Eastern Wrangellia – A New Ni-Cu-PGE Metallogenic Terrane in North America

L. Hulbert
Geological Survey of Canada
601 Booth St.,
Ottawa, ON, K1A 0E8

lhulbert@nrcan.gc.ca

W. Stone
Nevada Star Resource CP

Suit 355 Burrard St
Vancouver, BC V6C 2G8

wstone@nevadastar.com

SUMMARY

Triassic ultramafic-mafic intrusive complexes along the eastern margin of "Wrangellia" adjacent the Denali fault from east-central Alaska to northern British Columbia constitutes a newly recognized Ni-Cu-PGE metallogenic terrane that can be traced for at least 600 km. These sill-like intrusive centres acted as subvolcanic magma chambers that fed the extensive thick, overlying basalts and locally picritic pyroclastcs of the Nikolai Group in an oceanic plateau flood basalt setting. Confinement of the olivine-rich ultramafic sills, Ni-Cu-PGE mineralization, and more primitive coeval basalts and picrites exclusively to the eastern portion of Wrangellia is believed to be the product of melts forming in closer proximity to the hotter mantle plume tail or "axial jet" relative to the cooler more distal portions. The recent discovery of proximal, picritic volcanics with some of the larger mineralized ultramafic bodies in Alaska finally concludes the past paradox of tholeiitic parental magmas and primitive Ni-Cu-PGE ores in this terrane. The unprecedented levels of platinum group elements, the vast extent of this mineralized terrane, the temporal association with Siberian Trap magmatism, and the accompanying Noril'sk mineralizing event, suggest that mantle plume activity during the Permo-Triassic was unique with respect to the Phanerozoic record.

Key words: Wrangellia, new metallogenic terrane, nickel, PGE, Triassic

INTRODUCTION

An investigation of ultramafic-mafic rocks and associated Ni-Cu-PGE mineralization within the Kluane Ranges, Yukon, and its lateral extensions in northern British Columbia and Alaska was undertaken in order to better understand Triassic plutonic activity in this portion of the Cordillera: its age and tectonic setting, petrology of the intrusive rocks and relationship to the overlying volcanics, and the economic potential.

The findings of this study unequivocally demonstrate that this belt constitutes one of the largest tracts of Ni-Cu-PGE mineralized ultramafic-mafic rocks in North America, second only to the nickeliferous intrusions from the Proterozoic Circum-Superior Belt of Canada (i.e. Thompson Ni-Belt, Manitoba and Raglan Horizon, Cape Smith Belt, Quebec). Furthermore, striking similarities between the morphology of the eastern Wrangellia intrusions and those of the economic Circum-Superior deposits, and the consanguineous development of world-class Cu-Ni-PGE deposits in the Siberian Traps, Russia, lend additional support to the potential significance of this belt. Comparisons with the Pacific Margin, or western branch of Wrangellia are presented, and an explantion for the lack of Ni-Cu-PGE mineralization and ultramafic intrusions is proposed.

Early research (Lassiter, et al., 1995, Richards et al.; 1991) on the volcanics suggests that this exotic terrane formed in an oceanic plateau flood basalt setting. Twenty-five years ago oceanic plateau basalts were virtually unknown since direct observations was limited since most are covered by thousands of metres of water, and others have been consumed in subduction zones. It is proposed that Wrangellia may represent one of the best exposed and preserved large scale examples of oceanic plateau flood basalts on earth, and invalueable petrogenetic and metallogenic information could be gained by an extensive study of the terrane. Unfortunately, past research in Wrangellia was generally restricted to the easily accessible areas, particularily on Vancouver Island in the western portion of the terrane, and thus provided only the superficial characteristics of this magmatic province. Extensive research by the senior author over the past 10 years in the eastern Wrangellia has confirmed a number of the earlier researchers findings; however, it has also disclosed a number new volcanological, intrusive, geochemical, geochronological and metallogenic findings that will fundamentally change our understanding of Triassic magmatism in Wrangellia, and oceanic plateau flood basalt provinces in general. It also brings to the attention of the exploration community the significance of such environments when exploring for Ni-Cu-PGE deposits. Although this article will focus on the new Ni-Cu-PGE terrane associated with the eastern branch of Wrangellia it will draw heavily on our information acquired from extensive volcanological and chemostratigraphic studies conducted throughout the terrane and its application in mineral exploration.

Geological Setting

Wrangellia is one of the largest accreted terranes within the Cordillera of western North America (Fig. 1). It can be traced discontinuously southward along the Pacific margin of North America, from the Wrangell Mts. area of southern Alaska to the Queen Charlotte Islands and Vancouver Islands, Canada, and possibly as far south as eastern Oregon and western Idaho for a distance of over 2000 km (Jones et. al.; 1977).

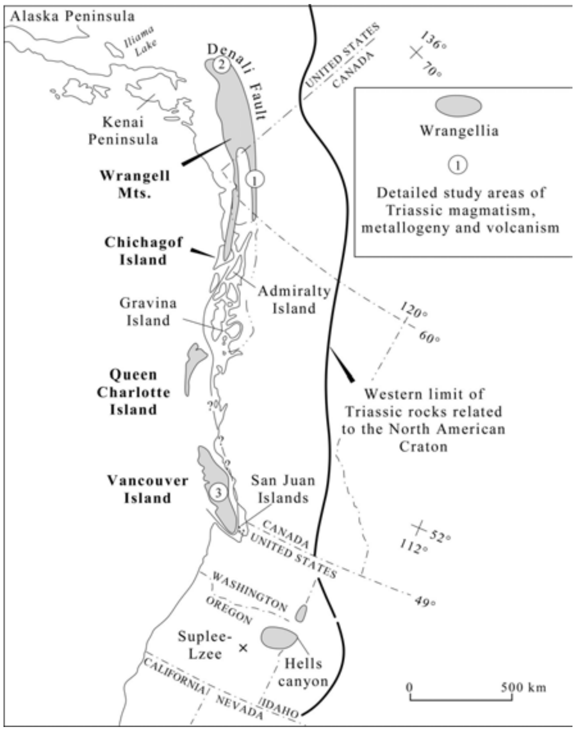

Figure 1. Map showing distribution of Wrangellia and location of detailed study areas (modified from Jones et al., 1977).

The northern part of Wrangellia occupies a large tract of central and southeastern Alaska, and has two southward extending branches which are separated by the Alexander Terrane. The western branch extends along the Pacific margin, whereas, the eastern branch borders the Denali fault, and extends southward tapering through the Yukon and into northern British Columbia.

The most diagnostic feature of Wrangellia is a similar sequence of Triassic rocks, including a thick pile of tholeiitic flows and pillow lavas (Nikolai Group – eastern Wrangellia and Karmutsen Formation – western Wrangellia) capped by inner platform carbonate. A generalized stratigraphic section for eastern Wrangellia is illustrated in Figure 2.

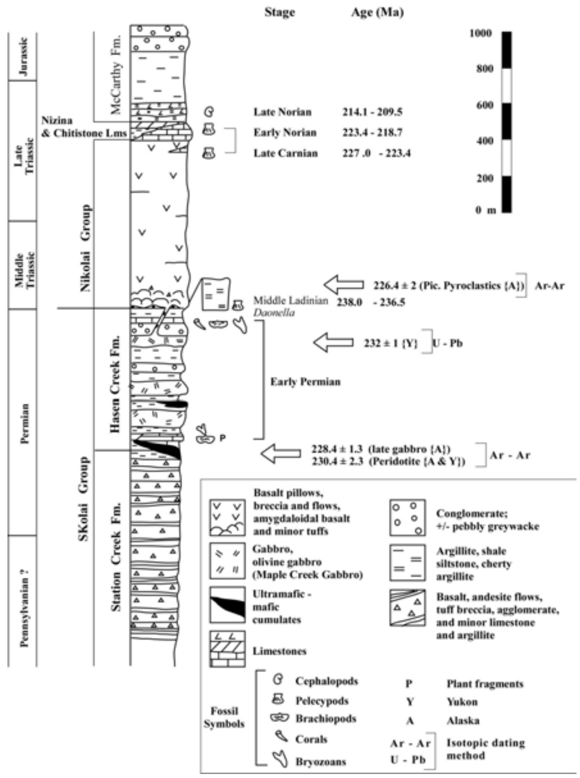

Figure 2.Generaalized stratigraphic section of Paleozoic and Mesozoic strata in the study area with an emphasis on the Yukon detailed study area (1) but applicable to the Mount Hayes area of Alaska (2). Modified from Read and Monger, 1976.

Investigation of Triassic mafic-ultramafic intrusions along the eastern branch of "Wrangellia" in northern British Columbia, the Yukon and in the Mount Hayes Quadrangle, east-central Alaska, has resulted in the recognition of a new Ni-Cu-PGE metallogenic belt (Hulbert, 1997) that can be traced along strike for at least 600 km. The location of some of the larger intrusions are illustrated in Figure 3; however, the belt is also comprised of a chain of smaller, discontinous bodies. This belt of mineralized mafic to predominantly ultramafic rocks is referred to as the "Kluane Mafic-Ultramafic Belt" since the only economic concentrations of Ni-Cu-PGE found to date are in the Kluane Mountain Ranges of the Yukon where the deposits have been studied in detail. On a North American scale this belt is second only, in size and extent, to the nickeliferous Circum-Superior Belt (CSB) of Canada, and has many similar features with respect to: lithological zonation, silicate mineralogy, distribution of ores and Ni-Cu-PGE grades. However, unlike the CSB intrusions/flows which are Proterozoic in age and of a komatiitic origin, the eastern Wrangellia intrusive complexes are clearly younger in age (Triassic), tholeiitic to picritic in composition, and generally much larger in size.

Kluane mafic-ultramafic intrusions originally had a well developed internal lithological zonation consisting of a thin gabbroic margin that envelopes the intrusion, and the complex becomes progressively more mafic towards the core of the intrusion giving rise to: mela-gabbro/olivine mela-gabbro, clinopyroxenite, olivine clinopyroxenite, wehrlite and dunite zones, respectively (Fig. 4). These zoned bodies were sill and lens-like in form and were clearly subvolcanic magma chambers that fed the overlying Triassic Nikolai volcanics. However, in the Rainy Creek area, Mount Hayes Quadrangle, Alaska, direct field, geochemical, petrological and geochronological evidence exits demonstrating that a period of late, proximal, picritic volcanism was associated with some large, near surface, hypabyssal, subvolcanic magma chambers; now occupied by ultramafic and mafic cumulates.

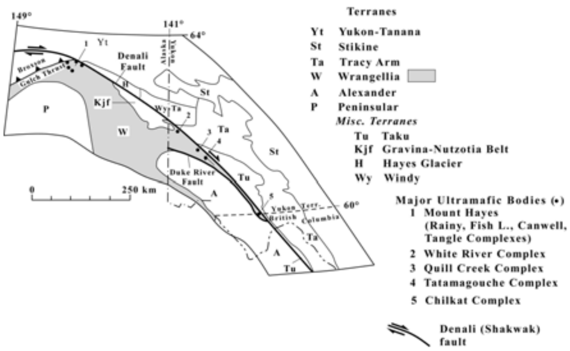

Figure 3. Map illustrating the tectonic framework of eastern Wrangellia and surrounds, and the lateral confines of Triassic ultramafic-mafic bodies extending from northern British Columbia (Chilkat Complex) to east-central Alaska (Mount Hayes.

This picritic and high-MgO volcanism preceeded the thick and extensive outpouring of more evolved tholeiitic lavas making up the Nikolai Group. In the Yukon and northern British Columbia, these ultramafic and associated mafic bodies bodies preferentially intrude the Pennsylvanian to Permian country rock sequence at or near the contact between the Station Creek and Hasen Creek Formations (Fig 2 & 4). This level marks an important litho-stratigraphic break from predominantly volcanic and volcanoclastics to argillite, chert and carbonate strata. Selective silling of magma at this level probably resulted from a combination of a change in the regional ambient stress field and the mechanical competancy and permiability of the strata at this horizon. However, in the Mount Hayes Quadrangle, Alaska, the ultramafic bodies can be seen to intrude the Pennsylvanian, Permian and possibly basal Triassic strata at random without any preference for a particular stratigraphic formation.

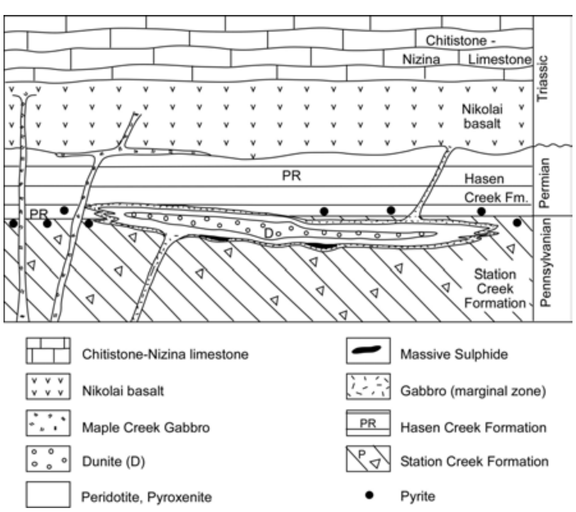

Figure 4. Schematic section of a typical ultramafic-mafic intrusive complex (pre-deformation) showing the outer marginal gabbroic envelope, and the zonal development of progressively more ultramafic rocks (pyroxenite, peridotite and dunite respectively) towards the core of the intrusion. Note the massive sulphide concentration at the base of the complex and the intrusions preferential emplacement at or near the pyritic Station Creek-Hasen Creek formations contact zone.

Results

In the Yukon, field relationships, geochemical and isotopic studies also suggest that the volatile, sulphur and Ba-rich Permian strata acted as an important source of magma contamination that subsequently initiated sulphide immicibility within successive incursions of olivine phenocryst charged magma. The best mineralization appears to be concentrated as a result of riffling of sulphide-bearing magma flowing over irregularities at the base of the intrusion. Economic concentrations always occur in the basal (marginal) gabbro, in the underlying sediments or at the contact between. Other styles of mineralization such as the Ni-rich "Offset" ores that occur well within the footwall strata of the White River Complex, "Skarn" ores juxtaposed the Permian carbonates at the Quill Creek Complex, disseminated sulphides within or above the gabbro-ultramafic zone contact in most intrusions, and PGE+Au-rich zones associated with hydrothermal (metasomatic) quartz-carbonate alteration that envelope the extremities of many intrusions, are also important reserves. In contrast, the coeval ultramafic intrusions in Alaska are not only much larger than their Yukon counterparts, but there also appears to be a different control on the localization of Ni-Cu-PGE sulphide mineralization and the metal tenor of the sulphides. Massive and semi-massive Ni-Cu-PGE concentrations preferentially occur well above the intrusive contact within ultramafic and melanocratic cumulates. Massive magmatic sulphides with up to 14% Ni and ounces of PGE can be associated with this type of mineralization.

Focused exploration and detailed research on the Wellgreen deposit, Quill Creek Complex, has disclosed three major and one minor zones of gabbro-hosted massive and disseminated sulphide mineralization. Some of this mineralization is very rich in gold and platinum-group elements. Mining of the Wellgreen deposit has demonstrated that basal accumulations of massive sulphides are generally up to 60 m in lenth, less than 20 m in thickness, and have average mill feed grades of 2.23% Ni, 1.39% Cu, 1300 ppb Pt, 920 ppb Pd, 171 ppb Au, 400 ppb Rh, 420 ppb Ru, 250 ppb Ir, 200 ppb Os, 200 ppb Re. Detailed geochemical profiles through these massive sulphide ores disclosed that some of the sulphides have experienced considerable PGE+Au fractionation. The lower half of some ore bodies are generally enriched in Os, Ir, Ru and Rh, with grades of 1000 to 2000 ppb for each. The best values generally occur associated with the most Ni-rich intervals; however, Pt/Pd ratios vary little through these bodies. This PGE+Au fractionation gives rise to a number of diverse chondrite normalized PGE profiles and should sound as a precaution to the exclusive use of these profiles to ascertain the nature of the parental magma from which the sulphides segregated.

Basal magmatic concentrations of sulphides in the Wellgreen deposit are representative of similar styles of mineralization elsewhere in Yukon. Detailed mineralogical investigations of the massive sulphides disclosed that this type of ore consists mainly of pyrrhotite, pentlandite, followed by chalcopyrite and magnetite. Approximately 70% of the pyrrhotite is of the hexagonal variety and 30% monoclinic, and were generally found to contain 0.81 wt% Ni. Platinum-group mineral (PGM) investigations disclosed that > 90% occur in pyrrhotite and are relatively small in size (largest 12 x 30 æm). The PGM are in decreasing order of abundance: merenskyite (49.3%), moncheite (22.0%), sudburyite (19.1%), testibiopalladite (4.7%), sperrylite (4.1%), Pt-Pd-bearing melonite (2.0%) and Au-Ag alloy (0.68%). Similar details pertaining to the other ore and mineralized types from the Quill Creek Complex are presented in order to provide valueable exploration and metallurgical information.

Sulphur isotope, S/Se ratios and geochemistry of sulphide mineralization throughout the belt has shown that although crustal contamination is a important pre-requisite for sulphide immiscibility and segregation within these Triassic intrusive complexes; excessive crustal contamination only gives rise to barren magmatic sulphides of a local nature. It is invisaged that the barren mineralization with ^{32}S-enriched compositions ($\delta^{34}S$ = down to -39‰) and high S/Se ratios (10,000 to 20,000) have not had an opportunity to equilibriate with the same mass of silicate magma as ore grade mineralization (with its distinctive signature, $\delta^{34}S$ = -5 to -8‰ and S/Se ratios of < 5000). This relationship between the mass of silicate magma/sulphide ratio and the metal grades of the mineralization is better known as the R-factor. Calculations suggest that the PGE-rich massive sulphides have R values of about 460; whereas their barren counterparts have values of 0. Similar calculations for ultramafic-hosted disseminated sulphides indicate R values of 40 and 1361 for barren and metalliferous mineralization, respectively.

Petrological investigations indicate that all mafic-ultramafic igneous complexes in the Yukon and northern British Columbia portion of the belt had the following crystallization order: olivine (± chromite, sulphides) : clinopyroxene : plagioclase : orthopyroxene : Fe-Ti-oxides. The scarcity of orthopyroxene within this intrusive suite in the Yukon probably reflects the silica undersaturated nature of these magmas, and the low crystallization pressures operative in this subvolcanic regime. This is not the case in Alaska where orthopyroxene is a more abundant cumulus and intercumulus phase. Olivine from ultramafic rocks in the Yukon generally has a limited range in composition (Mg# = 0.870-0.805, with most in the 0.870-0.820 interval). Nevertheless, the Quill Creek and Tatamagouche Creek complexs, both of which are known have massive sulphide bodies at their intrusive base, display a wider spread in compositions and also more Fe-rich differentiates (i.e., 0.865-0.795 and 0.858-0.707, respectively). In addition, it was found that the Ni content of olivine associated with or proximal to disseminated sulphides was approximately half that of olivine from unmineralized ultramafics containing olivine of equivalent Mg#. Thus Ni depletion associated with olivine could be used to assess the exploration potential of certain complexes. Olivine from the ultramafic intrusions in Alaska generally have a higher Mg# (up to 0.915), as is also the case for orthopyroxene and clinopyroxene. The Mg# of clinopyroxene from most ultramafic bodies in the Yukon is generally rather limited (0.895-0.840); however, relatively Fe-rich clinopyroxene compositions are also found associated with the Fe-rich olivines from the Quill Creek and Tatamagouche Creek complexes. Clinopyroxene associated with massive sulphides and thermally metamorphosed country rock have their own distinctive pyroxene quadrilateral compositions. Gabbroic rocks have clinopyroxene generally have Mg#'s in the 0.875 to 0.825 range, and are continuous with ultramafic-hosted compositions. Regardless, values as low as 0.530 can be found due to zoning and the development of late stage Fe-rich interstitial clinopyroxene crystallization products. Plagioclase in the Yukon is characteristically altered and thus gives rise to a spectrum of compositions (e.g. Ca# 0.850 to 0.00); whereas, that from Alaska is generally much fresher. Rare barium feldspars have been identified in both mafic and ultramafic rocks. Plagioclase, of a non-cumulate origin, from gabbroic rocks are pervasively altered, whereas those from cumulate rocks are remarkably fresh. This preferential alteration may be the outcome of non-cumulate types being more prone to contamination and ensueing alteration resulting from reaction with the volatile-rich Permian country rock sediments.

The most distinctive mineralogical feature associated with the Kluane Belt is the TiO_2-rich nature of chromite. Samples with up to 10.75 wt% TiO_2 have been recorded from the Quill Creek Complex. Although there is considerable variation within the investigated complexes, it would appear that unmineralized intrusions have a greater proportion of samples with low TiO_2 than mineralized intrusions. The only other intrusions known to contain chromite with comparable TiO_2 contents are those hosting the Ni-Cu-PGE ores of the Noril'sk region of Russia. No anomalous Zn values were detected in either mineralized or unmineralized Kluane chromites. Strong correlations between the behavior of NiO and TiO_2, and their enrichment in zones of anomalous sulphides, have been detected. Mineralized ultramafic rocks and intrusions were also found to contain a greater frequency of chromites with elevated $Fe^{3+}/(Cr+Al+Fe^{3+})$ ratios than their unmineralized counterparts. The high TiO_2 chromites from the Yukon, plus elevated values associated with and/or proximal to mineralized horizons, and the recognition of similar features from the near age-equivalent Noril'sk Ni-Cu-PGE camp of Russia suggest that this association should be persued further as a possible exploration tool. In addition, the refractory nature of chromite also makes it very amenable to regional stream geochemical and heavy mineral surveys.

Geochemical investigations of mineralized and unmineralized intrusions throughout the belt in the Yukon have revealed some rather interesting trends and associations pertinent to mineral exploration. It was found that macroscopically unmineralized ultramafic lithologies, from known mineralized intrusions, contain approximately twice the background levels of Ni as their barren counterparts from other intrusions in rocks with equivalent amounts of S. Since the marginal gabbros are seldom exposed this geochemical relationship with the more voluminus ultramafic rocks could prove to be a useful exploration guide. This relationship also holds for Pt and Pd. One of the most characteristic and unique geochemical features of this belt is the high concentrations of the rare platinum-group elements Os, Ir, Ru and Rh and the high Pt/Pd ratios relative to other magmatic sulphide occurences in Canada and abroad, particularily for sulphides of a tholeiitic affinity. Se demonstrates a strong chalcophile trend in all intrusions, but noticeably higher concentrations are associated with metalliferous sulphides relative to their barren equivalents. Highly anomalous amounts of Ba occur in ultramafic and mafic intrusive lithologies and in mineralized equivalents, but the coeval Nikolai, Chilkat and Karmutsen basalts do not appear to have anomalous Ba contents relative to this and other basaltic suites. Evidence is presented to show that the intrusive suites have inherited anomalous Ba concentrations as a consequence of crustal contamination by Ba-rich Permian sediments, and are not a geochemical characteristic of their mantle source melt.

Mineralogical, petrological, geochemical and isotopic investigations of the gabbroic chilled margins to the mafic-ultramafic complexes, coeval hypabyssal sills, dykes and Nikolai basalts in the Yukon clearly indicate derivation from tholeiitic parental magmas. Corroborating studies suggest that the initial pulse of magma that formed the thin chilled marginal zone gabbroic envelope was relatively fractionated (MgO = 6.2 wt%, Mg# = 0.523) and contained about 12.7% normative olivine. The more evolved nature of the earlier magma pulse may have resulted from the initial injection of magma being tapped off the top of a density stratified, fractionating, master magma chamber at depth. Ensueing crustal contamination accompanying intrusion would also modify this composition to a more evolved state. It is invisaged that subsequent ingressions of more representative and progressively more primitive, olivine phenocryst-bearing magma, (MgO = 8.53 wt%, Mg# = 0.679) containing about 20.6% normative olivine, was repeatedly injected into the magma chamber and gave rise to the remaining portion of the marginal gabbro and ultramafic zones. The Mg# of the primitive chills are compatible with the computed Mg# of the magma from which the associated olivine crystallized, based on a KD (Mg/Fe^{2+}) olivine-melt of 0.30 ± 0.03. Chilled margins from subsequent hypabyssal dykes that cut the intrusive complexes and feed overlying basalts, as well as Nikolai basalt compositions, once believed to be representative of the melt, suggest that some of these later magmas may have been as fractionated as 0.581. However, there appears to be a paradox when one compares the inferred parental magma composition with that of the metal tenor of the ores; particularily with respect to the PGE concentrations and chondrite-normalized PGE profiles. Throughout the belt ore-grade concentrations of magmatic sulphides have Pt/Pd, Os/Ir, Pd/Ir and concentrations of Os, Ir, Rh, Pt, Pd, and chondrite- normalized PGE profiles simliar to those found associated with komattitic magmas. The recent (2003) discovery by the author of Triassic picritic pyroclastics in the Alaskan study area (previously mapped as Pennsylvanian andesites and dacites) with MgO contents in the 16-20% range, containing strongly zoned primitive olivine phenocrysts (Mg# core compositions as high as 0.915) enclosed in a devitrified glassy matrix, and the proximity to ultramafic complexes hosting nickel and rare PGE-rich sulphides occurrences (up to 14 percent Ni, > 1000 ppb Os and Ir each) leaves little doubt as to the primitive nature of the parental magmas associated with Triassic magmatism and Ni-Cu-PGE metallogeny.

The most striking regional differences between the eastern and western branches of Wrangellia is the complete absence of ultramafic intrusions and Ni-Cu-PGE occurrences in the western branch. Comparison of detailed geochemical analyses through the near complete 3500 m thick Nikolai basalt section in the Mount Hayes Quadrangle of Alaska, and the complete 6500 m thick Karmutsen basalt section on Vancouver Is. respectively reveals that basalts in the lower 350 to 500m section in Alaska contains: much lower TiO_2 contents (0.5-0.8 wt. vs. > 1.15 wt. %), light REE depletion vs. light REE enrichment, striking Pt and Pd-depletion vs. normal Pt and Pd background values, anomalous sulphur concentrations vs. normal background values, and significantly higher MgO contents (8.5 to 11.9 wt %) vs. < 8.0 wt.%. Similar differences were noted with respect to other compatible, incompatible and high field strength element ratios. Geochemical trends and concentrations through the higher respective stratigraphic levels demonstrated a number of similar trends, but significant differences were also noted; one of the most noteable was the sulphur-depleted (< 50 ppm) nature of the basalts in the Nikolai section when compared to the Karmutsen section (> 200 ppm). Nikolai basalts in the Mount Hayes area were also found to contain on average approximately twice as much normative orthopyroxene as counterparts elsewhere in Wrangellia.

Geochronological investigations conducted during this study, and constrained paleontological data, reveal that the onset of Triassic magmatism began about 230 Ma and was complete by 223 Ma. This time span is recorded by precise Ar-Ar age determinations conducted on fresh intercumulus phlogopite from peridotites in the Yukon and Alaska which gave identical ages of 230.4 ± 2.3 Ma. An independent U-Pb age determination (Mortensen and Hulbert, 1991) of 232.3 ± 1.0 Ma on zircon from a hypabyssal gabbro sill that cuts the upper portion of the Tatamagouche Creek Mafic-Ultramafic Complex in the Yukon supports the Ar-Ar data for the crystallization age of these ultramafic and mafic intrusions in the belt. Phlogopite from a olivine-melagabbro mush-like body that appears to invade the enclosing ultramafic cumulates in the Rainy Creek Complex, Mount Hayes Quadrangle, Alaska was dated (Ar-Ar) at 228 ±1.3 Ma. Immediately overlying the roof of the Rainy Creek Complex lies a thick section (> 250 m) of picritic pyroclastics. The basal 20 -30 m of this section consists of a high-MgO olivine basalt with a kaersutite-rich groundmass. Ar-Ar dating of the kaersutite gave an age of 226.4 ±2.0 Ma. Scattered throughout this basal volcanic to pyroclastic interval are xenoliths of dunite and peridotite from the underlying Rainy Creek Complex. Field relations suggest that the subvolcanic magma chamber, now occupied by the Rainy Creek Complex, had its roof breached by a new injection of magma and/or volatile (H_2O) build up. As a result fragments of early cumulates were ripped up and ejected to surface along with the early pyroclastics and volcanics. Therefore, between the onset of this Nikolai picritic pyroclastic and volcanic activity at 226.4 ±2.0 Ma and the end of the Late Carnian stage (223.4 Ma) of the Triassic voluminous and extensive outpourings of tholeiitic basalt occurred on the ocean floor of what now constitutes Wrangellia. A three million year time span for the Triassic volcanism and a seven million year history of Triassic magmatism for Wrangellia is now well contrained.

Rb-Sr, Nd-Sm, Pb-Pb isotopic analyse were conducted on fourty samples spanning the Nikolai basalt and picritic volcanic stratigraphy in the Mount Hayes Quadrangle. Most samples are unaltered and retain their primary igneous mineralogy and textural fabric, and were selected on the basis of earlier detailed geochemical, mineralogical and petrographic studies. This baseline data allows comparison with similar isotopic studies conducted on the coeval Karmutsen basalts on Vancouver Is., basaltic rocks from other tectonomagmatic environments, and with the mineralized and mined Quill Creek Complex. In addition, Re-Os isotopic studies were conducted on a variety of samples from the Quill

Creek Complex. The Sr-isotopic systematics in some of the samples appear to have been modified by magmatic and postmagmatic fluids which have past through the rocks. However, Nd-isotope systematics appear to be the most robust and resistant to change by late fluids. Comparison of the tholeiitic Karmutsen and Nikolai sections demonstrate that the former generally have $\varepsilon Nd_{(230\ Ma)}$ in the +5 to +6 range with slightly lower and higher values near the base and top of the section respectively; whereas, the Nikolai generally have values in the +6 to +7 range, with the most chondritic (+7.8) occurring at the base of the section. Nevertheless, similar looking basalts within the proximal Nikolai picrite sections have depleted mantle signatures of +8.9. The picritic pyroclastics have values that generally range from +5.3 to +6.7, with the lowest value +4.7 occurrring at the base of the picritic section. The relatively lower values associated with the more primative picritic pyroclastics represents a mantle derived magma that has been isotopically modified in subvolcanic magma chambers experiencing sulphide immiscibilty due to contamination from the surrounding sulphidic Pennsylvanian and Permian strata. When comparing these Nd isotopic signatures with of the the best mineralized intrusion in the belt (Quill Creek Complex, Wellgreen deposit) the most chondritic signature (+2.89 to +4.49) occur in the ultramafic core of the intrusion whereas the least chondritic values are found in the mineralized marginal gabbros (+2.02 to +3.46). Nd isotope signatures associated with this intrusion, along with sulphur-isotope data, and other geochemical signatures leaves little doubt as to the role of contamination from sulphidic sediments and its influence in modifying mantle compositions. Os isotope magma mixing models confirms other presented models which suggest that as little a 5% contamination of the Quill Creek Complex magma can give rise to ores with isotopic systematics similar to those observed in the Wellgreen deposit of this complex.

Early proposals to explain the origin of Triassic magmatism in Wrangellia shared a common rifting property; however, inadequate evidence for such rifting has led to a petrotectonic interpretation based on a modification of the "mantle plume" initiation model of Richards et al., 1991. The proposed model along with new information from the eastern portion of Wrangellia adequately explains variations in volcanic chemistry, thickness, environment of deposition and the occurrence of mafic-ultramafic intrusions relative to the west. Geological and geophysical evidence suggests that the Mount Hayes area represents the centre of the Triassic magmatic plumbing system in Wrangellia as we now know it. Spatially it is envisioned as an area where picritic magmas were extracted from a hot mantle plume tail in a depleted source region. Geochemical and mineralogical evidence suggests that less primitive magma that gave rise to the intrusions in the Yukon and northern British Columbia are more distal the hot plume tail. Associated thick tholeiitic basalts are believed to be extracted from an enriched source located on the plume edges and ascend to surface and were trapped in magma chambers were they differentiated or mixed with more evolved melts and subsequently rose to surface.

CONCLUSIONS

1. Eastern Wrangellia is a new and unique Ni-Cu-PGE+Au metallogenic terrane in North America with impressive exploration potential.
2. All Ni-Cu-PGE mineralized and related none mineralized intrusions are Triassic in age.
3. Triassic volcanism in Wrangellia took place over a time span of 3 million years whereas the onset of magmatism appears to be as much as 4 million years earlier.
4. Parental magmas that segregated primitive Ni-Cu-PGE ores throughout the belt were picritic, and not thoeliitic, in composition.
5. These Triassic ultramafic intrusions have many similar features to Proterozoic komatiitic intrusions with respect to: lithological zonation, silicate mineralogy, distribution of ores and Ni-Cu-PGE grades.
6. Eastern Wrangellia contains ultramafic intrusions and more primitive olivine-rich volcanics since generated melts were derived from the hotter, axial portion of the mantle plume, whereas tholeiitic melts, particularily in western Wrangellia, were derived from more distal areas near the plume edge.
7. Ni-Cu-PGE sulphide immiscibility was the product of hotter, more primitive, picritic magma residing in subvolcanic magma chambers experiencing contamination from the enclosing Pennsylvanian and Permian sedimentary sulphides.
8. Pronounced geochemical differences exist between the basal volcanic sections from eastern and western Wrangellia.
9. Triassic magmatism and volcanism in Wrangellia appears to be the product of an oceanic plateau flood basalt environment.

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