GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

PAPER 60-24

TECTONIC FRAMEWORK OF SOUTHERN YUKON AND NORTHWESTERN BRITISH COLUMBIA

(Report and 7 figures)

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Price 50 cents

1961

CANADA

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By

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TECTONIC FRAMEWORK OF SOUTHERN YUKON AND NORTHWESTERN BRITISH COLUMBIA

INTRODUCTION

Recent work in southern Yukon Territory and northwestern British Columbia has provided much new information on the major geological elements of the region. Brief references to the broad tectonic features of this part of the Cordillera are contained in papers by Eardley (1947, 1948, 1951)[1], Kay (1951), and White (1959). McLearn and Kindle (1951) and Okulitch (1956) have dwelt on the regional aspects of the Mesozoic and Cambrian stratigraphy respectively in the eastern part of the region. The geology has been recently summarized by Mulligan (1957). The purpose of this paper is to synthesize briefly the available information on the northwestern Cordillera and to attempt to interpret the development of the main tectonic features. Much of this information was obtained from discussions with other officers of the Geological Survey who are familiar with the region.

That part of the Cordilleran region embracing southern Yukon Territory, northwestern British Columbia, and southeastern Alaska may be divided into three northwesterly trending belts of relatively unmetamorphosed stratified rocks separated by two zones of crystalline metamorphic and granitic rocks (Fig. 1, in pocket).

The eastern belt of stratified rocks embodies the Pelly, Cassiar, and northern Rocky Mountains. It is underlain mainly by Mississippian and older rocks in regularly bedded formations traceable for many miles. Pre-Upper Devonian rocks in this belt are essentially non-volcanic and have many features in common with those near the Rocky Mountain Trench in southeastern British Columbia. Upper Devonian and Lower Mississippian strata contain abundant volcanic material and attain great thicknesses.

The central or Tagish belt is composed principally of Mesozoic volcanic and sedimentary rocks intruded by numerous granitic plutons. The belt extends southeastwards from Fort Selkirk for more

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[1] Names and/or dates in parentheses are those of references cited in the Bibliography.

than 500 miles. It is interrupted just north of the British Columbia - Yukon border by the Atlin horst, a complexly upfaulted block about 250 miles long composed of incompetent late Palaeozoic rocks intruded by granitic plutons.

The western belt, comprising the St. Elias Mountains and southeastern Alaska is a structurally complex zone in which granitic batholiths have intruded formations of diverse composition and texture, including much volcanic material, ranging in age from Ordovician to Cenozoic.

The eastern crystalline zone is composed of granitic plutons of Mesozoic age including the Cassiar batholith and spatially associated metamorphic rocks ranging in age possibly from Precambrian to Mesozoic.

The western crystalline zone comprises the Coast Range intrusions which form a composite plutonic mass containing subordinate metamorphic areas. Outlying bodies of these intrusions cut rocks as young as Cretaceous.

Cenozoic strata are widespread. Volcanic rocks, including those of Pleistocene age, occur both in upland regions and in linear depressions. Non-marine sediments, however—except the Sustut group near the headwaters of the Stikine River—are restricted mainly to trenches. Marine sediments occur along the coast of the Gulf of Alaska.

Ultramafic rocks are scattered across this part of the Cordillera; they occur not only in the three belts of relatively unmetamorphosed rocks, but also in the intervening crystalline zones. They are particularly abundant in and around the Atlin horst.

STRATIGRAPHY

The following discussion deals with those aspects of the geological history that bear on the development and classification of the tectonic elements of the region.

Palaeozoic

Rocks of Palaeozoic age are best represented in the western and eastern belts of stratified rocks. Although the information is far from complete, the contrasting behaviour of these two belts during much of Palaeozoic time is evident (Fig. 2, in pocket).

During the Palaeozoic era, eugeosynclinal conditions existed in the western belt; it was a zone of volcanic and tectonic activity (Buddington and Chapin, 1929; Lathram et al., 1959; Muller, 1958). Volcanic breccias and flows occur in Ordovician, Silurian, Devonian, and Permian rocks in the Alexander Archipelago, and in the Devonian, Mississippian, and Permian rocks of the St. Elias Mountains. The volcanic rocks are chiefly andesites and basalts with subordinate felsites.

Tectonic activity in this belt during the Palaeozoic is attested by unconformities, conglomerates, and locally, great thicknesses of poorly sorted clastic sediments. For instance, in southeastern Alaska, the Middle Devonian and Permian formations each lie with angular unconformity upon older rocks. Other possible unconformities occur between mid-Ordovician and Silurian beds and within the Silurian and Devonian successions. In the St. Elias Mountains, Permian rocks apparently lie unconformably upon beds that are conformable with Devonian marble (Sharp, 1943). Throughout the belt all systems but the Pennsylvanian include conglomerate. Generally they are composed in large part of volcanic detritus, but those in the Upper Silurian and Middle Devonian of southeastern Alaska also contain coarse granitic fragments not unlike the rocks of the Coast Range intrusions. In particular, an Upper Silurian conglomerate in the Alexander Archipelago, as much as 1,500 feet thick, contains abundant cobbles and boulders of granitic rocks. Poorly sorted sediments such as greywacke, commonly rich in volcanic debris, form thick deposits in the Silurian and Devonian formations of southeastern Alaska and in the Devonian, Mississippian, and Permian of the St. Elias Mountains.

The presence of thick limestone and bedded-chert sequences in the Upper Silurian, Mississippian, and Permian of southeastern Alaska indicates that, in some localities at least, there were periods of tectonic stability during which volcanism was absent or unimportant.

Permian formations in the St. Elias Mountains contain much pyroclastic and clastic sedimentary material. On the other hand, Permian formations in southeastern Alaska, along the east flank of the Coast Mountains, and in the Atlin horst (Watson and Mathews, 1944) are characterized by thick sections of limestone, greenstone flows, and radiolarian ribbon-chert. Southwest of Atlin the Permian rocks apparently lie unconformably on granite (Aitken, 1955). Although precise correlations are not yet possible, it appears that during much of the Permian the region of the St. Elias Mountains was one of explosive volcanism and tectonic activity, whereas to the southeast the region was tectonically quiet. Rocks in the southeastern region, probably correlative with the Cache Creek group of British Columbia, were evidently deposited in extensive seas remote from a source of clastic sediment.

In contrast to the western belt the eastern one was mainly miogeosynclinal during the late Proterozoic and early Palaeozoic.

Non-volcanic marine sediments deposited in late Proterozoic time are probably more than 7,500 feet thick and those deposited between early Cambrian and pre-late Devonian time probably total no more than 9,000 feet in thickness.

Late Proterozoic rocks near McDame are predominantly calcareous and relatively fine grained (Gabrielse, in press). In this respect they differ from sub-Cambrian rocks to the south in Aiken Lake area (Roots, 1954), in Cariboo area (Sutherland-Brown, 1957), and in the northern Rocky Mountains west of Muncho Lake. In these areas the rocks are characteristically siliceous and argillaceous and contain considerable pebble-conglomerate.

A relatively thick and widespread quartzite member was deposited as the basal member of the Cambrian succession. Perhaps the quartzite represents the basal beds of an easterly transgressing sea as postulated for rocks of similar age and composition elsewhere in the Cordillera (Okulitch, 1949; Kay, 1951). A relatively thin unit of shale commonly overlies the quartzite sequence and is in turn overlain by fossiliferous limestone of early Cambrian age. The limestone was apparently deposited in shallow, well-aerated seas.

The remaining pre-Middle Silurian history of the eastern belt shows slight differences in behaviour between northern British Columbia and the Pelly Mountains to the north. In northern British Columbia post-early Cambrian and pre-late Ordovician time was marked by a deepening of the depositional basin west of the Rocky Mountain Trench. This is suggested by the extensive deposits of generally non-fossiliferous, thin-bedded argillaceous and calcareous Cambro-Ordovician strata. A probable change of facies from predominantly argillaceous rocks in the southwest to mainly calcareous rocks in the northeast suggests that calcareous material was derived from the east. Intraformational limestone conglomerates are not uncommon in the more easterly deposits. Black, pyritic, graptolitic shales of early and medial Ordovician age were perhaps deposited in isolated stagnant basins. Greenstone bodies are common in the Cambro-Ordovician strata. Although bodies of definite extrusive origin have not been recognized, some volcanism may have taken place at this time in this region, as in the Pelly Mountains.

A marked hiatus, indicated by a break in the faunal sequence, occurred in northern British Columbia between the deposition of the Ordovician graptolitic shales and that of the overlying

Silurian beds (Norford, 1959). In the northern Rocky Mountains along the Alaska Highway, Middle Silurian beds overlie rocks of possible Cambrian age (Williams, 1944; Lowdon and Chronic, 1949). East of Deadwood Lake, Middle Silurian strata rest disconformably on Middle and possibly Upper Ordovician shales. On the limbs of the McDame synclinorium, Lower or Middle Silurian siltstones overlie Lower Ordovician shales.

The Silurian coralline dolomites and interbedded sandy strata were evidently deposited as a widespread, fairly uniform plate on a slowly subsiding platform. Local graptolitic siltstones and shales of roughly the same age may have accumulated in relatively deep isolated basins within the subsiding platform. In northern British Columbia the graptolitic siltstones and shales have been recognized only on the limbs of the McDame synclinorium.

In the Pelly Mountains, argillaceous sediments were deposited from Middle Cambrian to early or middle Silurian time (Green, Roddick, and Wheeler, 1960a, 1960b). Minor green volcanic breccia and tuff interbedded with Middle and Upper Cambrian phyllites indicate some volcanism at this time. Black slates containing graptolites that range in age from early Ordovician to early or middle Silurian are widespread. The pre-middle Silurian hiatus demonstrated in northern British Columbia has not been established in the Pelly Mountains where the stratigraphy is not as well known. The graptolitic slates have a maximum thickness of about 750 feet. They represent a considerably condensed section in contrast to the carbonate section, more than 5,000 feet thick, which was deposited during approximately the same interval in Mackenzie Mountains 200 miles to the east (R. J. W. Douglas, personal communication 1959). Further volcanism took place in the Pelly Mountains in late Lower or early Middle Silurian time with the extrusion of as much as 300 feet of andesitic tuff and volcanic breccia.

In succeeding middle and late Silurian time, dolomite was deposited over much of the Pelly Mountains area under the same slowly subsiding conditions as in northern British Columbia. Thin-bedded sandy and silty dolomite was deposited in the southern Pelly Mountains.

Over much of the eastern belt, a succession of dolomitic sandstones, sandstones, and dolomites, generally lacking fossils and in part of middle Silurian age, underlies fossiliferous Middle Devonian strata. The source for the sands, perhaps similar to the 'Peace River High' (Webb, J. B., 1954), must have been Cambrian or Precambrian quartzose sediments. A few measurements on cross-bedding in the Pelly Mountains and near McDame indicate northerly or easterly flowing currents, thus suggesting a westerly or southwesterly source. The distribution of lower Palaeozoic rocks in the eastern belt is not well enough known, however, to allow further speculation on whether or not other source areas were present.

A widespread epeirogenic uplift probably occurred in late Silurian and early Devonian time in northern British Columbia as evidenced by a regional unconformity beneath Middle Devonian strata. Good evidence for this unconformity is found east of Deadwood Lake where dolomites of Middle Devonian age lie less than 1 mile from rocks of Silurian, Ordovician, and Cambro-Ordovician age.

In middle Devonian time an assemblage of highly fossiliferous, generally dolomitic rocks was laid down. Like the Silurian rocks they are uniform over wide areas and suggest accumulation in shallow, well-aerated seas on a slowly subsiding platform.

During late Devonian time the eastern part of the area underwent a marked change in tectonic activity and sedimentation. The general area of Cassiar Mountains in northern British Columbia and Pelly Mountains began to subside rapidly and became the site of volcanism, ultramafic intrusion, and tectonic activity. Thus, an area that had been relatively stable in late Proterozoic and early Palaeozoic time suddenly developed characteristics of a typical eugeosyncline. A great thickness of volcanic and sedimentary material was deposited in this eugeosyncline in a short time. The eugeosynclinal rocks were folded and overlain unconformably by limestone of Middle Mississippian age. The unconformity is most pronounced near the lower part of Turnagain River where Middle Mississippian limestones unconformably overlie Cambro-Ordovician strata. Farther west, in the McDame synclinorium, Middle Mississippian limestone unconformably overlies a thick sequence of Devono-Mississippian eugeosynclinal rocks.

The base of the Devono-Mississippian sequence is poorly dated, other than it postdates the deposition of fossiliferous Middle Devonian strata, and is believed to be of late Devonian age mainly on regional correlations. It seems probable that the change from stable to unstable conditions in the area roughly coincided with the advent of clastic sedimentation dated as late Devonian throughout the northern Rocky Mountains, Liard Plateau, and Mackenzie Mountains. The basal units may, of course, have not been strictly coeval, and the presence of latest Devonian brachiopods in a sandstone-dolomite sequence in Pelly Mountains suggests the possibility that, locally, eugeosynclinal conditions did not begin until latest Devonian or earliest Mississippian time.

In the southern part of the area at least, the preserved sediments of the Devono-Mississippian sequence were derived mainly or entirely from within the eugeosyncline. Thick successions of chert arenite, chert-pebble conglomerate, and greywacke could not have been derived from an eastern source. Northeast of Tintina Trench at the latitude of Fort Selkirk, however, the source of chert-pebble conglomerate is not as well established (Campbell, 1960). An alternative source there is a thick section of Ordovician and Silurian chert exposed to the northeast.

The eastern margin of the eugeosyncline is known only within the limits of a broad zone, and its location during Devono-Mississippian time is further complicated by the possibility of significant movements along faults in the Rocky Mountain and Tintina Trenches. A possible clue to the nature of the eastern margin of the eugeosyncline in northern British Columbia, however, is found east of Kechika River and north of Gataga River. There, clastic sedimentary rocks believed to be of Devono-Mississippian age unconformably (?) overlie Cambro-Ordovician strata. The clastic rocks have apparently been derived from sandstones and cherty limestones. As typical Silurian and Devonian strata are not present in nearby areas, an anticlinal ridge may have existed during Devono-Mississippian time, possibly separating an area characterized by volcanism to the west from an area without volcanism to the east.

Angular unconformities occur within the early Mississippian of the eastern belt and disconformities lie above Middle Mississippian strata in the eastern crystalline zone. These breaks illustrate that both deformation and uplift took place from time to time during sedimentation in the Devono-Mississippian eugeosyncline. Perhaps these uplifts provided a source for much of the Devono-Mississippian chert-bearing clastic sediments that were deposited in an exogeosyncline(?) (Kay, 1951) or clastic wedge on the northeastern side of the eugeosyncline. It is not known whether metamorphism and granitic intrusion accompanied these orogenic movements as they did in the Palaeozoic Appalachian and Caledonian eugeosynclines.

If plutonism did take place in Mississippian-Pennsylvanian time it must have occurred in an area bounded by the outer borders of the two crystalline zones because Mississippian and earlier formations to the east and west are relatively unmetamorphosed. Metamorphic rocks in the Coast Mountains of Stikine River area underlie Middle Permian beds (Kerr, 1948a), and granite bodies at the south end of Atlin Lake underlie Permian strata (Aitken, 1955; Christie, 1957) but their age and time of metamorphism are unknown. A potassium-argon age determination by the Geological Survey of Canada (Lowdon, 1960) on a composite sample of metamorphic rocks east of Teslin River and Teslin Lake indicates an age of 214 m.y. This suggests metamorphism in earliest Triassic time (Kulp, 1959) but at the same time raises the question as to why Permian strata nearby in the Atlin horst are unmetamorphosed.

Conglomerate including granitic and metamorphic pebbles just northwest of the Cassiar batholith contains Permian fusulinids (Poole, Roddick, and Green, 1960). If these fossils date the conglomerate, then granitic rocks were emplaced during Mississippian-Pennsylvanian time in the eastern crystalline zone. Furthermore, the conglomerate possibly marks the eastern margin of the Permian eugeosyncline.

The problem of possible Mississippian-Pennsylvanian plutonism will remain until pre-Permian granitic and metamorphic rocks in the Coast Mountains and the conglomerate northwest of the Cassiar batholith are accurately dated.

Whether or not an orogeny took place between the end of the Permian and the beginning of the Upper Triassic is far from clear. That some volcanism may have taken place is indicated by the presence in the western and Tagish belts of greenstone between Permian and Upper Triassic fossiliferous strata. Some uplift and tilting but not necessarily folding, is demonstrated by the absence of Lower Triassic strata and by unconformities between Permian and Upper Triassic formations west of Iskut River. These unconformities are recognizable only by the presence, over a distance of several miles, of lithologically different Permian beds beneath Upper Triassic strata. Conglomerate and greywacke in the lower part of the succession of probable Triassic age suggest derivation from a source of considerable relief. Granitic pebbles and cobbles occur in a conglomerate of probable Upper Triassic age east of Dease Lake and in lithologically similar rocks on the west side of the Cassiar batholith in Jennings River and Wolf Lake map-areas to the northwest (Poole, personal communication 1959). Poole suggests further that these rocks rest unconformably on Mississippian strata. Fine-grained clastic rocks and limestone of possible Middle Triassic age between Stikine and Taku Rivers indicate that, by this time, marine sediments accumulated in this region where source areas were either remote or of low relief. In summary, aside from the age-determination data on plutonism and the coarse clastic material in rocks of probable Triassic age west of Dease Lake, there is no compelling evidence for widespread orogeny at the end of the Permian. Plutonism, as indicated above, must have been confined to the two existing crystalline belts, if plutonic activity occurred at all.

Mesozoic

In Yukon Territory and northwestern British Columbia in late Triassic time volcanic islands probably existed along what is now the axis of the Coast Mountains and were flanked to the east by a marine trough (Wheeler, 1959). Mesozoic volcanic rocks (see Fig. 3, in pocket), principally andesites and basalts, occur mainly in the Upper Triassic and are mostly restricted to the flanks of the Coast Mountains. Furthermore, volcanic rocks with the coarsest fragmental material also lie along these zones and grade eastward into sedimentary rocks.

In Karnian time volcanism was probably more widespread than later. In Norian time volcanism was restricted to the Coast Mountains region. In the Whitehorse region, Norian volcanic rocks of local westerly origin grade eastward into graded-bedded clastic sediments. These in turn pass farther east into a more near-shore assemblage of grits, conglomerates, and thin limestone beds containing abundant fragments of molluscs and crinoid stems. The presence of marine sediments in the Upper Triassic at intervals along the Tagish belt suggests that the basin in southern Yukon Territory may have been part of the more or less continuous marine trough—named the Whitehorse trough by Wheeler (1956)—extending southeastward into British Columbia. By latest Norian time, volcanism had ceased and calcareous muds with a benthonic fauna were deposited across the entire trough.

The distribution of Triassic volcanic rocks in the southeastern part of the area is not as well known. Volcanic rocks of Triassic and Jurassic age are abundant however in Dease Lake area south of the Atlin horst (Geol. Surv., Canada, 1957).

In Yukon Territory and northwestern British Columbia the quiet period at the end of the Triassic was terminated abruptly by uplift of the dormant volcanic terrain and concurrent rapid subsidence of the adjoining trough. Clastic debris was supplied to the trough mainly from the west and subordinately from the east. Unconformities beneath the Jurassic rocks increase westward from the central part of the trough near Whitehorse; thick, deltaic lenses of coarse conglomerate pinch out eastward and pass into rapidly deposited fine-grained clastic sediments; conglomerate along the eastern margin of the trough near Whitehorse was apparently derived from the east. Uplift was not synchronous everywhere west of the trough judging by the appearance of conglomerates at different stratigraphic levels in the Lower Jurassic at different places. The sheet-like character of the conglomerate along the eastern margin of the trough suggests that source areas to the east suffered less violent and less irregular uplift than those west of the trough. The source area west of the trough was dominantly volcanic and granitic, whereas that to the east was dominantly volcanic and sedimentary with a few small areas of granitic rocks.

The rapid and sporadic uplift in early Jurassic time of the volcanic and granitic terrain west of the Whitehorse trough also took place in Taku and Stikine Rivers areas. Unconformities occurring within and beneath Lower Jurassic formations are more pronounced toward the southwest and lenses of conglomerate are thicker and contain coarser debris in the same direction (Kerr, 1948a, 1948b). In contrast to the Yukon, volcanic activity continued in these areas in early Jurassic time (Souther, 1960).

Conglomerates were also deposited in early Jurassic time southeast of Dease Lake (Geol. Surv., Canada, 1957). There, conglomerates locally rest directly on late Palaeozoic limestone but in most places they overlie Triassic and/or Jurassic rocks. In general, the Jurassic sedimentary rocks in this region become finer grained towards the top of the sequence.

In late Jurassic and early Cretaceous time the Whitehorse trough broke up into local basins. A non-marine basin north of the Atlin horst received siliceous clastic sediments and was the site of coal-forming plant accumulations. The sediments were probably derived partly from the quartzose and chert-bearing core of the tectonic land west of the trough and perhaps partly from the Devono-Mississippian chert-bearing clastic rocks to the northeast. Coal-bearing Upper Jurassic and Lower Cretaceous clastic sediments lacking marine fossils are restricted to an area northwest of the Atlin horst. Near Carmacks they lie, apparently conformably, on the older Jurassic rocks (Bostock, 1936) but a few miles northwest of Carcross they lie disconformably on Lower Jurassic beds. The clastic sediments are rich in quartz, chert, and plagioclase, but lack potash feldspar.

The quartzose core of the tectonic land west of the Whitehorse trough separated the non-marine basin northwest of the Atlin horst from the early Cretaceous sea in the western belt. The eastern margin of this sea is difficult to define although in a general way the shoreline probably lay near the present position of the Shakwak lineament. Meagre data suggest that the early Cretaceous seas may have transgressed eastward. Conglomerate occurs within a section containing Berriasian (Lowermost Cretaceous) marine fossils in an isolated area in the central St. Elias Mountains (Sharp and Rigsby, 1956), whereas conglomerate and associated coal occurs beneath Neocomian (early Lower Cretaceous) marine fossils east of Alsek River (Kindle, 1952).

A thick, monotonous succession of marine greywacke, shale, and pebble-conglomerate was deposited in the Bowser basin during late Jurassic and early Cretaceous times (Geol. Surv., Canada, 1957). Pebble-conglomerates in this succession were probably derived mainly from late Palaeozoic eugeosynclinal terrain. Clastic rocks of the Bowser basin apparently overlie unconformably late Palaeozoic rocks that form an inlier near the western boundary of the basin. The non-marine basin northwest of the Atlin horst may have been separated from the marine Bowser basin southeast of Telegraph Creek by a ridge. This is indicated by the disconformity beneath the Upper Jurassic and Lower Cretaceous beds northwest of Carcross and by the northward coarsening of equivalent marine rocks southeast of Telegraph Creek.

In mid-Cretaceous time the rocks in the Tagish belt were deformed and intruded by granitic masses. Subsequently some flat-lying volcanic rocks were locally deposited upon the folded Lower Cretaceous and older rocks and some of these in turn were intruded by granitic bodies.

Some deformation of rocks in the eastern belt probably accompanied deformation in the Tagish belt.

Upper Cretaceous and Cenozoic

During part of late Cretaceous and Tertiary times, volcanic and sedimentary rocks were deposited in many areas in the northwestern Cordillera. Possibly as much as 5,000 feet of coarse, conglomeratic, non-marine sediments of the Sustut group were laid down during late Cretaceous and early Paleocene time in a basin that extended for at least 200 miles southeast from the headwaters of Stikine River. Abundant granitic debris in the Sustut group in McConnell Creek map-area beyond the limits of the area under discussion were apparently derived from the Omineca intrusions to the east (Lord, 1948). Similarly, abundant granitic pebbles and cobbles in rocks of possible Sustut age around the upper Stikine River (E.F. Roots, personal communication 1959) were probably derived from source areas to the northeast as the rocks of the Bowser basin flanking the Sustut group on the southwest contain no granitic debris. Consequently, the Sustut group appears to have accumulated in an intermontane basin that existed in late Cretaceous and Paleocene time.

Elsewhere non-marine sedimentary rocks of Paleocene or Eocene age are restricted chiefly to trenches, i.e. the Sifton formation in the Rocky Mountain Trench (Hedley and Holland, 1941). The debris in these early Tertiary rocks is commonly of local origin and suggests that these trenches were in existence at that time.

In late Cretaceous time a considerable thickness of marine greywacke and argillite was deposited in the coastal region of the Gulf of Alaska (Miller, 1957; Plafker and Miller, 1957). East of Yakutat Bay these sediments were deposited on crystalline rocks.

Following the deformation of Upper Cretaceous rocks, Cenozoic clastic sedimentary rocks were deposited in the Yakataga geosyncline around the coast of the Gulf of Alaska. Sedimentation was not continuous throughout the geosyncline. For instance, in the Yakataga district 100 miles west of Yakutat Bay, 25,000 feet of sediments accumulated by the end of the Pliocene with only one minor break in the Oligocene. North of Yakutat Bay however, sedimentation was interrupted by at least three disturbances marked by unconformities within a succession at least 11,000 feet thick. In Paleocene(?) and Eocene times, sedimentation was predominantly non-marine; subsequently it was marine, including the deposition of marine tillite in the Pliocene.

Volcanism took place during the Tertiary and Pleistocene, both in the mountainous regions and within the trenches. In most areas the rocks of late Cretaceous age and younger are flat lying or gently tilted. They are locally folded near later faults. For example, rocks of the Bowser basin are thrust northeasterly over rocks of the Sustut group and the latter has been deformed into folds overturned to the northeast only in the westernmost part of its exposures (E.F. Roots, personal communication 1959).

In the western belt Cenozoic rocks have been involved to a greater or lesser degree in folding and thrusting. In the St. Elias Mountains west of Kluane Lake, Devonian and Permian formations have been thrust over Tertiary volcanic rocks (Muller, 1958).

The rocks in the Yakataga geosyncline have been involved in several local deformations. North of Yakutat Bay an unconformity within the Eocene succession exposes a fold of early Eocene rocks overturned to the southwest. The intensity of this intra-Eocene folding diminished westward. Miocene and Pliocene marine strata, deposited unconformably on older Tertiary rocks, display an anticline asymmetrical to the southwest. The upper beds of this anticline thin towards the crest and in turn are truncated by the younger beds of the succession. Evidently the anticline rose contemporaneously with sedimentation in the geosyncline. The magnitude of this uplift increased toward the east. In late Pliocene and early Pleistocene time the Chugach and St. Elias Mountains were uplifted and thrust southwest along north- and northeast-dipping faults, and the bordering belt of Cenozoic rocks was folded, faulted, and uplifted. This movement has continued intermittently to the present day with the earthquakes of 1899 and 1958 (Miller, 1960).

In contrast to the deformation of Tertiary rocks described above, the Eocene rocks in southeastern Alaska, apparently deposited in an intermontane trough, are relatively undisturbed (Buddington and Chapin, 1929).

TIME AND PLACE OF EMPLACEMENT OF INTRUSIONS

Ultramafic Rocks

Ultramafic rocks in southern Yukon and northwestern British Columbia comprise peridotite, dunite, pyroxenite, and serpentinite. Despite the scattered nature of the occurrences, the largest bodies are most common in structureless greenstones of Devono-Mississippian and Permian age, or in fault zones bordering them. They are particularly prevalent along the southwest border of the Atlin horst.

In the eastern belt a few ultramafic bodies are present in metamorphic rocks of Palaeozoic or earlier age, but by far the greatest number occur in predominantly structureless andesitic and basaltic rocks of Devono-Mississippian age. This and the presence of serpentine fragments in conglomerates of probable Mississippian age in the Pelly Mountains suggest that ultramafic rocks in this belt were intruded during Devono-Mississippian time. Ultramafic rocks in the Atlin horst were considered by Aitken (1955) to be of Permian age because of their common association with structureless greenstones.

With the exception of the region adjacent to the Atlin horst, the Tagish Belt contains few ultramafic bodies. Those found in Mesozoic rocks are small and commonly sheared. As they occur in many places along fault zones these bodies may have moved tectonically into younger rocks from their original positions of emplacement.

In the western belt the age of the ultramafic rocks is uncertain but some may be as young as Cretaceous (Ruckmick and Noble, 1959).

The significant feature of ultramafic bodies in southeastern Alaska is that many appear to have been little deformed following their emplacement (Walton, 1951; Ruckmick and Noble, 1959; Irvine, 1959). In marked contrast, ultramafic bodies east of the Coast Mountains crystalline belt are almost invariably associated with faults and shear zones and show evidence of severe deformation. Perhaps the differences between the ultramafic bodies in southeastern Alaska and those east of the Coast Mountains are in part the result of the longer and more complex structural history of the latter. Of significance in this regard is the occurrence of highly sheared ultramafic bodies in the St. Elias Mountains of the western belt. This region was more severely deformed during Tertiary time than was southeastern Alaska.

Although belts of ultramafic rocks east of the Coast Mountains follow belts of structureless volcanic rocks they show no obvious relationship to the crystalline belts. For example, the large ultramafic bodies along the southwest side of the Atlin horst trend obliquely to the two crystalline belts, and, moreover, the ultramafic belt near McDame is transected by the eastern crystalline belt (Gabrielse, 1955). Ultramafic bodies on trend with the McDame rocks thus occur in metamorphic rocks or as inclusions in granitic rocks to the northwest.

In summary, it is suggested that the ultramafic bodies in the northwestern Cordillera are broadly coeval with predominantly structureless mafic volcanic rocks—i.e. Devono-Mississippian in the eastern belt and Permian in the Tagish belt. Those in southeastern Alaska may be of Mesozoic, possibly Cretaceous, age.

Granitic Rocks

Granitic rocks in the Tagish belt and in its bordering zone were intruded extensively in mid-Cretaceous time and less so in Paleocene time (Baadsgaard, Folinsbee, and Lipson, 1959; Matzko, Jaffe, and Waring, 1958). Those in the bordering zones are part of plutonic complexes, whereas those within the Tagish belt and Atlin horst are individual post-tectonic plutons emplaced after deformation of the Mesozoic and older rocks. Stratigraphic evidence suggests however that some granitic bodies were exposed to erosion earlier in the crystalline zones bordering the Tagish belt. In regions adjoining the western crystalline zone, granitic cobbles and boulders are abundant in Silurian conglomerates in southeastern Alaska, Permian formations lie apparently unconformably on granitic rocks at the south end of Atlin Lake, and granitic boulders are abundant in Lower Jurassic conglomerates along the west side of the Tagish belt. In regions adjoining the eastern crystalline belt, granitic debris is contained in Jurassic conglomerates along the east side of the Tagish belt in Yukon Territory and Upper Triassic and/or Jurassic conglomerates east of Dease Lake. It remains for absolute age determinations on granitic rocks in these zones to determine whether they represent intrusions accompanying successive disturbances throughout much of Palaeozoic and Mesozoic time in the belts now occupied by crystalline rocks, or whether they were ancient granitic terrains repeatedly exposed to erosion. Age determinations so far available support the former hypothesis. Age determinations from the western crystalline zone indicate plutonism at 223 m.y. (latest Permian) (K/Ar - GSC), 176 m.y. (early Jurassic) (K/Ar - GSC), and 140 m.y. (mid-Jurassic) (K/Ar - GSC) - (Lowdon, 1960). For the eastern belt plutonism is indicated at 214 m.y. (earliest Triassic) (K/Ar - GSC), 95-100 m.y. (mid-Cretaceous) (K/Ar - Baadsgaard, Folinsbee, and Lipson, 1959), and 59 m.y. (Paleocene) (K/Ar - GSC).

There can be little doubt that the western crystalline belt was repeatedly active, as attested by unconformities along its bordering zones and by the repeated presence of granitic rocks available to erosion. This zone must have been partly emergent for significant periods at intervals since early Palaeozoic time. The eastern zone shows, though not so clearly, the same tendency toward periodic plutonic activity, possibly from early Mississippian time and certainly since earliest Triassic time and periodic emergence since the early Mesozoic. Plutonism and tectonic activity began at an earlier time in the western crystalline zone than in the eastern zone.

Perhaps the most important inference from this discussion is that plutonism, at least during the Mesozoic era, was concentrated mainly in the zones of repeated uplift and only manifested itself in the intervening depressed region after the rocks there had been deformed.

STRUCTURAL GEOLOGY

Western Belt

Southeastern Alaska — The structural features of southeastern Alaska are known only in a general way (see Fig. 4, in pocket). According to Buddington and Chapin (1929) Palaeozoic strata are exposed along an anticlinal axis from Glacier Bay south-southeastwards to Prince of Wales Island. A synclinorium containing Mesozoic strata lies between the anticlinorium and the granitic and metamorphic rocks of the Coast Mountains. Palaeozoic strata are strongly deformed. Near the Coast Range intrusions the beds are isoclinally folded and overturned to the southwest. Thin-bedded, incompetent strata are commonly isoclinally folded. The difference in the degree of folding between incompetent and competent strata makes it exceedingly difficult to recognize unconformities.

Air-photo studies (Twenhofel and Sainsbury, 1958) indicate that the major structures in southeastern Alaska are crossed by numerous faults. These are primarily long, northwesterly or northerly trending faults, and short, northeasterly or east-northeasterly trending faults. Recent field work near Juneau (Barker, 1957; Lathram et al., 1959) supports the interpretation that many faults are present. The major northwest- and north-trending faults apparently divide the region into blocks of different tectonic styles, governed principally by differences in the competency of the rocks.

St. Elias Mountains—The St. Elias Mountains are separated along most of their length from the Coast Mountains crystalline belt by the Shakwak and Chatham Strait lineaments. The central part of the range is underlain principally by metamorphic and granitic rocks that include fault blocks of unmetamorphosed Lower Cretaceous rocks (Sharp and Rigsby, 1956). The structure of the crystalline rocks is irregular in detail but foliation trends are generally northwesterly, parallel with a band of Devonian limestone that extends northwestwards from Alsek River just north of the British Columbia - Yukon boundary. The structure in the eastern part of the St. Elias Mountains is highly complex. This zone is characterized by southwest-dipping thrust faults and associated folds overturned to the northeast. West of Kluane Lake, where the Duke River thrust zone converges on the Shakwak lineament, the deformation in the intervening zone is particularly intense and is marked by counter thrusts directed towards the southwest (Muller, 1958). Tertiary rocks have been overthrust by Palaeozoic formations both along the Duke River thrust and by the counter thrusts.

On the southwest side of the St. Elias Mountains, crystalline rocks have been thrust southwestward over Upper Cretaceous beds along thrust faults dipping 45°NE (Plafker and Miller, 1957). Thrust faults within Tertiary strata farther southwest dip from 30 to 40° N. Folds associated with these thrust faults are asymmetrical and overturned toward the southwest. The latest thrusting took place in late Pliocene or early Pleistocene time. Movement along these faults continues to the present day, judging by the earthquakes of 1899 and 1958 (Miller, 1960).

Central Belt

Tagish Belt—In general, the rocks in the Tagish belt were deformed within a framework of crystalline rocks into northwest-trending folds locally modified to some extent by later intrusions (see Fig. 5). The competency of the deformed rocks has been an important factor in determining the nature of the structure produced. Where great thicknesses of conglomerate, greywacke, and volcanic rocks prevail, the folds are open—for example, west of Whitehorse. However, incompetent rocks such as argillite, limestone, or thin-bedded units, form tight, irregular folds, like those in the central part of the Tagish belt north of the Atlin horst, and in the southwest part of the Bowser Basin southeast of Telegraph Creek.

The axes of the folds in the northern part of the Tagish belt are roughly parallel with the axis of the belt. Near Whitehorse the axial planes of the folds commonly dip toward the centre of the belt.

South of the Atlin horst the interpretation of the structure in the Tagish Belt is hampered by large areas of volcanic rocks of uncertain age having few planar structures. Immediately south of the horst, beds and major faults trend slightly north of west, roughly parallel with the southern border of the horst. Rocks of probable Triassic age are thrust southward onto Lower Jurassic strata that in turn overlie a large area of volcanic rocks of uncertain age. The structural trends in the western part of the Tagish Belt south of the Atlin horst occur locally at marked angles to the regional northwesterly trend west and north of the horst. Westerly and northerly trends are found south of Telegraph Creek where a highly complex salient of pre-Mesozoic and granitic rocks extends into the Tagish Belt.

Fold axes in the Upper Jurassic and Lowermost Cretaceous rocks of the Bowser basin are parallel with the regional northwesterly trend except near the northwestern margin of the basin (Geol. Surv., Canada, 1957). There the folds swing northeasterly so that their axes are roughly parallel with the northwestern margin. It was inferred above that a ridge probably existed northwest of Telegraph Creek, in which case the belt of anomalous folds may occur near the northwestern limit of sedimentation in the Bowser basin. These folds may consequently reflect either deformation of Upper Jurassic and Lowermost Cretaceous rocks within a pre-existing tectonic relief, or deformation around the salient of crystalline rocks south of Telegraph Creek. The rocks within the basin, principally argillite and greywacke, are incompetent and are tightly and irregularly folded.

Rocks of the Sustut group are highly deformed near the major southwesterly dipping thrust fault that delimits the southwestern border of the group. Farther east and northeast the rocks are flat lying or gently dipping.

Atlin Horst—Upper Palaeozoic rocks in the Atlin horst are highly deformed. Massive, competent greenstone and limestone units are strongly folded on a relatively broad scale, whereas thin-bedded units, particularly cherts and slates, are intensely folded and sheared on a small scale.

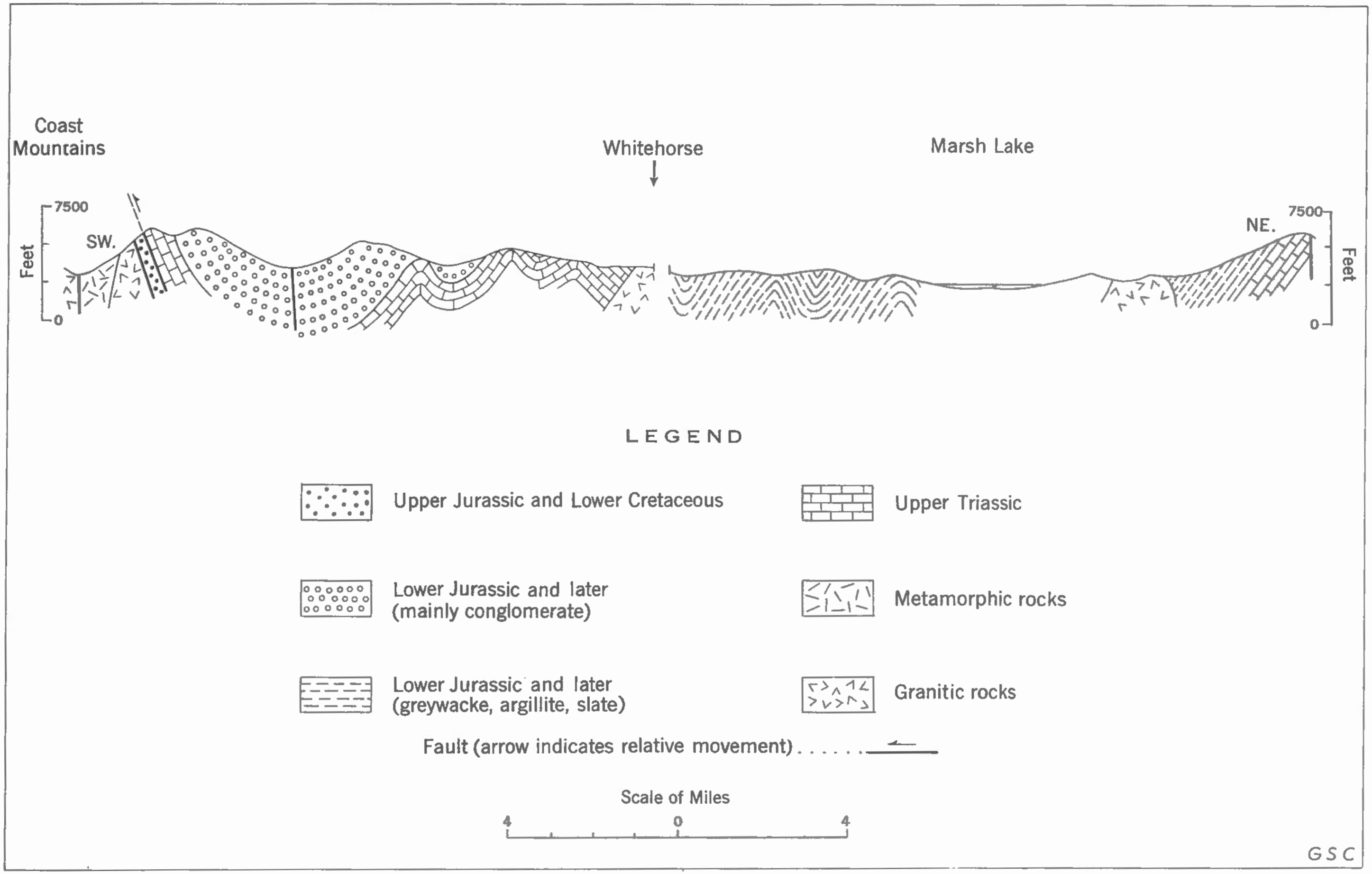

Figure 5. Representative structure-section across the Tagish belt, southern Yukon Territory

Folds in the southeastern half and the northeastern corner of the block trend northwest, parallel with the long axis of the horst. Locally the folds are profoundly deflected near granitic bodies. West of Dease Lake the axial planes of minor overturned and asymmetrical folds on a northwesterly plunging synclinorium dip northeast (see Fig. 6, and Aitken, 1960).

Along much of its southwestern border the Atlin horst is bounded by a steep thrust fault that brings Permian strata against beds of Jurassic and probably Triassic age. Along its northwestern border the horst is faulted against Jurassic rocks, and there it appears to have moved up and to the west with respect to the Mesozoic rocks (Wheeler, 1956). Southeast of Teslin Lake, Permian rocks are separated from Mesozoic strata by a steep fault that is later than granitic rocks that intrude Mesozoic formations. Between Carcross and Atlin the nature of the western margin of the horst is difficult to determine because over much of this distance rocks of uncertain Permo-Triassic age separate the Permian limestone from Jurassic sediments. West of Atlin Lake, however, Jurassic sediments dip toward the Permian rocks within 2,000 feet of the contact, which indicates that a fault separates the two formations. The structure near the northeast corner of the horst is not fully understood (R. Mulligan, personal communication 1958).

Although the latest movement on faults bounding the Atlin horst postdates deformation of rocks in the Tagish Belt and also their subsequent intrusion by some granitic bodies, movement along these faults may have begun at a much earlier time. As much of the uplifted area appears to have been relatively elevated in late Jurassic and early Cretaceous time, this block may have begun to rise in the late Jurassic.

Eastern Belt

The structural trends of sedimentary rocks in Cassiar, Pelly, and northern Rocky Mountains are northwesterly, except where they conform roughly to the borders of granitic plutons.

The Cassiar batholith in southern Yukon is flanked by two synclinal areas. The southwest border of the batholith is marked by a fault in Wolf Lake map-area (Poole, 1957). The structure of the synclinal area southwest of the batholith is exceedingly complex and the presence of numerous granitic plutons contributes to a heterogeneous map-pattern. In a general way, however, the structure appears to plunge gently southeast.

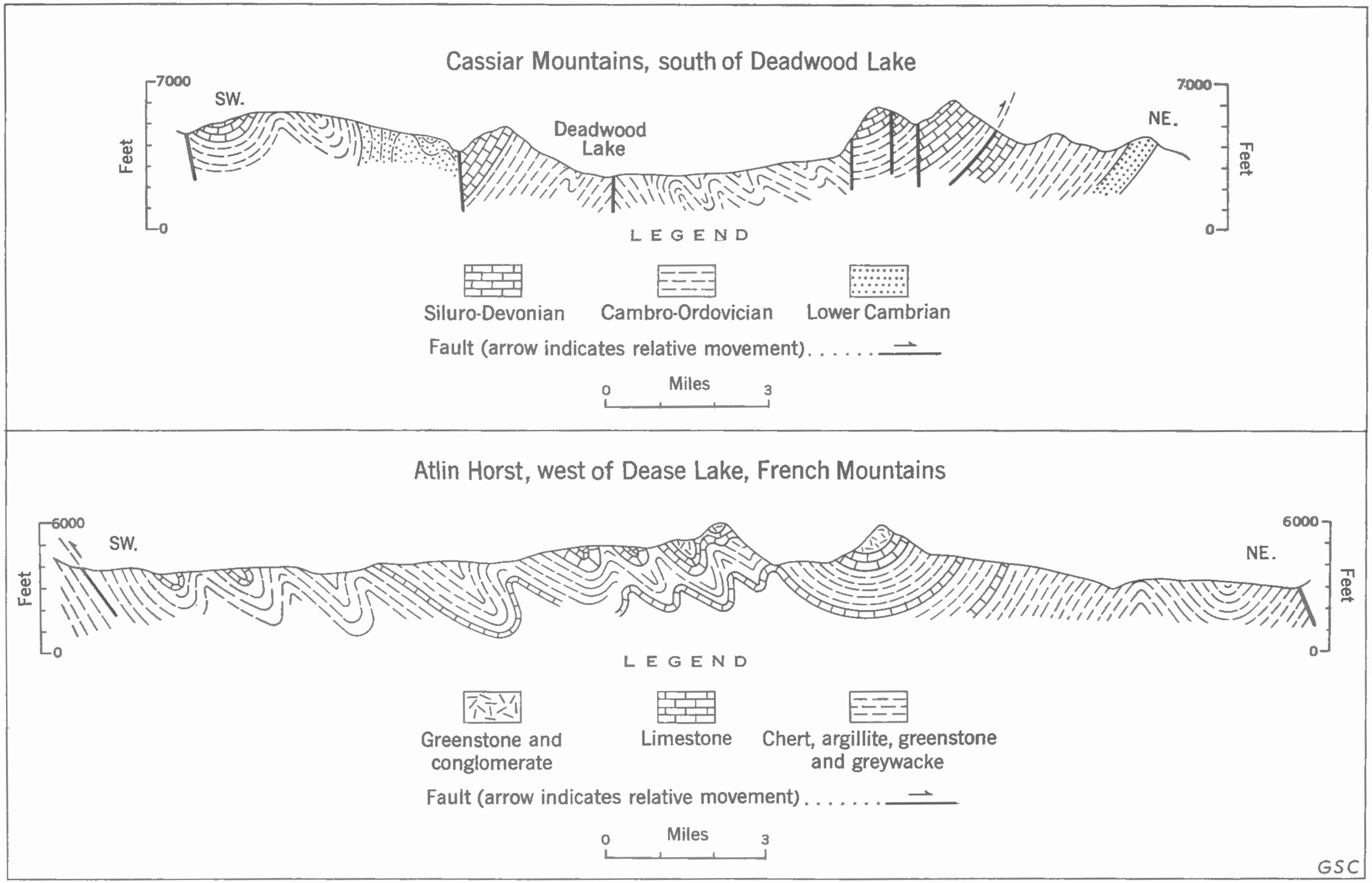

Figure 6. Representative structure-sections

The synclinal area northeast of the Cassiar batholith extends southeasterly beyond McDame, British Columbia and is flanked to the northeast by a faulted anticlinorium. That part of the anticlinorium between Turnagain River and about latitude 59° is overturned and thrust at a low angle southwesterly away from a major fault. Overturning and thrusting in this area is directed towards a salient of lower Palaeozoic strata that extends southwesterly to Turnagain River between granitic rocks of the eastern crystalline belt. To the northwest and southeast the structures pass into asymmetrical but essentially upright anticlines. Northeast of the fault and west of the Rocky Mountain Trench the structure is complex, in part due to the tight folding of incompetent Cambro-Ordovician strata and in part due to the large number of northwest- and northeast-trending faults.

Strata flanking the Rocky Mountain Trench to the northeast are tightly folded and overturned to the northeast (Gabrielse, in press). Trends of folds are intersected by the more northerly trending trench at an acute angle of from 10 to 20 degrees. West of Muncho Lake the major structure in the Rocky Mountains appears to be a broad anticlinorium overturned to the northeast, probably complicated by easterly directed thrust faults.

The structure of Palaeozoic rocks between the crystalline rocks of the Pelly Mountains and Tintina Trench can be related to two zones (Fig. 7). Southwest of the Porcupine thrust the structure is characterized by moderate dips and extensive low-angle thrust faults. The latter are mainly directed towards the northeast and some apparently have been folded. In general, competent Siluro-Devonian strata have slid along Cambrian to Lower Silurian phyllites and slates onto Mississippian volcanic rocks and incompetent clastic sediments. Locally, Cambrian phyllites have been thrust over Siluro-Devonian dolomites. In the southern Pelly Mountains, metamorphic rocks have been carried eastward along an undulating thrust fault onto Mississippian sediments. Within the latter are fault blocks and anticlinal areas of Siluro-Devonian rocks in turn cut by northeasterly directed thrust faults. Some structures in the western part of this belt have been directed toward the southwest. Cambrian rocks have been brought over crystalline rocks along a reverse fault and Siluro-Devonian rocks have been deformed into a southwesterly overturned anticline. The thrust sheets have been subsequently broken into elongate blocks by steep, north-northwesterly trending normal faults, and have been further complicated by northeasterly trending faults. Some of the latter originated before or during thrusting because they do not pass through the thrust sheet into the underlying rocks.

Northeast of the Porcupine thrust the structures are featured by steep dips, tight upright folds and fault slices bounded by steep faults.

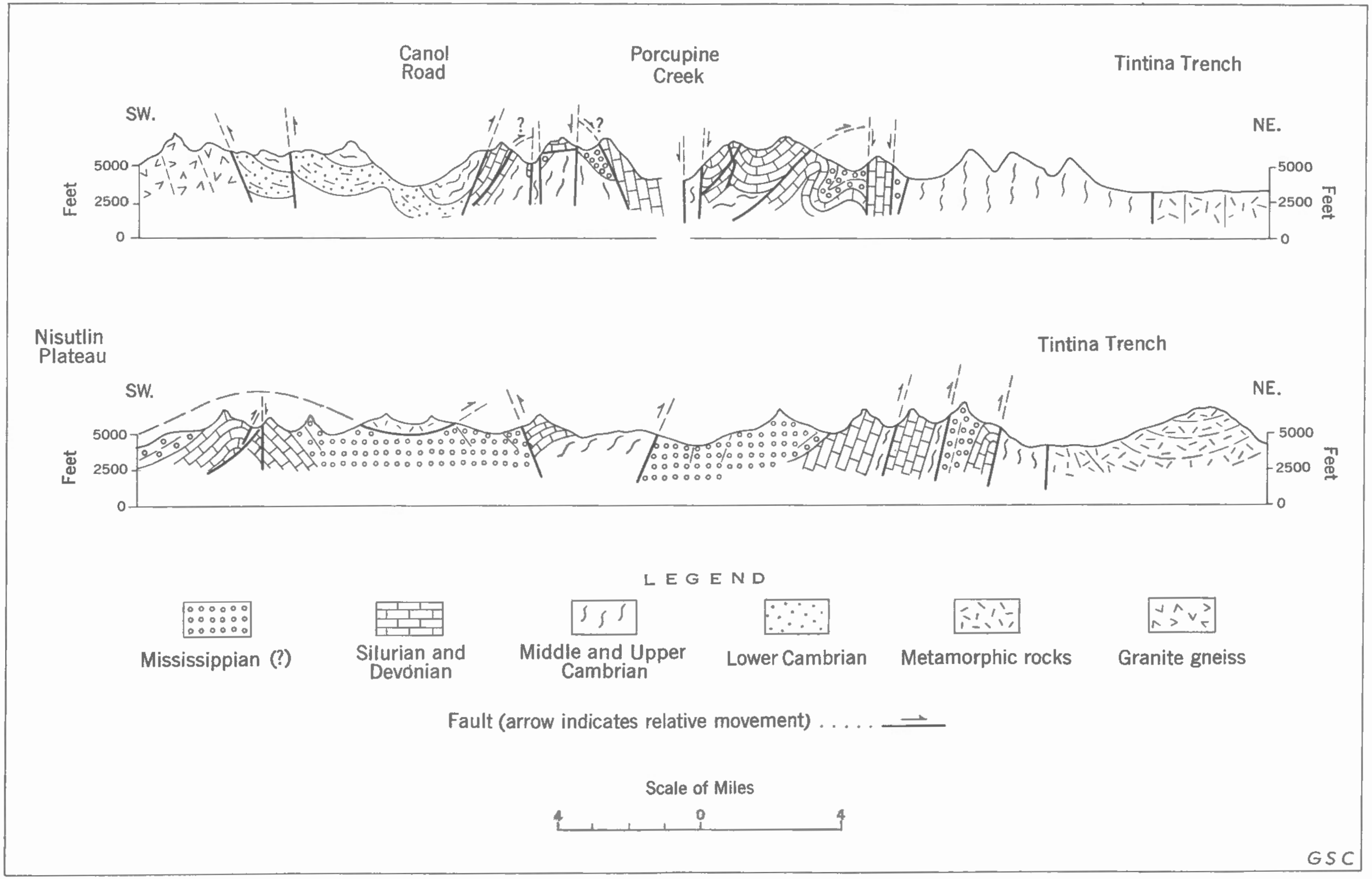

Figure 7. Representative structure-sections in Pelly Mountains

It appears that, although essentially the same stratigraphy persists throughout the eastern belt west of the Rocky Mountain and Tintina Trenches, the tectonic style in the Pelly Mountains is considerably different from that in northern British Columbia. The reasons for this are not yet understood but may be related to uplift of the Pelly Mountain crystalline belt and a consequent sliding off to the northeast of the Palaeozoic formations.

Main Lineaments and Faults

Several persistent lineaments and faults traverse the northwestern Cordillera. Most of these trend northwest parallel with the regional structural trend. St. Amand (1957a, 1957b) has discussed the fault tectonics of the region and, from a study of the distribution of earthquake epicentres, recent movement along established faults, geomorphic and geological evidence, and first-motion studies on earthquakes along the northeastern margin of the Pacific basin, he concludes that significant right-lateral movement has taken place along several of the faults. Recent movement along the Fairweather fault during the earthquake of July 9, 1958 was such that the southwest side moved 21 1/2 feet northwest and up 3 1/2 feet (Miller, 1960). During the Queen Charlotte earthquake of October 22, 1949 the southwest side of the fault moved down (Hodgson and Milne, 1951).

It is not known whether the Fairweather fault, which is either vertical or dips steeply to the west, joins the Chugach - St. Elias fault, which dips 45°NE. In any case both mark the western boundary of crystalline rocks in the St. Elias Mountains. The Fairweather fault may continue southeastward across Chichagof and Baranof Islands.

The fault along the Shakwak Trench is continuous with the Denali fault of St. Amand. Its connection with possible splits along Chatham Strait and Coast Range lineaments is uncertain. The Shakwak fault splits at Dezadeash Lake and is deflected southward. The valleys in northwesternmost British Columbia along which the Shakwak fault, if continuous, would lie, are filled with drift. If Watson's (1948) correlation of Mesozoic rocks in the area between Alsek River and the Coast Mountains in northwesternmost British Columbia is correct, the existence of a major fault in this area would seem most doubtful.

If the Shakwak fault is in some manner connected to the Chatham Strait lineament as St. Amand suggests, it is interesting to speculate on the effects of a 150-mile right-lateral displacement along the system. St. Amand's geomorphic evidence of displacement of two high-mountain masses implies essentially horizontal movement in relatively recent geological time. Reversing the proposed movement along the postulated fault brings rocks west of the system just north of the British Columbia - Yukon border against those east of the system west of Juneau. The rocks in Yukon consist of Lower Cretaceous sediments flanked successively to the west by Triassic and/or Jurassic volcanic rocks and sediments and late Palaeozoic limestone. Those west of Juneau comprise sediments like those containing Lower Cretaceous fossils at the south end of Admiralty Island, flanked to the west by volcanic rocks and sediments containing fossils of probable Upper Triassic and probable Permian age. Furthermore, the belt of Tertiary volcanic and sedimentary rocks in eastern St. Elias Mountains is brought on trend with rocks of similar age and lithology in southeastern Alaska. Upper Triassic rocks west of Kluane Lake are non-volcanic and if displaced southeast 150 miles would lie in British Columbia near the Yukon border. This would place them within 40 or 50 miles of postulated sources of explosive volcanism to the east. Consequently, the proposed movement along the Shakwak - Chatham Strait system of faults, while suggesting a possible solution to some problems, creates others.

Muller (1958) interpreted the Shakwak fault as having a long history, perhaps beginning as a normal fault or zone of flexure and subsequently becoming a zone of thrusting. Movement along this fault has disturbed recent unconsolidated surficial deposits (Bostock, 1952).

Tintina Trench is a remarkably straight lineament extending from the head of Liard River for more than 450 miles northwest to beyond the Alaska border. It has many of the features that St. Amand (1957b) and Moody and Hill (1956) considered characteristic of transcurrent faults—for example, remarkable linearity, trench-like form, the separation of rocks of different age and lithological character along most of its length, and the occurrence of younger rocks, first on one side of the trench and then on the other. Proof of transcurrent movement is exceedingly difficult, however, because of the lack of well-defined stratigraphic successions on one or both sides of the valley, for most of its length. It remains for future mapping to demonstrate the continuation of the structure to the southeast and the possible correlation of other faults near the head of Liard River with those in the Rocky Mountain Trench or with other faults to the east.

It is probable that the thrust fault bounding the southwest side of the Sustut group is a continuation of the Omineca and Pinchi fault zones in McConnell Creek and Fort St. James map-areas (Lord, 1948; Armstrong, 1949), as indicated by White (1959). It is not known whether strata of the Bowser group remote from the thrust fault were appreciably deformed at the time of thrusting, or whether deformation, as in rocks of the Sustut group, was largely restricted to the area near the fault. Undoubtedly, rocks in the Bowser basin had been considerably folded prior to the period of thrusting.

Two prominent thrust faults have been recognized in the Dease Lake area. They trend east-southeast and appear to dip moderately to the north. Along the more northerly one, Pennsylvanian(?) and Permian strata have been thrust southerly over rocks of probable Upper Triassic age. The latter have in turn been thrust southerly over a Lower Jurassic sequence (Geol. Surv., Canada, 1957). The northerly fault or fault zone may be continuous with a fault bordering the southwest side of the large ultramafic body that crosses Taku River. Tertiary volcanic rocks obscure the westerly extension of the southern fault but farther west in Tulsequah area a prominent thrust fault has been mapped by Souther (1960); it involves similar strata and probably represents a continuation of the same fault. Minor structures near the faults suggest that major movement has been essentially parallel with the dip of the fault.

The northern thrust fault marks the southern and southwestern borders of the Atlin horst. The structure seems to represent a major, deep-seated fracture, possibly having localized to some extent the emplacement of ultramafic bodies in Permian time, and later determining the southern and southwestern borders of the Atlin horst. Perhaps the limits of the Atlin horst were controlled by this fracture and by the belt of crystalline rocks to the northeast. The presence of both prior to major Mesozoic orogeny could explain the relative rise of the horst as a wedge during Mesozoic compression. This would also explain the concordance of fold trends with the trend of the fault.

The southern fault probably represents a similar, major, deep-seated fracture that may have been initiated earlier than the post-Lower Jurassic movement indicated by stratigraphic data.

The northern part of the Rocky Mountain Trench is bordered by complexly folded and faulted lower Palaeozoic strata. Trends of strata in the Cassiar Mountains are slightly more westerly than those in the Rocky Mountains and both trends are truncated by the trench at acute angles. Southwest of the trench near the mouth of Gataga River, beds are thrust towards the trench and overturned in the same direction. The most obvious faults near this area are those that trend northwesterly in the Cassiar Mountains and bound blocks of competent and incompetent strata. Locally, north of Gataga River, however, a fault coincides with the southwest side of the topographic trench. Whether the faults in the Cassiar Mountains swing into the trench or whether they are cut off by a major fault or fault zone is not known.

On the northeast side of the Rocky Mountain Trench, strata are overturned to the northeast and may also be involved in thrusting to the northeast. Cambrian(?) rocks in the wedge between Gataga and Kechika Rivers are tightly folded and overturned northeasterly. Compelling stratigraphic evidence, including the continuity of limestone beds, suggests that the conspicuous Gataga River lineament does not represent a fault or fault zone.

Everywhere in the area under consideration the trench is underlain by highly folded and sheared, incompetent Cambro-Ordovician strata. The problem that remains is the relative importance of erosion along fault zones versus the erosion of weak strata unrelated to faulting in the evolution of the Rocky Mountain Trench in this area.

The western margins of both crystalline zones are smoothly sinuous in contrast to the highly irregular eastern margins. In addition, the western margins are bounded by faults along much of their length[1], whereas along the eastern margins granitic bodies protrude from the plutonic complexes discordantly into the adjoining belts of stratified rocks. Possibly during early and middle Mesozoic times, the repeatedly uplifted crystalline zones were separated by faults from adjoining depressed regions of bedded rocks. If so, further movement probably took place along these faults in mid-Cretaceous time as a result of differential movement between the relatively incompetent, unmetamorphosed stratified rocks and the competent crystalline zones. Perhaps mid-Cretaceous and later post-tectonic intrusions obliterated signs of earlier faults. This is suggested by the distribution of the youngest of the Coast Range intrusions near the eastern border of the western crystalline zone (Buddington and Chapin, 1929; Kerr, 1948a, 1948b; Christie, 1958), and by relations of crystalline rocks to unmetamorphosed rocks on the eastern side of the eastern crystalline belt in the Pelly Mountains. There, Palaeozoic formations are faulted against presumably older granitic gneiss in one locality but are intruded by granitic bodies protruding from the plutonic complex in others. In some localities, as in the southern part of the Cassiar batholith, granitic plutons are intrusive into the bedded rocks on both sides of the crystalline zone.

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1 H. S. Bostock (personal communication 1960) suggests that the crystalline rocks in the northern Pelly Mountains are separated by a fault from the Palaeozoic rocks in the northern part of the Tagish belt.

CONCLUSIONS

1. The three belts of unmetamorphosed stratified rocks have contrasting histories and characteristics. Miogeosynclinal and shelf conditions prevailed in the eastern belt during late Proterozoic and much of Palaeozoic time and was succeeded by eugeosynclinal conditions in late Devonian and early Mississippian time. Eugeosynclinal conditions existed in the Tagish belt from Permian to near the end of late Triassic time in Yukon Territory, but continued into the early Jurassic in northwestern British Columbia. The more or less continuous, deeply subsiding, marine trough that existed from late Triassic to middle Jurassic time was broken up in late Jurassic time into separate basins. Eugeosynclinal conditions persisted in the western belt from Ordovician to Cretaceous time. In the Cenozoic, narrow, non-marine troughs formed in the central part of the belt whereas a deeply subsiding geosyncline formed along the margin of the Gulf of Alaska. This received a thick sequence of clastic sediments derived from the mountains along the coast.

2. The two crystalline belts are of some antiquity. The eastern belt may possibly have evolved as early as early Mississippian but certainly was established by earliest Triassic time. The western belt may possibly be as old as Silurian and was certainly established some time before the Permian. Once established, the crystalline belts were the principal loci of plutonism and uplift in the northwestern Cordillera and consequently they controlled the distribution and character of Mesozoic strata and, to some degree, the manner in which they were deformed.

3. The Devono-Mississippian eugeosyncline of the eastern belt was not initiated on a simatic crust but followed deposition of perhaps a minimum of 16,500 feet of sediments of typical miogeosynclinal and shelf character during Proterozoic and lower Palaeozoic time.

4. The volcanic source west of the Whitehorse trough in late Triassic time may have been analogous to the present-day island arcs. If so, the volcanic islands were built upon a silicic crust. Evidence for this lies in the presence of pre-Permian granites and metamorphic rocks in the Coast Mountains of northern British Columbia, earliest Triassic granite northwest of Whitehorse, and highly quartzose metamorphic rocks of probable pre-Mesozoic age southwest of Whitehorse.

5. The tectonic behaviour of the eugeosyncline in the Tagish belt seems to have been much more stable in Pennsylvanian and Permian time than during late Triassic and early Jurassic times. Probably volcanism during the Permian in this belt was principally submarine in contrast to important contributions by explosive volcanoes in the late Triassic.

6. Ultramafic rocks in the belts of unmetamorphosed rocks are most commonly restricted to greenstones of Mississippian and Permian age. By contrast they are conspicuously absent from the zone of late Triassic explosive volcanism.

7. The rates of uplift and subsidence in the tectonically mobile zone of the western Cordillera have varied widely. Subsidence during the Devono-Mississippian in much of the eastern belt was many times greater than formerly. The rate of subsidence increased abruptly and appears to have ended almost as abruptly. Rocks deposited in the eugeosyncline during late Devonian and early Mississippian time may be as much as twice as thick as those deposited in previous recorded time dating back to the late Proterozoic. In the Whitehorse trough, subsidence must have been rapid in late Triassic time when it received volcanic debris but then decreased when volcanism ceased. Subsequently, in early Jurassic time, the rate of subsidence increased rapidly as uplift took place to the west. Uplift was spasmodic and took place at slightly different times along the western margin of the trough. This variable behaviour eventually included the trough so that by late Jurassic time it was broken up into differentially subsiding non-marine and marine basins. Yet another illustration is the differential uplift and subsidence that occurred at least twice during the Cenozoic in the Yakataga geosyncline.

8. In the eastern belt, important disconformities occur beneath Middle Silurian, Middle Devonian, and Devono-Mississippian strata, and a pronounced angular unconformity is recorded beneath Middle Mississippian strata. In several places in northern British Columbia the rocks beneath these breaks become progressively older to the east. In the central belt a marked hiatus is indicated by the lack of Lower Triassic and the scarcity of Middle Triassic rocks. Important unconformities occur locally at the base of Lower Jurassic, Upper Jurassic - Lower Cretaceous, and Upper Cretaceous - Paleocene sequences. In the western belt, angular unconformities have been reported beneath Middle Devonian and Permian rocks, and breaks occur between medial Ordovician and Silurian beds and within Silurian and Devonian successions.

Palaeozoic deformations are suggested by stratigraphic relationships in the western and eastern belts. It is possible that rocks in the central belt were involved in an early Triassic orogeny. Deformations during the Mesozoic reached a climax during the mid-Cretaceous in the western and central belts and in at least part of the eastern belt. Tertiary deformations strongly affected the St. Elias and Rocky Mountains but had much less influence on rocks in the central belt.

9. The major structural divisions coincide with the three belts of unmetamorphosed stratified rocks and their two intervening crystalline zones. The latter have undoubtedly had a great influence on the evolution of structures in the northwestern Cordillera. On a regional scale, major northwesterly trending fractures, perhaps including both transcurrent and thrust faults, are abundant and remarkably persistent. In many cases they may represent deep-seated structures of considerable age, and if so, they could have been of great importance during subsequent deformations. Much of the complexity of northwestern Cordilleran geology can be related to the heterogeneity of rock types and their irregular distribution.

The belts of stratified rocks have differing and characteristic structures. The eastern belt may be subdivided into two structural provinces separated by the lineaments of Tintina and Rocky Mountain Trenches. These structural provinces in turn have contrasting tectonic styles between northern British Columbia and southeastern Yukon. The eastern province of the Rocky Mountains is featured by northeasterly directed asymmetry of its structure. The western province in the Cassiar Mountains is characterized by more or less steeply dipping faults and folds, overturned to the southwest in some northwesterly trending fault blocks, and to the northeast in others. By contrast, similar structures in the Pelly Mountains have been superimposed on rocks that had been previously deformed by northeasterly directed, gently dipping and undulating thrust faults.

Rocks of the Tagish belt appear to have been deformed largely within a framework of pre-existing tectonic relief primarily controlled by the two bounding crystalline zones. In addition, major faults such as that along the south side of the Atlin horst further controlled the direction of fold-trends and were probably important factors in breaking up the Tagish belt into blocks. Some modification of fold trends apparently resulted from the intrusion of discordant granitic plutons into previously folded rocks.

The western belt can be subdivided into two structural provinces separated by the Chatham Strait lineament. Northwest of this lineament is the St. Elias province, which from Yakutat Bay northeast to Kluane Lake, displays a crude symmetry. The central crystalline core, bounded possibly on both sides by inward-dipping faults, is flanked by beds thrust and overturned to the northeast on the northeast side, and to the southwest on the Pacific side. Deformation is most intense near the Shakwak Trench. The St. Elias province in southeastern Alaska is anticlinorial. Thrust faults and folds are directed southwestward east of Glacier Bay on what is probably the east limb of the anticlinorium. Mesozoic beds on the west coast of Chichagof Island dip west (Reed and Coats, 1941). Possibly the metamorphosed and intruded Palaeozoic rocks forming the crystalline core in the St. Elias Mountains deformed as an uplifted wedge as part of the same anticlinorium around Glacier Bay. Southwest of the Chatham Strait lineament the southeastern Alaskan province is a region of great structural heterogeneity broken by numerous faults.

In all three structural and stratigraphic belts the competency of rocks has profoundly influenced the tectonic style.

PROBLEMS OF NORTHWESTERN CORDILLERAN GEOLOGY

Problems of major importance are listed below. Many may be answered by further field work, with perhaps in places, detailed examinations of critical areas. The solution of other problems may become apparent when more abundant absolute age determinations become available. In some areas seismic and gravity data might be useful. In any event it should be apparent that many basic data are still required for a more complete and accurate synthesis of northwestern Cordilleran geology. A statement of some of the problems may help to direct further field work in the region.

1. Where was the western extremity of miogeosynclinal deposition in Proterozoic and early Palaeozoic time ?

2. What is the stratigraphic relationship between Proterozoic rocks west of the Rocky Mountain Trench in northern British Columbia and those east of the Trench ?

3. Where was the source of widespread sand in Silurian and (?) Devonian strata ?

4. What was the palaeogeography at the time of deposition of the graptolitic shales and siltstones ?

5. What was the nature of the eastern boundary of the Devono-Mississippian eugeosyncline in the eastern belt ?

6. How far west did the typical Devono-Mississippian eugeosyncline of the eastern belt extend ?

7. Does the eastern crystalline belt roughly coincide with the trend of the Devono-Mississippian eugeosyncline ?

8. Where was the eastern margin of the Pennsylvanian-Permian eugeosyncline ?

9. Is there any relationship between the trends of major thrust faults and large ultramafic bodies in the central belt and the local trend of the Pennsylvanian-Permian eugeosyncline ?

10. What are the ages of the ultramafic rocks and what controlled their distribution ?

11. What were the dates of orogeny and plutonism preceding the widespread orogeny in the mid-Mesozoic ?

12. What was the origin of the major lineaments such as the Tintina, Shakwak, and Rocky Mountain Trenches, etc. ?

13. What are the reasons for the different structural patterns of rocks in parts of the Pelly Mountains and those in the eastern Cassiar Mountains in British Columbia ?

14. Was there an exogeosyncline(Kay, 1951) or clastic wedge related to deformation of the Devono-Mississippian eugeosyncline, i.e. towards the craton from the eugeosyncline, and do thick deposits of chert-pebble conglomerate, chert arenite, etc. along the eastern outcrops of Devono-Mississippian eugeosynclinal sediments represent such a wedge ?

15. What is the significance of the remarkably smooth and linear western contacts of both crystalline belts, and why are the youngest intrusions apparently concentrated along the eastern margin of the Coast Mountains belt ?

16. What is the origin of the persistent faults that border the crystalline belts in many places ?

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