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GEOLOGIC SETTING OF THE WINDY CRAGGY DEPOSIT NORTHWEST BRITISH COLUMBIA

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ABSTRACT

INTRODUCTION

This paper is based on field and laboratory studies completed by the British Columbia Ministry of Energy, Mines and Petroleum Resources (MacIntyre, 1983; 1984; 1985) in the Tatshenshini (Windy Craggy) map area. This work has benefitted greatly from the contributions and assistance of Falconbridge Nickel Mines Limited, Geddes Resources Limited, Stryker-Freeport Resources Limited, Bear Creek Mining Co. Limited, the Geological Survey of Canada and the United States Bureau of Mines.

The Windy Craggy massive sulphide deposit is located in the northwest corner of British Columbia (fig 1). This area is part of the rugged St.Elias Mountains. The nearest town is Haines Alaska located approximately 70 kilometres to the southeast. Access is via helicopter from the Haines cut-off road or via float plane to Tats Lake located 8 kilometres south of the deposit.

The Windy Craggy deposit was discovered by J. McDougall of Falconbridge Nickel Mines Limited in 1956. The size of the deposit was confirmed by diamond drilling completed by Falconbridge and Geddes Resources during the 1981, 1982 and 1983 field seasons. Estimated reserves are 300 million tonnes averaging 1.5 percent copper and 0.08 percent cobalt. These reserves include a higher grade core of approximately 90 million tonnes averaging 3.0 percent copper and 0.09 percent cobalt. Significant gold interesections have also been reported. An extensive stringer sulphide zone cuts chlorite altered basalts and green cherts that underlie the massive sulphide body. This zone represents several 100's of millions of tonnes of low grade copper mineralization of equivalent or better grade to British Columbia's largest porphyry copper deposits.

The combined reserves of the Windy Craggy deposit make it one of the largest massive sulphide deposits yet to be discovered anywhere in the world. The purpose of this paper is to describe the geologic setting of this gigantic deposit.

REGIONAL TECTONIC SETTING

The Windy Craggy deposit occurs within the Alexander Terrane (Berg et.al.,1978; Campbell and Dodds,1983). This terrane (fig.2) includes a thick succession of Precambrian to Permian carbonate and clastic rocks of basinal and platformal affinity unconformably overlain by Late Triassic calcareous turbidites and basalt (fig.3). Paleomagnetic data indicates that this terrane has migrated northward from low paleolatititudes (Hillhouse and Gromme, 1980). The Paleozoic stratigraphy of the Alexander Terrane is strikingly similar to that of the Rocky Mountain fold and thrust belt and it is possible that it represents a slice of the continental margin that has been moved northward and stepped westward to its present position along major transcurrent fault systems (e.g.Jones et al,1972; Muller,1977).

The Alexander Terrane is bounded to the west and east by the Wrangellian and Taku terranes respectively (fig.2). These terranes are characterized by a mid to late Paleozoic island arc sequence that is unconformably overlain by a thick sequence of Mid to Late Triassic basalt (e.g. Karmutsen/Nikolai assemblage), limestone and calcareous sediments (fig 3). Like the Alexander Terrane, the Wrangellian terrane has moved to its present position from low paleolatitudes (Jones et. al.,1977; Hillhouse, 1977).

The timing of suturing of these two terranes is a matter of considerable debate. Recently Davis and Plafker (1985) have suggested they were united by Triassic time, a conclusion favoured by this writer. Parts of these terranes have been dislocated by movement along bounding and cross-cutting transcurrent faults in Mesozoic and Cenozoic time. Much of this movement is probably in response to oblique subduction of oceanic lithosphere under the leading edge of the North American continent.

The Alexander, Wrangellian and Taku terranes are all overlain by continental volcanic arc and flysh deposits of Jurassic to Cretaceous age (i.e. the Gravina-Nutzotin assemblage). This implies that these terranes were amalgamated by this time. These flysh deposits have also been offset by as much as 300 kilometres of right lateral offset along the Denali fault system in Tertiary time (e.g.Eisbacher, 1976).

Outboard of Wrangellia is the Chugach terrane, a melange-subduction complex also of Jura-Cretaceous age.

All of the terranes of the northern Insular belt are intruded by granitic rocks of Jurassic, Cretaceous and Tertiary age. Tertiary volcanics also occur locally.

GEOLOGY OF THE WINDY CRAGGY AREA

General Geology

The geology of the Windy Craggy area is shown in figure 3. The deposit is hosted by a sequence of Late Triassic sedimentary and volcanic rocks that are preserved within a fault bounded area surrounded by Ordovician to Devonian carbonate and clastic rocks (MacIntyre, 1984; Campbell and Dodds, 1983). The lower part of the Triassic succession is mainly calcareous turbidites and the upper part is predominantly massive and pillowed basalt flows. Several granitic intrusions of Jurassic or Cretaceous age occur in the area. A coarse grained hornblende diorite intrudes the Triassic rocks. Hornblende from this intrusion recently yeilded a K-Ar isotopic age of 35 Ma.

Structure

The Triassic and Paleozoic rocks are folded into large anticlinal and synclinal folds that are truncated by high angle axial planar reverse or thrust faults and northeast trending cross cutting strike-slip faults. Tight isoclinal folds occur on the limbs of major fold structures, particularly where less competent beds are sandwiched between massive volcanic units . Fold structures are mostly assymetric and overturned with vergence to the southwest. Fold axes typically plunge moderately to the northwest. The massive pyrrhotite-pyrite-chalcopyrite body at Windy Craggy displays this type of tight isoclinal folding (MacIntyre, 1983).

Stratigraphy

A preliminary stratigraphic column for the Windy Craggy area is presented in figure 5. This column is based on a type section defined northeast of the deposit (MacIntyre, 1984). In addition, Mike Orchard of the Geological Survey of Canada has identified earliest Late Norian conodont fauna in samples of limy argillite and siltstone collected at various localities within the map area thus providing excellent fossil control.

Black calcareous siltstones and shales comprise the lower part of the Late Triassic succession in the Windy Craggy area. The contact with underlying Paleozoic rocks is not observed but is assumed to be an unconformity as it is elsewhere in the Alexander Terrane (H.Berg, personal communication). Estimates of the thickness of this lower sedimentary unit are difficult because of the degree of folding but it may exceed 1000 metres.

Going up section microdioritic sills and amygdaloidal basalt flows become increasingly abundant, with progessively fewer intercalated sedimentary beds. These massive rocks form a resistant unit that overlies the lower sedimentary part of the section. This unit is up to 1000 metres thick and is overlain by up to 500 metres of amygdaloidal and/or glomeroporphyritic massive and pillowed basalt, with intercalations of calcareous siltstone, shale and a few thin limestone debris flows (with Devonian clasts). The Windy Craggy deposit occurs within this unit (MacIntyre, 1984). In the footwall of the deposit green cherty rocks are intercalated with the pervasively chloritized basalts. Similar cherty rocks have not been observed away from the deposit.

A thick section of pillow basalt (+2000 metres ?) with little or no intercalated sedimentary rocks constitutes the upper part of the Late Triassic succession in the Windy Craggy area. These rocks indicate that a period of tremendous outpouring of basaltic lava in a submarine environment post dated formation of the Windy Craggy deposit.

The top of the pillow basalt sequence is not observed in the Windy Craggy area but elsewhere in the Alexander Terrane it is known to be overlain by Jura-Cretaceous flysh of the Gravina-Nutzotin assemblage (Berg, personal communication).

Microdioritic sills and dykes are very common in the Windy Craggy area and occur throughout the section. These rocks have similar compositions and textures to flows in the section and are often difficult to recognize as intrusive. They are believed to be comagmatic with the volcanic rocks. The huge hydrothermal system that formed the Windy Craggy deposit may have developed above one of these sills.

Comparison with other parts of the Alexander Terrane

The Late Triassic stratigraphic succession in the Windy Craggy area is very similar to that observed in other parts of the Alexander Terrane e.g. Glacier Creek area and Southeast Alaska (fig. 6). In general, calcareous turbidites and, in southeastern Alaska erosional conglomerates, occupy the lower part of the sequence and grade up section into thick pillow basalt units. Fossil control is lacking in many areas where inferred Triassic rocks occur (e.g. MacIntyre, 1985) but, where present, fauna are mainly Norian in age (Berg, 1980). A few Karnian ages have also been reported. Karnian age fossils have not yet been found in the Windy Craggy area.

A significant difference between the Windy Craggy area and other parts of the Alexander Terrane is the absense of quartz-sericite-talc schist and phyllite zones in the Late Triassic sequence. These rocks, which are believed to be sheared rhyolitic tuffs or rhyolites, occur in the lower sedimentary or middle mixed sedimentary-basalt parts of the Triassic successions of southeastern Alaska and the Glacier Creek area. Polymetallic massive sulphide and barite deposits (e.g. Glacier Creek, Annette and Gravina Islands) are associated with these felsic rocks (Berg and Grybeck, 1980; MacIntyre, 1985). The presense of both basalt and felsic volcanic rocks in the section suggests Triassic volcanism in the Alexander Terrane was bimodal in nature.

A LATE TRIASSIC METALLOGENIC PROVINCE

Berg and Grybeck (1980) suggest that a Late Triassic metallogenic province extends the length of the Alexander Terrane in southeastern Alaska. The Windy Craggy deposit and new discoveries in the Mt. Henry Clay area (MacIntyre, 1985) extend the northern limit of this province into the St.Elias ranges of Northwest British Columbia and the Yukon. This province includes both polymetallic massive sulphide deposits that are associated with sheared felsic volcanic rocks and cuprous massive sulphide deposits such as Windy Craggy that have a mafic volcanic association (figure 7; table 1). The occurrence of both types of deposits in the same volcanic sequence is well documented in other metallogenic provinces or mineral districts e.g. Noranda camp (Fox, 1984). Such provinces typically occur in epicontinental rifting environments e.g. immature island arc or back arc basin.

BASALT GEOCHEMISTRY

The chemistry of volcanic rocks that host massive sulphide deposits has been the subject of many previous studies (e.g.Fox, 1984). This data can provide important clues (with certain limitations) to the environment in which the host volcanic rocks have been formed e.g. oceanic ridge, island arc, etc.

Samples from the Windy Craggy area have been analyzed for major and trace elements by the British Columbia Ministry of Energy, Mines and Petroleum Resources analytical laboratory. Whole rock analyses of drill core have also been provided by Falconbridge Nickel Mines Limited for comparative purposes. In addition, Joe Fox, Teck Exploration, Toronto provided immobile and rare earth analyses on six selected samples from the area. In addition, in the following plots the field occupied by basalts from the Wrangellian and Taku Terranes is plotted for comparison. This data includes 24 analyses of the Nikolai greenstone and Chilkat metabasalts (Davis and Plafker, 1985), 12 analyses of Karmutsen basalts (A.Sutherland Brown, personal communication) and six analyses of Anyox basalts (Sharp, 1980). All of these basalts are low K-tholeiites that were probably extruded during the early stages of marginal basin rifting in Middle Triassic time.

Major Oxide Analyses

Whole rock analyses of rocks from the Windy Craggy area are characterized by relatively low TiO_2 and high Na_2O and K_2O compositiions relative to mid ocean ridge basalts (MORB). When plotted on an alkalies-totaliron-magnesium ternary diagram (AFM) these rocks consistenly plot in the calc-alkaline field (figure 8). whereas those of the Wrangellian/Taku terranes plot in tholeiitic field. The same conclusion is derived from the Al_2O_3-Normative Plagioclase plot (fig.9) of Irvine and Baragar (1971) and Kuno's (1966) alkalies-SiO_2 plot (fig.10). On the FeO-MgO-Al_2O_3 plot (fig.11) the Windy Craggy rocks fall mainly within the Orogenic field (Island Arc); the Wrangellia/Taku rocks have higher Al/Fe ratios and plot toward the Ocean Island field.

The trend toward alkali enrichment illustrated in the alkalies-silica plot is in part due to pervasive weak albitization (spilitization) of the volcanic rocks in the Windy Craggy area.

Immobile Elements

The immobile elements e.g. Ti, Cr, Zr, Nb are now commonly used to determine the petrogenetic provenance of basalts (e.g. Garcia, 1978; Pearce, 1976; Pearce and Cann, 1973). On the Ti versus Cr plot of figure 12 the majority of Windy Craggy samples plot within the island arc basalt (IAB) field i.e. they are mainly calc-alkaline; samples from the Wrangell/Taku terrane plot in the MORB or tholeiite field.

Only 6 samples from Windy Craggy have been analyzed for zirconium. These samples show considerable scatter on the Ti versus Zr diagram of figure 13 although in general there is a calcalkaline basalt trend. Samples from the Wrangellian and Taku terranes plot along a well defined linear trend that falls within the ocean floor basalt field. This plot further illustrates the more alkaline composition of the Windy Craggy basalts compared to the predominantly tholeiitic compositions of the Nikolai, Chilkat, Karmutsen and Anyox basalts.

Rare Earth Elements

The relative rare earth concentration pattern for a sample of basalt from the Windy Craggy area is plotted in figure 14. The plot shows a strong enrichment in the light rare earths relative to the generally flat distribution patterns for Chilkat-Nikolai and other low-K tholeiites. Light rare earth enrichment is characteristic of the more alkaline volcanic rocks (Haskin et. al., 1966) suggesting the high alkali contents of basalts from the Windy Craggy area are a primary feature of these rocks. Primitive basalts such as those from mid ocean ridges (MORB) are typically depleted in the light rare earths. The Windy Craggy and Chilkat-Nikolai basalts clearly do not belong to this category of basalt. Rather, the rare earth patterns suggest a more fractionated parental magma.

TIMING AND STRUCTURAL SETTING OF TRIASSIC VOLCANISM AND ASSOCIATED MASSIVE SULPHIDE DEPOSITS

Cuprous massive sulphide deposits of inferred Triassic age also occur in the Wrangellian and Taku terranes (e.g.Juneau gold belt deposits, Anyox,?). What are the relationships between these occurrences and those of the Alexander Terrane? As shown in figure 14 and summarized in table 2 the Triassic stratigraphy of the Alexander terrane is significantly different from that of adjacent terranes. The Wrangell/Taku basalts are Karnian age, low K-tholeiites that were extruded in both submarine and subaerial environments with little accompanying sedimentation. The thick and extensive nature of the basalt sequences implies extensive rifting and subsidence accompanied the outpouring of basaltic lava. By contrast, the Alexander Terrane was apparently an exposed area during Karnian time.

In Norian time limestone and calcareous sediment was deposited on the thick basalt sequences of the Wrangellian and Taku terranes. At the same time a sedimentary basin developed on the thick continental crust of the Alexander Terrane. Calcareous turbidites possibly derived by erosion of platformal carbonates of adjacent terranes (assuming suturing of these terranes had occurred by this time) were deposited in this basin with increasing extrusion of calc-alkaline to alkaline basalt and rhyolitic rocks with time. This implies the Alexander Terrane was the site of subsidence and extensional rifting in Norian time. Magma reservoirs may have developed high within the extended crust with periodic tapping of volatile rich differentiates producing the more felsic rocks (fig.15). Submarine calderas may have formed in response to periodic evacuation of magma reservoirs in a manner analogous to that of the Kuroko distirct of Japan (Ohmoto and Takahashi, 1983). This process was apparently lacking in the Windy Craggy area and adjacent terranes as indicated by the absense of Triassic polymetallic massive sulphide deposits of felsic association.

Magmatic activity accompanied formation of the Windy Craggy deposit as indicated by the number of dioritic sills in the Windy Craggy section. These sills may be related to a larger body at depth that was never ruptured and cooled slowly providing the heat necessary to drive the huge hydrothermal system that produced the Windy Craggy deposit.

If we assume that Wrangellia and the Alexander Terrane were sutured by Triassic time then there is an apparent eastward shift in the locus of basalt extrusion from Karnian to Norian time. This corresponds to an eastward compositional change from relatively primitive low-K tholeiites to more highly differentiated alkaline volcanic rocks. This transition has been documented in several young island arcs of the southwest Pacific.

SUMMARY

The main conclusions of this paper based on the information available to date are;

(1) The Windy Craggy deposit is hosted by a sequence of Late Triassic calc-alkaline submarine basalts and intercalated calcareous and cherty sedimentary rocks that were probably deposited in a marginal or back arc basin.

(2) The stratigraphic sequence that hosts the Windy Craggy implies that the deposit formed during a period of extensional rifting and basinal subsidence that was accompanied by increasing extrusion of basaltic magma.

(3) The hydrothermal system that formed the deposit probably developed above a magma reservoir that was emplaced at a shallow level within the basin.

(4) The Windy Craggy deposit is part of a Late Triassic metallogenic province that runs the length of the Alexander Terrane. This province includes cuprous massive sulphide deposits of mafic association such as Windy Craggy and polymetallic massive sulphide and barite deposits of felsic association.

ACKNOWLEDGMENTS

REFERENCES

Fig 1

LOCATION AND TRANSPORTATION ROUTES

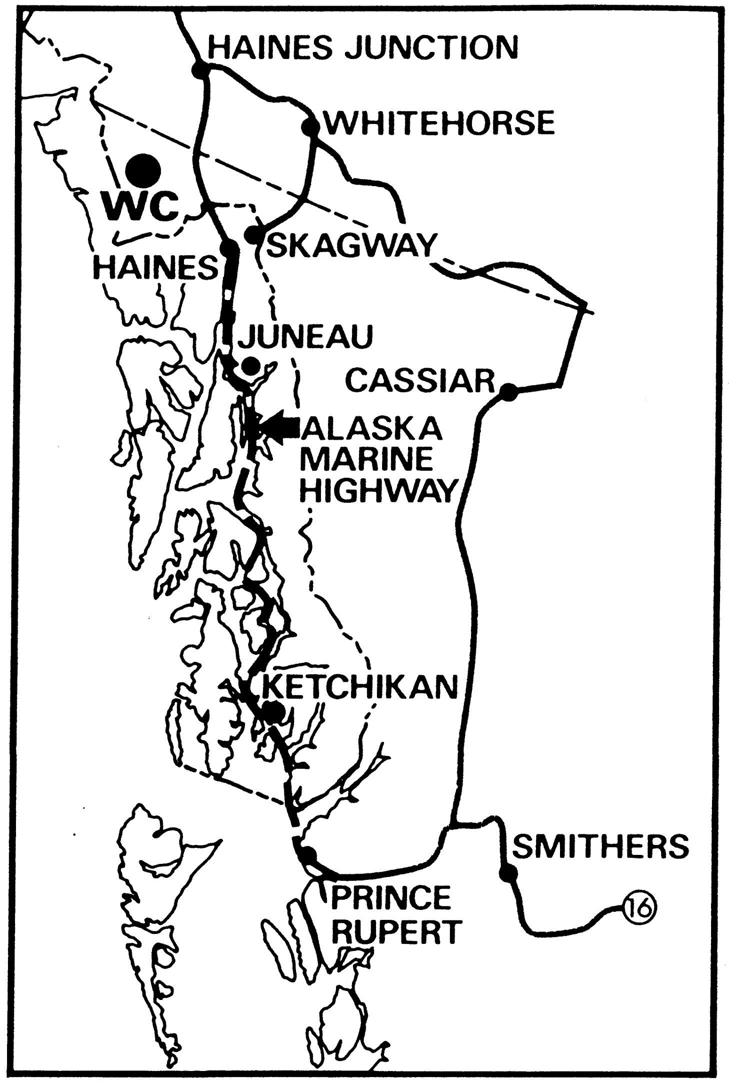


Fig 2

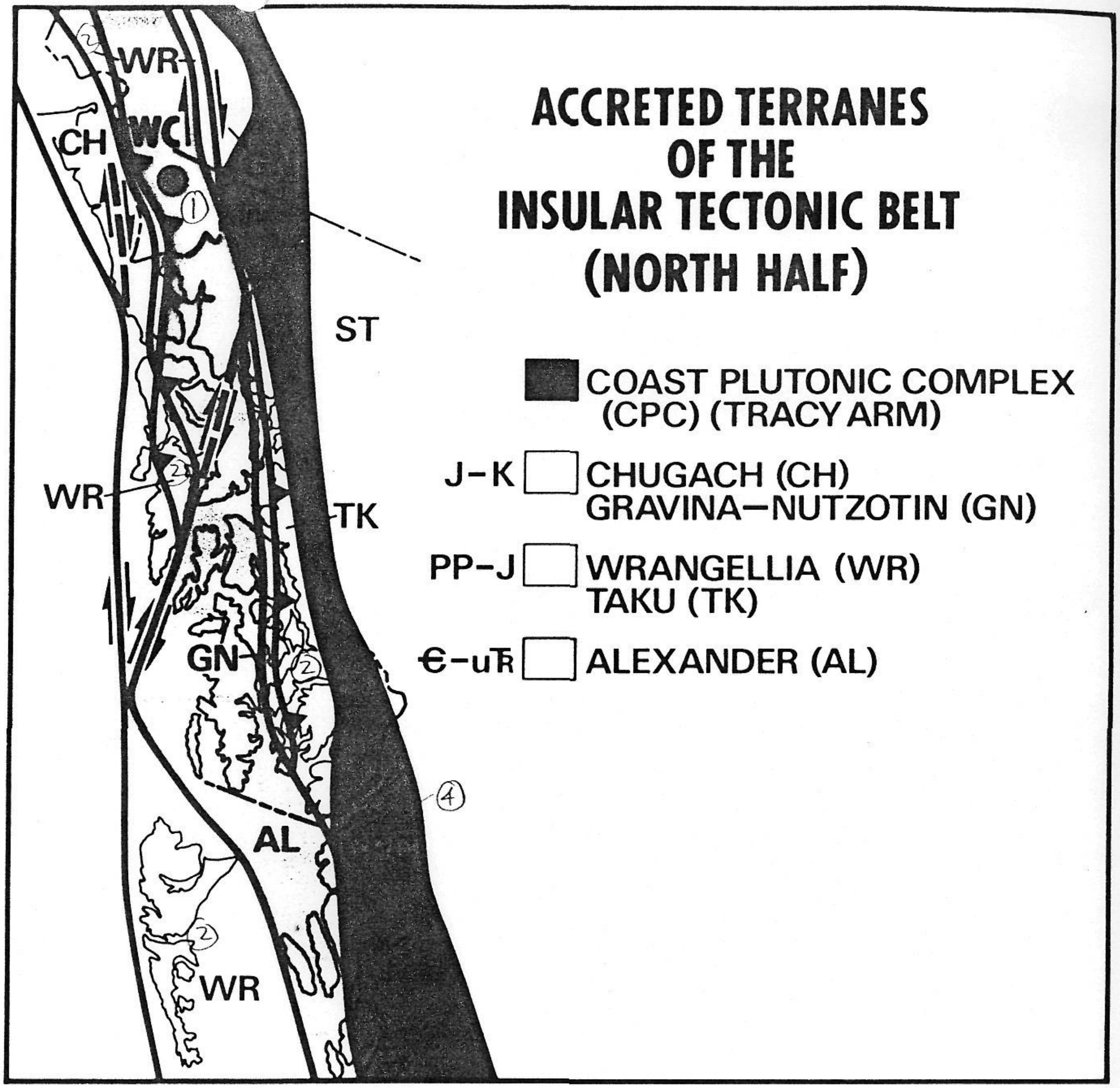
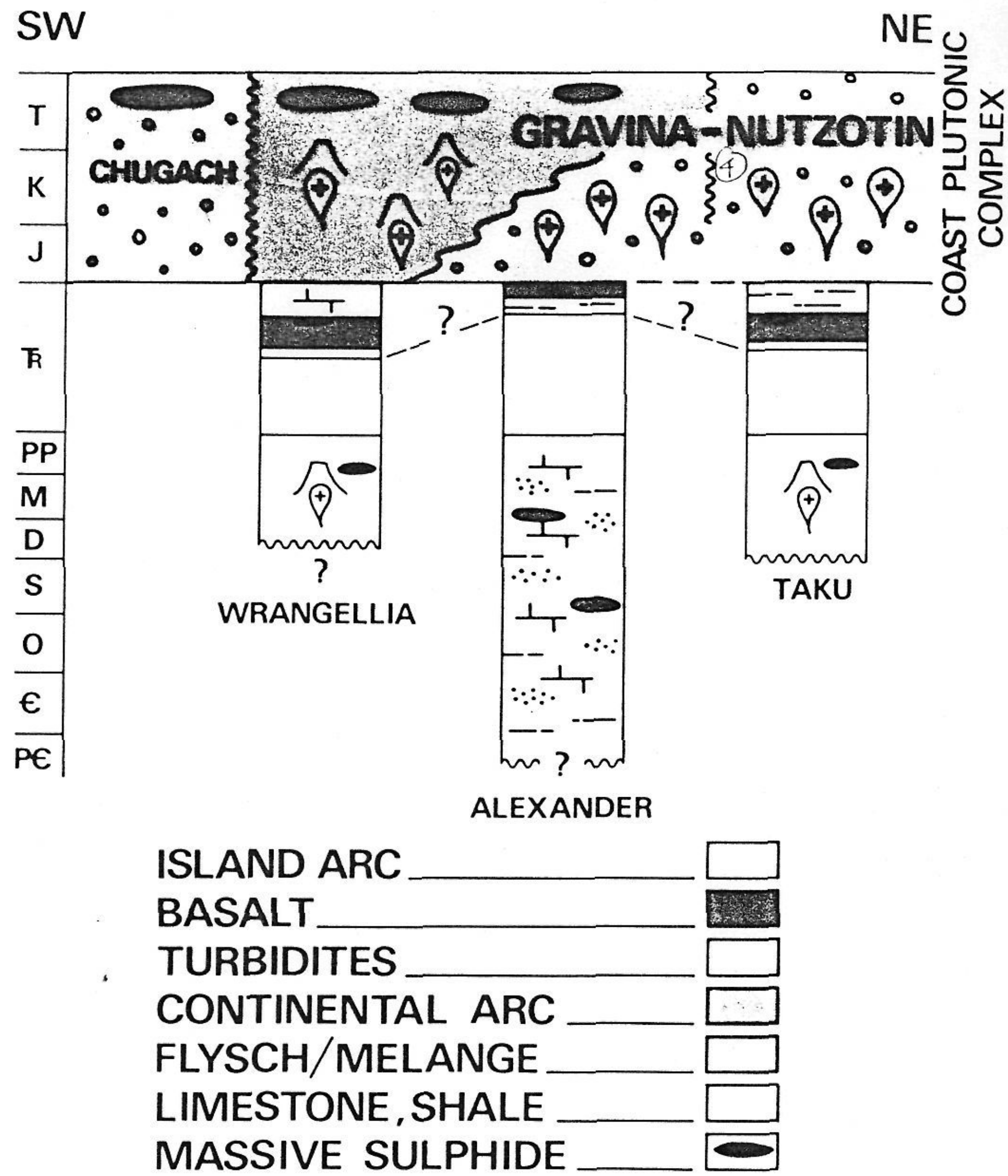

ACCRETED TERRANES
OF THE
INSULAR TECTONIC BELT
(NORTH HALF)
COAST PLUTONIC COMPLEX
(CPC) (TRACY ARM)
J–K
CHUGACH (CH)
GRAVINA–NUTZOTIN (GN)
PP–J
WRANGELLIA (WR)
TAKU (TK)
Є–uTR
ALEXANDER (AL)
WR
WC
CH
ST
WR
TK
GN
AL
WR

Fig 3



SW
NE
COAST PLUTONIC COMPLEX
T
K
J
Ŧ R
PP
M
D
S
O
Є
PЄ
CHUGACH
GRAVINA-NUTZOTIN
?
?
?
WRANGELLIA
?
ALEXANDER
TAKU
ISLAND ARC
BASALT
TURBIDITES
CONTINENTAL ARC
FLYSCH/MELANGE
LIMESTONE, SHALE
MASSIVE SULPHIDE

Fig 4

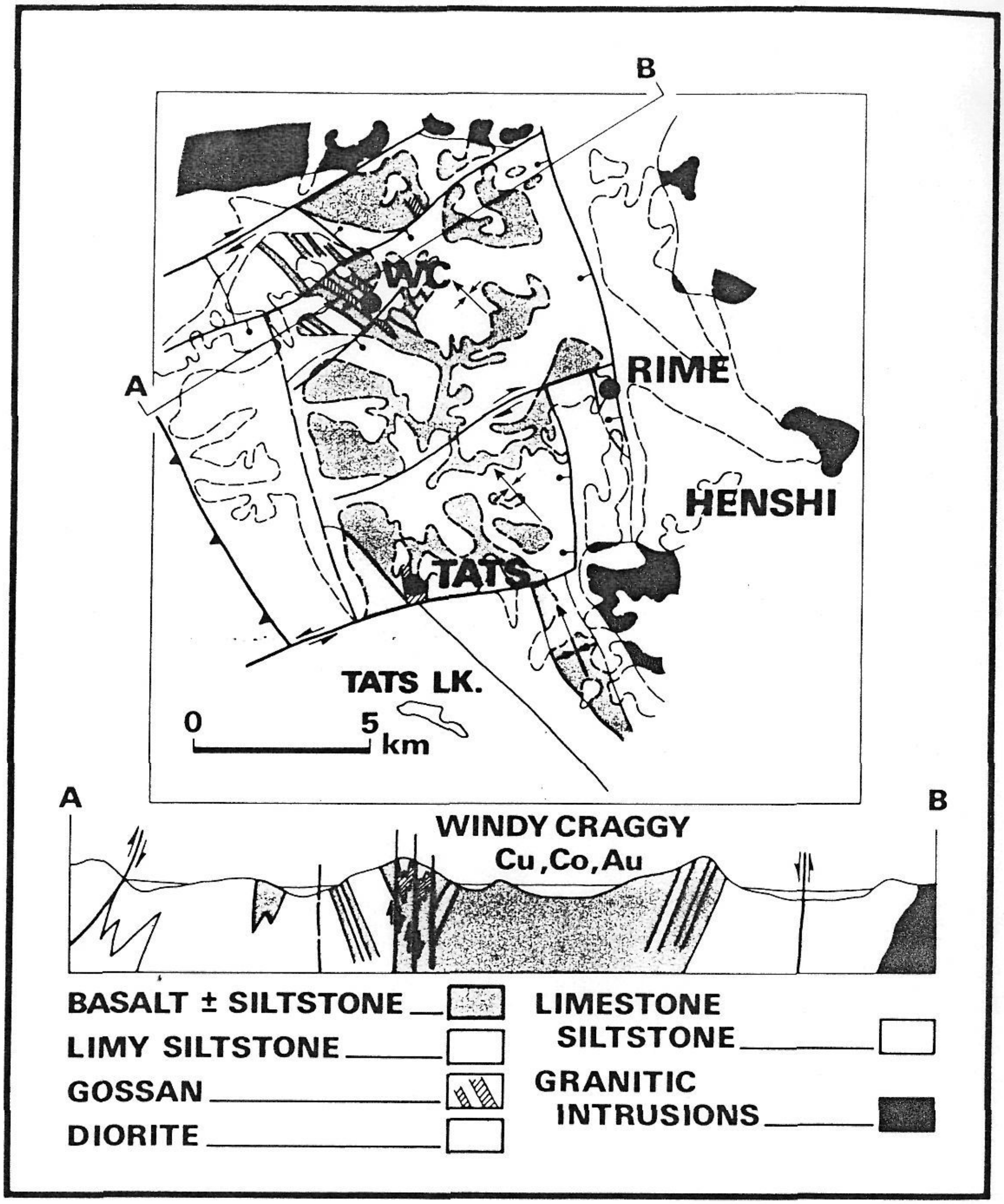

B
A
WC
RIME
HENSHI
TATS
TATS LK.
0
5
km
A
B
WINDY CRAGGY
Cu,Co,Au
BASALT ± SILTSTONE
LIMY SILTSTONE
GOSSAN
DIORITE
LIMESTONE
SILTSTONE
GRANITIC
INTRUSIONS

Fig 5

PRELIMINARY STRATIGRAPHIC COLUMN

WINDY CRAGGY AREA

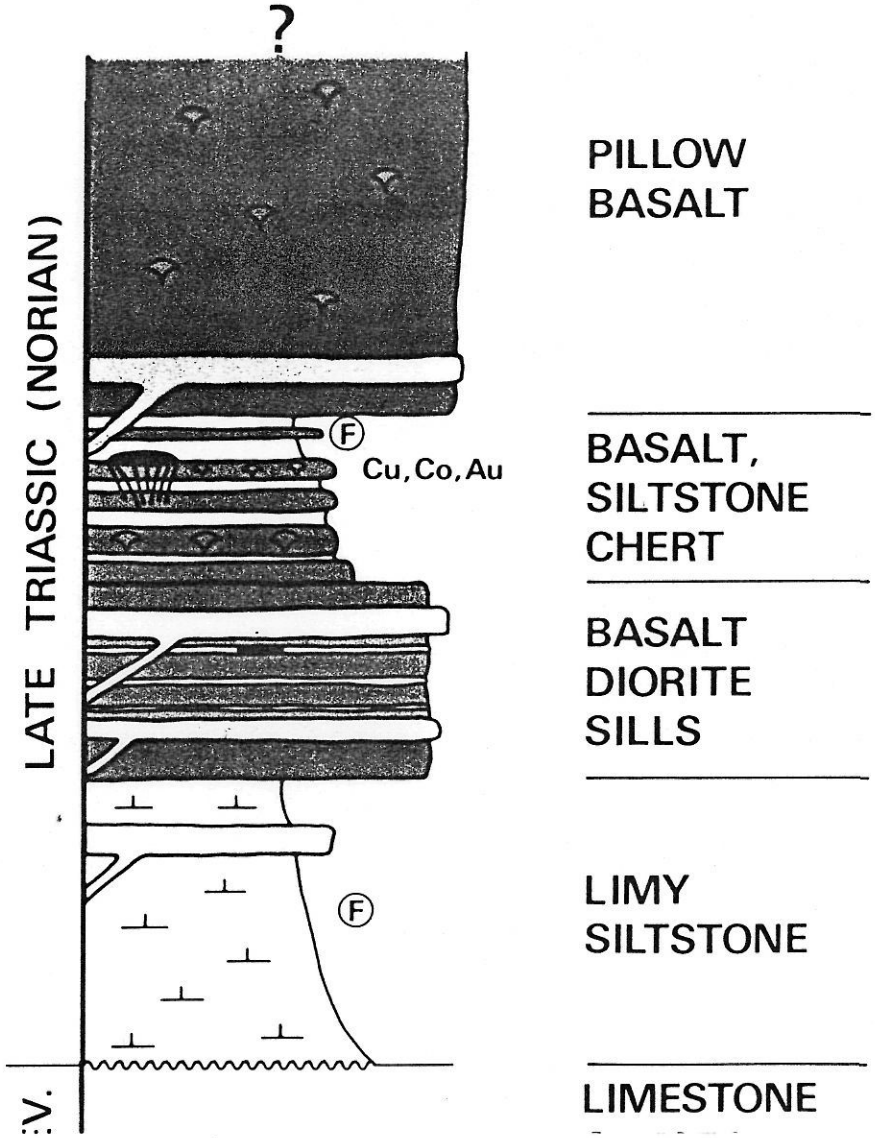


Fig 6

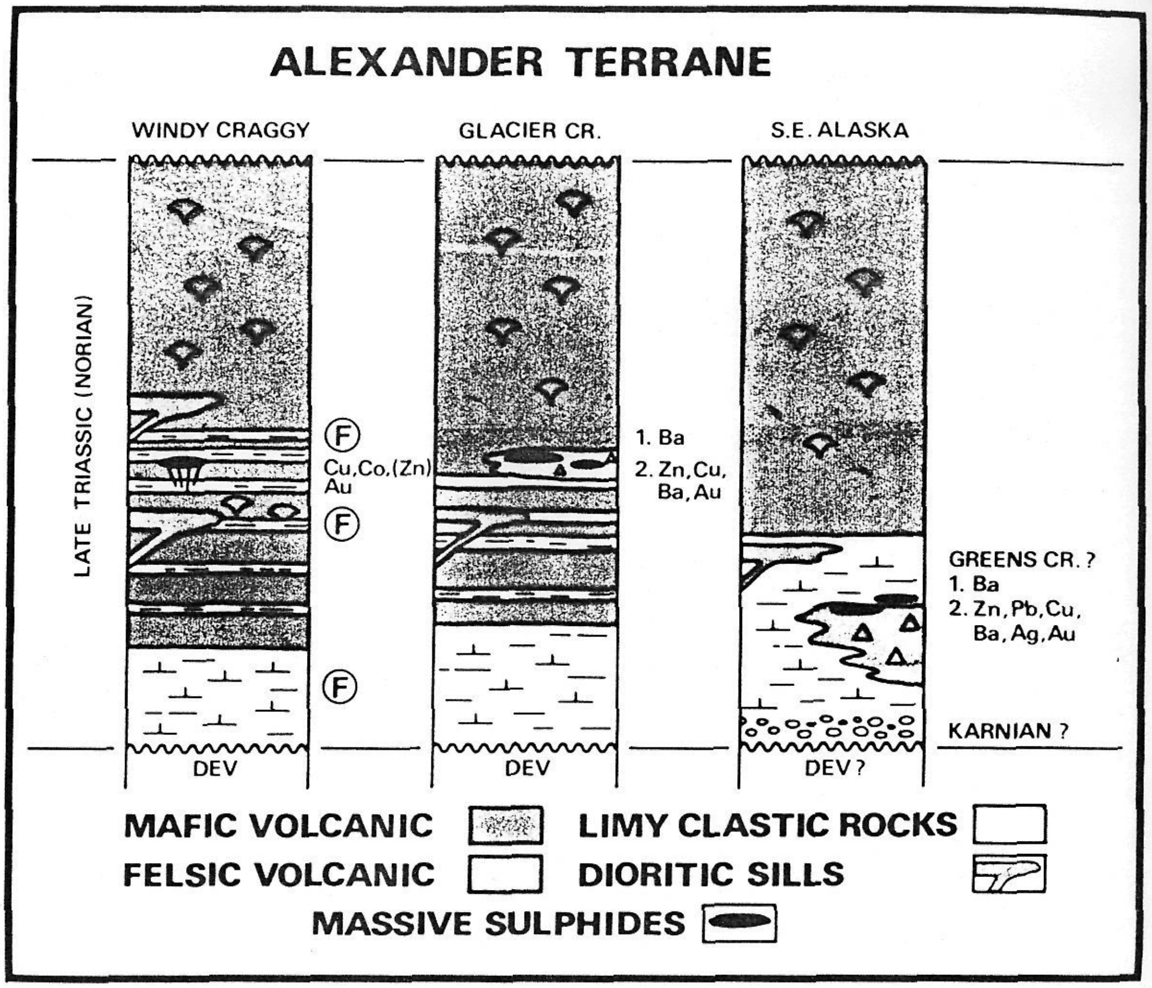
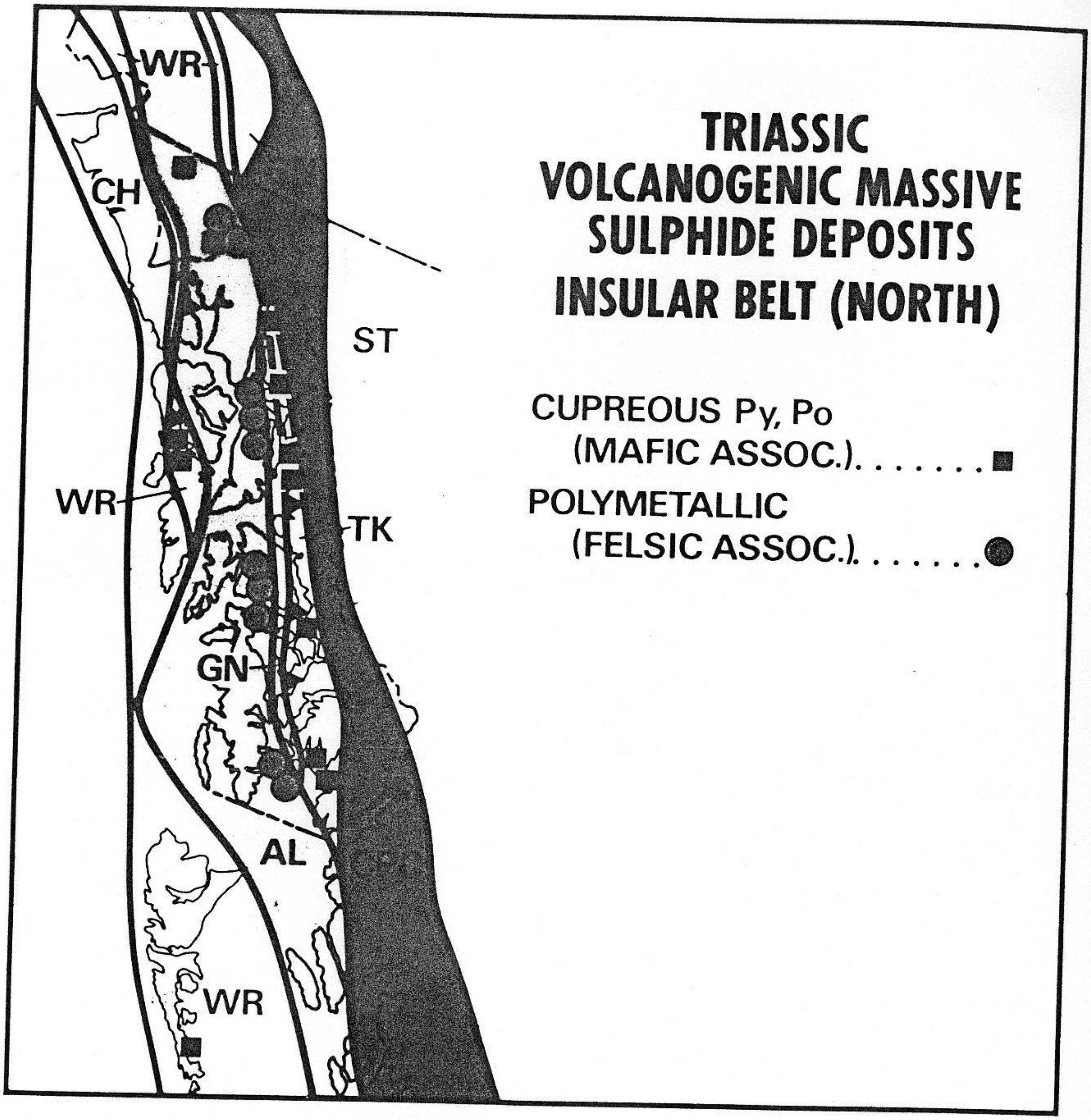

ALEXANDER TERRANE
WINDY CRAGGY
GLACIER CR.
S.E. ALASKA
LATE TRIASSIC (NORIAN)
F
Cu,Co,(Zn)
Au
F
F
1. Ba
2. Zn,Cu,
Ba,Au
GREENS CR. ?
1. Ba
2. Zn,Pb,Cu,
Ba,Ag,Au
KARNIAN ?
DEV
DEV
DEV ?
MAFIC VOLCANIC
LIMY CLASTIC ROCKS
FELSIC VOLCANIC
DIORITIC SILLS
MASSIVE SULPHIDES

Fig 7


TRIASSIC
VOLCANOGENIC MASSIVE
SULPHIDE DEPOSITS
INSULAR BELT (NORTH)
CUPREOUS Py, Po
(MAFIC ASSOC.)
POLYMETALLIC
(FELSIC ASSOC.)
WR
CH
ST
WR
TK
GN
AL
WR

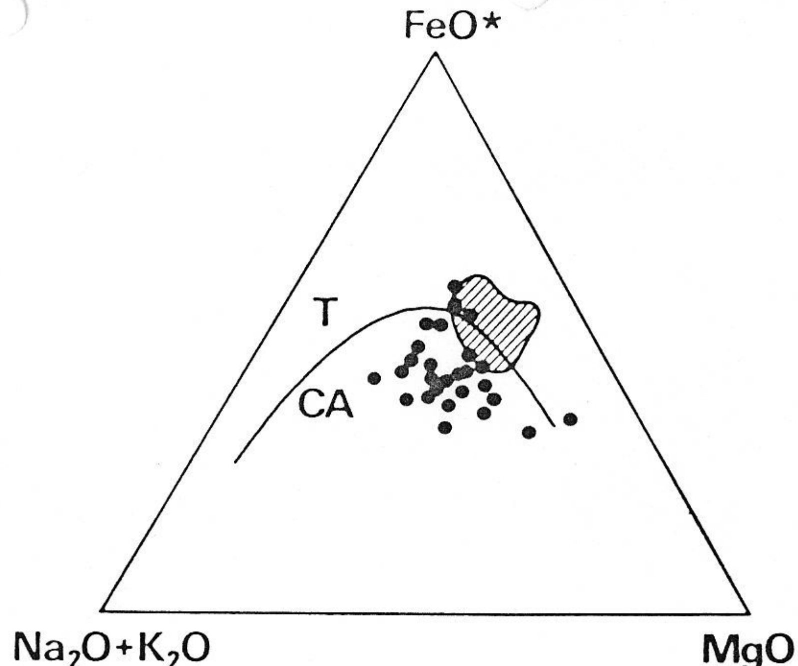


Fig 8

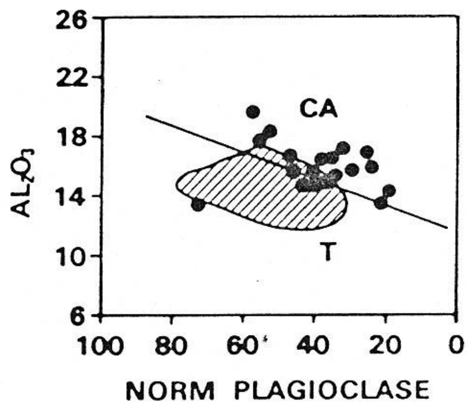


Fig 9

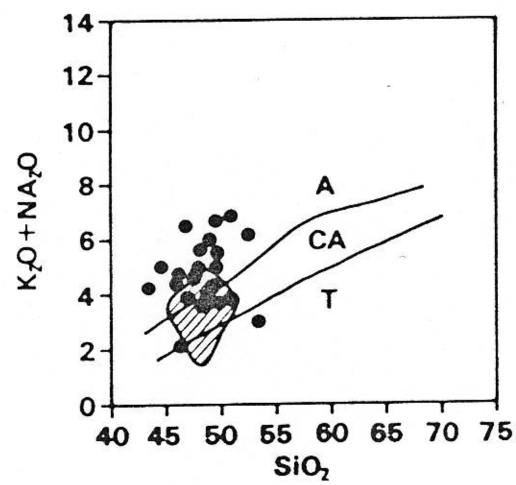
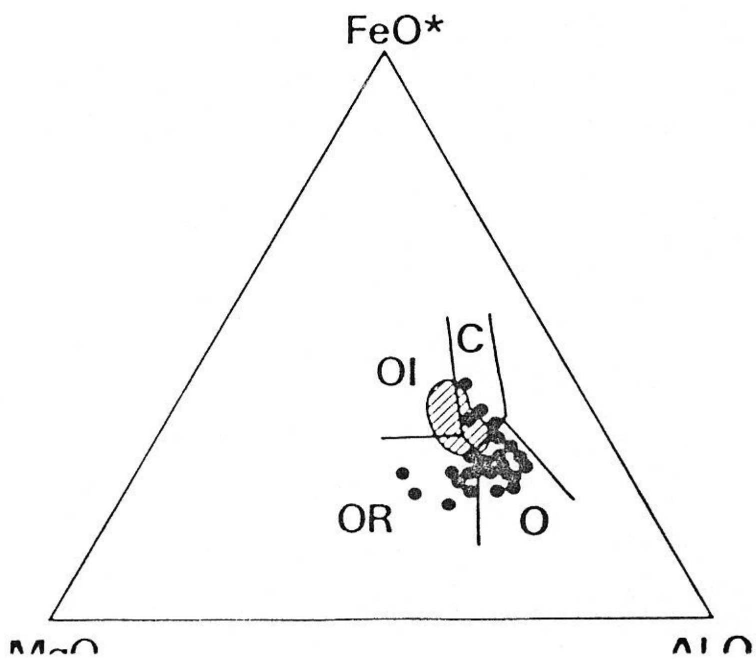


Fig 10



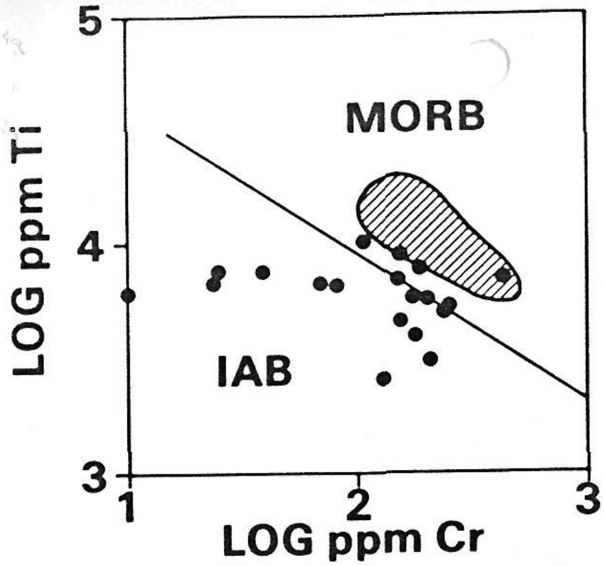


Fig 12

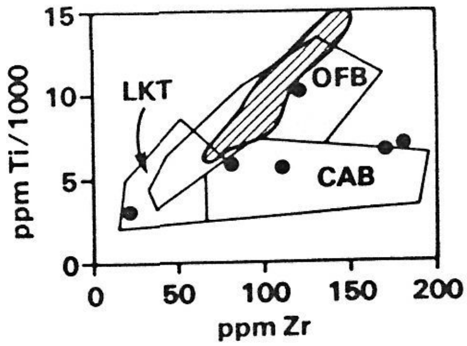


Fig 13

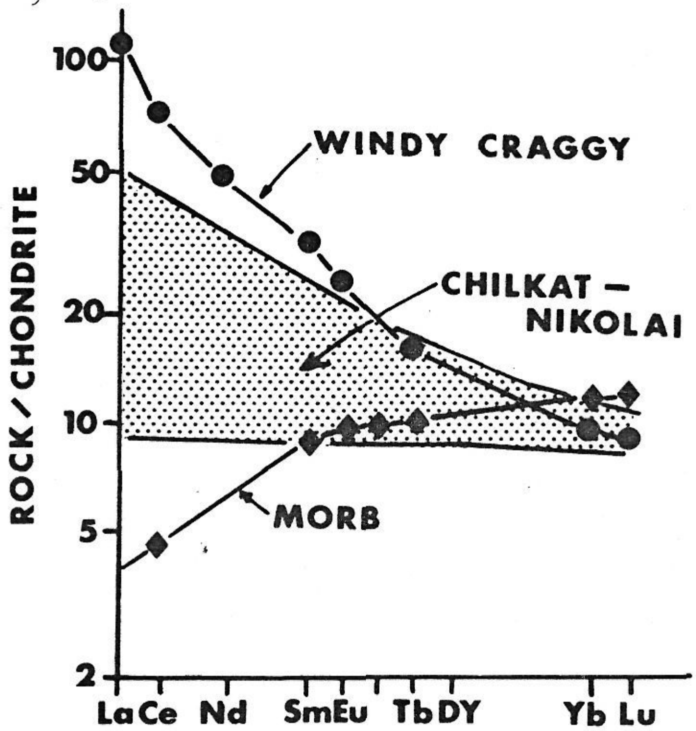


Fig 14

Fig 15

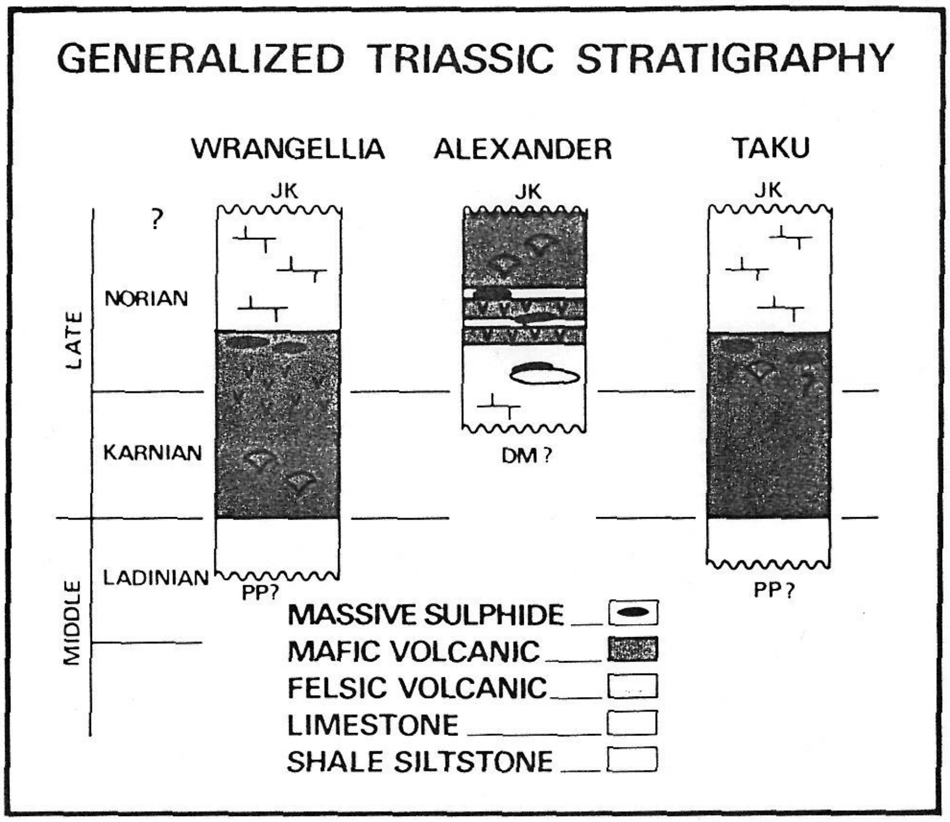
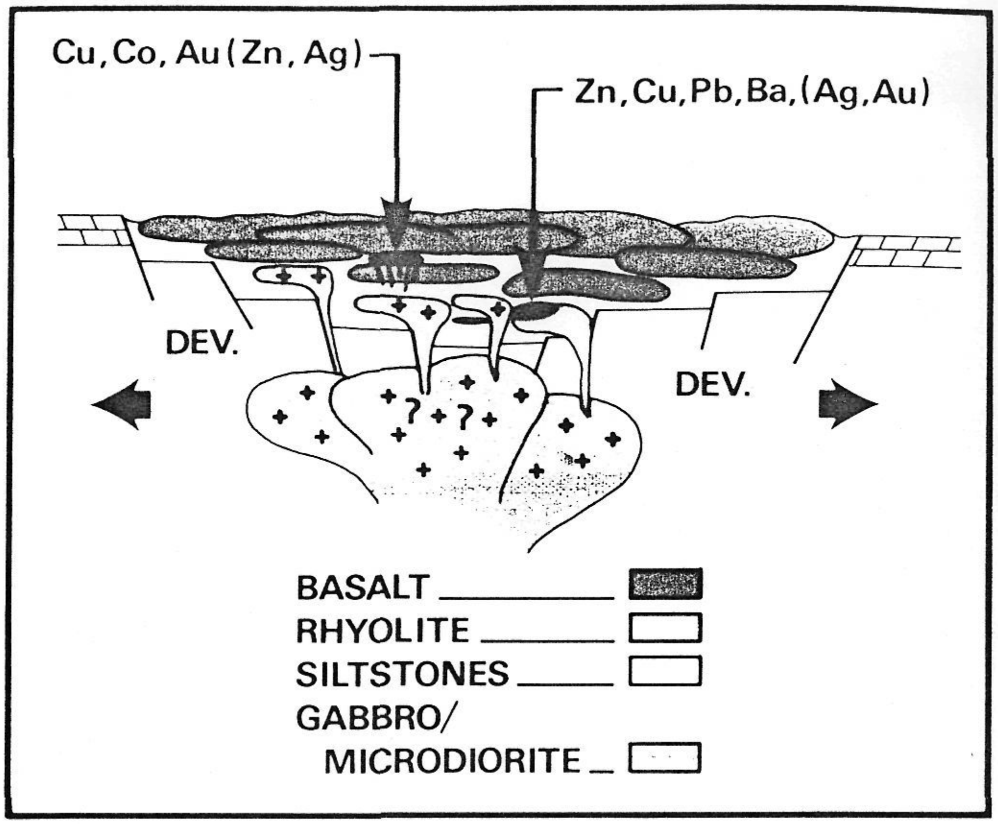

GENERALIZED TRIASSIC STRATIGRAPHY
WRANGELLIA
ALEXANDER
TAKU
JK
JK
JK
?
NORIAN
LATE
KARNIAN
LADINIAN
MIDDLE
PP?
DM ?
PP ?
MASSIVE SULPHIDE
MAFIC VOLCANIC
FELSIC VOLCANIC
LIMESTONE
SHALE SILTSTONE

Fig 16



Cu, Co, Au (Zn, Ag)
Zn, Cu, Pb, Ba, (Ag, Au)
DEV.
DEV.
?
?
BASALT
RHYOLITE
SILTSTONES
GABBRO/
MICRODIORITE

Table 1

LATE TRIASSIC VOLCANOGENIC MASSIVE SULPHIDE DEPOSITS ALEXANDER TERRANE		
VOLC. ASSOC.	MAFIC	FELSIC
TYPE	CUPREOUS Py/Po M.S.	POLYMETALLIC M.S.
COMMODITIES	Cu, Co, Au	Zn, Cu, Pb, Ba, Ag, Au
MINERALOGY	Po/Py, Cp (Mt, Sp)	(a) Py, Sp, Cp, ± Gl, Ba (b) Ba ± Sp, Cp, Gl
ALTERATION	CHLORITE	SERICITE, CHLORITE, QZ
STRINGER ZONES	YES	?
MICRODIORITE SILLS	YES	?
EXAMPLES	WINDY CRAGGY TATS	GLACIER CREEK Mt. HENRY CLAY GREENS CREEK GRAVINA/ANNETTE ISL. CASTLE ISLAND

COMPARISON OF TRIASSIC SUCCESSIONS

TERRANE	WRANGELLIA/TAKU	ALEXANDER (WINDY–CRAGGY AREA)
PRE–TRIASSIC	VOLCANIC ARC (PENN.–PERM.) UPLIFT/EROSION	CONTINENTAL BASIN/PLATFORM (PC–PERMIAN) UPLIFT/EROSION
TRIASSIC SEQUENCE	SED–SILLS/FLOWS–LST (EMERGENT)	SED–SILLS/FLOWS/SEDS–FLOWS (SUBMERGENT)
AGE	LADINIAN–NORIAN	NORIAN (KARNIAN?)
ENVIRONMENT	SUBMARINE/SUBAERIAL	SUBMARINE
VOLUME	EXTENSIVE/THICK	LOCAL?/THICK
VOLCANIC TYPES	BASALT (UNIMODAL)	BASALT + RHYOLITE (BIMODAL?)
CHEMISTRY	LOW K THOLEIITES	CALC–ALKALINE–ALKALINE
MINERAL DEPOSITS	CUPROUS MS (FE SKARN) AU–AG	CUPROUS MS/POLYMETALLIC MS/ BARITE AU–AG
TECTONIC SETTING	IMMATURE ISLAND ARC? EARLY RIFTING	BLACK ARC BASIN ? EXTENSION/RIFTING
POST TRIASSIC	JUR–CRET. ANDESITIC VOLCANIC ARC FOLDING/FAULTING GRANITIC INTRUSIONS	JUR–CRET. FLYSH FOLDING/FAULTING GRANITIC INTRUSIONS