The Geological Framework of the Yukon Territory
by C. Hart

The Yukon Territory occupies the northern portion of a large geologic (and physiographic) province known as the Cordillera. This province is composed of relatively young mountain belts that range from Alaska to Mexico. Like most of the Cordillera, Yukon is composed of a diverse array of rock types that record more than a billion years of geological history. Most of the rocks have been affected by folding, faulting, metamorphism and uplift during various deformation events over at least the last 190 million years. This deformation has resulted in a complex arrangement of rock units and the mountainous terrain we see today. In Yukon, there are two main geological components which are largely separated by a major, northwest-trending fault (the Tintina): 1) the northeastern region is composed of a thick, older sequence of sedimentary rocks which was deposited upon a stable geological basement; and 2) the southwestern region is composed of a younger, complex mosaic of varying rock types that amalgamated and accreted to the stable sedimentary package.

This paper briefly describes the geological framework of Yukon south of 65 degrees N and, with some exceptions, uses the Tectonic Assemblage Map of the Canadian Cordillera (Wheeler and McFeely 1991) and the Terrane Map of the Canadian Cordillera (Wheeler *et al.* 1991) as a foundation. However, some of the names used on these maps have been superseded by new terminology and they are included in this paper. Recent brief syntheses of Yukon physiography and geology are rare (Tempelman-Kluit, 1979; 1981), although geological compilations of Cordilleran geology are numerous and contain useful information about Yukon geology (Monger *et al.*, 1982; Monger, 1989; Gabrielse and Yorath, 1992).

MORPHOGEOLOGICAL BELTS

The Canadian Cordillera is composed of five northwest-trending morphogeological belts that are parallel to the continental margin: from west to east they are the Insular, Coast, Intermontane, Omineca and Foreland belts (Figure 1). Together these five belts form the Cordilleran continental crust which varies from less than 3 km thick in the west to 50 km thick in the east. These belts reflect the sum of geological processes which interacted over the past billion years to produce the geological framework of Yukon. Each belt is different due to the different rock types contained and the different geological history, as well as the varied effects of climate and glaciation. The close ties between geology and physiography has led some to call these morphogeological belts. Generally speaking, younger mountain belts are more topographically extreme. The age of a mountain belt refers to the timing of its uplift and not the age of the rocks.

The ***Insular Belt*** comprises very high, huge and craggy mountain ranges that are composed of mainly volcanic and sedimentary rocks of oceanic origin. Much of the Insular Belt has been tectonically uplifted during the last 15 million years at a rate of approximately 3 cm/year, or 3 km every million years. Rapid uplift combined with several periods of extensive glaciation, as well as erosion in the past 1.6 million years have resulted in the extreme topography we see today.

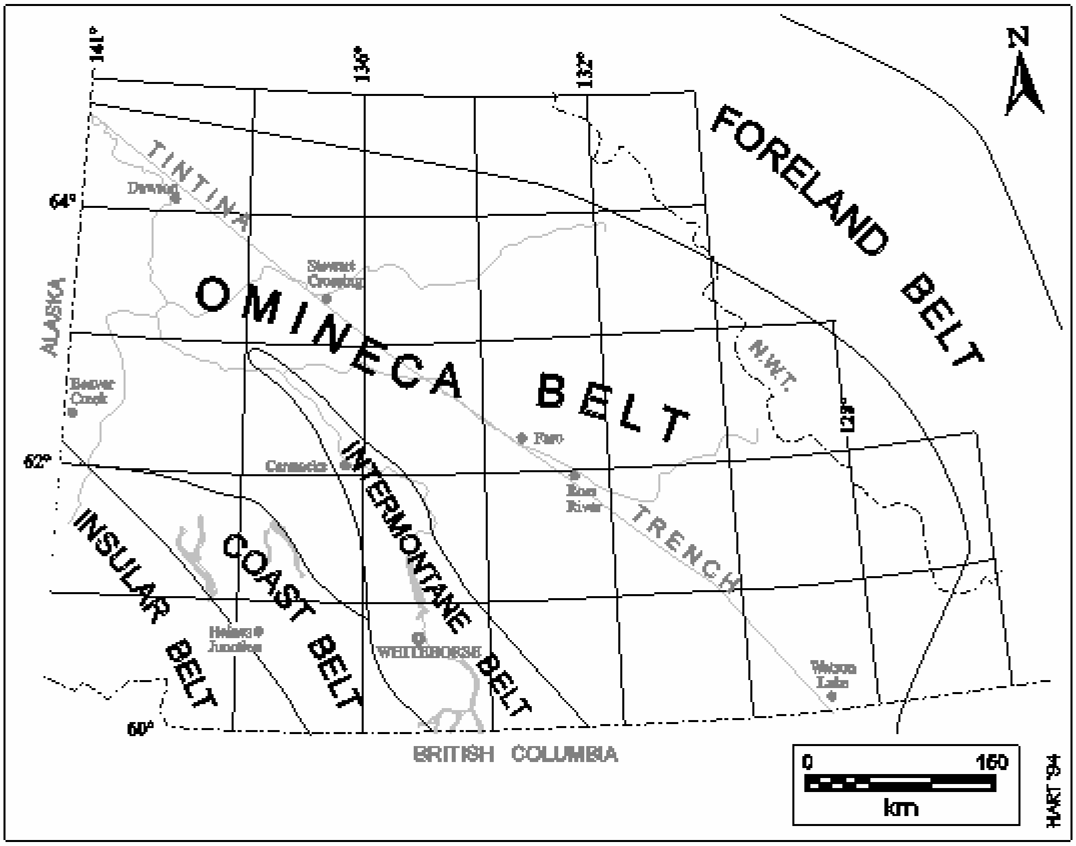

Figure 1. *Location of the five physiographic or morphogeological belts of the Yukon. The belts underlie regions that have similar geology or have undergone similar geological histories. The Yukon north of 65 degrees is underlain by the Foreland Belt. The lines of latitude and longitude define the 1:250 000 NTS grid.*

The rugged, high relief, steep-sided mountains of the ***Coast Belt*** are mainly composed of granitic rocks. These rocks are rich in silica which is resistant to weathering, however welldeveloped fractures, or joints which are typical of granitic rocks result in steep or vertical mountain sides. Like the Insular Belt, the Coast Belt has also experienced dramatic tectonic uplift, but about 50 million years ago. Coast Belt topography has been modified by numerous glacial events, and more recently by excessive precipitation which has steepened the mountain sides by intensive gully erosion.

The ***Intermontane Belt*** is characterized by subdued relief and rounded or flat-topped mountains with long, straight slopes. This character is largely the result of the recessive nature of the sedimentary rocks composing this belt, and slow and continuous erosion over most of the past 100 million years. This region has also not experienced the tectonic uplift that affected the Insular and Coast Belts.

The ***Omineca Belt*** is the most complex and varied in Yukon and is composed of variably metamorphosed sedimentary rocks and granites. Most of this belt contains large mountain ranges with localized centres of high mountains called massifs. However, the northwestern part of this belt is characterized by low, rolling, heavily vegetated hills. This area was not reached by northward advancing glaciers. Consequently, millions of years of erosion has established a thick cover of soil and weathered bedrock. Where glaciated, this cover has been scoured away and exposed craggy bedrock. Massifs in the glaciated portion are usually centred around granitic intrusions whose heat cooked and hardened the surrounding sedimentary rocks. The boundary between the Omineca and the Foreland Belts is defined by the easternmost exposures of granitic rocks.

The ***Foreland Belt*** contains long, linear ranges of mountains composed entirely of sedimentary rocks. Unlike the Intermontane Belt, the Foreland Belt rocks have been affected by a period of deformation that stacked and thickened the sedimentary rocks along numerous, generally northwest-trending, folds and thrust faults. The larger faults constitute zones of weakness in the rock which easily erode and give rise to long linear valleys (e.g. upper Hess, Stewart, Bonnet Plume, Wind and Snake Rivers) between the mountain ranges.

GEOLOGY

Yukon's geology divides into two essential components that are, for the most part, separated by the Tintina Trench. Rocks northeast of the Tintina Trench are old (>1000 to 300 million years), mainly sedimentary and represent the *Ancient North American* margin. Rocks southwest of the Tintina Trench are mostly young (350 to 20 million years old), mainly igneous and metamorphic, and represent numerous crustal fragments called *accreted terranes* whose place of origin is uncertain. During most of the Yukon's geological history, the terranes were not attached to North America, but were accreted to the western margin of Ancient North American between 190 and 120 million years ago. Rocks in the zone between the accreted terranes and Ancient North America have been extensively deformed and form a belt known as the *Teslin Suture Zone*. This belt has subsequently been cut by the Tintina Fault which has caused some complexity in this region.

Ancient North America

Prior to 190 million years ago, the western edge of the Ancient North American continental craton extended far out into the ancient Pacific Ocean. This submerged continental shelf is composed of crystalline basement rocks (akin to the Canadian Shield) that are at least 1.7 billion years old. These rocks provided a stable continental *platform* upon which sediments, dominantly limestone and sandstone accumulated for over a billion years. Shale, sandstone and chert accumulated in regions of deeper water known as *basins*. These two different depositional environments (platforms and basins) gave rise to differing packages of rocks characterized mainly by limestone and shale, respectively. Today, millions of years later, these limestone and shale packages are largely in fault contact with each other.

Sediments deposited on the platform formed a thick succession of rocks that are now exposed in the Mackenzie and Cassiar Mountain Ranges. The Mackenzie and Cassiar Platforms (Figure 2) accumulated between 5 and 25 kilometres of mainly limestone and sandstone over a one billion year period. The limestone accumulated during quiescent periods in warm, shallow and clear water. The sandstone accumulated from detritus that eroded from exposed rocks of the Canadian Shield craton which were carried west by ocean currents. Each platform is composed of rocks of the Wernecke Supergroup and the Mackenzie Mountains Supergroup. These two thick stratigraphic packages include the Mackenzie, Purcell, Wernecke, Windemere, Rapitan, Pinguicula and Gog assemblages. Although parts of the Cassiar Platform are west of the Tintina Trench, the rocks there are so similar to those on Ancient North

America margin that it is certain they are North American in origin but have been displaced along the Tintina Fault. On some maps the displaced fragments of North American continental margin are called the Cassiar and Dorsey Terranes (Figure 3).

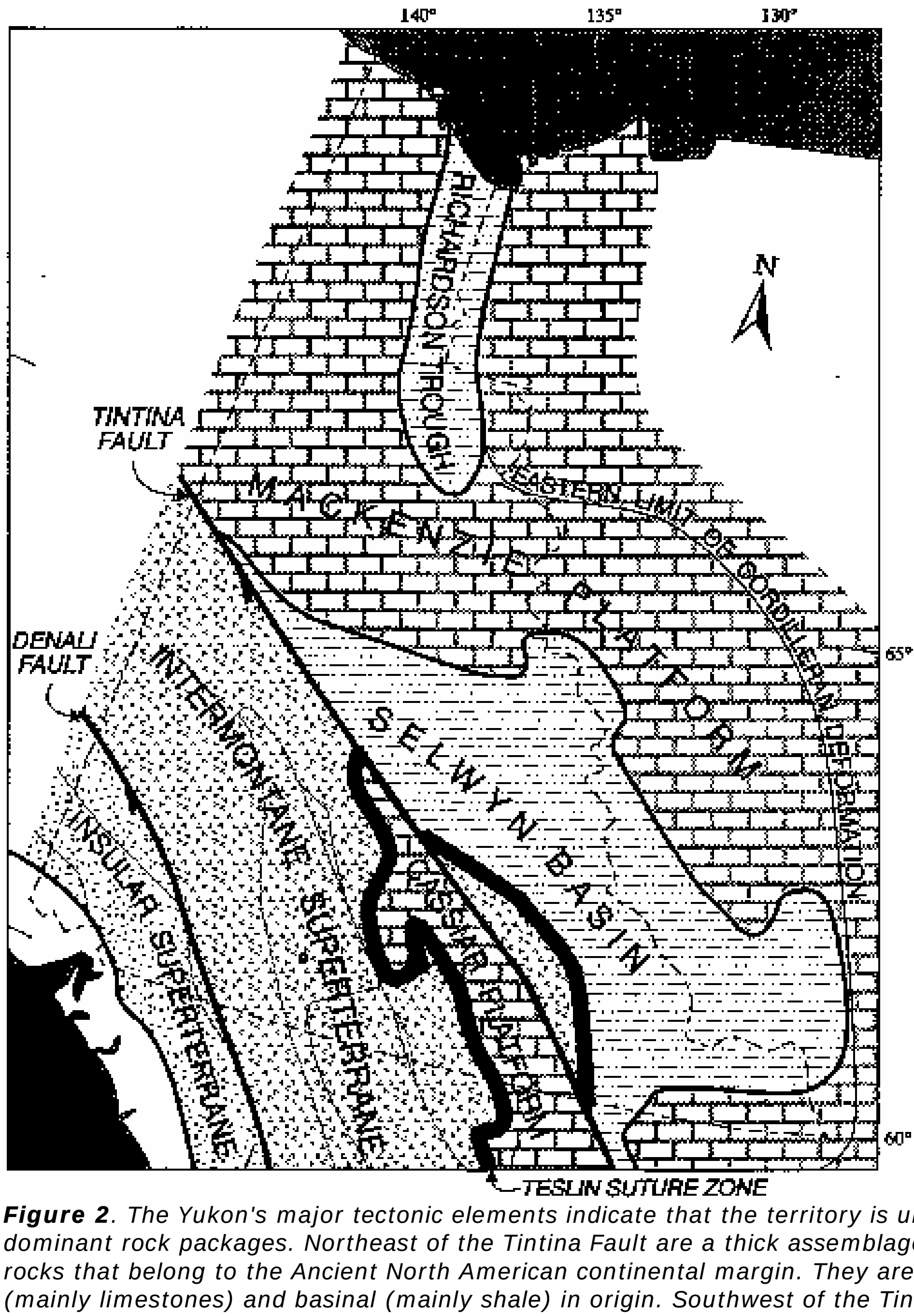

Figure 2. *The Yukon's major tectonic elements indicate that the territory is underlain by two dominant rock packages. Northeast of the Tintina Fault are a thick assemblage of sedimentary rocks that belong to the Ancient North American continental margin. They are platformal (mainly limestones) and basinal (mainly shale) in origin. Southwest of the Tintina Fault are numerous dissimilar crustal fragments called Terranes. The terranes were amalgamated into the Insular and Intermontane Superterranes prior to their accretion to the Ancient North American margin. The zone of deformation between the accreted terranes and Ancient North America is represented by the Teslin Suture Zone.*

The Selwyn Basin and Richardson Trough were two major basins that formed within the platforms. Because the basins create regions of much deeper water, limestone growth is impossible and the currents which move the sands that form sandstone are not as strong. Instead these basins slowly accumulated muds and biogenic silica that later formed successions of black shale and chert. These shale basins existed from about 800 to 320 million years ago. Rock units in the basins are dominated by: the sandstone, maroon and green shales and rare marble of the Hyland Group; the chert and black shales of the Road River/Rocky Mountain Group and the black shale and chert-pebble conglomerate of the Earn and Imperial Groups. The black shales host numerous deposits of zinc-lead-silver and barite such as those at Faro and Macmillan Pass.

Accreted Terranes

Southwest of the Tintina Trench there exists a mosaic of rock packages that are different from each other and are separated by faults. Individual rock packages or crustal fragments are known as *terranes*. Most terranes are different from rocks of the Ancient North American margin and their place of origin is uncertain. These are called *suspect* terranes. Some terranes are similar to Ancient North American rocks but cannot be absolutely correlated -- these are called *pericratonic* terranes. Other terranes have features that indicate that they formed in an environment totally unlike that of Ancient North America -- these are called *exotic* terranes. The one thing that all of these terranes have in common is that they were accreted to the ancient western margin of ancient North America - consequently they are all called *accreted* terranes. The Yukon is composed of ten of these terranes (Figures 2 and 3). Geological evidence further suggests that several of these terranes may have amalgamated with each other prior to their accretion to Ancient North America. These groups of terranes constitute *composite* and *superterranes* -- three of these are found in Yukon.

Yukon-Tanana Composite Terrane

The Yukon-Tanana Terrane is a name that was not included on recent compilation maps but is preserved here because of its common and continued usage in Yukon. The Yukon-Tanana Terrane is the largest of Yukon's terranes, covering a large portion of the Omineca Belt, and extending into adjacent Alaska and British Columbia (Figure 3). The Yukon-Tanana Terrane is composed of several metamorphic rock assemblages -- from oldest to youngest they are the Nisling assemblage (or Terrane), the Nasina assemblage, the Pelly Gneiss and the Nisutlin assemblage. Each of these components appear to have been deposited upon one another during this Terrane's 500 million year long history.

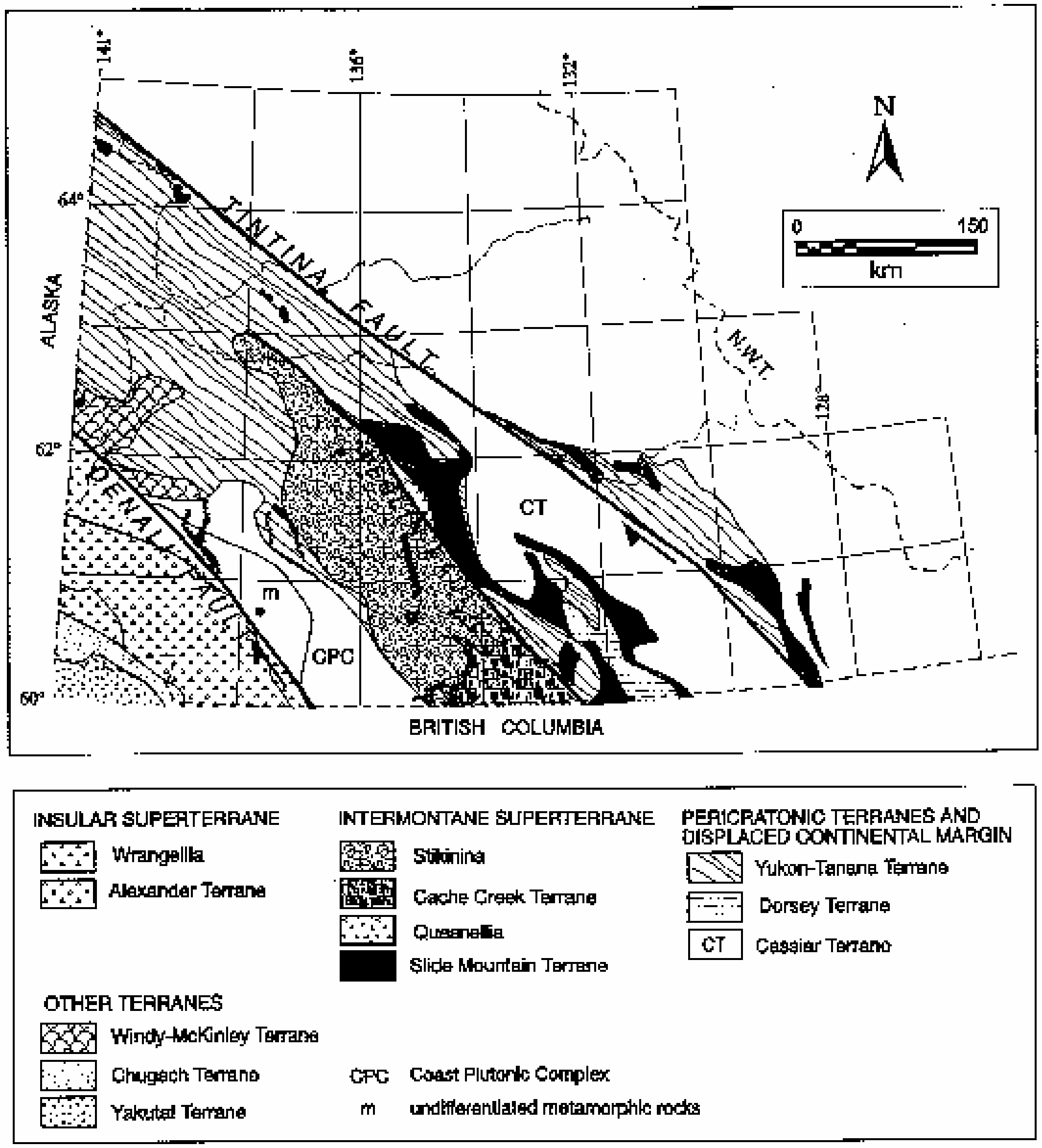

Figure 3. *The numerous terranes that comprise the accreted terrane portion of the Yukon include fragments of oceanic floor, volcanic island arcs, oceanic basins and old metamorphosed crust. Since their accretion to North America over 120 million years ago, their positions have been complicated by displacements along numerous faults.*

The Nisling assemblage is a metasedimentary package composed of quartzite, quartz-mica schist and marble that is at least 400 million years old but may be as old as a billion years old. The 400-320 million year old Nasina assemblage rocks are also dominated by quartzite and schist, but contain large amounts of carbon that make these rocks black, or graphitic. The Pelly Gneiss and Nisutlin assemblage are composed of 350 to 250 million year old granitic and volcanic rocks respectively, that have been subjected to heat and pressure which has deformed and metamorphosed them. The Pelly Gneiss still retains its granitic composition but is strongly foliated and locally displays mineral banding. The metamorphism has turned the Nisutlin assemblage into a light green quartz-mica schist package that underlies the Klondike goldfields and is known as the Klondike schist. The complexity of the Yukon-Tanana Terrane largely results from the diversity of rock types and the numerous metamorphic events it has undergone throughout its long history. The metamorphism is locally of extremely high temperature (650 degrees C) and high pressures that correspond to crustal depths of approximately 25 kilometres.

Most of the metamorphic rocks that comprise Yukon-Tanana Terrane were originally sedimentary rocks. The stratigraphy, or the order in which the different sediments were deposited, is similar to that of rocks on Ancient North America. This has resulted in the Yukon-Tanana Terrane's assignment as a pericratonic terrane. However, the Yukon-Tanana Terrane encloses, and is amalgamated with the terranes that comprise the Intermontane Superterrane. This has led many geologists to include the Yukon-Tanana Terrane as part of the Intermontane Superterrane.

Intermontane Superterrane

The Intermontane Superterrane is composed of five dissimilar terranes that were amalgamated approximately 180 million years ago, including Stikinia, Quesnellia, Slide Mountain, Cache Creek and Windy-McKinley.

Stikinia is the largest terrane in the Cordillera, but in Yukon is restricted to the area of the Intermontane Belt. Stikinia is composed of a linear belt of 220 million year old volcanic rocks of the Lewes River Group. The volcanoes formed in an oceanic setting called an island arc that is similar to present-day Japan. A seven-kilometre-thick sequence called the Whitehorse Trough consisting of slightly younger (210-160 million years) sedimentary rocks was deposited in a marine basin adjacent to the Lewes River arc. These rocks are mainly sandstone, conglomerate and limestone of the Laberge and Lewes River Groups. These rocks are exposed between Whitehorse and Carmacks, and include the limestone of Grey Mountain and the conglomerates near Braeburn. The limestone unit hosts the copper deposits of the Whitehorse Copper Belt.

Quesnellia in Yukon is composed of volcanic rocks known as Nikolai Group that are the same age and similar to those in Stikinia. Although they cover a large area in British Columbia, Quesnellia in the Yukon is represented by only a few small fragments east of the Teslin River.

Slide Mountain, Cache Creek and Windy-McKinley Terranes are composed of volcanic rocks that formed on the oceanic sea floor, as well as overlying successions of chert, limestone and shale. These terranes are similar in age and range from 320 to 190 million years old. Both Slide Mountain and Cache Creek Terranes are thought to represent ancient oceans that existed between other terranes. Slide Mountain Terrane represents the up-thrusted remains of the ocean floor that once separated Quesnellia from North America, whereas the Cache Creek Terrane represents the ocean floor that existed between Stikinia and Quesnellia/Yukon-Tanana. Locally, Slide Mountain, Cache Creek and Windy-McKinley Terranes have outcrops of ultramafic rocks. These are rocks that are rich in iron and magnesium and originally formed the base of the oceanic crust. Ultramafic rocks that are faulted up and exposed on the land surface contain the Clinton Creek and Cassiar asbestos deposits, and form the Midnight Dome at Dawson City. Sedimentary rocks of the Cache Creek Terrane contain a particular assemblage of fossils that are found in Asia and not in Ancient North American rocks. This suggests that the Cache Creek Terrane likely originated far from North America and may have existed on the other side of the Pacific Ocean. It is therefore considered *exotic*. These Cache Creek limestones form the large white mountain across from Jakes Corner and Bove Island.

Insular Superterrane

The Insular Superterrane is mainly composed of two older terranes that were amalgamated by 320 million years ago -- they are Wrangellia and Alexander Terrane. Both of these terranes are composed of island arc and ocean floor volcanic rocks with thick assemblages of overlying oceanic sedimentary rocks that range in age from 400 to 220 million years old. Wrangellia in particular, has a several-kilometre-thick package of platform-type limestones. The Insular Superterrane hosts a 230-million-year-old package of volcanic rocks (the Nicolai Group) that contains the Windy Craggy copper-cobalt-gold deposit in northernmost British Columbia and the Wellgreen nickel-copper-platinum deposit near Burwash. The Chugach and Yakutat Terranes are not part of the Insular Superterrane, but are within the Insular Belt. These two terranes are composed of young (20-90 million year old) sedimentary rocks that were originally deposited on the floor of the Pacific Ocean. These sedimentary rocks were subsequently scraped off of the ocean floor by tectonic processes and accreted onto the western margin of North America.

Overlapping Assemblages

Numerous rock packages were deposited, for the most part, after all the terranes were amalgamated and accreted to North America. These *overlapping assemblages* of rocks are not specific to one terrane, but are found on or in two or more terranes, or on Ancient North America. These post-accretionary assemblages could be felsic plutonic (igneous) rocks that intrude two or more terranes, or volcanic or sedimentary rocks that are deposited on, or across two or more terranes.

Felsic Plutonic Rocks

Many felsic plutons intrude into Yukon's basement rocks (the assembled terranes and Ancient North America) in all morphogeological belts, except for the Foreland Belt. These rocks vary in composition from granite to granodiorite to quartz monzonite to diorite to syenite, however to simplify terms for this summary, all these variable compositions are referred to as "granites". The largest concentration of plutons occurs in the Coast and Omineca belts.

The Coast Plutonic Complex takes up most of the Coast Belt. It is not a terrane, but rather a linear belt composed almost entirely of felsic plutons. The plutons of this vast granitic region are bounded to the east by western margins of Stikinia and the Yukon-Tanana Terrane, which they intrude, and are truncated on their western margin by the Denali Fault. The Coast Plutonic Complex ranges in age from 185 to 55 million years with most of the older rocks along its eastern margin. The western margin of the Coast Plutonic Complex experienced a tremendous amount of uplift about 50 million years ago that has exposed rocks that were previously 20 km deep in the crust. These rocks are exposed near Haines Junction and Skagway, Alaska.

The remaining felsic plutonic rocks are grouped into suites according to their age and composition. Granitic plutons of the Klotassin suite are approximately 210-180 million years old and intrude the Yukon-Tanana Terrane and western Stikinia. Granitic plutons of the St. Elias suite are approximately 130 million years old and underlie parts of the St. Elias and Icefield Ranges in the extreme southwestern part of the territory. Granitic rocks of approximately 120-65 million years of age comprise several plutonic suites that range from the Kluane Mountains across all the terranes of the Yukon into Ancient North American rocks as far east as the Northwest Territories. This most widespread and voluminous age of granite pluton formation includes the Kluane, Whitehorse, Cassiar, Surprise Lake, Tombstone and Selwyn plutonic suites. These plutons are important since they are responsible for the formation of numerous deposits of copper, gold, molybdenum, tungsten and tin including Mactung, Logtung and Cantung tungsten deposits, Red Mountain molybdenum deposit, Casino Copper, Brewery Creek and Dublin Gulch gold deposits as well as the deposits of the Whitehorse Copper Belt. Plutons of approximately 55 million years in age are common in the Coast Plutonic Complex and western Yukon-Tanana Terrane and locally host copper-molybdenum mineralization, but are rare in eastern Yukon.

Volcanic Rocks

There are four main packages of post-accretionary volcanic rocks. Mount Nansen Group rocks are about 100 million years old and are sporadically located across Stikinia and the western Yukon-Tanana Terrane. Rocks of the similar-aged South Fork volcanics form huge caldera complexes on Ancient North America north of Ross River. The younger Carmacks Group (75 million years old) forms numerous thick successions of volcanic rocks along the contact between Stikinia and Yukon-Tanana Terrane and through the Dawson Range northwest of Carmacks. This volcanic event is responsible for much of the mineralization in the Dawson Range including the Laforma gold veins and the huge Casino copper-molybdenum-gold deposit. The 55-million-year-old Skukum Group forms discreet volcanic calderas that occur in a linear array from the south end of Atlin Lake (in British Columbia) to Bennett Lake and on to Aishihik Lake. This group of rocks hosts the Mount Skukum gold deposit southwest of Whitehorse.

The Yukon's youngest volcanic rocks are the less than 10 million year old Fort Selkirk, Miles Canyon and Tuya basaltic lavas that occur near Fort Selkirk, Whitehorse and Watson Lake, respectively. One of the youngest volcanic events represented in the Yukon is so young that it is not even a rock yet. The thin strip of white ash that is common near the top of road-cuts in western Yukon is the White River Ash. This ash resulted from a volcanic explosion in the St. Elias Range near the Yukon-Alaska border about 1250 years ago. Lavas near Fort Selkirk were formed even more recently, during the early 19th century.

Sedimentary Rocks

There are few occurrences of young (<150 million years old) sedimentary rocks in the southern Yukon. The Dezadeash Formation is composed of a thick succession of muddy sandstone called greywacke that was deposited in a huge submarine fan about 150-100 million years ago. The Front Ranges, as seen from Haines Junction, are composed of these rocks. These rocks stretch from north of Haines, Alaska, northerly to Dezadeash Lake and Haines Junction and were deposited on the Insular Superterrane and the Yukon-Tanana Terrane. The Tantalus Formation occurs in small isolated exposures that range from south of Whitehorse to Carmacks and to just south of Dawson. These exposures are mainly of quartz-rich sandstone and conglomerate and host the Whitehorse, Division Mountain, Tantalus Butte and Haystack Mountain coal deposits. Tantalus Formation rocks range in age from 140 to 60 million years old and are deposited on Stikinia, Quesnellia and Yukon-Tanana Terrane. Unnamed, localized deposits of conglomerate were deposited within the Tintina Trench about 55 million years ago. These deposits also host coal deposits most notably near Dawson and Ross River. The youngest package of sedimentary rocks in the Yukon consists of the Amphitheater Formation conglomerate and sandstone that occur in three main areas: near the upper White River, Burwash and Dalton Post. These 25-million-year-old rocks also contain deposits of coal but because of their youthful age the coal is low grade lignite.

Faults

There are two major faults which extend across the Yukon (Figures 2 and 3).

Tintina Fault

The long, linear depression that extends northwesterly across the Yukon from Watson Lake along to Ross River, Faro and Dawson, and then into Alaska is referred to as the Tintina Trench. It is the northern continuation of the Northern Rocky Mountain Trench in British Columbia. The Tintina Trench is the physiographic expression of the Tintina Fault. Tectonic forces caused the block of rocks southwest of the fault to grind up against the stable North American block and, during a history of innumerable earthquakes, moved the southwestern block northwest towards Alaska. The grinding along the fault caused the rock to break up and become less resistant which, with erosion, led to the formation of the trench. Most geological evidence suggests that there was at least 450 km of right-lateral displacement (area southwest of the fault moved northwest) along the Tintina Fault, although there may have been as much as 1200 km offset. Volcanic rocks were deposited in the trench about 55 million years ago - probably at the same time as some of the motion along the Tintina Fault. These volcanic rocks host the Grew Creek gold deposit.

Denali Fault

The Denali Fault originates (on land) at Haines, Alaska and continues north into the Yukon to the south end of Kluane Lake, and further northwest into eastern Alaska. This fault, and the associated Duke River Fault, are still active and cause a steady stream of small earthquakes. The Denali Fault separates the very high mountains of the Insular Belt from the lower mountains east of the fault. The tectonic forces that are causing uplift in the Insular Belt are also responsible for displacement along the Denali Fault. This transfer of force along the fault prevents the region east of the fault from being affected by the tectonic forces that form the high mountains. There has been at least 350 km of right-lateral offset along the Denali fault.

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