mid-Cretaceous, because that is the probable age of the intrusive rocks that post-date the folding in which the unit was involved. Unit 15 is therefore assigned to the Lower Cretaceous. It is unlikely that unit 15 represents older rocks thrust over the Mesozoic formations because no older rocks that resemble the siltstones are known in the area or the surrounding region.

Rocks similar to those of unit 15 occupy the same stratigraphic position above Lower Cretaceous orthoquartzites in east central Alaska, where they form Member B (interbedded siltstone and argillite) of the Kandik Formation (Brabb and Churkin, 1964). In northern Yukon Territory Jeletzky (1958a, 1960, 1961a) has described the Barremian (Lower Cretaceous) Upper Shale - Siltstone Division that also overlies Lower Cretaceous quartz sandstones. Member B of the Kandik Formation and the Upper Shale - Siltstone Division may be time equivalents of unit 15 (Figs. 7 and 9; Table II).

Intrusive Rocks

Three types of plutonic rocks, all intruded about mid-Cretaceous time, outcrop in Tombstone area. Diabase and gabbro of unit 16 were emplaced prior to deformation of the Mesozoic rocks they intrude, whereas diorite (unit 17) and syenite (unit 18) were intruded after the deformation.

Map-unit 16

Distribution, Relations, and Volume

A dozen or more separate, subparallel, northeast-trending diabase sills (unit 16) occur in Tombstone area, where they intrude the folded and faulted sequence of rocks belonging to unit 13. Because the stratigraphy and structure of unit 13 was not previously understood, it was not recognized that the dozen or more separate sills are structural repetitions of one and the same diabase sill. The diabase sill intrudes the black slate member of unit 13 (i.e., unit 13a) throughout Tombstone area and there is only one thick sill in this stratigraphic member. The sill transgresses about 200 feet in 25 miles; in the southwest part of the map-area it is near the base of unit 13a and in the northeast part it lies in the middle of that member. Because there is only one thick sill and because that sill follows unit 13a it has been useful as a stratigraphic marker horizon in delimiting structures.

One or two additional thin diabase sills (10 to 50 feet thick) occur above the main diabase sill but also within unit 13a. These thin sills are not laterally continuous and they cannot be traced across thrust faults like the main diabase sill.

The main diabase sill varies from a maximum thickness of about 800 feet in the southwest to about 400 feet in the northeast part of the map-area. It continues for 25 miles along the length of Tombstone area and its probable width in the northeast part (accounting for structural repetitions), is at least 10 miles. Its width in the southwest, again taking structural repetition into account, is at least 30 miles. The total volume of intruded diabase in Tombstone area is therefore about 60 cubic miles or more.

Lithology

Characteristically brown weathering tholeiitic diabase and gabbro constitute unit 16. The rocks are resistant and well exposed: they form cliffs and sharp ridges and commonly underlie prominent dip-slopes. The main diabase sill shows distinct textural and mineralogical differentiation from bottom to top, similar to that found in diabase sills elsewhere. Grain-size increases gradually from the margin to the centre of the sill resulting in its textural variation. Narrow (5 feet) chilled margins at the bottom and top of the sill consisting of an aphanitic groundmass with clusters of small phenocrysts of olivine, augite, and plagioclase lend the rock a glomeroporphyritic texture. Toward the centre, where grains reach a maximum length of 5 mm or more, the texture changes through ophitic and subophitic to hypidiomorphic. In central parts, the sill exhibits a marked flow layering parallel with the walls, which is the result of subparallel orientation of plagioclase crystals.

The mineralogical variation across the sill is more subtle than the textural change. It is marked by the disappearance of olivine and hypersthene about 200 feet above the base of the sill and by increase in the proportion of plagioclase from bottom to top.

Plagioclase and augite constitute about 75 per cent of the rock, plagioclase between 35 and 60 per cent. Its composition ranges from An_{55} to An_{65} with the more albitic feldspars occurring in the upper parts of the sill. Composition zoning occurs rarely in individual crystals. Plagioclase is found as subhedral laths enclosed by, and intergrown with, augite; it generally shows Carlsbad-Albite twinning. The mineral commonly is partly saussuritized or altered to aggregates of sericite and carbonate. Augite constitutes 25 to 35 per cent of the rock. It is brownish in thin sections and occurs as anhedral grains and as subhedral, short, prismatic crystals twinned on (100). Its optic angle generally lies between 46° and 52° and varies only slightly in individual thin sections; optical angles from 40° to 60° were measured. The augite is commonly unaltered around grain margins.

Hypersthene occurs only in the lower half of the sill, where it composes as much as 20 per cent of the rock. It forms subhedral and anhedral grains and is commonly altered to serpentine around the margins. The altered parts contain subparallel microscopic blebs and rods that are probably relicts of augite exsolution plates in the hypersthene. Pigeonite is fairly abundant in some thin sections but is lacking in most; where it occurs it is intergrown as anhedral grains with augite. Olivine occurs sparingly and is found as anhedral grains in the lower part of the sill as well as in the chilled margins. It is rimmed and veined by serpentine that contains tiny grains of an opaque mineral.

Quartz is ubiquitous and forms between 7 and 15 per cent of the rock. This mineral is most abundant in the upper parts of the sill, where it occurs interstitially, commonly forming micrographic intergrowths with feldspar.

"KENO HILL QUARTZITE", YUKON TERRITORY

Late magmatic, greenish brown hornblende rims augite and occurs as discrete grains. Locally it constitutes 25 per cent of the rock, but generally is less abundant. Brown biotite is present in small amounts.

Skeletal grains of ilmenite are found throughout and form between 1 and 7 per cent of the rock. They are commonly intergrown with augite and are partly altered to leucoxene. Apatite occurs as euhedral acicular crystals intergrown with biotite and hornblende. Kelyphitic rims of tremolite-actinolite on augite or hornblende are found in some thin sections.

Contact Metamorphic Effects

The black slates of unit 13a, which are intruded by the diabase sill, are commonly altered to greenish, spotted, phyllitic slates within 100 feet of the diabase contact. The spotted slate has a dark olive-green groundmass of fine-grained (about 0.01 mm) intergrown muscovite, biotite, and quartz, and contains numerous ellipsoidal spots (as long as 0.5 mm), crowded with carbonaceous inclusions that are probably incipient cordierite crystals. Close to the diabase sill orthoquartzite is bleached white and recrystallized to a mosaic of interlocking, equant quartz grains, with strongly sutured boundaries. These changes are typical of rocks around diabase intrusive sheets and indicate low grades of thermal metamorphism (albite-epidote-hornfels facies). They do not reflect the high temperatures of the intrusive diabase magma, which must have been about 1,000°C. Presumably the slates did not have time to reach equilibrium with the high temperature of the diabase, because the volume of magma was small and its heat rapidly dissipated. Lack of volatiles in the basic magma may also have restricted metamorphic reactions in the surrounding rocks.

Age and Correlation

Diabase (unit 16) intrudes strata of unit 13 assigned to the Lower Cretaceous, and is truncated by quartz monzonite (unit 18), thought to have been emplaced about mid-Cretaceous time. Unit 16 was therefore probably intruded during the Early Cretaceous Epoch. There is no evidence to indicate whether emplacement of the diabase was before, during, or after deposition of units 14 and 15, but seems most likely to have occurred after. The diabase sill is folded and faulted with the intruded sedimentary rocks and must therefore have been emplaced prior to deformation.

The basic sills that occur throughout the Keno Hill - Tombstone River belt are lithological equivalents of unit 16. In Mayo district these sills are sheared, metamorphosed, and altered to greenstones (McTaggart, 1960, pp. 12-17). Basic intrusive rocks are not known in the northern Yukon or east central Alaska.

Map-unit 17

Unit 17 occurs only in the northeast part of Tombstone area, where it forms two steeply south-dipping dykes that are between 100 and 200 feet thick and several miles long. The dykes intrude rocks of units 13, 14, and 15 and although they follow bedding locally they transect it at most places.

The unit consists of porphyritic hornblende diorite that contains roughly equal proportions of hornblende and plagioclase phenocrysts in a fine-grained groundmass of plagioclase(?) and minor quartz. Hornblende occurs as euhedral, short prismatic crystals

(3 mm or less in length), that show yellowish green to brownish green pleochroism and that are marginally altered. The plagioclase (An_{55}) phenocrysts are thick, tabular crystals (5 mm) that are commonly partly or completely sericitized. Phenocrysts make up about half the rock. Chilled margins are narrow and sedimentary rocks around the dykes are not altered. Few xenoliths occur in the dykes.

The dykes post-date the folding of the Mesozoic rocks and they are therefore mid-Cretaceous or younger. It is not known whether the dykes were emplaced before, during, or after intrusion of unit 18. Units 17 and 18 may be related, but the dyke rocks associated with the quartz monzonites (unit 18) are trachytes, unlike the porphyritic diorite that forms unit 17.

Map-unit 18

Distribution

Syenite and quartz monzonite stocks (unit 18) occur in central and northern Tombstone area where they intrude strata of units 4, 5, 11, 13, 16, and the Road River and Tahkandit Formations. Similar rocks, considered to have been intruded contemporaneously, are found southeast of the map-area (Fig. 11).

The syenite (unit 18) is well exposed in an area where peaks and shear cliffs form rugged and imposing mountains (*Frontispiece*, Fig. 2). The Tombstone stock occupies an area of roughly 35 square miles and the Brenner stock outcrops over an area of 8 square miles. Two smaller plutons occur in the northwest part of the area.

Lithology

The Tombstone intrusions range from nordmarkite (alkali syenite) to quartz monzonite and quartz diorite. Syenite makes up about three-quarters of the stocks and occurs in their central parts. Quartz monzonite and quartz diorite form marginal phases of the intrusions. The alkali syenite varies in grain-size, texture, and composition. It is commonly porphyritic and medium grained allotriomorphic; medium- and coarse-grained non-porphyritic types are locally important. The stocks show a concentric trachytoid texture by virtue of alignment of tabular orthoclase phenocrysts.

The alkali syenite consists of orthoclase with subordinate amounts of pyroxene and plagioclase; where the proportion of plagioclase is high the rock is monzonitic.

An estimated mode for the alkali syenite is given below:

Orthoclase	55 – 95 per cent
Plagioclase	0 – 25
Quartz	0 – 5
Pyroxene	0 – 20
Amphibole	0 – 10
Biotite	0 – 10

Orthoclase is micropertthitic and somewhat sericitized. In porphyritic varieties it makes up the phenocrysts and occurs also in the groundmass. The phenocrysts are subhedral, thick, tabular crystals as much as an inch across that show ubiquitous Carlsbad twinning and rare simple zoning. In the medium-grained, non-porphyritic varieties and in the groundmass of porphyritic rocks, orthoclase forms intergrowths of anhedral, equant, and generally untwinned grains, as much as 5 mm across.

Plagioclase (andesine) occurs in both the porphyritic and non-porphyritic syenites, but is more abundant in the former, and occurs as subhedral, tabular grains, several millimetres across, enclosed by orthoclase, and interstitial to it. In non-porphyritic syenites plagioclase occurs with quartz as small, euhedral grains around the margins of the orthoclase crystals.

Pyroxene is the general mafic constituent of the syenite. Its properties vary; in central parts of the stocks this mineral is commonly pleochroic in yellowish green and deep grass green colours, elsewhere it is a paler green or colourless variety. The pyroxenes are members of the aegirine-augite series; variation in their properties indicate a trend from more sodic to less sodic varieties away from the central parts of the stocks. Amphiboles show a parallel change. Where the pyroxene is soda-rich an arfvedsonitic amphibole accompanies it, and where the pyroxene is augite, hornblende is the amphibole. Pyroxene, amphibole, and biotite are interstitial to the feldspars and occur as intergrown aggregates of small, anhedral equant grains 1 or 2 mm across. Biotite is absent or subordinate in most rocks.

Accessory minerals are fairly abundant and include sphene, zircon, apatite, and opaques. They are usually intergrown with the mafic minerals, or enclosed by them. Melanite garnet occurs locally. Myrmekitic intergrowths along the rims of orthoclase crystals are fairly common in the coarse-grained syenites. Deuteric fluorite, calcite, and galena occur interstitially in some of the coarse-grained leucocratic syenites.

Quartz monzonite is generally medium grained, with hypidiomorphic granular texture. Porphyritic varieties are common and as with the syenites they show trachytoid textures. The quartz monzonite differs from the syenite only in its higher content of quartz and plagioclase and the two are not readily distinguished in the field; they probably grade into one another. The estimated mode for the quartz monzonite follows:

Orthoclase	40 - 45 per cent
Plagioclase	25 - 35
Quartz	10 - 20
Pyroxene	0 - 15
Hornblende	0 - 20
Biotite	1 - 15

Orthoclase and plagioclase (andesine) show the same textural characteristics in the quartz monzonite as in the syenite. The pyroxenes in the quartz monzonite are aegirine-augite and are less sodic than those of the syenite; they are commonly partly uralitized. Amphiboles have the properties of hornblende and are more abundant than pyroxene in the quartz monzonites. They form subhedral, stout prismatic grains several millimetres long that are commonly intergrown with lesser amounts of biotite. Accessory minerals are not as abundant in the quartz monzonite as in the syenite; they include sphene, zircon, apatite, and opaque minerals.

Granodiorite and quartz diorite constitute a narrow marginal phase along the northern contacts of the Tombstone and Brenner stocks and form most of the smaller stocks. They are characterized by abundant fresh plagioclase (andesine) and contain little orthoclase. The granodiorite and quartz diorite are fine grained or medium grained with an hypidiomorphic granular texture. Biotite is the chief mafic mineral and pyroxene is generally absent.

Pseudoleucite tinguaitite (unit 18a) occurs along the southern margin of the Tombstone stock, where it forms a marginal phase or a dyke as wide as half a mile. It occurs also in a restricted area near the centre of the Tombstone stock. The rock is medium grey and contains phenocrysts of sanidine, orthoclase, and aegirine-augite as well as white, euhedral crystals of pseudoleucite, less than an inch across, all in a fine-grained groundmass of trachytic orthoclase and aegirine-augite. The pseudoleucite crystals were described by Knight (1906); they contain a fine-grained aggregate of nepheline, orthoclase, and scapolite.

Few dykes cut the country rocks; most of them are less than 20 feet thick and do not extend beyond the stocks for more than a mile. They are trachytes with thin, tabular phenocrysts of orthoclase as large as an inch across, small subhedral crystals of oscillatory zoned andesine, small equant euhedral crystals of uraltized sodic pyroxene, and small books of brown biotite set in a fine-grained trachytic groundmass of feldspar and aegirine-augite. The trachytic texture parallels the dykes' walls. Garnet phenocrysts occur in some dykes.

Variations in mineralogy of the rocks of unit 18 indicate a general trend from peralkaline, silica-deficient nordmarkite at the centres of the stocks to calcic, silica-saturated quartz diorite at their margins. This composition variation may be the expression of differentiation of single intrusive masses, but it may also reflect several stages of acid intrusion, in which case the stocks would be composite. The absence of observed sharp contacts between the various phases supports the former view. The various rocks of unit 18 are evidently all related to the same period of intrusion and are lithologically similar to syenites, monzonites, quartz monzonites, and granodiorites that occur southeast of the map-area (Bostock, 1948b; Green and Roddick, 1962).

Contact Metamorphic Effects

A contact metamorphic aureole, less than a mile wide, surrounds the Tombstone and Brenner stocks. Slates (units 11 and 13a) are commonly altered to biotite quartz schists, chialstolite slate, and cordierite andalusite hornfels. The following assemblages of minerals occur in the metamorphosed pelitic rocks:

- Quartz - biotite
- Quartz - biotite - muscovite
- Quartz - andesine - biotite
- Andalusite - quartz

The sandy limestones of unit 13b are metamorphosed to various medium-grained calc-silicate rocks that contain the assemblages:

- Quartz - diopside
- Quartz - diopside - hornblende - plagioclase
- Diopside - quartz - calcite - plagioclase
- Wollastonite - quartz sphene

Diabases (unit 16) are changed to amphibolites containing the assemblage:

- Hornblende - biotite - plagioclase - quartz

Near the intrusive rocks orthoquartzites (unit 13) are recrystallized and bleached white. Their grain-size is notably increased (0.4 mm) and their texture is changed so that the rocks consist of interlocking mosaics of quartz grains with strongly sutured and interpenetrating boundaries.

A large xenolith of white marble (probably Tahkandit Formation), within the Tombstone stock has a skarn, consisting of a varied assemblage of coarsely crystalline calc-silicate minerals, around its margin. It contains, in order of abundance, idocrase, garnet (grossularite), scapolite (mariolitic), actinolite, epidote, calcite, fluorite, and sphene.

The rocks and mineral assemblages around the Tombstone and Brenner stocks are typical of those found in contact metamorphic aureoles around acid intrusive stocks and reflect the varied response of rocks of different composition to a thermal gradient. Most mineral assemblages belong to the hornblende-hornfels facies of thermal metamorphism, but some are transitional to the lower temperature albite-epidote-hornfels facies, whereas others reflect the higher temperature conditions of the pyroxene-hornfels facies. Metasomatism appears to have been slight. Boron was probably introduced in restricted areas where the proportion of tourmaline is high, and scapolitization and silica metasomatism have occurred in the marble xenolith.

Mode of Emplacement

The contacts of the two larger, roughly circular stocks of Tombstone area are sharp and dip outward at angles steeper than 60 degrees. The stocks are markedly discordant and sharply truncate stratigraphic units, folds, and thrust faults. The axes of some folds are bent near the margins of the larger stocks and the country rocks dip steeply along the northern margin of the Tombstone stock, but intrusions have not otherwise disrupted the host rocks. Tombstone stock contains several large (one is 3 miles long) xenoliths of rocks belonging to units 11 and 13. One of the xenoliths, composed of coarsely crystalline marble, is probably derived from the Tahkandit Formation. The marble xenolith and the large one belonging to unit 11 cannot be roof pendants and were evidently brought up from a depth of about 5,000 feet; they may have been rotated in the process. Sharp contacts between intrusive and country rocks suggest that assimilation was slight. The intrusive rocks probably crystallized from a magma emplaced singly, or in stages, by intrusion into the country rocks. There is little evidence to suggest forceful intrusion at the present exposed level of the stocks, a fact that may be interpreted as indicating that the present exposed level is close to the upper surface of the stocks. The intrusions are epizonal in character, indicating they were emplaced at relatively high levels under comparatively low load pressures. Stratigraphic evidence suggests that the present exposed level of the stocks was at least 3,000 feet below the land surface at the time of intrusion (3,000 feet is the thickness of units 15, 14, and part of 13 now eroded). Structural data suggest that the present level may have been considerably deeper (in the order of 10,000 feet), if the overthrust Precambrian rocks (above the North Fork thrust) in the southeast part of Tombstone area extended northwestward beyond their present position.

Age and Correlation

The syenites (unit 18) intrude Lower Cretaceous orthoquartzites (unit 13) and diabase (unit 16) and they postdate the deformation in which the probable Lower Cretaceous units 13-16 were involved. Stratigraphic data do not provide an upper limit for the age of intrusion in Tombstone area and evidence for the age of the syenite must be sought elsewhere.

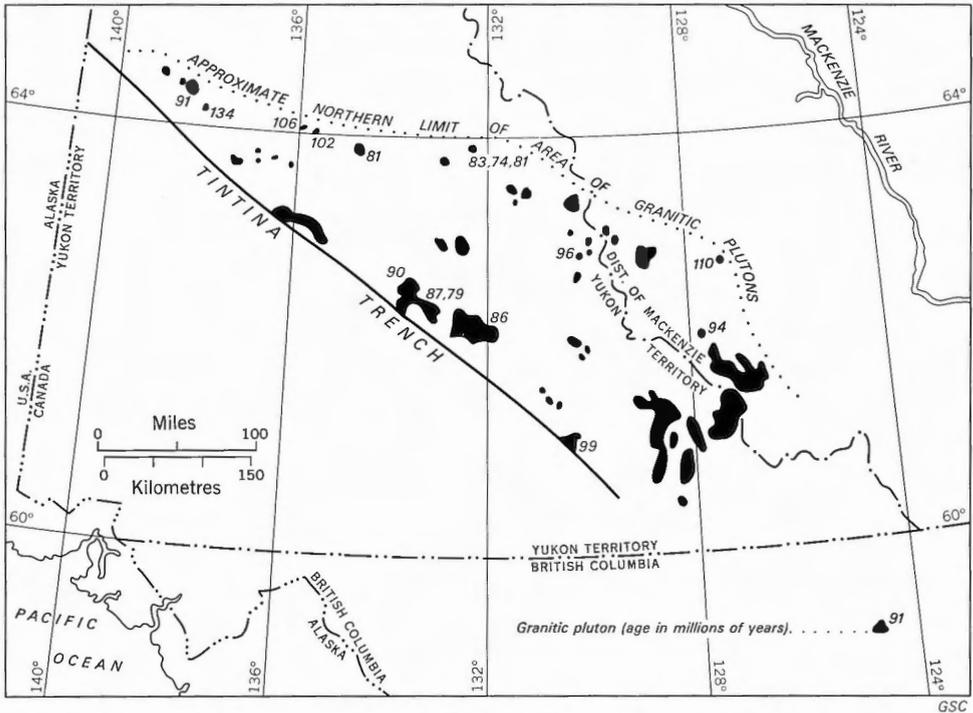


FIGURE 11. Potassium argon age determinations of granitic rocks north of the Tintina Trench.

One potassium-argon absolute age determination on biotite from a sample of hornblende biotite quartz monzonite from the Tombstone stock yielded an age of 91 ± 5 million years (m.y.)¹. This date indicates an early Late Cretaceous time of emplacement for the Tombstone intrusions (unit 18) on presently accepted geological time scales.

The Tombstone and Brenner stocks are two of forty or more lithologically similar bodies of acid igneous rocks that occur in a broad region north of Tintina Trench (Fig. 11). Potassium-argon age determinations on granitic rocks from some of the stocks in this belt of plutons fall within the range 74 to 134 m.y. (Appendix II, Fig. 11) and a grouping of the ages about 80 to 100 m.y. is evident. The single potassium-argon date from Tombstone stock agrees with the other age determinations from these related plutons and the suggested early Late Cretaceous time of emplacement is therefore thought reliable.

Stratigraphic data indicate that an orogeny² took place about late Early Cretaceous time in Alaska (Mertie, 1930a, p. 110). In parts of Alaska intrusion is thought to have accompanied or followed this orogeny (Gates and Gryc, 1963, pp. 272, 273). The post-orogenic Upper Cretaceous and younger conglomerates and sandstones in east central Alaska extend along Tintina Trench to within 20 miles of Tombstone area (Fig.

¹The associated hornblende in this sample has recently been dated at 80 ± 13 m.y. by the potassium-argon method.

²The term orogeny is used throughout this report to indicate an episode of mountain making by folding and faulting; it may have been accompanied or followed by intrusion of igneous rocks.

7). These rocks contain potash feldspar (Brabb and Churkin, 1964), which suggests that by the time they were being deposited (i.e., Late Cretaceous) plutonic rocks (? unit 18 and equivalents?) were available for erosion. The maximum and minimum ages indicated by the stratigraphic evidence and the absolute age suggested by the radiometric data support each other and an early Late Cretaceous time of emplacement is presumed for the Tombstone intrusions.

The age relations of intrusive rocks south of Tintina Trench in southern Yukon Territory and northern British Columbia were investigated by Gabrielse and Reesor (1964). They demonstrated three periods of major plutonic activity, indicated by radiometric ages and corresponding to three distinct stratigraphic breaks in the Mesozoic succession. The three igneous episodes in the region south of the Tintina Trench occurred during Late Triassic, post-Early Jurassic and pre-Late Cretaceous, and post-Earliest Tertiary times. Radiometric evidence in the area north of the Tintina Trench suggests that only the second of these plutonic events is represented there.

Discussion of Stratigraphic Data

The general absence of recognized Lower and Middle Triassic strata and the regional unconformity below the Upper Triassic in much of the western Canadian Cordilleran belt suggest that early Triassic time in southern Alaska, south-central Yukon Territory, and western British Columbia was a period of widespread diastrophism, plutonism, and volcanism (Dott, 1961). Dott has summarized the evidence and related the late Triassic transgression that followed this diastrophic interval to the eugeosynclinal parts of the Cordilleran geosyncline. Tozer (1958) subdivided the Triassic of the western Cordillera into an eastern and western system. His eastern system, in which Lower, Middle, and Upper Triassic are represented, occurs in the Rocky Mountains and Foothills and contains siltstones, shales, and limestones, but lacks volcanic rocks. Tozer's western system, which occurs in the southern Yukon and western British Columbia, is characterized by the presence of the Upper Triassic alone and includes abundant volcanic rocks. The Triassic rocks of Tombstone area evidently belong to Tozer's eastern system, indicating that miogeosynclinal conditions prevailed there during the Triassic and showing that the extensive, early Triassic diastrophism that affected the western Cordilleran region 200 miles south of Tombstone area did not extend to parts of central Yukon Territory north of the Tintina Trench.

The apparent completeness and relative thinness of the Mesozoic succession in Tombstone area indicate that this region was one of comparatively uninterrupted, largely marine, and probably miogeosynclinal sedimentation during that era. The continuity of the Mesozoic formations along the Keno Hill - Tombstone River belt further indicates that these conditions were not restricted to Tombstone area, but that they prevailed in much of the central Yukon. This area, which was previously thought to have been a highland throughout the Mesozoic, appears therefore to have been an area of marine sedimentation during Triassic, Jurassic, and early Cretaceous times. The region was tectonically quiet throughout the early Mesozoic, but in late Early Cretaceous time the rocks were intruded by diabase and folded and faulted; intrusion of syenitic rocks followed soon after this orogenic event.

Many lithologic, stratigraphic, and faunal similarities between the Mesozoic rocks that occur in Tombstone area and those found in east central Alaska and the northern Yukon have been cited. These similarities imply parallel conditions of sedimentation and development and suggest a direct connection between the basins in which the Mesozoic rocks of the northern and central Yukon were deposited. The Mesozoic rocks of the northern Yukon and those of east central Alaska are part of one continuous depositional basin, that is now truncated on the southwest by the Tintina fault zone (Figs. 7 and 10). Similarly the Mesozoic rocks of the Keno Hill – Tombstone River belt are part of another continuous basin now also truncated at its southwestern extremity by the Tintina fault zone (Fig. 10). If, as seems likely, a connecting basin existed between these two, now separate, depositional areas during the Mesozoic, it should be on the southwest side of Tintina fault zone. Such a probable connecting basin is shown on Figure 10. Mertie (1937) has mapped rocks of the Kandik Formation southwest of the Tintina Trench in the Yukon – Tanana region of Alaska (about 250 miles west of Tombstone area). Mertie's Kandik Formation is probably in large part stratigraphically equivalent to units 11, 13, 14, and 15 of Tombstone area. The occurrence of rocks of the Kandik Formation southwest of the Tintina Trench therefore provides a possible connection between the Mesozoic basins of northern and central Yukon Territory, and furnishes a reasonable basis for measuring the displacement on the Tintina fault zone (subject still to proof of equivalence of Mesozoic strata in these regions). If one assumes the correlations above to be valid, the dextral strike-slip on the Tintina fault would be about 250 miles. This possibility is explored in the section devoted to the Keno Hill – Tombstone River belt.

Gross lithologic and stratigraphic similarities are apparent between the Mesozoic succession of Tombstone area (and the Keno Hill – Tombstone River belt) and that of the eastern Cordillera in northeastern British Columbia. It is conceivable that these two miogeosynclinal regions were connected in Mesozoic time, although no Mesozoic rocks have so far been found in the 450-mile gap that separates these regions.

STRUCTURAL GEOLOGY

Introduction

Thrust faults and folds that attest to a style of deformation not previously recognized in central Yukon Territory dominate the structure of Tombstone area. The Lower Cretaceous strata are cut by a number of southeast-dipping thrust faults that form an imbricate zone between a plane of basal detachment and a major thrust that repeats Precambrian rocks. Strata in the thrust slices are folded concentrically above the sole structure that lies at the base of the Lower Cretaceous orthoquartzites (unit 13). The structures pre-date the probable mid-Cretaceous syenite intrusions and were evidently formed in late Early Cretaceous time. Internal structures in the Paleozoic and older rocks are different from those in the overlying Mesozoic strata, suggesting they may have formed prior to deposition of the Permian Tahkandit Formation.

Structures in Tombstone area trend north and northeast in the south and change to eastward trends in the northeast part, describing a broad arc that is concave to the southeast. Bedding follows the trend of structures and generally dips to the southeast.

The following pages contain a description and interpretation of the structures of Tombstone area. Internal structures in the Precambrian and Paleozoic rocks are briefly characterized and structures in the overlying Mesozoic strata are described in some detail. Finally, the structures in the Lower Cretaceous rocks are discussed and compared to similar structures elsewhere.

Structure of the Lower Division

The overall structure of the Lower Division is not known, because its stratigraphy is poorly understood and because outcrops in the western part of the area, where it occurs, are scarce. The following descriptions are therefore necessarily brief.

Minor folds are common in the rocks of unit 4 and the Road River Formation, but other units of the Lower Division are apparently devoid of such structures. Most of the minor folds in unit 4 are a foot or two feet across; they trend northward and plunge to the north and south at low angles. The folds have rounded hinges and their apical angles are about 40 degrees. Most of the observed folds are anticlinal crests and a sense of movement could not be determined. The minor folds have steeply east-dipping axial planes parallel with which a slaty cleavage is locally poorly developed. No lineation was found.

Minor folds in the Road River Formation (Fig. 12) are open concentric structures several feet across that generally plunge slightly west of south at gentle angles. Their axial planes range from horizontal to vertical, but most dip to the east. Axial plane cleavage is poorly developed and no lineation is seen.

The only large structure recognized in the Lower Division is an open north-northeast trending anticline with gently dipping limbs that is outlined by bedding in rocks of the



D.H. T-K. 3-7-64

FIGURE 12. Small scale concentric folds in chert and slate of the Road River Formation on the south side of Chert Mountain (looking west). Man gives scale.

Road River Formation on Chert Mountain. This fold probably does not extend north of Tombstone River and was not recognized south of Little Twelve Mile River.

South of Little Twelve Mile River the contact between unit 5 and the Road River Formation is folded into open, southeast-trending anticlines and synclines that are between 500 and 1,000 feet across. These structures are similar to those described by Green and Roddick (1962) along the north side of the Tintina Trench. They are thought to be related to pre-Tertiary dextral strike-slip faulting along that valley.

Age of Deformation of the Lower Division

The style and orientation of minor folds in the Lower and Upper Divisions differ. Minor folds in the Lower Division are more open than those in the Upper and trend northward at an angle to the northeast-trending minor structures of the Upper Division.

Axial planes of minor folds in the Upper Division dip consistently to the southeast at moderate angles, whereas those of minor folds in the Lower Division range from horizontal to vertical. Although such contrasting structures may simply reflect the different responses of two lithologically dissimilar groups of rocks to the same stress, it is thought equally probable that they indicate two different periods of deformation. If this latter interpretation is valid the Lower Division must have been deformed prior to deposition of the Tahkandit Formation, presumably during the Variscan orogeny.

Structure of the Upper Division

The structure of the Upper Division has become clear through a knowledge of the internal stratigraphy and stratigraphic relations of unit 13. Three marker horizons within the Lower Cretaceous succession have been used in delineating the large scale thrust faults and folds. The value of these marker beds in interpreting the structure cannot be over-emphasized; they are, from top down:

- Unit 14 – Green and red phyllitic slate, separated by about 500 feet of massive orthoquartzite from
- Unit 13b – 50 to 100 feet of sandy limestone, separated by about 700 feet of massive orthoquartzite from
- Unit 13a – 200 to 400 feet of black slate, which occurs about 500 feet above the base of unit 13 and which is intruded by about 600 feet of diabase of unit 16.

Unit 14 is distinctive and easily recognized on the ground, but it can be mistaken for unit 13 at a distance. Unit 13b is readily recognized from afar by its characteristic buff-weathering colour, but the unit can be overlooked on the ground because its sandy limestones resemble the orthoquartzites of unit 13. Its recessive weathering character makes mapping of unit 13a difficult, but because the diabase sill (unit 16) intrudes it, unit 13a is easily identified. Units 13a and 13b were traced through much of Tombstone area, but because their significance as marker horizons was not recognized until late in this study they are not mapped everywhere they occur. The massive orthoquartzites above and below units 13a and 13b are, for all practical purposes, identical and cannot be differentiated.

The description of the structure is illustrated with cross-sections and Map 1248A (*in pocket*). Cross-sections are vertical and at right angles to the structural trend. Some of the longer cross-sections are offset slightly to include areas of better structural control. There is reasonable surface control on cross-sections between elevations of 7,000 and 2,500 feet. As there is no subsurface information from the area or its vicinity the projected structures below 2,500 feet are hypothetical.

The part of Tombstone area underlain by the Upper Division is subdivided to simplify description and discussion of the structures. Four breaks are arbitrarily taken as the boundaries of the structural subdivisions. From northwest to southeast these boundaries are: 1) the contact between rocks of units 11 and 13; 2) the Spotted Fawn Gulch thrust; 3) the Wolf Creek thrust; and 4) the Robert Service thrust. Structures in the northeast part of the map-area are described separately because some of these faults

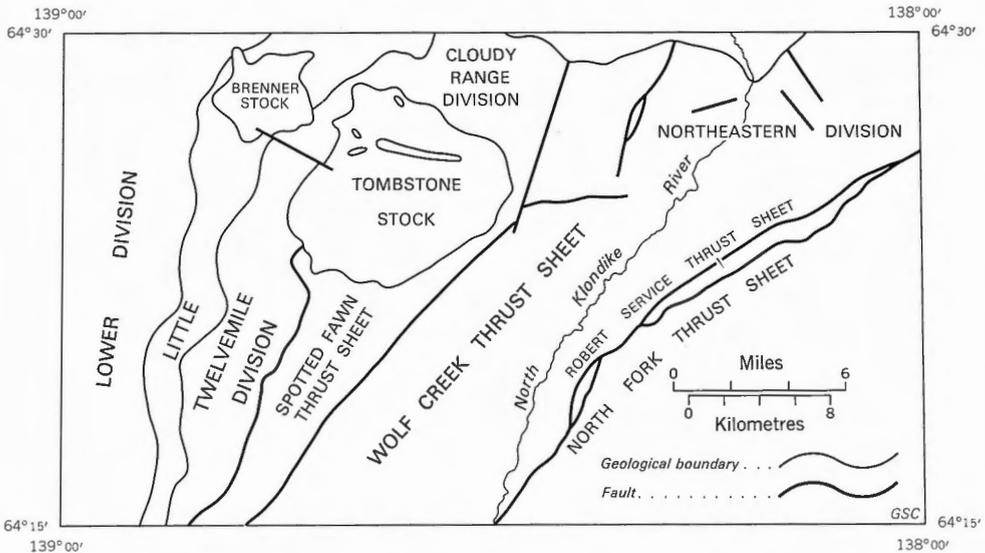


FIGURE 13. Structural subdivisions of the Tombstone area.

terminate there. Structures north of the Tombstone stock in Cloudy Range are also discussed separately. The structural subdivisions are as follows (Fig. 13):

- Little Twelve Mile Division
- Spotted Fawn Gulch Thrust Sheet
- Wolf Creek Thrust Sheet
- Robert Service Thrust Sheet
- North Fork Thrust Sheet
- Northeastern Division
- Cloudy Range Division

Thrust Faults

Although thrust faults dominate the structure of Tombstone area, it was not until near the end of the present study, when the stratigraphy was understood, that the extent and number of these structures were recognized. The occurrence of the Robert Service and North Fork thrusts, earlier established on stratigraphic evidence, and the extreme thickening of the Lower Cretaceous succession in Tombstone area had suggested the existence of such structures. The fact that folds alone cannot explain the structure and recurring stratigraphic pattern of units 13a, 16, 13b, and 14 has led to the recognition of the thrust faults within the Lower Cretaceous rocks. The faults themselves are not conspicuous, even where the displacement is large, and the fault surfaces are rarely exposed. As in other areas where thrust faults are recognized, the presence, position, and extent of these structures is inferred from the distribution of strata and the truncation of folds.

A number of subparallel, northeast-trending thrust faults occur within the orthoquartzite sequence of unit 13. A thrust fault (Robert Service thrust) that brings Triassic and Jurassic rocks above Lower Cretaceous strata is also demonstrated. The presence of a thrust fault (North Fork thrust) that places Precambrian on Mesozoic strata previously recognized by Green and Roddick (1962, p. 18) is confirmed.

Most thrust faults in Tombstone area are several miles long; few continue for more than 20 miles. The surface traces of the thrust faults diverge toward the centre of the map-area from its southwest and northeast parts. A folded thrust fault (Scoutcar Creek thrust) and several back-limb thrusts¹ are recognized. Strata above the thrusts have moved northwestward relative to those below them. The stratigraphic throw is generally 2,000 feet or less, but on the Robert Service and North Fork thrusts the throw is considerably larger. The thrusts dip to the southeast at moderate to steep angles, as inferred from the distribution and attitude of strata above and below them, and from the few exposed thrust surfaces. Many thrust faults end in the northeast part of the map-area, have their maximum throw in the central part, and tend to lose stratigraphic throw near the southern margin.

Folds

Folds in Tombstone area range in size from minor structures, less than a foot between limbs, to much larger anticlines and synclines that are more than a mile across. The larger structures are well exposed and readily recognized. Some large folds extend for many miles, others die out and are replaced by new structures. The large scale folds are concentric and range from symmetrical anticlines and synclines with gently dipping limbs, to asymmetrical folds, with steeply dipping northwest limbs and more gently dipping southeast limbs. The folds are asymmetrical and open along the southeast margin of the map-area. The large scale folds plunge gently northeastward and expose successively younger stratigraphic units in that direction.

The scale and style of folds in the various lithological units are different. In unit 11 only small scale similar folds are recognized, whereas unit 13 (excepting unit 13a) has only large scale concentric folds. Folds in units 14 and 15 conform to the large scale structures of the underlying rocks of unit 13, but internal minor structures are also found in these units.

Little Twelve Mile Division

The Little Twelve Mile Division in the western part of Tombstone area (Fig. 13) is bounded by the lower contact of the Tahkandit Formation and the Spotted Fawn Gulch thrust. It extends from the southern margin of the map-area to the Tombstone and Brenner stocks. This division includes two different lithological units, whose strongly contrasted styles of internal deformation separate it into a lower and upper part. Slates of unit 11 in the lower part of the Little Twelve Mile Division contain small-scale minor folds, but lack the large-scale folds and thrust faults that characterize the orthoquartzites of unit 13 in the upper part of the division. The contact between units 11 and 13 is a

¹The more gently dipping limb of an asymmetrical anticline is generally referred to as its back limb; a back-limb thrust is a reverse fault that repeats strata on the more gently dipping limb of an asymmetrical anticline.

plane of décollement above and below which the lithologically different strata are deformed independently.

Structures in Unit 11

The small scale folds in unit 11 are of two types. They consist of an older set of minor similar folds found mainly in the upper part of the unit and a superposed set of chevron folds that are restricted to its lower part. The early minor folds are rarely more than a foot across. They are subsoclinal, northeast-trending, overturned structures outlined by bedding. Axes are subhorizontal and no preferred plunge direction was noted. The axial planes of the small folds dip southeastward at moderate angles; axial plane cleavage, which is well developed in most of the minor folds, cuts bedding at acute angles. In cross-section viewed from the southwest many minor folds are shaped like the letter S, indicating that overlying beds moved northwestward relative to underlying strata. Incomplete minor folds, showing only anticlinal crests separated by small slip planes or faults, and lacking the complimentary synclinal parts, are common. A poorly developed wrinkle lineation, parallel with fold axes, occurs locally.

Chevron folds in the lower part of unit 11 trend eastward at right angles to the similar folds described above. They are comparatively large structures as much as 500 feet across, with vertical axial planes and moderate to steeply dipping limbs. The east-trending chevron folds are younger than the northward-trending similar folds, for they deform the latter, causing plunge reversals in these early structures. The chevron folds are found only south of Tombstone River; they are like, and probably related to, the east-trending folds that deform the contact between unit 5 and the Road River Formation in the south part of the Lower Division. As such they are probably associated with pre-Tertiary faulting along the Tintina Trench. In most of Tombstone area the Tahkandit Formation, at the base of the Little Twelve Mile River, dips gently southwestward or eastward, but on the southeast flank of Chert Mountain steep dips in this formation outline symmetrical eastward-trending folds, several hundred feet across, immediately beneath the chevron folds in unit 11.

The Décollement Contact between Units 11 and 13

The contact between units 11 and 13 is a well-marked topographic and structural boundary that separates the recessive weathering slates of unit 11 from the resistant, massive orthoquartzites (unit 13) above them. Where observed the contact is abrupt and sharp and although it locally truncates bedding in either the underlying or overlying strata, or both, it is parallel with bedding in most outcrops. Slates immediately below the contact are locally changed to phyllonites and orthoquartzites above it are fractured and cut by numerous, narrow, irregular veinlets filled with white quartz. The contact is apparently not folded with the overlying strata of unit 13 because anticlines in that formation do not contain cores of slate belonging to unit 11. In most of the area the contact dips southeastward at about 20 degrees, and its outcrop trace across large valleys indicates that this attitude persists to some depth. Near the Tombstone and Brenner stocks the contact is locally vertical reflecting structural modification by doming and rotation of the strata near these intrusions.

The striking contrast in the internal structures of units 11 and 13 and the relations at the contact between these two units indicate that this surface is a plane of detachment above which the massive orthoquartzites (unit 13) are folded and faulted independently

of the underlying slates. The term *décollement* (literally, unsticking or uncementing), which is applied where a series of cover strata is detached by independent sliding from its substratum, would seem to be applicable. Additional structural evidence for a *décollement* at the base of the Lower Cretaceous succession is discussed in the structural summary.

The contact between units 11 and 13 may also be interpreted as a thrust fault on which the younger, competent orthoquartzites have moved independently above the older, underlying, incompetent slates as a result of structural readjustment between them. Such thrust faults are known in Idaho, Utah, and Nevada (Hazzard and Turner, 1957) where they are termed *décollement* thrusts. South of Little Twelve Mile River diabase (unit 16) directly overlies unit 11, indicating stratigraphic omission of the lower part of unit 13 and showing that a fault relationship exists there at the upper contact of unit 11. The relations south of Little Twelve Mile River are like those of a *décollement* thrust that follows a stratigraphic horizon in the upper part of unit 11.

The contact between units 11 and 13 is referred to as the *décollement* in the following pages. No topographic name is applied because a fault relationship is not demonstrated along most of the length of this contact.

Structures above the Décollement

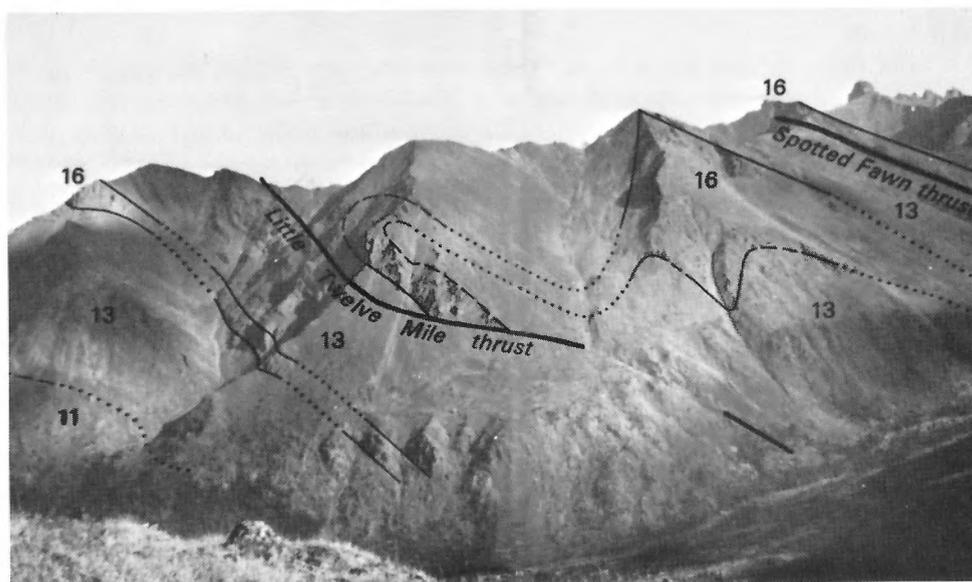
The structure of the Little Twelve Mile Division above the *décollement* is characterized by large, north-trending asymmetrical folds and thrust faults that are outlined by the diabase sill (unit 16) intruded into unit 13. Structures are simplest in the south where the Little Twelve Mile Division is narrowest and become progressively more complex northward as the division widens.

In the southern part of the Little Twelve Mile Division the diabase sill is folded into two, somewhat asymmetrical, open anticlines with an intermediate syncline. North of Mount Jeckell these two anticlines are separated by an unnamed thrust fault above which the eastern syncline and anticline continue northward. The two eastern folds become smaller northward and probably end below the Spotted Fawn Gulch thrust, north of Little Twelve Mile River. The unnamed thrust fault beneath the Spotted Fawn Gulch thrust repeats strata of unit 13; its maximum stratigraphic throw, measured from the displacement of unit 13b, is about 1,500 feet. The fault extends from near Mount Jeckell to Little Twelve Mile River and it probably ends north of that stream, perhaps merging with the Spotted Fawn Gulch thrust above it.

The folds immediately above the Little Twelve Mile thrust change from an anticline with several smaller associated folds in the south to a single, larger anticline in the vicinity of Little Twelve Mile River (cross-section AB, Map 1248A). This single anticline in turn gives way northward to a pair of anticlines separated by a syncline, and south of Tombstone River a second syncline appears on the west flank of these structures (cross-section FG, Map 1248A; Fig. 14). Where the individual folds terminate, their axes probably merge on the flanks of the through-going structures as shown on Map 1248A.

The southeast-dipping Little Twelve Mile thrust lies west of the structures just described, and truncates them; the fault may merge with the *décollement* south of Little Twelve Mile River, but exposures are too poor to indicate this.

The Little Twelve Mile thrust continues for about 7 miles and is truncated north of Tombstone River by a cross-fault. It repeats strata of units 13 and 16 south of



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FIGURE 14. Folded and thrust-faulted diabase sill (unit 16) intruded into unit 13. Looking north across the valley of the Little Twelve Mile River near the centre of Tombstone area.

Tombstone River, but north of this river the fault brings unit 11 above units 13 and 16 showing that displacement on the fault increases northward and indicating a maximum stratigraphic throw of about 2,500 feet.

Spotted Fawn Gulch Thrust Sheet

The Spotted Fawn Gulch thrust sheet, in the south central part of Tombstone area, is bounded by the Spotted Fawn Gulch and Wolf Creek thrust faults (Fig. 13). It extends northeastward from the south margin of the map-area and terminates abruptly against the Tombstone stock. The structure changes along the length of the thrust sheet; it is simplest in the south where the thrust sheet is narrowest.

Spotted Fawn Gulch Thrust

This thrust fault continues for 10 miles and brings diabase (unit 16), intruded into slates of unit 13a, above stratigraphically higher rocks of unit 13 (cross-sections AB and FJ, Map 1248A). The stratigraphic throw decreases southward and ranges from a maximum of about 2,000 feet near Little Twelve Mile River to about 500 feet near the south margin of the map-area. The fault dips southeastward at between 20 and 50 degrees as inferred from the distribution of strata above and below it; a 40-degree dip would give a displacement of as much as 5,000 feet locally (cross-section FJ, Map 1248A).

Spotted Fawn and Mount McIntyre Folds

Five large folds, outlined by rocks of units 13 and 14, occur between the Spotted Fawn Gulch and Mount McIntyre thrust faults on Mount McIntyre. From northwest to southeast they are the Spotted Fawn syncline and anticline, the Mount McIntyre syncline

and anticline, and the syncline (unnamed) between the Mount McIntyre anticline and thrust fault.

The folds are well exposed on Mount McIntyre (Fig. 15) in the centre of the map-area. They are asymmetrical structures 3,000 feet across; anticlines have steeply dipping northwest limbs and more gently dipping southeast limbs, so that the axial planes of the folds dip southeastward at 60 degrees or more (cross-section HJ, Map 1248A). Large subisoclinal drag folds, 100 or 200 feet across, occur on the limbs of the main folds. The folds trend northeast and have near horizontal axes. They continue for 3 miles in the widest (northwest) part of the Spotted Fawn Gulch thrust sheet, and are replaced southwest of Mount McIntyre by two thrust faults (cross-section AB, Map 1248A) that die out in the northwest limbs of the Spotted Fawn and Mount McIntyre anticlines. The stratigraphic throw on these two thrust faults is about 500 feet immediately south of Mount McIntyre. Evidence for their southwest extent is scanty, but it is likely that they end in the narrow part of the Spotted Fawn Gulch thrust sheet, where an apparently unbroken stratigraphic succession between the Spotted Fawn Gulch and Mount McIntyre thrusts exists.

Mount McIntyre Thrust

The Mount McIntyre thrust fault immediately overlies and truncates the upper unnamed syncline on Mount McIntyre. It dips southeastward, and brings rocks of

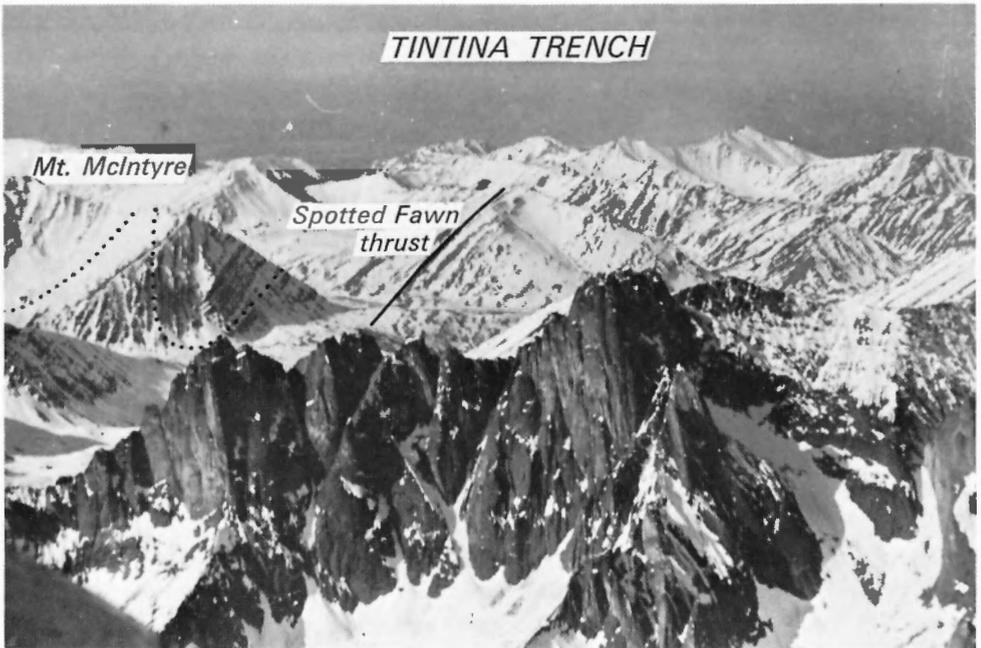


FIGURE 15. Aerial view of the south central part of Tombstone area, looking southward. Tombstone Mountain in the foreground is underlain by syenite (unit 18) and orthoquartzites (unit 13) underlie the mountains in the middle distance. Note that the structures trend toward the wide flat-floored Tintina Trench in the background. The view includes the Little Twelve Mile Division (right, below the Spotted Fawn Gulch thrust) and the Spotted Fawn Gulch thrust sheet (left).

units 13a and 16 above those of unit 14 in the vicinity of Mount McIntyre. The maximum stratigraphic throw (about 2,000 feet) is near Little Twelve Mile River (cross-section HL, Map 1248A), southwest of which the throw decreases. Near the south boundary of the map-area, where the fault repeats unit 16, the throw is 1,000 feet or less. The maximum dip-slip displacement on the fault may be as much as 5,000 feet locally.

Folds above Mount McIntyre Thrust

On the divide between Wolf Creek and Little Twelve Mile River the diabase sill immediately above the Mount McIntyre thrust is folded and viewed in cross-section from the south looks like a letter M lying on its side (cross-section KL, Map 1248A). The folds are asymmetrical and have southeast-dipping axial planes. Rocks of units 13 and 14 above this structure are folded into small, somewhat asymmetrical synclines and anticlines (cross-section KL, Map 1248A).

The structure in the south part of the map-area between the Mount McIntyre and Wolf Creek thrusts is poorly understood because outcrops are scarce. Diabase, probably repeated by folds and perhaps by minor faults, lies there between these thrust faults.

Wolf Creek Thrust Sheet

The Wolf Creek thrust sheet (Fig. 13), the largest structural subdivision of Tombstone area, includes the region between the Wolf Creek and Robert Service thrusts and lies along the southeastern margin of the map-area. In the northeast part of the thrust sheet, the boundary with the Northeastern Division is arbitrarily taken as the Grizzly Creek anticline. Thrust faults dominate the structure of the southwest part of the Wolf Creek thrust sheet and folds are most prominent in the northeast, reflecting a progressive decrease in structural complexity from southwest to northeast. The thrust sheet trends northeastward, but in plan its structures delineate a broad arc concave to the southeast. Southwest of Benson Creek the structure is unknown because outcrops are scarce.

The Wolf Creek thrust sheet includes rocks of units 13, 14, 15, and 16. Units 13 and 16 are found mainly in the southwest part, and units 14 and 15 occur in the northeast. The older rocks in the southwest and younger ones in the northeast indicate a general northeastward plunge of structures within this thrust sheet.

Wolf Creek Thrust

The position and attitude of Wolf Creek thrust is best defined on the ridge at the head of Wolf Creek, where rocks of unit 13 overlie those of unit 14. The fault has been traced for 18 miles and extends from the south margin of Tombstone area to Grizzly Creek. At the head of Grizzly Creek the Wolf Creek thrust is apparently displaced by the Axeman Creek fault, although exposures do not clearly establish this. The position of the Wolf Creek thrust is poorly defined southwest of Benson Creek, where it repeats diabase. Where the fault brings orthoquartzites of unit 13 onto similar rocks (i.e., near Wolf Creek), its position is also approximate.

Stratigraphic throw on the Wolf Creek thrust ranges from 500 feet or less near the southern boundary of the map-area to about 2,000 feet (maximum) in the vicinity of Wolf Creek. Near Grizzly Creek the fault dies out in the southeast limb of the Grizzly Creek anticline. At the head of Wolf Creek the fault dips southeastward at between 30 and 45 degrees and on this basis its displacement must be about 4,000 feet (cross-section KM, Map 1248A).

Structures between the Wolf Creek and Scoutcar Creek Thrusts

The southeast-dipping succession of rocks of units 13 and 16, between the Wolf Creek and Scoutcar Creek thrust faults, is broken by two thrusts that trend northeastward, parallel with the Wolf Creek thrust. Evidence for the existence of the two thrusts, whose surface traces were not seen, is: 1) the repetition of units 13a and 16; 2) the occurrence of unit 13b some distance southeast of the Wolf Creek thrust, below stratigraphically lower diabase of unit 16; and 3) the thickness of the succession between the Wolf Creek and Scoutcar Creek thrusts, which is much thicker than the normal stratigraphic succession.

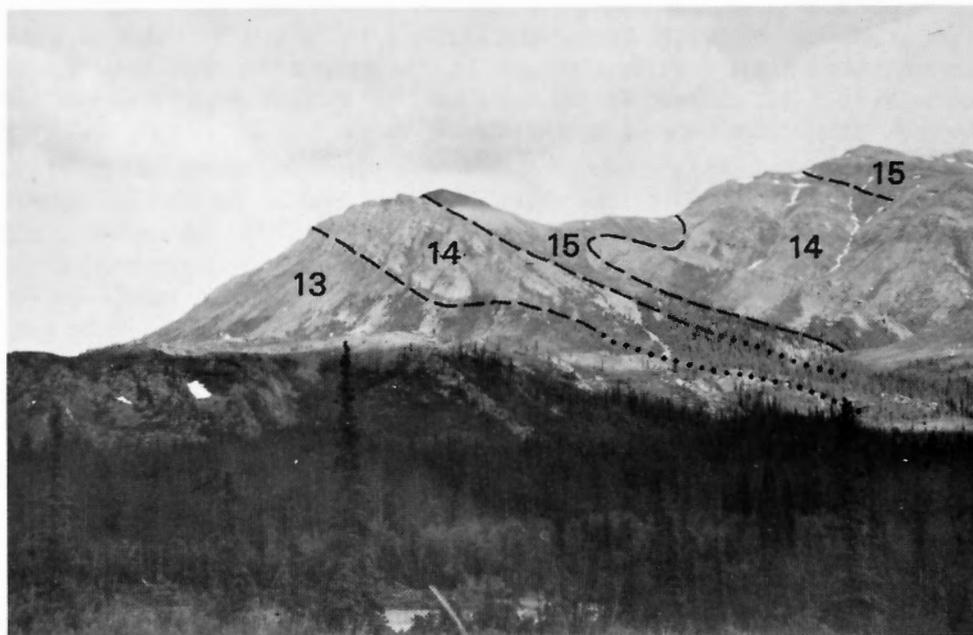
Stratigraphic throw on the two faults between the Wolf Creek and Scoutcar Creek thrusts increases from about 500 feet in the southwest to about 1,000 feet on the south side of Wolf Creek. There is no evidence to indicate whether or not the two faults extend northeast of Wolf Creek, but they probably end near where they cross that stream. The thrust faults probably dip southeastward at moderate angles because the strata between the Wolf Creek and Scoutcar Creek thrusts dip uniformly southeastward at about 35 degrees. In the southwest part of the Wolf Creek thrust sheet the dips flatten and the structures are replaced by several small folds.

Scoutcar Creek Thrust

The Scoutcar Creek thrust in the south central part of the Wolf Creek thrust sheet repeats strata of unit 13 intruded by diabase. The fault continues for 10 miles or more and probably ends to the northeast near where it crosses Wolf Creek. It probably extends southwestward to the margin of the map-area, but exposures southwest of Benson Creek are poor and the position of the fault is approximate.

The trace of the Scoutcar Creek thrust describes an S-shaped pattern at the head of Scoutcar Creek, where the thrust is folded by the Scoutcar Creek syncline and anticline. The folds in the fault surface plunge gently northeastward and change from relatively closely spaced structures in the southwest to open symmetrical structures in the northeast.

The dip-slip displacement on the Wolf Creek thrust is in the order of 10,000 feet (cross-section LM, Map 1248A), although the stratigraphic throw is only about 1,000 feet. Along most of its exposed length the thrust lies immediately above the slaty rocks of unit 13a, in places cutting down through these slates to the diabase sill (unit 16) that intrudes them. The Scoutcar Creek thrust dips southeastward at moderate angles except on the front-limb of the Scoutcar Creek anticline. Farther southeast the dip may flatten beneath the back-limb of the Scoutcar Creek anticline (cross-sections BC and LM, Map 1248A). The distribution



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FIGURE 16. Looking west across the valley of the North Klondike River in the east part of the Wolf Creek thrust sheet. Large sub-synclinal drag fold in green and red slates (unit 14) on the back-limb of the Grizzly Creek anticline. Massive orthoquartzites (unit 13) underlie the drag fold and siltstones (unit 15) form Mount Robert Service on the right.

of strata and similarity of the Scoutcar Creek thrust to folded thrusts in southern Alberta suggests that the folded part of the Scoutcar Creek thrust extends northeastward to Wolf Creek.

Structures above the Scoutcar Creek Thrust

Two northeast-trending folds, the Scoutcar Creek syncline and anticline, lie above and southeast of the Scoutcar Creek thrust. These folds extend for most of the length of the Wolf Creek thrust sheet, a distance of some 20 miles. The folds are symmetrical along much of their length and broaden progressively from southwest to northeast; their limbs dip at moderate and gentle angles. The folds plunge northeastward at about 5 degrees. Their axes diverge from the southwest and northeast toward the central part of the Wolf Creek thrust sheet, where several subsidiary folds occur on their limbs.

Numerous small-scale folds occur within rocks of units 14 and 15 in the northeast part of the Wolf Creek thrust sheet. Those in unit 14 are invariably asymmetrical or overturned with southeast-dipping axial planes (Fig. 16). They range in size from a foot to several hundred feet across and have rounded fold hinges. Axial plane cleavage is well developed in the slates of unit 14 and its intersection with bedding gives rise to a locally prominent lineation. The minor folds in the siltstones of unit 15 differ from those of unit 14 in that the larger

ones, 100 feet or more across, are symmetrical chevron folds, with nearly vertical axial planes and sharp fold hinges. The smaller folds, several feet between limbs, are asymmetrical and like those of unit 14. The axes of the small scale folds in units 14 and 15 conform to the trend of the axes of larger structures and generally plunge northeastward at low angles.

The Scoutcar Creek anticline is broken by a northwest-trending, normal cross-fault about 2 miles west of the mouth of Wolf Creek, in the zone of steepest plunge. This cross-fault brings the northeast side up relative to the southwest and dips steeply to the southwest so that the fault plane is roughly perpendicular to the axis of the Scoutcar Creek anticline. The cross-fault dies out rapidly on the flanks of the anticline and its maximum displacement is at the crest of the fold, where the throw is about 1,500 feet; lateral displacement is negligible. Normal cross-faults, like the one described above, occur typically in the steeply plunging parts of an anticline, where they are thought to be localized during folding by longitudinal stretching of the anticlinal arch (de Sitter, 1956, p. 208). The cross-fault lies in the plane of minimum compressive confinement and is a tension fault.

Three thrust faults, the longest of which continues for 6 miles, occur near Ying Yang Creek on the southeast side, or back limb, of the Scoutcar Creek anticline. The faults dip steeply to the southeast (as inferred from the distribution and attitude of the intervening strata) and repeat rocks of units 13a and 16; maximum stratigraphic throw occurs between Peasoup and Ying Yang Creeks and is about 1,000 feet. Strata between the thrusts dip uniformly to the southeast at about 60 degrees. These back-limb thrusts resemble those found in the Foothills region of southern Alberta, where these structures generally merge with the underlying major thrust. It is assumed therefore that the back-limb thrusts of the Wolf Creek thrust sheet show similar relations and that they merge with the Scoutcar Creek thrust at depth (this interpretation is shown in cross-sections BC and LM, Map 1248A).

Two other back-limb thrusts similar to those already described, and southeast, occur on the southeast limb of the Scoutcar Creek anticline. These faults repeat unit 13b and dip southeastward; like the other back-limb faults their maximum throw (about 1,000 feet) occurs between Ying Yang and Peasoup Creeks and they end northeast and southwest of these streams.

The Peasoup Creek syncline and anticline, outlined by units 13b and 14, are somewhat asymmetrical in the southwest and become symmetrical and broader in the northeast. Both folds extend for about 20 miles along the length of the Wolf Creek thrust sheet, but their axes converge and the syncline dies out against the anticline near Peasoup Creek. The continuity of both these folds from Ying Yang Creek to North Klondike River is uncertain because there is no outcrop. A small anticline flanked by two synclines and outlined by rocks of unit 14 lies southeast of the Peasoup Creek anticline and below the Dipslope Mountain thrust. The continuity of this group of folds is unknown.

The Dipslope Mountain thrust faults unit 13a with the intruded diabase sill (unit 16) above unit 14 and the upper part of unit 13. The fault is well exposed on Dipslope Mountain where it is only about an inch wide. It contains little or

no gouge and the fault surface is nearly parallel with bedding in the underlying orthoquartzites. The diabase immediately above the fault is sheared and slickensided, but not noticeably more than in many other outcrops. The fault surface dips uniformly to the southeast at 45 degrees. It cuts the underlying syncline and apparently transects the anticline outlined above it by the diabase sill. The fault itself is inconspicuous and its characteristics are similar to those found at thrust surfaces in other regions.

Other than the truncated anticline (cross-section CD, Map 1248A), the structures above the Dipslope Mountain thrust are unknown, because exposures on the dipslope into North Klondike River are poor. There is no outcrop on the east side of North Klondike River beneath the North Fork thrust, and the structures there are also unknown.

Robert Service Thrust Sheet

The narrow belt of rocks of units 10 and 12 that lies along the southeast margin of Tombstone area, between the Robert Service and North Fork thrust faults, constitutes the Robert Service thrust sheet (Fig. 13). In places the North Fork thrust appears to have completely overridden the Robert Service thrust sheet so that the latter appears on the map as two disconnected segments. No large folds or faults are recognized within the Robert Service thrust sheet, although small-scale folds are common. Minor folds in unit 12 are like those described from unit 11 of Little Twelve Mile Division; they have the same size and shape and they trend roughly northeastward parallel with the strike of bedding. A small syncline and anticline occur in rocks of unit 12 immediately above the Robert Service thrust along part of its length (cross-section RS, Map 1248A).

Robert Service Thrust

This important fault appears from below the North Fork thrust at two places in the map-area and undoubtedly extends between them beneath the overthrust strata, continuing for at least 15 miles. The Robert Service thrust dips southeastward at moderate angles and has brought Triassic (unit 10) and Jurassic (unit 12) rocks above the Lower Cretaceous strata (units 14 and 15). The stratigraphic throw on the fault is about 5,000 feet and dip-slip displacement is probably twice that or more. Because the displacement on the Robert Service thrust is large it probably is more continuous than the thrust faults already described. The possibility that this fault extends eastward beyond the map-area to Mayo district beneath overthrust strata of the North Fork thrust sheet is discussed in the section on the Keno Hill - Tombstone River belt.

The relationship between the Robert Service and North Fork thrusts is unknown because there is no outcrop where the two faults are presumed to intersect. The difference in the dips of the two faults observed elsewhere (i.e., gentle dip of the North Fork thrust and moderate dip of the Robert Service thrust on Mount Robert Service) suggests that the North Fork thrust truncates the Robert

Service thrust. Another interpretation, in which the two faults merge above, is also possible and perhaps more likely in view of evidence from other thrust-faulted regions.

North Fork Thrust Sheet

The fault that marks the southeast margin of the map-area was first recognized by Green and Roddick (1962, p. 18) and is herein named the North Fork thrust, after the North Klondike River whose valley the fault follows for 20 miles. The North Fork thrust is a low-angle, reverse fault that dips southeastward at 15 degrees or less, an angle estimated from the map-pattern of the fault trace. Probable Precambrian strata directly overlie Mesozoic rocks indicating that displacement on this fault is much larger than that on the other faults in the map-area. The stratigraphic throw is at least 11,000 feet (thickness of Lower and Upper Divisions combined), and probably considerably more. The dip-slip movement on the North Fork thrust must be at least 10 miles if its 15-degree surface dip persists to depth.

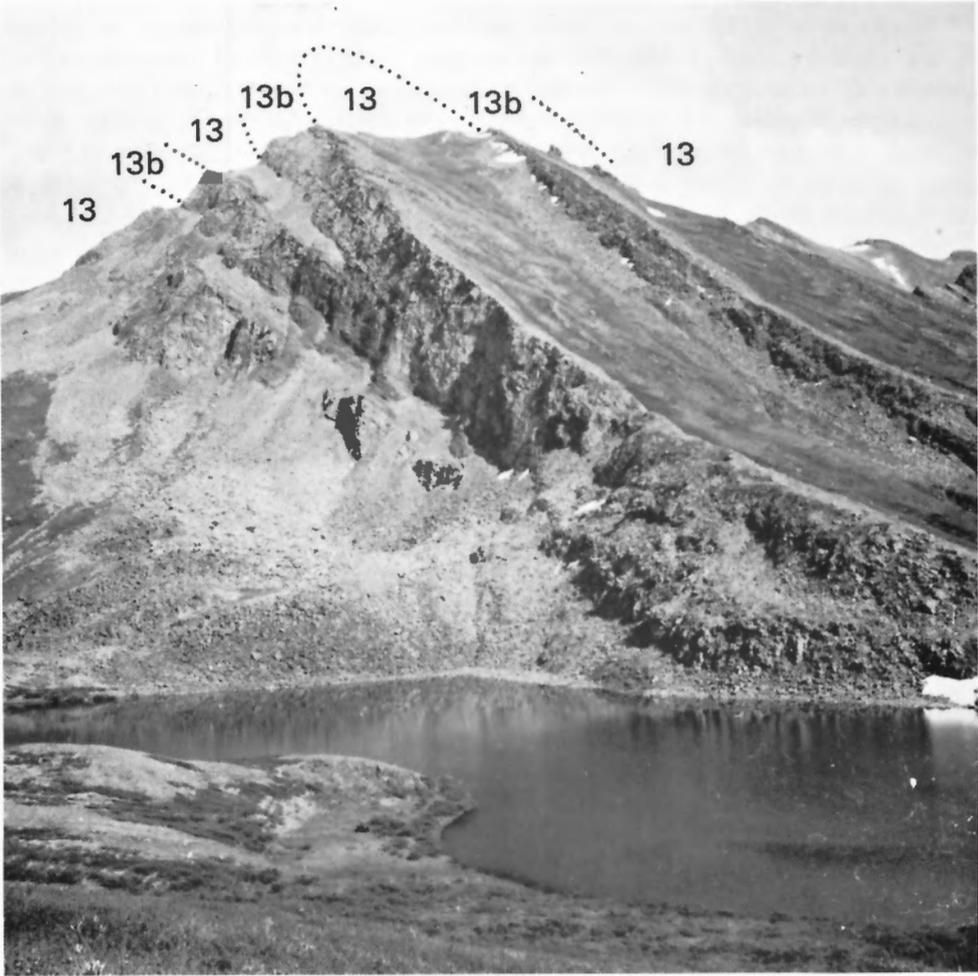
A distinct topographic break, along which the overthrust strata stand in pronounced relief above those that occur below the fault, marks the position of the North Fork thrust. This break is emphasized by the different weathering characteristics of the Precambrian and Mesozoic rocks. The fault surface is not exposed in the map-area, because talus from the overthrust strata covers it.

The structure of the North Fork thrust sheet has not been investigated in this study, but a few remarks may be made from a cursory examination of these rocks. Small-scale, subisoclinal, similar overturned folds are common in the overthrust strata. They are generally about 5 feet across but some as large as 100 feet were seen. The folds have rounded hinges and southeast-dipping axial planes and their axes trend northeastward, roughly parallel with the North Fork thrust. The orientation of the minor structures indicates north or northwest movement of overlying beds relative to underlying strata. No lineation was seen.

Northeastern Division

The Northeastern Division (Figs. 1, 13) which lies north of the Wolf Creek thrust-Grizzly Creek anticline and east of Tombstone stock, includes rocks of units 11, 13, 14, 15, and 16. Folds are the most prominent structures, but two thrust faults and several tear faults disrupt the strata.

Structures of the Northeastern Division trend eastward in contrast to those of other subdivisions of the map-area, where northeast trends predominate. The folds expose successively younger strata from west to east indicating an overall gentle eastward plunge of these structures similar to the one found in the adjoining Wolf Creek thrust sheet to the south. Most folds are asymmetrical, with steeply dipping north limbs and more gently dipping south limbs (Figs. 19, 20). Their sizes change across the Northeastern Division with larger folds in the south than in the north. Many structures continue along the length of the subdivision and the larger folds can be traced across the tear-faults.



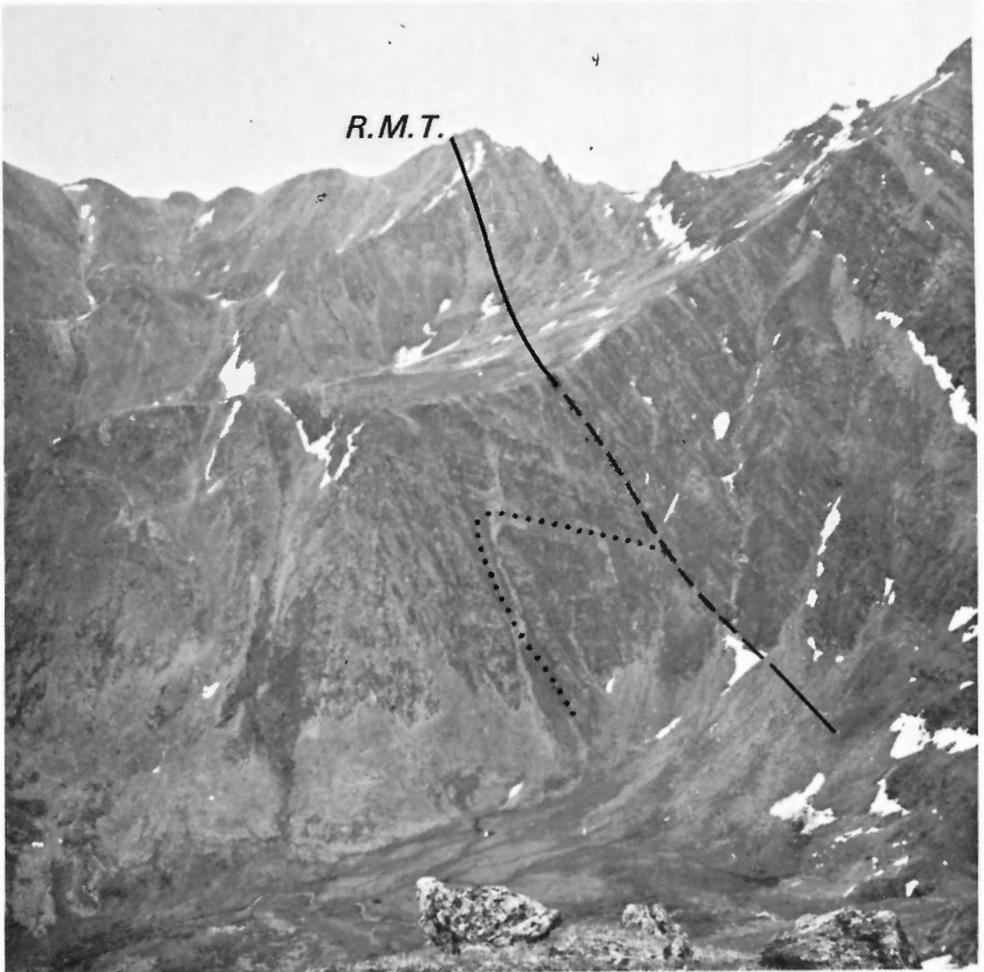
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FIGURE 17. The unnamed overturned syncline and anticline pair in the Northeastern Division outlined by sandy limestone (member 13b) looking east across a small lake on Fold Creek.

Structures in rocks of unit 11 are small-scale east-trending folds like those already described from the Little Twelve Mile Division. In the Northeastern Division the contact between units 11 and 13 is a sharp, planar break that is sub-parallel with bedding in the rocks above and below it (Fig. 8). The contact dips southward at relatively shallow angles of between 20 and 30 degrees (as seen in outcrops and inferred from the map-pattern), and follows approximately the same stratigraphic horizon in unit 13 along the length of the Northeastern Division. As elsewhere in Tombstone area, large folds in unit 13 do not carry cores of strata belonging to unit 11, indicating that the contact between units 11 and 13 is a plane of detachment or décollement.

Structures below the Rockcandy Mountain Thrust

Rocks of units 13 and 16 below the Rockcandy Mountain thrust are broken by an unnamed thrust fault that lies in the northern part of the Northeastern Division. This unnamed thrust continues along most of the length of the subdivision (about 9 miles) and is offset by the Fold Creek tear fault. It repeats strata of units 13a and 16 and the stratigraphic throw is between 100 and 500 feet along much of its length (cross-sections NO, QR, TU, Map 1248A). On the west the unnamed thrust is truncated by the Axeman Creek tear fault. The unnamed thrust fault dips southeastward at moderate angles (as inferred from its map-



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FIGURE 18. The Rockcandy Mountain thrust (RMT) in the Northeastern Division looking east near the head of Fold Creek. The fault repeats orthoquartzites of unit 13. Note that beds above the thrust are parallel with it and that the thrust truncates a small anticline (outlined by bedding in unit 13) below it.



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FIGURE 19. The Fold Mountain anticline and syncline looking southeast across the structural trend in the Northeastern Division. The structures are outlined by beds of massive orthoquartzite (unit 13).

pattern), and its dip-slip displacement is approximately 2,000 feet. The fault probably merges with the décollement at depth approximately as shown in the cross-sections. Strata below the unnamed thrust fault are folded into relatively small asymmetrical synclines and anticlines with southeast-dipping axial planes (e.g., cross-section TU, Map 1248A).

As in other parts of the map-area, the slates of unit 13a contain numerous east-trending minor folds (about 6 inches across). These small folds are subisoclinal, overturned structures with rounded fold hinges; in cross-section viewed from the west they look like the letter S. Axial plane cleavage cuts the bedding at acute angles giving rise to a poorly developed, east-trending lineation.

An asymmetrical syncline and anticline pair, with southeast-dipping axial planes outlined by rocks of units 13a, 16, and 13b, lies below the Rockcandy Mountain thrust. These folds are open west of the Fold Creek tear fault; and have smaller subsidiary folds on their limbs, but east of the tear fault the syncline and anticline are tight and slightly overturned (Fig. 17). The folds probably continue east of North Klondike River where an open syncline-anticline pair, that may be their counterpart, occurs roughly along strike.

Rockcandy Mountain Thrust and Structures above It

The Rockcandy Mountain thrust lies above an anticline and extends for 10 miles or more along the length of the Northeastern Division. The fault is offset by the Fold Creek tear fault, which has moved its eastern portion northward and/or downward, relative to its western part. The Rockcandy Mountain thrust truncates strata of units 13 and 16 and brings unit 16 above unit 13b along much of its length. Stratigraphic throw is between 1,000 and 1,500 feet. The fault is well exposed at the head of Fold Creek, where it is clearly visible from a distance (Fig. 18), but from nearby it is inconspicuous and easily overlooked. The fault surface dips southward at about 50 degrees and is marked by a narrow (1 inch), slickensided gouge zone, below which the orthoquartzites are fractured and veined with quartz. On the west the Rockcandy Mountain thrust is truncated and offset to the south by the Axeman Creek tear fault, southwest of which it is cut



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FIGURE 20. The Fold Mountain anticline and syncline outlined by strata of unit 13 in the Northeastern Division looking west toward Fold Mountain.

by the Tombstone stock. The surface traces of the Rockcandy Mountain and Mount McIntyre thrust faults on the northeast and southwest sides of Tombstone stock are along strike and these two faults may be equivalent, having been connected prior to intrusion of syenite.

A series of asymmetrical folds that involve rocks of units 13, 14, and 16 lies above and south of the Rockcandy Mountain thrust (cross-section QR, Map 1248A). From north to south these are the Fold Mountain syncline and anticline (Figs. 19, 20), Mount Cairnes syncline and anticline (Figs. 21, 22), and Grizzly Creek syncline and anticline. In the west part of the Northeastern Division the Fold Mountain anticline is more than 3,000 feet across and lies directly above the Rockcandy Mountain thrust (cross-section NO, Map 1248A). East of the Fold Creek tear fault this single large structure is replaced by three fold pairs each about 500 feet between limbs (cross-section QR, Map 1248A).

The asymmetrical Mount Cairnes and Grizzly Creek syncline-anticline pairs, which lie south of the structures just described, are four large folds of which the anticlines are each about 3,000 feet across (cross-section QR, Map 1248A). They extend from the eastern margin of the map-area to the Fold Creek tear fault, a distance of 6 or 7 miles. The Grizzly Creek anticline is apparently not offset by the Fold Creek fault (although exposures are poor where it crosses Grizzly Creek), but continues westward along Grizzly Creek, becoming smaller in that direction. The Mount Cairnes syncline and anticline, however, terminate against the Fold Creek fault and do not reappear west of it.

Fold Creek, Axeman Creek, and Other Tear Faults

The Fold Creek tear fault, in the centre of the Northeastern Division, disrupts strata of units 13, 14, and 16. It is vertical on the ridge west of Fold Creek and describes a sinuous pattern extending south-southwestward from the décollement to Grizzly Creek, a distance of 5 miles. Exposures are not good where the tear fault meets the décollement but it probably does not offset that surface. The Fold Creek tear fault cuts folds and thrust faults and is not confined to a single thrust slice. Strata on its east side have moved north and/or downward, relative to those on the west side. The amount of relative lateral displacement of structures, measured along the fault, decreases from north to south or away from the décollement. The folds east of the Fold Creek tear fault are more compressed than those on the west; the displacement of fold crests (e.g., about 4,000 feet for the Fold Mountain anticline) has been dominantly horizontal with a small vertical component.

Many similarities between the Fold Creek and Axeman Creek tear faults are readily apparent. The Axeman Creek tear fault trends N15° E. It is a straight, vertical break that extends for 4 or 5 miles from near Wolf Creek to North Klondike River. Although there is no evidence, because of lack of exposures, to indicate whether the Axeman Creek tear fault continues north of the North Klondike River, it seems likely that it does, but the fault does not offset the décollement contact between units 11 and 13. Movement on the Axeman Creek tear fault has brought the east side northward and/or downward relative to the west side, indicating the same sense of displacement as on the Fold Creek tear fault. The relative lateral displacement decreases southward from a maximum of about 8,000 feet (as measured from the offset on the Rockcandy Mountain thrust). The displacement on the Axeman Creek tear fault, like that on the Fold Creek tear fault, is dominantly horizontal with a relatively small vertical component.

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A third smaller tear fault, that trends N25°E, lies between the Fold Creek and Axeman Creek tear faults. Its displacement is of the same sense as that on the two larger tear faults, but unlike those, this small tear fault is confined to the thrust slice below the Rockcandy Mountain thrust. The displacement is less than that on the Fold Creek tear fault (about 300 feet) and has been dominantly in a horizontal direction.

Two small northwest-trending (N45°W) tear faults occur east of the North Klondike River in the Northeastern Division. Both are vertical and both have the same sense of displacement (i.e., east side south and/or up relative to the west side: opposite to the movement on the northeast-trending tear faults). The displacement is in the order of 1,000 feet with a dominant horizontal component as indicated by the offsets of fold crests. The eastern of these two small tear faults is well exposed where it meets the décollement and it does not offset that surface, but ends abruptly on it. The significance of the tear faults is discussed under “Structural Summary”.



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FIGURE 21. Looking west on the south flank of Mount Cairnes toward the asymmetrical Grizzly Creek anticline, outlined by beds of massive orthoquartzite (unit 13). The beds in the right foreground are overturned on the front limb of the fold.

Cloudy Range Division

This division in the north central part of the map-area lies along the north margin of the Tombstone stock between the Axeman Creek fault on the east and an unnamed cross-fault on the west (Fig. 13). Although exposures in Cloudy Range are good and most of its structures, considered separately, are clear, the overall structure is not well understood because the rocks have been thermally metamorphosed and stained by iron oxide so that only one stratigraphic marker (the diabase sill) can be recognized. Several large folds occur in the division, but thrust faults, which probably occur, cannot be delineated (except for two in the east part of the division).

The unnamed, west-trending cross-fault that lies south of Yoke Mountain offsets the contacts of the Brenner and Tombstone stocks and cuts the Mesozoic strata between them. The fault is nearly vertical where seen and strata on its north side are dropped down relative to rocks on the south. Its stratigraphic throw is about 1,000 feet and because there is no evidence of lateral displacement this figure approximates the dip-slip movement; some rotational movement may have occurred to account for the difference in dips on the north and south sides of the fault. The fault post-dates intrusion and is not related to folding of the Mesozoic rocks.

On Yoke Mountain north of the cross-fault, the diabase sill outlines a large asymmetrical anticline with a steeply dipping northwest limb and a nearly flat-lying back limb. This fold is probably the continuation of the structures immediately above the Little Twelve Mile thrust in the Little Twelve Mile Division. The Yoke Mountain anticline is truncated against the Tombstone stock north of Yoke Mountain, but the diabase sill in its steeply dipping northwest limb continues northeastward for 4 miles to the vicinity of Azure Lake. Near the lake the sill ends, but the nature of the termination is unknown.

The diabase sill outlines two anticlines and an intermediate small syncline in the northeast part of the Cloudy Range Division (Fig. 23). These folds may be the continuation of the Yoke Mountain anticline with which they are on strike. The front limb of the northern anticline may be truncated against the décollement, but exposures are poor and other faults may be present.

The northeastern folds are probably separated from the anticline south of them by a thrust fault, because no syncline is found between these two structures, and because the thickness of strata is incompatible with a normal stratigraphic succession. The position of this probable fault is unknown, because no stratigraphic markers were recognized between the two structures.

Two thrust faults occur in the southeast part of the Cloudy Range Division, south of the North Klondike River. They are truncated by the Axeman Creek fault and are the offset equivalents of the Rockcandy Mountain thrust and the thrust fault below it in the Northeastern Division. The upper of the two faults repeats strata of 13b; its stratigraphic throw is about 1,000 feet. The lower fault repeats the diabase sill on the back limb of the large anticline.

The structures of Cloudy Range illustrate clearly the slight effect that the syenite intrusions had on the invaded sedimentary strata. Two structural features are thought to have resulted from intrusion. A few tight folds about 500 feet across, with nearly vertical limbs and sinuous axes, are found within a few hundred feet of the intrusive contacts along the north margin of Tombstone stock. These structures may have formed during intrusion, but may also be pre-intrusion folds that were compressed and reoriented at the



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FIGURE 22. The asymmetrical Mount Cairnes anticline in the Northeastern Division looking west toward Mount Cairnes. The fold is outlined by beds of massive orthoquartzite (unit 13) capped with green and red slate (unit 14) and appears strongly overturned because the view is across the structural trend.

time the country rocks were invaded. Between the Tombstone and Brenner stocks the sedimentary strata stand with nearly vertical dips, but away from this confined zone the dips flatten and become more normal. The steep dips probably resulted from rotation of the beds caused by confinement between the two stocks.

Age of Deformation of the Upper Division

In Tombstone area Mesozoic strata were thrust and folded at a time that clearly preceded intrusion of acid igneous rocks. The period during which this deformation could have occurred is limited, as the youngest deformed rocks (unit 15) are probably mid-Lower Cretaceous and as the intrusive rocks were probably emplaced about the mid-Cretaceous. Thrusting and folding probably occurred during late Early Cretaceous time in Tombstone area.

Thrusting and folding of the rocks of Tombstone area probably corresponds to the Aptian orogeny that affected much of Alaska (Gates and Gryc, 1963). In east central Alaska this orogenic event is represented by an angular unconformity between Lower and

Upper Cretaceous rocks (Mertie, 1930a; Brabb and Churkin, 1964). A stratigraphic hiatus that includes part of the Albian and Aptian in northern Yukon Territory (Jeletzky, 1961a) may also correspond to this orogenic episode, even though a period of extensive deformation and mountain building is not indicated in that region. Gabrielse and Reesor (1964) have shown that deformation and intrusion occurred about mid-Cretaceous time in much of the Cordilleran region south of Tombstone area, that is, in British Columbia and southern Yukon Territory.

Structural Summary and Discussion

The important structural features of Tombstone area are summarized on the following pages. Their significance and interrelations are discussed and the structural scheme is briefly compared and contrasted to that of other thrust-faulted and folded regions.

1. The Lower Cretaceous succession of Tombstone area is repeated by a number of thrust faults whose position and extent is inferred from the distribution of strata and the truncation of folds. The thrust faults diverge toward the centre of the map-area from its southwest and northeast parts. The thrusts dip southeastward at angles of between 30 and 60 degrees; strata above them are moved northwestward relative to underlying beds. The maximum stratigraphic throw on the thrust faults within the Lower Cretaceous strata is between 1,500 and 2,500 feet and their maximum dip-slip displacement is in the order of 5,000 feet. The maximum throw occurs in a zone that coincides with the area where individual thrust sheets are widest and is approximately in the line of cross-section EM (see Map 1248A); most thrust faults lose stratigraphic throw southwest of this line and end northeast of it. A folded thrust fault, the Scoutcar Creek thrust, with several associated back-limb thrusts occurs in the southeast part of Tombstone area.

2. The strata between the thrust faults are folded concentrically. Folds change in cross-section both along and across the structural trend: their size and shape show an apparent relationship to the stratigraphic level at which the folds occur. In the southeast part of the area, where the highest stratigraphic units are exposed, anticlines are large and symmetrical, being separated by narrow synclines. In contrast anticlines in the northwest and north parts of Tombstone area, where low stratigraphic units occur, are small and symmetrical with broad intermediate synclines (cross-sections NP, QS, and TV, Map 1248A). The folds plunge gently northeastward away from the zone of maximum stratigraphic throw on the thrust faults. In asymmetrical anticlines the northwest limbs invariably dip more steeply than the southeast limbs so that the axial planes of folds dip southeastward. Small scale drag folds, which are related to the larger structures, occur in the incompetent strata.

3. A series of northeast- and northwest-trending, vertical tear faults disrupt the strata in the Northeastern Division. These faults offset thrust faults and folds within the competent Lower Cretaceous strata, but they do not cut the underlying Jurassic slates. The thrust faults and most folds have counterparts on both sides of the tear faults, but the shape of individual folds differs on either side. The tear faults define two complementary shear directions (N20°E and N45°W) on which oppositely sensed movement with a dominant horizontal component has occurred; sinistral displacement characterizes the northeast-trending tear faults.

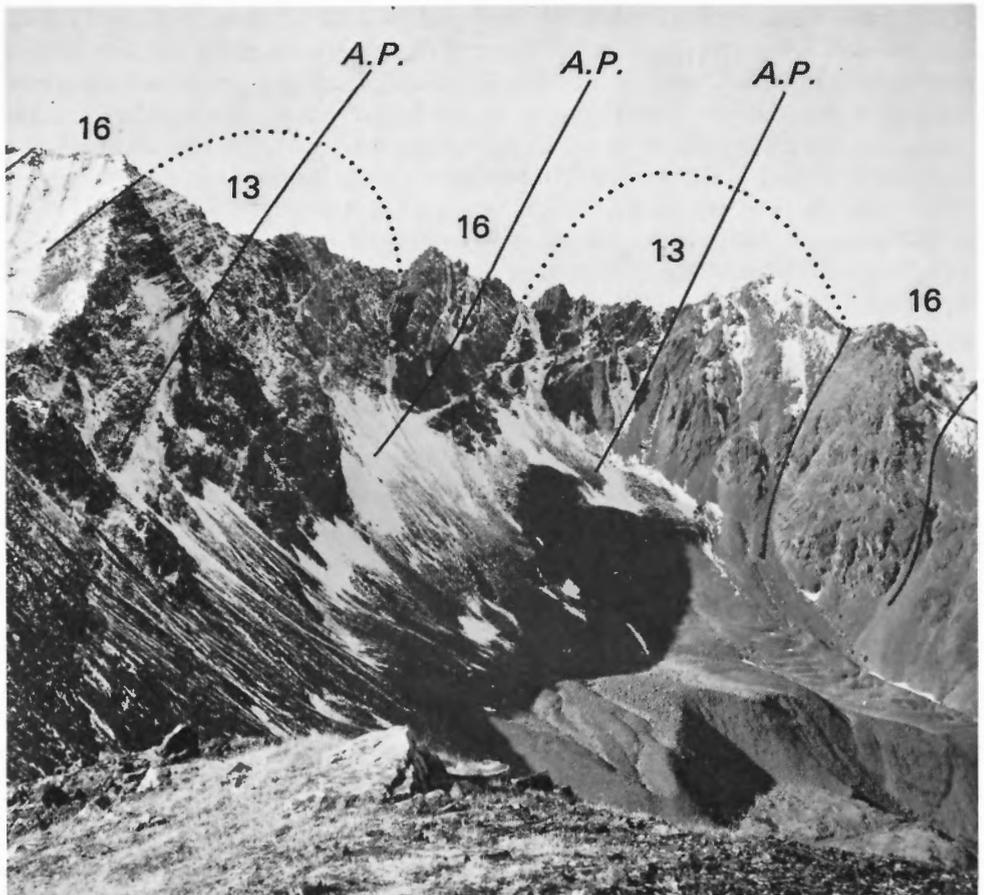
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4. The succession of Lower Cretaceous strata is faulted and folded above a surface of basal detachment or *décollement* and below a major thrust fault, the North Fork thrust. The *décollement* separates competent Lower Cretaceous rocks from underlying incompetent Jurassic strata and the North Fork thrust brings Precambrian above Mesozoic rocks. Structures within the Lower Cretaceous sequence define a series of imbricate thrust slices between the *décollement* and the North Fork thrust.

5. The folded and faulted Early Cretaceous strata are intruded by probable mid-Cretaceous syenite stocks indicating that deformation took place in late-Early Cretaceous time.

Outcrop Width of the Lower Cretaceous Strata

The most striking feature about the belt of Lower Cretaceous rocks of Tombstone area is its change in outcrop width from northeast to southwest. This change is directly related to the amount of structural thickening of unit 13 by thrust faults and folds. In the



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FIGURE 23. Folded diabase sill in the Cloudy Range Division looking west near the north margin of Tombstone area; numbers refer to map units and axial planes are indicated (A.P.).

central part of Tombstone area, where displacement on the thrust faults is a maximum, and where individual thrust sheets are thickened most by internal folding, the orthoquartzite sequence is 14 miles wide and repeated about 20 times, so that its cumulative thickness is nearly 50,000 feet. In contrast the outcrop width of unit 13 in the northeast part of Tombstone area, where most thrust faults end, is only 4 miles and its thickness repeated by folds is about 10,000 feet. Along the south margin of Tombstone area, where displacement on the thrusts decreases and where the thickness of the thrust sheets diminishes, the orthoquartzite belt is only 10 miles wide.

Structural Shortening and Rate of Movement

The maximum stratigraphic throw and displacement on individual thrust faults has been indicated in the foregoing structural description. It is interesting to note the total maximum displacement and to use this as a measure of the total crustal shortening involved in the deformation. The total maximum throw on the thrusts within the Lower Cretaceous strata (this excludes the Robert Service thrust and the North Fork thrust) is about 20,000 feet and a rough but conservative estimate of the total dip-slip displacement is about 11 miles. The horizontal component of the dip-slip displacement, which may be used as an approximation of the crustal shortening, is between 6 and 8 miles, assuming an average dip on the thrust faults of between 30 and 45 degrees. Shortening as a result of the thrusts within the Lower Cretaceous rocks is therefore about 7 miles. This figure does not account for additional shortening from folding with the Mesozoic rocks by perhaps half as much again, which brings total shortening within the Lower Cretaceous rocks to about 10 miles. To this figure must be added the shortening caused by at least 3 miles (but probably more) of dip-slip displacement on the Robert Service thrust and the shortening produced by a minimum of 10 miles of movement on the North Fork thrust. A total shortening in the order of 20 or 25 miles is therefore indicated.

Units 13-16 were emplaced and deformed during an interval of about 40 m.y. (between 135 m.y. and 95 m.y. ago). If the time required for deposition of the sediments can be evaluated, an estimate can be given of the time during which deformation took place. If one assumes a conservative rate of sedimentation of 300 feet per million years (Kay, 1955) it might have taken 15 m.y. to deposit units 13, 14, and 15. This time is probably excessive if no breaks in sedimentation occurred. The time taken to emplace and cool the diabase sill (unit 16) is minimal and negligible in this calculation. This leaves at least 25 m.y. in which thrusting and folding of the rocks could have been accomplished. The slowest average rate of movement on all the thrust faults that can accommodate the minimum of 25 miles of displacement on them in the 25 m.y. interval is one mile per million years if deformation is assumed (perhaps unrealistically) to have immediately followed sedimentation and to have been continuous throughout the 25 m.y. time span.

Estimates of the average rate of displacement on individual thrust faults range from one mile per million years (Ruby and Hubbert, 1959, p. 196) to several miles per million years (Oriol and Armstrong, 1966, p. 2615), and a rate that extrapolates to about 15 miles per million years has been measured locally on an active thrust over a short time span (Gilluly, 1949, p. 564). Oriol's and Armstrong's (1966) estimate is probably the more realistic average and if their figure applied in Tombstone area the displacement on

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the thrust faults, and the accompanying folding, could have been accomplished during an interval of 10 m.y., sometime between 120 and 95 m.y. ago.

Bedding Plane Thrusts

Many thrust faults in the Lower Cretaceous strata of Tombstone area bring the diabase sill, which is intruded into black slates of member 13a, above rocks of units 13 and 14. This is probably significant and not coincidental. Unit 13a is the only thick incompetent member in the otherwise competent succession of Lower Cretaceous strata and it therefore provides the only probable zone of bedding plane slippage in that succession (Fig. 5). Many geologists have demonstrated that thrust faults generally follow bedding in incompetent strata for long distances and cut diagonally across bedding in competent rocks. Therefore the path length of any thrust in incompetent strata is longer than that in competent beds so that in most exposures the thrust will lie in a zone of bedding plane slippage. For this reason most thrust faults in Tombstone area lie within rocks of unit 13a and below the diabase sill intruded into it.

In view of the foregoing it is surprising that there are not more thrust faults in the area that repeat the thick incompetent succession of Jurassic slates (unit 11) and bring it above the Lower Cretaceous orthoquartzites of unit 13, for the slates of unit 11 might be expected to provide a good zone of bedding plane slippage. Only the Little Twelve Mile and the Robert Service thrusts fault unit 11 above unit 13. A possible interpretation of this situation is that most thrust faults do not cut down below the competent Lower Cretaceous strata into unit 11, but merge instead with the décollement at the top of unit 11. Evidence from the tear faults supports this hypothesis.

Relationship Between Fold Plunge and Throw of Thrust Faults

The gentle northeastward plunge of folds in the northeast half of Tombstone area (i.e., parts of the Wolf Creek thrust sheet and the Northeastern Division) is apparently related to the northeastward decrease in the stratigraphic throw on the thrust faults away from the line of cross-section EM (Map 1248A). This relationship suggests that the fold plunge is a reflection of the loss of stratigraphic throw on the thrusts. If this is valid, a complementary southwestward plunge is to be expected because the thrusts also lose stratigraphic throw southwest of the line of cross-section EM (Map 1248A). Such a plunge to the southwest is not evident in the map-area, but a brief examination of the region south of Tombstone area, where unit 14 is present, suggests that a southwestward plunge does occur there. These relations imply that the plunge of the folds within the thrust sheets of Tombstone area is related to, and in the direction of, decreasing throw on the thrust faults.

Size and Shape of Folds – Depth of Folding

The size and shape of the folds in the Lower Cretaceous rocks of the Northeastern Division show a relationship to the stratigraphic level at which the folds occur: at low stratigraphic levels anticlines are narrow, sharp-crested, and separated by broad synclines; at high levels anticlines are broad and separated by narrow synclines. This relationship is characteristic of areas where the strata are concentrically folded. It shows that the folds die out upward and downward from a level of maximum flexure which occurs, in Tombstone area, a few hundred feet below the top of unit 13. The condition of

concentric folding requires a plane of structural discontinuity, detachment or décollement, below which the strata are not folded with the overlying rocks. The depth of this detachment surface can be calculated approximately from the geometry of any anticline in the folded strata above it, if it is assumed that there is no volume change attendant upon folding. The relation used in this calculation is given below:

$$d = \frac{bh}{1-b} \quad (\text{Billings, 1947, p. 56})$$

where d is the depth of folded strata beneath the anticline

b is the wavelength of the anticline

h is the height or amplitude of the anticline

l is the length of any folded horizon in the anticline.

As an example the equation is applied to the Mount Cairnes anticline. The measurements are taken from cross-section QR (Map 1248A) and apply to the horizon at the contact between units 13 and 14.

$$b = 2,700 \text{ feet} \quad h = 1,600 \text{ feet} \quad l = 4,000 \text{ feet}$$

$$d = \frac{2700(1600)}{4000-2700} = 3,300 \text{ feet}$$

The depth of folding beneath the Mount Cairnes anticline coincides roughly with the projected position of the contact between units 11 and 13 – the décollement surface. Similar calculations for other folds in the Northeastern Division show that the depth of folding changes from north to south and becomes progressively deeper southward. These calculations indicate that the detachment surface dips gently southward at about 15 degrees in the Northeastern Division. The calculated depth of folding roughly coincides with the probable position of the contact between units 11 and 13 throughout the Northeastern Division and this corroborates field evidence for a décollement at this contact. The depth of folding calculations also provide a rough check of the thickness of unit 13.

Depth of folding calculations like those used above involve several assumptions and approximations, which decrease their accuracy and make them rather more qualitative than these figures might suggest. First, the cross-sections from which the measurements are taken are assumed to be accurate in every detail – rarely if ever can a geological cross-section be more than schematic and the actual dimensions of folds are probably considerably different from those measured in the geological cross-section. Second, it is assumed that pure concentricity applies throughout the folded succession – this is rarely true because a certain amount of internal deformation during concentric folding probably occurs leading to a combination of concentric and similar folding. The errors introduced by non-adherence to these two assumptions are difficult to estimate, but may be in the order of 25 per cent. The depth of folding calculations should therefore be regarded as qualitative approximations, which are nevertheless useful as no better method is available.

A third and very important assumption in the depth of folding calculations is that the fold to which the calculation applies lies directly above the décollement and that no thrust fault or other structural discontinuity lies between. Where a fold lies above a thrust the depth calculation will give only the depth of the thrust and not the depth of the décollement. Because it is reasonably certain that the folds in the Northeastern Division do lie directly above the detachment surface, this condition probably exists. In other

parts of Tombstone area the applicability of this condition could not be determined and there depth of folding calculations may not be valid.

Tear Faults

The tear faults in the Northeastern Division cut thrust faults and folds and movement on them must therefore have followed thrusting and folding. However, some folding postdates the tear faults because folds are more tightly compressed on one side of each tear fault than they are on the other. The orientation of the tear faults and the displacement on them shows that they formed as a result of the same northwest-southeast compressive stress that produced the thrust faults and folds and which indicates that the tear faults are shear fractures related to that deformation. The tear faults displace the competent strata above the décollement, but there is no evidence to indicate that they offset rocks below that surface. On the contrary, at least one tear fault (the eastern one in the Northeastern Division) ends abruptly on the décollement, immediately above which its maximum displacement occurs. These features indicate that the competent Lower Cretaceous strata slid independently above the décollement moving differentially on either side of the tear faults. The dominantly horizontal displacement of fold crests on either side of the tear faults also indicates that the décollement dips gently to the south, for if this surface were steeply dipping the displacement would be dominantly vertical. A gently south-dipping décollement surface is in accordance with indications from the depth of folding calculations.

The tear faults furnish evidence that some of the thrusts in the Lower Cretaceous rocks probably do not cut down beneath the décollement, a suggestion made earlier in the section concerning bedding plane thrusts. The reasoning is as follows:

1. Post-thrusting movement has occurred on the décollement because a) tear faults cut thrust faults, b) movement on tear faults was accomplished by differential sliding of adjacent fault blocks on the décollement.
2. The décollement surface must have been reasonably flat while this movement occurred and it is inconceivable that this surface was broken by thrust faults.
3. If the thrust faults in the strata above the décollement did offset that surface the upthrust wedges would prevent post-thrusting displacement on the décollement.

This line of reasoning therefore implies that some of the thrust faults in the Lower Cretaceous rocks merge with the décollement at depth, perhaps following that surface for long distances. This interpretation is adopted in cross-sections TU, QU, and NO (Map 1248A).

Sequence of Formation of the Structures

The various related structures in the Lower Cretaceous rocks of Tombstone area formed in a fairly well-defined sequence. Deformation was probably initiated by broad flexuring of the Mesozoic strata. The thrust relations between units 11 and 16 in the Little Twelve Mile Division indicate stratigraphic omission of the lower 500 feet of unit 13 and show that broad folding of the contact between units 11 and 13 must have occurred prior to formation of the Little Twelve Mile thrust. The broad flexuring was followed by initiation of the thrust faults, and movement on them. Disharmonious deformation between the incompetent Jurassic rocks (unit 11) and the competent Lower

Cretaceous strata probably commenced when thrusting began, resulting in development of the décollement between these formations. Internal disharmonious folding of the Lower Cretaceous and Jurassic strata followed or accompanied thrusting. The folded Scoutcar Creek thrust indicates that it at least formed prior to some of the folding. Back-limb thrusts like those of the Wolf Creek thrust sheet are thought to have formed as a result of differential stress in the back limb of an asymmetrical anticline, when that limb was favourably oriented with respect to the stress field (Douglas, 1950, 1958). As such they probably formed during folding and perhaps after the major movement on the larger thrusts. The cross-fault in the Wolf Creek thrust sheet evidently formed during folding and the tear faults in the Northeastern Division originated about the same time. The tear faults cut thrust faults, but were formed before folding was completed, because folds on one side of each of them are more tightly compressed than those on the other. Movement on the décollement probably continued throughout deformation and until folding was completed, because it occurred as a direct result of structural readjustment between two disharmoniously deformed sequences.

Deforming Stress

The geometry and orientation of the various structures in Tombstone area give a fairly clear and consistent indication of the compressive, shear, and tensional strain directions that prevailed during deformation. The following factors are thought significant in this regard:

1. The overall northeastward trend of the thrust faults and folds in Tombstone area. The average trend ($N55^{\circ}E$) defines the direction of minimum compressive stress and shows that the maximum stress was directed northwest-southeast.
2. The trends of tear faults ($N20^{\circ}E$ and $N45^{\circ}W$), which define two directions of shear failure attendant upon folding.
3. The trend of the cross-fault in the Wolf Creek thrust sheet ($N20^{\circ}W$), a tension fault, formed during folding.
4. The sense and direction of movement on the thrust faults and the asymmetry of folds, which indicate that, during deformation, overlying beds moved northwestward relative to underlying strata.

The various structures are all the result of the same period of deformation and the interrelationships and orientations of the structures with respect to one another show that they are also the result of the same stress pattern.

The arc described by the structures in Tombstone area can be interpreted as the reflection of variation in the magnitude of stress of a uniformly oriented stress pattern, or it can be presumed to show that the orientation of the stress pattern varied. The former interpretation is preferred, because variation in the amount of strain is demonstrated by the differential movement on the thrust faults and changes in the amount of folding in individual thrust sheets. Differential movement on the thrust faults and variations in the degree of folding can therefore account not only for the changes in outcrop width of the Lower Cretaceous rocks, but also for the arcuate pattern of this deformed belt. The underlying cause for this variation in strain, which presumably reflects a variation in stress, is not known.

The Décollement Problem

The main structural problem of Tombstone area concerns the continuity of structures to depth and the extent to which the strata beneath the décollement are involved in the deformation that affected the rocks above it. Is the décollement the surface beneath which the strata are completely unaffected by the deformation as is thought to be so in the Jura Mountains? Or is this surface only a prominent structural discontinuity above and below which the strata were deformed differentially at the same time? And if the latter is true what is the effect of the deformation on strata beneath the décollement? These questions are partly answered by data from the map-area. The décollement is real enough: it is a surface of pronounced structural disconformity on which folds and tear faults in the overlying deformed rocks terminate, and with which at least some of the thrusts in the overlying strata are thought to merge. However, some thrust faults, like the Robert Service and North Fork thrusts, bring strata from beneath the décollement above those overlying it and some of the minor folds in unit 11, below the detachment surface, are evidently genetically related to the large folds above it. The décollement is therefore not the absolute base of the deformation and one is faced with the question of how deep the structures continue. Is there some other lower décollement surface, or are the structures of Tombstone area part of a large thrust slice whose sole fault lies north of the map-area? There is no evidence in the map-area or its vicinity to answer these questions, and although this evidence may become available with further work, it is interesting to speculate by comparing the structures with those of other well-studied regions.

One of these regions is the fold belt of the Jura Mountains to which the structures of Tombstone area bear some resemblance. Both areas are characterized by northeast-trending, broadly arcuate thrust faults and folds, and the deformed belt of Mesozoic rocks of Tombstone area resembles a scaled-down version of the Jura belt. The folds and thrust faults in the Jura Mountains lie above a surface of basal detachment on which the strata above are deformed independent of the rocks below. The thickness of beds involved in the Jura folding (about 6,000 feet) is about the same as that above the décollement in Tombstone area. Both the Juras and Tombstone area have prominent north-trending tear faults that disrupt the deformed rocks above the décollement. On the other hand none of the thrust faults in the Juras show displacement of the magnitude found on the Robert Service and North Fork thrusts, which bring strata from below the décollement above those overlying it. The strong asymmetry of the structures in Tombstone area is not evident in the Juras, where most folds are symmetrical, broad, open structures and where both northwest- and southeast-dipping thrust faults occur. Box folds, considered the typical jura fold style, are also not found in Tombstone area. The total shortening in Tombstone area is about the same as that in the Juras, or perhaps more, but whereas this shortening is effected in a 50 mile-wide fold belt in the Juras, it is concentrated in a belt only 10 or 15 miles wide in Tombstone area. The overall pattern of the Juras although similar to that of Tombstone area, is not the same. The main differences lie in the style and intensity of the deformation and the absence of any important involvement in the deformation of the basement beneath the Jura décollement.

Comparisons were also made with the thrust structures of the Northwest Highlands of Scotland and those of the Appalachian Mountains. There is little similarity between

the structures of Tombstone area and those of the Scottish Highlands, and the Appalachians appear to be similar to the better understood Alberta Rocky Mountains.

Structures of Tombstone area may profitably be compared to those of the Foothills region of the southern Alberta Rockies, from where a wealth of surface and deep-drilling information is now available. The Alberta Rockies are made up of a series of large, westward-dipping thrust sheets, superposed on one another, and deformed apparently independently of the underlying Precambrian basement. Individual thrust sheets in the Rockies are broken by numerous subsidiary imbricate thrusts, between which the strata of the thrust sheets are folded. The thickness of strata involved in the deformation in the Rockies exceeds 20,000 feet.

An analogy can be drawn between the structure of Tombstone area and that of the upper part of a single large thrust sheet in the Rockies. This interpretation is shown schematically in cross-section B (Fig. 24, *in pocket*). In this analogy the northern of the two thrust faults of cross-section B might be considered as the sole structure, and the North Fork thrust the sole of the next overlying thrust sheet, whereas the smaller thrusts within the Mesozoic rocks of Tombstone area would be thought of as the imbricates within the thrust sheet. The striking similarity of the individual planar, folded, and back-limb thrusts, folds, and tear faults of Tombstone area to those of the Rocky Mountains support the analogy. In this light the role of the décollement is relatively unimportant; it could be thought of as a plane of structural discordance on which a certain amount of disharmonious movement has taken place within the thrust sheet. This comparison implies that the strata below the décollement may also be repeated by thrust faults and folds. Consequently the style of deformation found in Tombstone area may extend over a much larger region in the central Yukon.

The strong similarity between the Rockies structures and those of Tombstone area imply that the décollement of Tombstone area is not of the same fundamental importance in the central Yukon as it is in the Juras. This similarity also implies that the Lower Division of Tombstone area is involved in the deformation, but until further work is done in the region north of Tombstone area and until the stratigraphy of the Lower Division is understood, its part in this deformation will remain obscure.

THE KENO HILL – TOMBSTONE RIVER BELT

Stratigraphic and structural data from Tombstone area impose modifications on the age of the entire Keno Hill – Tombstone River belt, and lead to certain conclusions and interpretations regarding its stratigraphy and structure. The following chapter contains an outline of the general geology of the Keno Hill – Tombstone River belt and includes a reassessment of its structure in the light of evidence from Tombstone area.

General Geology and Structure

Bostock (1947, 1948b) and Green and Roddick (1962) mapped the regional distribution of rocks of the Keno Hill – Tombstone River belt (Fig. 24) and numerous workers have studied its eastern part in some detail (Keele, 1904, 1906, 1910; Cairnes, 1915, 1916; Cockfield, 1918a, 1919a, 1920, 1921a, 1923, 1924; Stockwell, 1926; Bostock, 1943, 1947, 1948b; Kindle, 1955; McTaggart, 1950, 1960; Green, 1957, 1958; Boyle, 1965; Poole, 1965).

Two formations occur along the length of the Keno Hill–Tombstone River belt (Fig. 24). The older, a slate unit (unit 11 of Tombstone area), which is represented in the east by quartz–mica schist, is known informally as the “Lower Schist”. The younger, made up of orthoquartzite (unit 13 of Tombstone area), is called the “Keno Hill Quartzite” in Mayo district. Strata that do not occur along the length of the Keno Hill – Tombstone River belt overlie the “Quartzite” at the belt’s two extremities. In the east the overlying formation is known as the “Upper Schist”, in the west slate (unit 14) and siltstone (unit 15) overlie the quartzite (Table III). No other formations are volumetrically important in the belt, but thin units of Permian (Tahkandit Formation) and Triassic (unit 9) rocks underlie “Lower Schist” locally (not shown on Fig. 24).

Stratigraphic evidence for the age of units 11 and 13 in Tombstone area indicates a Jurassic age for the “Lower Schist” and a Lower Cretaceous age for the “Keno Hill Quartzite”. The formations are correlated with similar rocks in east central Alaska and the northern Yukon (Figs. 7 and 9; Table II).

Precambrian and Lower Paleozoic strata underlie and overlie rocks of the Keno Hill – Tombstone River belt along its length (Fig. 24). In Tombstone area the lower contact of the belt rocks (which there include the Tahkandit Formation and units 9 through 15) is unconformable; similar relations probably exist elsewhere at this contact. Green and Roddick (1962) have mapped a thrust fault (the continuation of the North Fork Thrust) along part of the upper contact of the belt (Fig. 24).

The structure of the Keno Hill – Tombstone River belt has been investigated in detail only near its eastern and western extremities. Less is known concerning the structure of the intervening central part. Rocks of the Keno Hill – Tombstone River belt are folded on east-trending axes and dip generally southward at moderate angles. Major and minor

structures attest to northward tectonic transport of overlying beds relative to underlying beds along the entire belt.

The style of deformation in the “Keno Hill Quartzite” at the east and west ends of the Keno Hill – Tombstone River belt differs (Fig. 24). In the west (i.e., Tombstone area), where rocks are unmetamorphosed, the quartzite is deformed by large-scale thrust faults and concentric folds. Minor folds and lineation are not developed in the quartzite in Tombstone area. In Mayo district, where all rocks have been metamorphosed to greenschist facies, the “Quartzite” lacks recognized large scale thrusts and major faults, but minor subisoclinal similar folds, microscopic shear planes, and linear structures are well developed. A major fold which involves the entire quartzite sequence has been mapped by Green and McTaggart (1960) in Davidson Mountains, and thrust faults have been postulated in the “Keno Hill Quartzite” on Keno Hill by McTaggart (1960, pp. 33, 35). In essence the differential movement during deformation was restricted, in Tombstone area, to discrete, widely spaced surfaces, but in Mayo district it has pervaded the entire rock fabric and was accompanied by metamorphism.

Unlike those of the “Quartzite”, structures in the “Lower Schist” are the same at the east and west ends of the Keno Hill – Tombstone River belt. Minor subisoclinal, similar folds with well-developed axial plane cleavage occur everywhere in the “Lower Schist”, but large-scale internal structures are not recognized.

Block faulting that is related to formation of the McQuesten anticline (Bostock, 1947) and that may be also related to silver–lead–zinc mineralization, has disrupted rocks of the Keno Hill – Tombstone River belt in Mayo area (Fig. 24). This faulting clearly postdates the folding and thrusting that affected rocks of the belt.

Interpretation and Discussion

The following interpretations are tentatively suggested as working hypotheses for future studies.

“Upper Schist” in Mayo District

The stratigraphic relations of the “Upper Schist” (Table III; Fig. 25) to rocks of the Keno Hill – Tombstone River belt in Mayo district are not known and require elucidation. This unit has been regarded as Precambrian and included in the Yukon Group, but its spatial and lithological affinities to rocks of the belt suggest the possibility of a much younger, Mesozoic, age, in keeping with the ages of the other formations of the belt. Evidence from Tombstone area suggests three possible correlatives of this unit (Table IV) if the “Upper Schist” is in fact Mesozoic.

First, the “Upper Schist” may represent the metamorphosed equivalents of the Robert Service thrust sheet (i.e., units 10 and 12 of Tombstone area; Table IV). If this is so, the “Upper Schist” is in large part equivalent to the Jurassic “Lower Schist”, but it would also include Triassic strata. The “Upper Schist” resembles the “Lower Schist”, for both units are made up of graphitic schists and quartz–mica schists. Limestones that occur at and near the base of the “Upper Schist” would in this interpretation probably be Triassic and equivalent to unit 10 of Tombstone area.

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TABLE III *Formations of the Keno Hill - Tombstone River Belt*

Stratigraphic Succession at west end of belt in Tombstone area	Structural Sequence of east end of belt in Mayo district
Unit 15 Siltstone +2,000 feet	"Upper Schist" Graphitic quartz-mica schist thin limestone near base
Unit 14 Red and green slate 500 feet	
Unit 13 Orthoquartzite 1,800 feet	"Keno Hill Quartzite" Meta-quartzite
Unit 11 Black slate ± 1,500 feet	"Lower Schist" Graphitic quartz-mica schist

Second, the "Upper Schist" may represent the metamorphosed equivalent of the Lower Cretaceous units 14 and 15 of Tombstone area (Table IV). The graphite and limestone beds found in the "Upper Schist" do not occur in units 14 and 15, and such a correlation would require facies changes.

Third, it is possible that the "Upper Schist" represents the metamorphosed equivalent of units 14 and 15, and 10 and 12 of Tombstone area (Table IV).

The first correlation presented above is better than the second because it requires no facies changes and the writer prefers it over the third because the "Upper Schist" contains no rocks that he would consider likely as the metamorphosed equivalents of units 14 and 15.

The correlations above are based on the possibility that the "Upper Schist" is Mesozoic. If this unit is Precambrian, however, it may represent a fairly distinctive member, low in the "Grit Unit". At present there is no compelling evidence to support or negate either a Precambrian or Mesozoic age and both must be considered possibilities of equal merit, but in either interpretation a thrust relationship must exist between the "Keno Hill Quartzite" and the "Upper Schist". If the "Upper Schist" is Mesozoic a thrust must also occur between the "Grit Unit" and the "Upper Schist".

TABLE IV *Three Possible Correlations for the "Upper Schist"*

Structural Sequence in Tombstone area	Structural Sequence in Mayo district
Unit 12 } Unit 10 } Unit 15 } Unit 14 }	1 3 2
Unit 13	"Upper Schist"
Unit 11	"Keno Hill Quartzite"
	"Lower Schist"

“Keno Hill Quartzite” in Davidson Range

In Davidson Range (Fig. 24), “Keno Hill Quartzite” is underlain and overlain by “Lower Schist”. Occurrence of “Lower Schist” above “Keno Hill Quartzite” is incompatible with the normal stratigraphic relations between these formations and a thrust or fold repetition must be postulated. The former is probable because the contact between the two units is folded. Two superposed phases of folding on eastward-trending axes would be required to explain a fold repetition and only one such phase is known. Extensive thrusting has been demonstrated to the west in Tombstone area and repetition by this mechanism is therefore reasonable. Accordingly a folded thrust fault is postulated at the upper contact of the lens of “Keno Hill Quartzite” in Davidson Range (Fig. 24).

“Keno Hill Quartzite” in “Upper Schist” near Mayo Lake

North of Mayo Lake (Fig. 24), Kindle (1955) has mapped a four-mile lens of “Keno Hill Quartzite” within “Upper Schist”. Its presence there lends indirect support to the correlation of the “Upper Schist” with the “Lower Schist”. This lens may represent an upthrust segment of “Keno Hill Quartzite” and a thrust is postulated at its upper contact (Fig. 24).

Eastward Extent of the Keno Hill – Tombstone River Belt

Keele (1906, pp. 168, 169) reported fossiliferous Upper Triassic limestones in the upper Stewart River region about 50 miles east of Keno Hill. He also assigned the shales and sandstones associated with these limestones to the Triassic. The shales and sandstones may be equivalents of the “Lower Schist” and “Keno Hill Quartzite” in which case they probably constitute the eastward extension of the Keno Hill – Tombstone River belts. The belt may not continue far east of the upper Stewart River region, if indeed it extends that far, because no Mesozoic rocks are known in a large area east and southeast of there.

Structure

Contrasting structures in the “Quartzite” at the east and west ends of the Keno Hill – Tombstone River belt (Fig. 24) indicate that the competency of the “Quartzite” was markedly less in the east than in the west at the time of deformation. The reason for the reduced competency of this unit in the east is probably a direct result of the metamorphism that affected the rocks of Mayo district. Similarity of structures in the “Lower Schist” at the east and west ends of the Keno Hill – Tombstone River belt suggests that the competency of this already incompetent rock unit was not reduced by metamorphism. Similarity of the structures in the “Lower Schist” and “Keno Hill Quartzite” in Mayo district also indicates that the competency difference between these two units was slight during deformation. In Tombstone area a large difference in the competencies of these two formations at the time of deformation is indicated by the marked difference in structures in the “Lower Schist” and “Keno Hill Quartzite” (i.e., units 11 and 13). These relationships indicate that metamorphism in Mayo district reduced the competency of an otherwise competent unit (“Keno Hill Quartzite”) to about that of a slate. The metamorphism of the rocks of Mayo district is ascribed to burial of the region during deformation. This suggestion is investigated further in the discussion of the regional setting of the Keno Hill – Tombstone River belt.

The contact between units 11 and 13 is interpreted as a plane of *décollement* in Tombstone area. It extends from Tombstone area to Mayo district (Fig. 24) and the question naturally arises: do similar contact conditions prevail everywhere? If the *décollement* in Tombstone area is interpreted as a direct reflection of the difference in competency between these two units during deformation, the reduction in competency difference between these two formations, by metamorphism in Mayo district, would imply that a *décollement* condition is not necessary there.

Changes in the outcrop width of the "Keno Hill Quartzite" in Tombstone area have been related to the amount of structural repetition within that formation by thrusting and folding (*see* Structural Summary). The relationship between outcrop width and amount of structural repetition is probably valid throughout the Keno Hill - Tombstone River belt and if it is, the structural complexity or amount of structural repetition within the "Quartzite" can be estimated at different points along the belt. Accordingly, Figure 24 suggests that structural thickening of the "Quartzite" has occurred extensively only at its eastern and western extremities, where its outcrop width is markedly greater than elsewhere.

Regional Structural Relations

The Keno Hill - Tombstone River belt in the southern Ogilvie Mountains lies in a region where the general structural pattern is understood only in its barest outlines and where detailed structural data are lacking. The relationship of the structures of the Keno Hill - Tombstone River belt to the remainder of Ogilvie Mountains is therefore obscure and only a general discussion can be given here. The inset map of Figure 24 shows the known structures, structural trends, and inferred ages of deformation of Ogilvie Mountains. Two generalized, schematic cross-sections of parts of the Ogilvie Mountains are also shown.

The northwestern Ogilvie Mountains are folded into a series of broad, open, north-trending anticlines and synclines that involve rocks as young as Late Cretaceous and that are therefore of Laramide age¹ (Douglas, *et al.*, 1963, p. 7). The Laramide folds lie east of (below) a major, northward trending, west-dipping, folded thrust fault (Norris, *et al.*, 1963) that locally brings Precambrian rocks of the Tindir Group above Upper Cretaceous strata and that must therefore also be Laramide. (The folded thrust fault locally truncates the north-trending folds of the northwestern Ogilvies, which suggests that some of these folds may be pre-Laramide; H. Gabrielse, personal communication, 1966.) The north-trending northwestern Ogilvie Mountains terminate abruptly to the south, where they meet the east-trending northern Ogilvies (Fig. 24). The interrelationship of the two mountain belts at this right angle bend is unknown, but the change from north to south trends is sharp, taking place over a distance of only a few miles, and the data suggest that the two fold belts meet in a northeast-trending structural depression toward which the folds of both mountain belts plunge (Fig. 24).

¹The term Laramide is herein used in its narrower sense, to indicate a period of post-Cretaceous diastrophism.

Regional mapping (Green and Roddick, 1962; Norris, *et al.*, 1963) has shown that a series of open, east-trending folds, with several minor south-dipping thrust faults dominate the structure of northern Ogilvie Mountains (cross-sections AA' and BB'; Fig. 24). In contrast the structure of southern Ogilvie Mountains is controlled by two major south-dipping thrust faults that repeat Precambrian and younger rocks, bringing them above late Paleozoic and Mesozoic strata (cross-sections AA' and BB'; Fig. 24) (Green and Roddick, 1962). Cross-section AA' (south part) shows an interpretation of the structures of Tombstone area and their relation to the associated features to the north. The interpretation shown is that the thrusts within the Lower Cretaceous rocks are imbricate faults above the Jurassic strata and below the overthrust Precambrian (*see* Structural Summary). Structures shown in the south part of cross-section BB' (Fig. 24) are based on the hypothesis that the "Upper Schist" of Mayo district is the thrust-faulted repetition of the "Lower Schist". In Mayo district the interpreted thrust faults and the strata between them are folded and faulted by the McQuesten anticline, a younger structure.

Tombstone area provides evidence of a late Early Cretaceous time of deformation in much of the southern Ogilvie Mountains. If it is assumed that the northern thrust fault in the southern Ogilvies is of the same age as the North Fork thrust (Fig. 24), it is reasonable to expect that some of the folds in the northern Ogilvies (which lie immediately below this northern thrust) are also late Early Cretaceous. There is, however, good evidence of Laramide folding in the northern Ogilvies, for the Monster syncline (Fig. 24), which is one of the east-trending folds of that region, involves Upper Cretaceous (and Tertiary?) strata (Green and Roddick, 1962; Mountjoy, 1967b). These data indicate that the Ogilvies are a composite mountain chain of which the southern part is older than the northern, suggesting that shallow, marine sedimentation may have continued in what are now the northern Ogilvies during deformation in the southern Ogilvie Mountains. By Late Cretaceous time non-marine conglomerates and arkosic sandstones were being deposited in the northern Ogilvies (i.e., Monster syncline) (Green and Roddick, 1962, p. 14), and these sediments probably represent the erosion products of the late Early Cretaceous orogeny in the southern Ogilvie Mountains.

The northern Ogilvie Mountains are probably the continuation of the Laramide Mackenzie Mountains to which they are structurally similar (Martin, 1963; Gabrielse, *et al.*, 1965), but the southern Ogilvies are a separate entity with a structural style characterized by more significant crustal shortening than is evident in the northern Ogilvie and Mackenzie Mountains. The southern Ogilvie Mountains coincide with the region north of the Tintina Trench that is intruded by mid-Cretaceous granitic plutons (Fig. 11) and the Selwyn Mountains (Fig. 24), which also contain such intrusions, may be their continuation. The northern limit of the granitic intrusions (Fig. 11) may mark the approximate boundary between the northern Ogilvie – Mackenzie Mountains and the southern Ogilvie – Selwyn Mountains.

Figure 24 shows a spatial relationship between the zone of greenschist metamorphism and the faulted, post-mid Cretaceous (Laramide?) McQuesten and Mayo Lake anticlines in Mayo district. The geometry of the McQuesten anticline (south part of cross-section BB', (Fig. 24) suggests that the rocks now exposed in Mayo district originated at considerable depth (in the order of 10,000 feet deeper than the level at which they presently occur) and that they have been brought up to the surface by the

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McQuesten anticline. These relationships explain the metamorphosed state of the rocks of Mayo district to which the “deeper” style of deformation, also found there, has been attributed.

Tintina Trench

Little has so far been said of the most prominent of all the structures shown on Figure 24, the Tintina Trench, believed, because of the marked dissimilarity of rocks on either side of it, to be the topographic expression of a major fault. The Tintina Trench has been briefly described by Bostock (1947) and Aho (1959) and regional geological data are now available for much of its length (Geological Survey of Canada, Map 30-1963). The Tintina Trench extends (Fig. 25) northeastward from the southern Yukon (where it is *en echelon* with the northeastern extension of the Rocky Mountain Trench) to central Alaska, about 600 miles. In Alaska the Trench is on strike with a narrow, arcuate belt of Tertiary strata that is in turn aligned with a 250-mile-long strike-slip fault, the Kaltag, that extends westward from central Alaska to Norton Sound (Fig. 25) (Gates and Gryc, 1963, p. 276). The Tintina Trench is covered by Upper Cretaceous and Tertiary sedimentary rocks in parts of east central Alaska (Brabb and Churkin, 1964, 1965), but for most of its length in the Yukon Tintina Trench contains only Tertiary and younger, partly consolidated deposits and locally basalt. Zones of fault gouge and breccia are

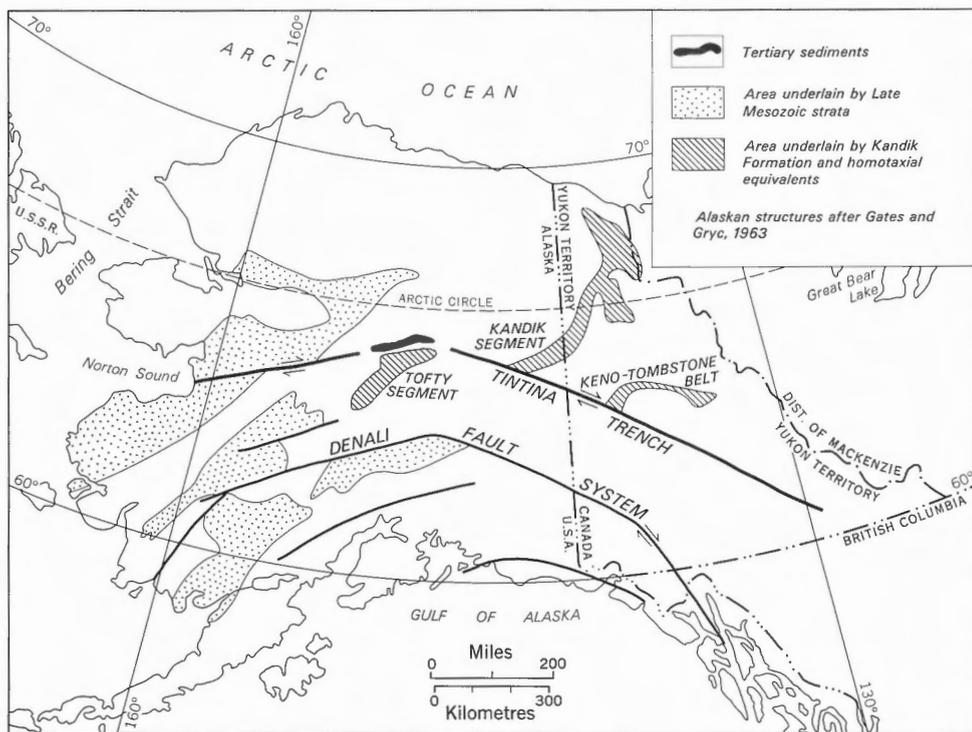


FIGURE 25. Map of Alaska and Yukon Territory showing the relationship of the Tintina Trench to aligned and associated features.

known in and near Tintina Trench in the vicinity of Dawson (Aho, 1959). The metamorphic grade of the rocks on either side of Tintina Trench differs and correlations across the valley have so far proven difficult. In the southeastern Yukon rocks on the north side of the Trench are of higher metamorphic grade than those on the south side (Wheeler, Green and Roddick, 1960), but the converse is found in the western Yukon (Green and Roddick, 1962) and eastern Alaska (Gates and Gryc, 1963).

Evidence discussed above in the section on Stratigraphy strongly suggests that the Mesozoic rocks of Tombstone area are homotaxial equivalents of the Kandik Formation that is found north of Tintina Trench in Charley River Quadrangle (Kandik segment of Fig. 25) (Brabb and Churkin, 1964) and south of the Trench in central Alaska (Tofty segment of Fig. 25) (Mertie, 1937). If one assumes that the correlations are valid and that the Kandik and Tofty segments formed one continuous depositional basin with the Keno Hill – Tombstone River belt (the latter supposition is at present completely unsupported), a dextral strike-slip displacement of 250 miles is indicated along the Tintina fault.¹ Differences in the metamorphic grade of rocks on either side of Tintina Trench suggest that considerable vertical movement may have accompanied the strike-slip displacement.

The main displacement on the Tintina fault evidently occurred in latest Cretaceous or earliest Tertiary time although some movement may also have taken place later. Upper Cretaceous and Tertiary(?) rocks in the Trench (in eastern Alaska; Brabb and Churkin, 1964) are folded, and Tertiary rocks in central Alaska are synclinal and not strongly faulted (Gates and Gryc, 1963, p. 276). Paleocene beds in the Tintina Trench in the southern Yukon (Wheeler, Green and Roddick, 1960) are tilted but not strongly disrupted.

The Kaltag fault that extends from Norton Sound to central Alaska and that is on strike with Tintina Trench (Fig. 25) “. . . displaces late Mesozoic geosynclinal deposits and Paleozoic geanticlinal rocks in such a way that right lateral displacement of at least a few tens of miles is indicated” (Gates and Gryc, 1963, p. 276). Tertiary strata, although slightly deformed are mainly flat lying, implying that the major movement on this fault also occurred in latest Cretaceous or earliest Tertiary time. This evidence suggests that the east-trending fault in Alaska and the Tintina fault are parts of a single 1,000-mile-long, dextral strike-slip fault system of Laramide age (termed the Tintina fault system). As such this structure is comparable and perhaps related, to the Denali fault system of southern Alaska (Fig. 25). The Denali fault system, like the Tintina, is thought to be a zone of dominantly pre-Tertiary strike-slip movement on which a few tens of miles of right lateral displacement can be demonstrated in southeastern Alaska (Gates and Gryc, 1963, p. 276), and on which as much as 150 miles of dextral movement has been postulated by St. Amand (1957, p. 1366). The Tintina and Denali fault systems are concentric about a common point in the Gulf of Alaska, having radii of curvature of 800 and 620 miles, respectively. St. Amand has correlated the displacement on the Denali and San Andreas faults with other geologic, geodetic, and geophysical evidence and has advanced the interesting theory that the northern Pacific basin has been and is rotating counter clockwise perhaps under the influence of a large convection cell. The sense and

¹ Since this was written a paper by J.A. Roddick (1967) entitled “Tintina Trench” has appeared in the *Journal of Geology*. It is interesting that, using a somewhat different line of reasoning, Roddick has arrived at a total right lateral displacement of 240 to 260 miles for the Tintina fault, a figure that is, for all practical purposes, identical to the one arrived at here.

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magnitude of the displacement on the Tintina fault system may lend some support to his hypothesis.

The 250-mile-displacement postulated for the Tintina fault is based on speculative and qualitative data and should be regarded only as a possibility that justifies further critical work. Although the amount of movement seems excessive, it is not impossible, especially in view of the associated large faults in adjacent parts of Alaska. Displacements of similar magnitude to that postulated for the Tintina fault have been suggested for the San Andreas fault (Hill and Dibblee, 1953) and the Alpine fault in New Zealand (Wellman, 1955), and 65 miles of strike-slip displacement has been demonstrated on the Great Glen fault (Kennedy, 1946).

SUMMARY AND CONCLUSIONS

Tombstone area is underlain by a relatively complete succession of Mesozoic rocks that was formerly included in the Yukon Group and thought to be Precambrian.

Fossiliferous Lower, Middle, and Upper Triassic impure limestone and siltstone constitute the base of the Mesozoic succession. Lower and Middle Triassic strata have not previously been recognized in the central Yukon and their occurrence indicates that this region was tectonically quiet during the early Triassic in contrast to much of the southern Yukon, where the early Triassic was a period of widespread diastrophism and volcanism.

Slates that are the lateral equivalents of the "Lower Schist" of Mayo district overlie the Triassic strata disconformably. They are stratigraphic and lithologic equivalents of structurally repeated strata in which Middle and Upper Jurassic ammonites were found and are therefore assigned to the Jurassic.

The lateral equivalents of the "Keno Hill Quartzite" of Mayo district overlie the Jurassic slates. In Tombstone area the "Keno Hill Quartzite" consists of an 1800-foot-thick succession of massive, grey, thick-bedded orthoquartzites that contain a 250-foot black slate member 500 feet above the base of the unit and a 50-foot sandy limestone member about 1,000 feet above the base. The orthoquartzites are made up of moderately sorted, fine-grained sands composed almost entirely of quartz with minor chert; the grain-size distribution is unimodal, symmetrical, and leptokurtic. The "Keno Hill Quartzite" is a multicycle sandstone derived from a sedimentary source in the northern Yukon and deposited in a near-shore marine environment. The upper part of the formation may be non-marine.

Two formations of slate and siltstone, previously included with structurally repeated Jurassic rocks overlie the "Keno Hill Quartzite".

No diagnostic fossils were found in the "Keno Hill Quartzite" or the two younger formations, but the age of these strata is limited to the Lower Cretaceous by the underlying Jurassic slates and by probable mid-Cretaceous syenite stocks that post-date the deformation in which the Mesozoic rocks were involved. The Jurassic and Lower Cretaceous formations of Tombstone area are correlated with homotaxial equivalents in east central Alaska (Kandik Formation) and the northern Yukon.

The lithology and thinness of the areally extensive Mesozoic succession of Tombstone area indicate that miogeosynclinal conditions prevailed in much of central Yukon Territory during a large part of the Mesozoic, an era during which this region was formerly believed to have been highland. The stratigraphic data suggest that the Keno Hill - Tombstone River belt may have been connected with the Mesozoic basin of east central Alaska and the northern Yukon. Strata of the Kandik Formation that may provide

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this connection are known in central Alaska south of the Tintina Trench and their occurrence implies a possible 250-mile, right lateral, strike-slip displacement on the Tintina fault.

A single, remarkably continuous, 600-foot, vertically differentiated diabase and gabbro sill intrudes the slate member of the "Keno Hill Quartzite". This sill, equivalent to the greenstones of Keno Hill and injected in late Early Cretaceous time, prior to deformation of the Mesozoic rocks, is a useful marker horizon that has helped in the elucidation of the internal structures of the "Keno Hill Quartzite".

Several discordant stocks of plutonic rocks, surrounded by contact metamorphic aureoles, intrude the Mesozoic strata. Variations in their mineralogy outline a general trend from peralkaline, silica-deficient nordmarkite at the centre of the stocks to calcic, silica-saturated quartz diorite at their margins. The stocks crystallized from a magma that was forcefully emplaced about mid-Cretaceous time.

The Lower Cretaceous succession of Tombstone area is repeated by a number of thrust faults, whose position and extent is defined by the distribution of strata and the truncation of folds. These thrusts dip southeastward and strata above them are moved northwestward relative to underlying beds. Maximum throw on the thrusts ranges from 1,000 to 10,000 feet and occurs in a zone that coincides with the region of greatest thickening of the Mesozoic succession in the central part of Tombstone area.

Strata between the thrust faults are folded concentrically. The folds plunge gently northeastward away from the zone of maximum throw on the thrust faults. Most folds are asymmetrical and anticlines have northwest limbs that dip more steeply than their southeast limbs.

A series of northeast- and northwest-trending vertical tear faults offset thrust faults and folds within the competent Lower Cretaceous strata, but they do not cut the underlying Jurassic slates.

The succession of Lower Cretaceous strata is faulted and folded above a surface of basal detachment or décollement and below a major thrust fault, the North Fork thrust. The décollement separates the competent Lower Cretaceous rocks from the underlying incompetent Jurassic strata, and the North Fork thrust brings Precambrian above Mesozoic rocks. Thrusts within the Lower Cretaceous sequence define a series of imbricate thrust slices between the décollement and the North Fork thrust and indicate a structural style not previously recognized in the central Yukon. Many of the imbricate thrusts are thought to merge with the décollement at depth. A total crustal shortening of at least 20 miles has occurred as a result of the deformation. The slate member of the "Keno Hill Quartzite" has provided the only important zone of bedding-plane slippage in the otherwise competent Lower Cretaceous succession.

Deformation was initiated by broad flexuring, which was closely followed by thrusting and folding; tear faults formed after thrusting and folding. Deformation probably occurred in late Early Cretaceous time.

The thrust faults, folds, and tear faults are all related and give a fairly clear idea of the deforming stress. The maximum compressive stress was directed northwest-southeast. Changes in strain, indicated by differential movement on the thrust faults, are probably a reflection of changes in magnitude of a uniformly directed stress field. These changes can account for the broad arc described by structures of Tombstone area and can also explain marked changes in the outcrop width of the Lower Cretaceous succession.

SUMMARY AND CONCLUSIONS

The décollement of Tombstone area is unlike that found beneath the folded Jura Mountains. Structures in Tombstone area are similar to those of the Alberta Rocky Mountains.

The "Upper Schist" of Mayo district may represent the thrust-faulted repetition of the "Lower Schist".

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APPENDIX I

Paleontology

Fossils collected during the present investigation were examined by paleontologists of the Geological Survey of Canada and the following lists and comments are from their office reports.

A. Fossils from the Road River Formation

by B.S. Norford

<i>Field Number</i>	<i>Locality</i>	<i>G.S.C. Location</i>
T065 - F429B	N64°24'/W138°54'	69163

Collected about 50 feet above the base of the Road River Formation in black graphitic slate.

graptolite fragments, 2 spp.
? *Climacograptus* sp.

Age: Early Ordovician to early Early Silurian, probably Middle or Late Ordovician.

by D.H. Collins

<i>Field Number</i>	<i>Locality</i>	<i>G.S.C. Location</i>
T064 - 88C	N64°29 ³ / ₄ /W138°49 ¹ / ₂ '	

Collected about 200 feet below the top of the Road River Formation in a thin bed of black crystalline fetid limestone.

Virgoceras sp.
coiled cephalopod — tarphycarid or barrandeocerid

“Species of *Virgoceras* Flower 1939 have previously been reported from the Middle Silurian of Indiana and Czechoslovakia. Consequently, the fauna is tentatively assigned to the Middle Silurian.”

B. Fossils from the Tahkandit Formation

by E.W. Bamber

<i>Field Number</i>	<i>Locality</i>	<i>G.S.C. Location</i>
T064 - F187	N64°27 ¹ / ₂ /W138°50'	64868

Collected about 20 feet above the base of the Tahkandit Formation in crystalline limestone.

? Horridonid brachiopod
? *Spiriferella* sp.

Age: Probable Permian.

<i>Field Number</i>	<i>Locality</i>	<i>G.S.C. Location</i>
T064 - F92	N64°26 ¹ / ₂ /W138°52'	64867

Collected about 30 feet above base of the Tahkandit Formation in crystalline limestone.

Spiriferella saranae (de Verneuil)

Horridonia sp.

productoid brachiopod

echinoderm columnals

Age: Permian, probably Leonardian or Wordian. This fauna occurs in the Tahkandit Formation.

Field Number	Locality	G.S.C. Location
T064 - F91d	N64°26'/W138°52½'	64866

Collected about 20 feet above the base of the Tahkandit Formation in crystalline limestone.

Spiriferella sp.

Age: Permian.

Field Number	Locality	G.S.C. Location
T064 - F96	N64°29'/W138°51'	64865

Collected about 30 feet above base of the Tahkandit Formation in crystalline limestone.

horn coral indet.

Spiriferella sp.

? *Spirifer striato-paradoxus* Toulou

Age: Permian, probably Leonardian or Wordian.

Field Number	Locality	G.S.C. Location
T065 - F419	N64°26'40''/W138°50'	69164

Collected 17 feet above base of the Tahkandit Formation in crystalline limestone.

Horridonia sp.

Waagenoconcha sp.

? *Cleiothyridina* sp.

Dictyoclostid brachiopod

Bryozoan indet.

Age: Permian, probably Leonardian or Wordian.

Field Number	Locality	G.S.C. Location
T065 - F419a	N64°26'40''/W138°50'	69167

Collected 30 feet above base of the Tahkandit Formation in crystalline limestone.

Waagenoconcha sp.

Spiriferella cf. *keilhavii* (von Buch)

Dictyoclostid brachiopod

Plerophyllid coral

Age: Permian, probably Leonardian or Wordian.

C. Fossils from unit 9

by E.T. Tozer

Field Number	Locality	G.S.C. Location
T065 - F425A	N64°23'45''/W138°52'	68900

Collected about 190 feet above base of unit 9 in dark grey fetid carbonaceous limestone.

Monotis subcircularis Gabb

Age: Upper Triassic, Upper Norian.

<i>Field Number</i>	<i>Locality</i>	<i>G.S.C. Location</i>
T065 - F425	N64°23'45"/W138°52'	68899

Collected about 90 feet above base of unit 9 in grey fetid silty limestone.

Daonella cf. *D. tyrolensis* Mojsisovics

Age: Middle Triassic, probably Lower Ladinian.

<i>Field Number</i>	<i>Locality</i>	<i>G.S.C. Location</i>
T065 - F430B	N64°23'45"/W138°52'	69117

Collected about 20 feet above base of unit 9 in greyish brown siltstone.

Posidonia cf. *P. Oeberg*

Age: Probably Lower Triassic (Smithian).

D. Fossils from unit 12

by H. Frebold

<i>Field Number</i>	<i>Locality</i>	<i>G.S.C. Location</i>
T065 - F274	N64°30'/W138°10'	68091

Collected about 300 feet above base of unit 12 from black slates containing spherical chert – ironstone concretions as much as inches across.

Cardioceras sp.

Age: Early Oxfordian (early part of Late Jurassic).

At this locality *Arctocephalites* and *Cadoceras?* were found in 1961 by L.H. Green (G.S.C. Loc. 47219). They are Bathonian and Callovian, respectively (middle and upper parts of Middle Jurassic).

<i>Field Number</i>	<i>Locality</i>	<i>G.S.C. Location</i>
T065 - 408	N64°19'56"/W138°23'	7044

Collected about 300 feet above base of unit 12 from black slates containing abundant spherical chert – ironstone concretions as much as six inches across.

Cardioceras? sp. indet.

Pleuromya

Age: Oxfordian?

E. Trace fossils from unit 13

by Tempelman-Kluit; after Hantzschel (1962)

Zoophycos Massalongo 1885

This trace fossil has also been described under the name *spirophyton* and occurs in Devonian to Tertiary rocks of Europe, North America, and Africa.

Laevicyclus Quenstedt 1879

Known from the Lower Cambrian of Pakistan and the Triassic and Jurassic of Europe.

Protovirgularia? M'Coy 1850

Occurs in the Ordovician in England and Middle Devonian in Germany.

Nereites? MacLeay 1839

Described from Paleozoic rocks of all continents.

Other unidentified trace fossils occur.

F. Trace fossils from unit 15

by Tempelman-Kluit; after Hantzschel (1962)

Helminthoida? Schafhaufl 1851

Known from Cretaceous and Tertiary rocks in Europe, Alaska, Chile, and Trinidad.

Scolicia de Quatrefages 1849

Described from Cambrian to Tertiary strata in Europe, North Africa, North America, and Asia and presumed to represent gastropod trails.

Planolites Nicholson 1873

Ranges from the Precambrian through the Mesozoic and known from all continents. A number of other unidentified trace fossils occur.

APPENDIX II
Radiometric Ages

Potassium-Argon Ages of Igneous Rocks Probably Equivalent to Unit 18

Age (m.y.)	Lithology	Location	Ref.
74		N62°56'/W132°27'	4
79		N62°17'/W133°03'	4
81	Porphyritic quartz diorite	N63°54'/W134°46'	3
81		N62°54'/W132°27'	4
83		N63°57'/W132°30'	4
86		N62°15½'/W132°03½'	4
87		N62°17'/W133°03'	4
90		N61°46'/W133°26½'	4
91		N64°27'/W138°33'	4
94	Quartz monzonite	N62°05'/W127°40'	1
96	Granodiorite	N62°55'/W130°10'	1
99		N61°23'/W130°33'	4
102	Biotite quartz monzonite	N64°02'/W135°26'	3
106	Granodiorite	N64°02'/W135°50'	3
110	Quartz monzonite	N62°50'/W127°40'	2
134	Biotite feldspar porphyry	N64°09'/W138°10'	3

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1. Baadsgaard, H., *et al.* (1961).
2. Gabrielse, H., *et al.* (1965).
3. Leech, G.B., *et al.* (1963).
4. Unpublished.

APPENDIX III

Measured Section of Unit 13 (Composite)

See Figure 5.

Section 4

Overlying beds: unit 14: sharp contact.

Orthoquartzite, light grey and white, massive, fine-grained, poorly bedded, thick-bedded (10 feet)	95 1771
Covered; black slate float	43 1676
Orthoquartzite, light grey to white, massive, fine-grained, thick-bedded (5 feet), contains 1 per cent black shale chips, 1/2-inch interbeds of black slate.	67 1633
Covered; black shale and slate, and minor black argillaceous fetid limestone float	55 1566
Orthoquartzite, light grey, massive, fine-grained, poorly bedded, thick-bedded (5-10 feet) weathers white	25 1511
Covered; black slate and minor brown siltstone float	30 1486
Orthoquartzite, brownish grey, grey weathering, massive, thick-bedded (5 feet), poorly bedded, rust spots after pyrite. Intraformational breccias with as much as 10 per cent black shale chips (3 inches) at 15 feet, few lime-cemented brownish concretions (10 feet) near base	40 1456
Covered; scattered outcrops of interbedded black platy slate and 6-inch interbeds of medium grey orthoquartzite, minor siltstone	75 1416
Unit 13b; sandstone, calcite-cemented, medium-grained, brownish, grain-size varies to coarse sand; interbedded black, platy slate makes up about 10 per cent; pyrite and rust spots: black slate chips constitute 5 per cent of rock in upper part.	45 1341
Covered; float in lower 10 feet of black slate, above is lime-cemented sandstone float	41 1296
Orthoquartzite, medium grey, fine-grained, massive, thick-bedded (3-10 feet) small shale chips (less than 2 mm) makes up 1 per cent throughout; minor interbeds of black slate as much as an inch thick	94 1255
Covered; scattered outcrops of massive grey orthoquartzite minor black slate float, trace fossils in slate	40 1161
Orthoquartzite, medium grey and brownish grey, fine-grained, massive, thick-bedded (10 feet), 1/4-inch interbeds of black slates, straight quartz veinlets. Intraformational breccia with 5 per cent black slate chips as much as 5 mm at 53 feet	70 1121
Covered; black slate float with minor brownish siltstone	12 1051
Orthoquartzite, medium to dark grey, locally brownish, massive, fine-grained, thick-bedded (10 feet); few lime-cemented, brownish concretions a foot across; minor interbedded black slate in 1/2-inch beds. Intraformational breccia at 72 feet has black shale chips as long as 5 mm and weathers rusty	92 1039
Covered, grey massive orthoquartzite float	12 947
Orthoquartzite, medium grey, massive, fine-grained, thick-bedded (8 feet); straight white quartz veinlets; some black shale chips; minor 1/2-inch black slate interbeds	25 935

Covered; grey massive orthoquartzite and black slate float	20	910
Orthoquartzite, medium grey and brownish, massive fine-grained, thick-bedded (3-10 feet); interbedded black slate as much as a foot thick near base	153	890
Break in section above here measured east of North Klondike River, section 4		
Unit 13a; slate, phyllitic slate, shaly slate, black, minor interbedded, brownish, laminated limy siltstone. Intruded by diabase (unit 16) altered to green spotted slate near diabase. Thickness varies 0-500 feet. Minor folds preclude measurement – average thickness scaled from cross-sections	250	737

Section 3

Break in section below here measured west of North Klondike River, section 3		
Orthoquartzite, medium grey to brownish, massive, thick-bedded (5 feet), fine-grained, grey weathering; interbedded black slate as much as a foot near top	94	487
Covered, massive quartzite and black slate float	118	393
Orthoquartzite, medium grey, massive, thick-bedded (5-10 feet) fine-grained	29	275
Chert and slate, black, interbedded; chert is banded, constitutes about 60 per cent, in 3-inch beds; slate beds thinner	3	246
Orthoquartzite; blue-grey to dark grey, black weathering, massive, fine-grained, thick-bedded (3-6 feet); slaty partings as much as 1/4-inch thick	25	243
Covered; scattered outcrops and float of blue-grey, massive, fine-grained quartzite; black slate interbeds as thick as 1 foot in lower outcrops	73	218
Orthoquartzite; medium grey, white weathering, massive, fine-grained.	16	145
Orthoquartzite; medium grey, brownish yellow, weathering, poorly laminated locally, mainly massive, fine-grained, minor black slate chips	27	129
Covered; black platy slate float	14	102
Orthoquartzite; medium grey, fine-grained, massive, fractured, rusty spots, thick-bedded (6 feet), poorly bedded	56	88
Orthoquartzite; medium grey, brownish weathering, massive, fine-grained, minor small black slate chips	10	32
Orthoquartzite; locally calcareous, medium to dark grey, massive, fine-grained, quartz veinlets plentiful	22	22
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