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THE POTASSIUM-RICH VOLCANIC ROCKS AT TILLICUM MOUNTAIN — THEIR GEOCHEMISTRY, ORIGIN, AND REGIONAL SIGNIFICANCE (82F/13, 82K/4)

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INTRODUCTION

This report presents some major and trace element analytical results from a suite of mafic metavolcanic rocks of uncertain age at Tillicum Mountain, situated approximately 30 kilometres south of Nakusp in southeastern British Columbia. The analyses indicate that the volcanic rocks represent arc-type, potassium-rich basalts belonging to the absarokite-shoshonite series (Iddings, 1895). Such lavas are of interest through their association with porphyry copper-gold and epithermal gold-type mineralization, and because they are believed to result from the termination of a subduction zone due to plate collision (Barberi, *et al.*, 1974; Kolios, *et al.*, 1980; Venturelli, *et al.*, 1984). Consequently, their presence at Tillicum Mountain is possibly significant with regard to both the tectonic environment of the volcanism and the source of the skarn-related precious metal mineralization in the district (Ray, *et al.*, this volume). The peculiar composition of the Tillicum Mountain volcanic rocks suggests that they correlate with either the Lower Jurassic Rossland Group, which is mainly shoshonitic (Beddoe-Stevens, 1982), or, less likely, with the central belt of the Upper Triassic Nicola Group, which is also shoshonitic (Spence, 1985).

GEOLOGY OF THE TILLICUM MOUNTAIN AREA

The metavolcanic rocks analysed in this study form part of a predominantly metasedimentary succession within the highly deformed, easterly trending Nemo Lakes belt (Parrish, 1981). This belt represents a 5-kilometre-wide roof pendant; to the north and west it is intruded by the Goatcanyon-Halifax Creeks stock of Jurassic and/or Cretaceous age (Hyndman, 1968), while to the south it is invaded by the Nemo Lakes quartz monzonite stock of Eocene age (Parrish, 1981).

Supracrustal rocks of the Nemo Lakes belt in the Tillicum Mountain area are dominated by metamorphosed siltstone, calcareous siltstone, arkose, and wacke, with lesser amounts of mafic volcanic rock, tuff, argillite, impure carbonate, and marble layers. No marker horizons are recognized in the supracrustal succession, which exhibits rapid lateral and vertical changes in lithology (Ray, *et al.*, 1985). Despite the deformation and metamorphism, some sedimentary structures, including grading and crossbedding, are locally preserved. The supracrustal rocks underwent a post-Early Jurassic phase of regional metamorphism and folding (Hyndman, 1968; Parrish, 1981) that predates the Middle to Late Jurassic intrusion of the granitoid stocks (Read and Wheeler, 1976). This resulted in sillimanite grade metamorphism throughout most of the Nemo Lakes belt (Parrish, 1981); however, the metamorphic grade was lower around Tillicum Mountain and resulted in the formation of biotite, muscovite, chlorite, and amphibole. In addition to the regional metamorphism, the rocks were locally subjected to two episodes of contact metamorphism. The first is associated with swarms of dioritic sills that probably accompanied the regional deformation; these sills are apparently related to some gold and silver-bearing skarns in the district (Roberts and McClintock, 1984; Ray, *et al.*, 1985). The second hornfelsing is related to intrusion of the large granitoid stocks and postdates the regional deformation.

The age, stratigraphy, and structure of the supracrustal rocks at Tillicum Mountain is uncertain. Little (1960) included them in the Triassic to Early Jurassic (?) Slocan and Lower Jurassic Rossland Groups, while Hyndman (1968) split the section, correlating the basic volcanic rocks on the northwestern slopes of Tillicum Mountain with the Triassic Kaslo Group, and the remaining metasedimentary rocks with the Pennsylvanian to Triassic Milford Group. Ray, *et al.* (1985) concluded from structural data and sedimentary tops that the volcanic and volcaniclastic sequence at Tillicum Mountain is older than the largely metasedimentary succession lying further south and southeast. However, no evidence of either a structural break or an unconformity was found between the two.

GEOLOGY OF THE TILLICUM MOUNTAIN VOLCANIC ROCKS

The mafic volcanic rocks sampled in this geochemical study are largely confined to an area north and west of Tillicum Mountain (*see* Fig. 3-1, Ray, *et al.*, this volume), where they are interlayered with mafic tuff, volcanic breccia, and some argillite. This volcanic-volcaniclastic-argillite sequence forms an arcuate, apparently folded unit over 500 metres in outcrop width. The volcanic rocks are massive to weakly layered to schistose; they comprise hornblende and calcic plagioclase, with lesser amounts of biotite, chlorite, tremolite-actinolite, and carbonate. Some flows are characterized by flow brecciated margins and deformed, feldspar-filled amygdales up to 0.5 centimetre in diameter. The tuffs and coarse volcaniclastic rocks locally contain coarse hornblende crystals up 1.5 centimetres in diameter and some stretched clasts.

GEOCHEMISTRY OF THE TILLICUM MOUNTAIN VOLCANIC ROCKS

Five analyses of basalts from a restricted area near the gold-rich Heino Money zone (Ray, *et al.*, 1985) were published by Kwong (1985); these are now interpreted to be shoshonites. For this study, whole rock analyses were completed on 12 samples of the Tillicum volcanic rocks (Table 4-1); these rocks were also analysed for Zr, Y, Cr, Sr, Rb, and Ba (Table 4-2). The samples were collected from volcanic flows over a wide area north and west of Tillicum Mountain, and care was taken to ensure they were not affected by skarn alteration. Various plots of this data, including the five analyses published by Kwong (1985), are illustrated on Figures 4-1 to 4-9.

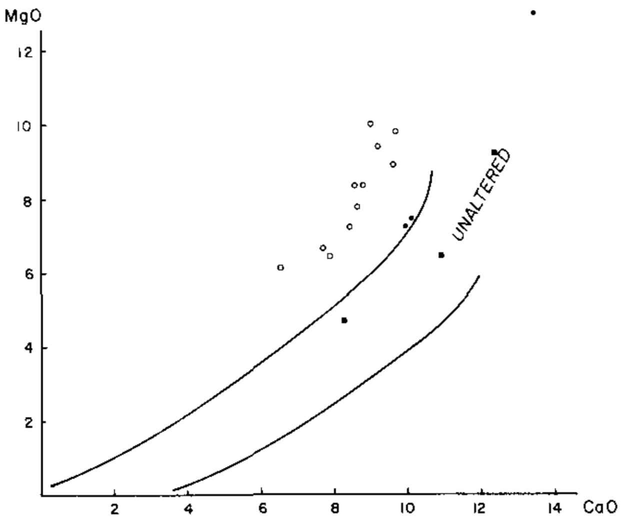

Figure 4-1. Weight percent MgO:CaO plot designed to screen 'unaltered' (filled symbols) and 'altered' (open symbols) samples. Circles: data from this study (least altered samples as filled circles), squares: data from Kwong (1985). Unaltered domain from de Rosen-Spence (1976).

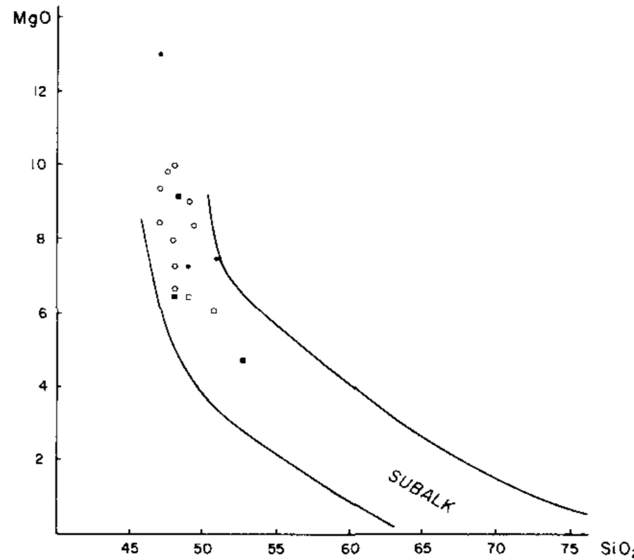

Figure 4-2. Weight per cent $MgO:SiO_2$ plot. All Tillicum Mountain basalts plot in the subalkaline domain. Sample with highest MgO is a pyroxenite. Boundaries from de Rosen-Spence (1976).

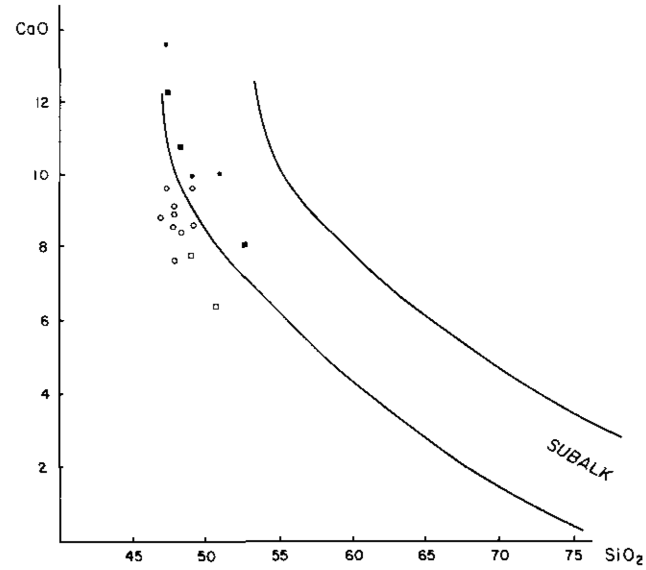

Figure 4-3. Weight per cent $CaO:SiO_2$ plot shows 'unaltered' and least altered samples in the subalkaline domain. Altered samples have lost CaO. Boundaries from de Rosen-Spence (1976).

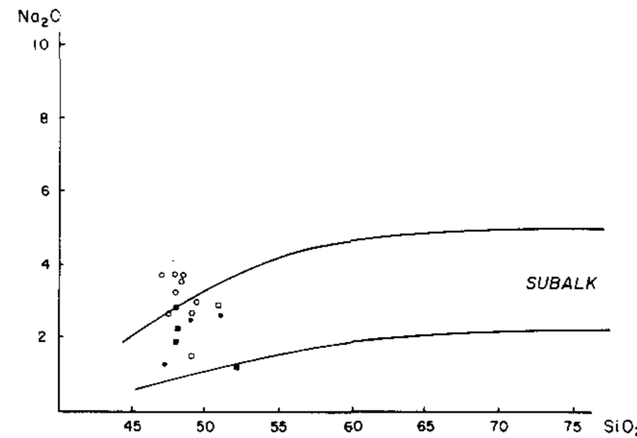

Figure 4-4. Weight per cent $Na_2O:SiO_2$ plot shows 'unaltered' and least altered samples in the subalkaline domain. Several altered samples have gained Na_2O. Boundaries from de Rosen-Spence (1976).

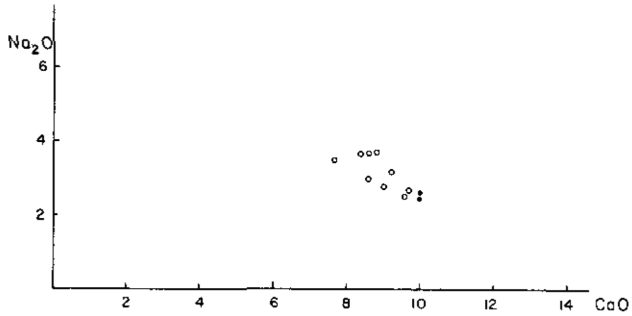

Figure 4-5. Weight per cent $Na_2O:CaO$ plot shows increase in Na_2O with decrease in CaO in altered samples, which indicates spilitization.

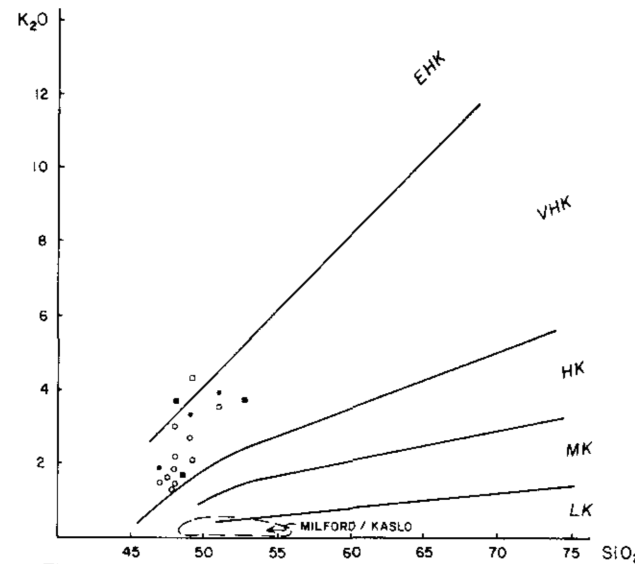

Figure 4-6. Weight per cent plot demonstrates the consistently very high K_2O content of the Tillicum Mountain basalts. Low (LK), medium (MK), and high (HK) K_2O domains from Gill (1981); very high (VHK) and extreme high (EHK) K_2O domains from Spence (1985). Note the Milford-Kaslo Groups volcanic rocks plot in the low K_2O (LK) field.

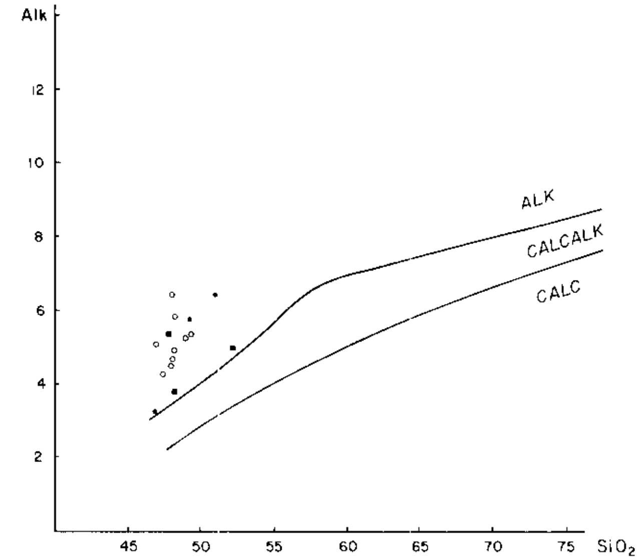

Figure 4-7. Weight per cent Alk:SiO_2 plot illustrates the alkaline nature of the Tillicum Mountain basalts. Boundaries from Kuno (1966), high-Al domain relabelled 'calc-alkaline' and tholeiitic domain 'calcic.'

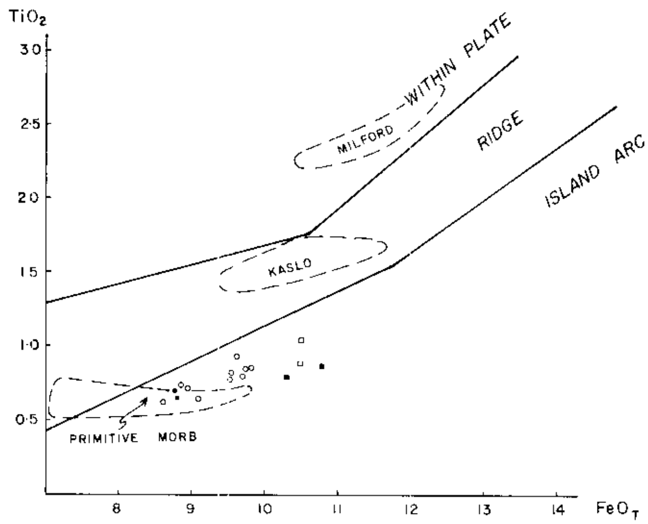

Figure 4-8. Weight per cent TiO_2:FeO_T plot designed for basalts with SiO_2 between 48 and 50.5 per cent. The Tillicum Mountain basalts are distinctly arc-type; Milford and Kaslo Group volcanic rocks plot in the within-plate and ridge domains in keeping with their setting in the Slide Mountain Terrane.

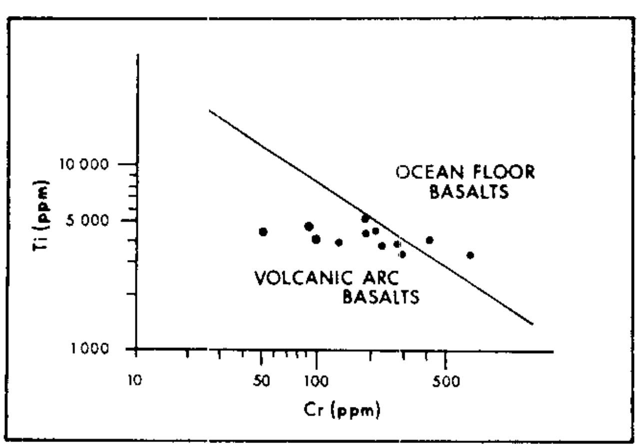

Figure 4-9. Log titanium-log chromium plot (after Pearce, 1975) of the Tillicum Mountain basalts listed in Table 4-2, showing their volcanic arc characteristics.

The MgO:CaO plot on Figure 4- . illustrates that the majority of the Tillicum Mountain basalts are 'altered' and/or may possess olivine cumulates in the more magnesium-rich samples. However, three samples presented by Kwong (1985) plot in the 'unaltered' field and may assist in confirming the magmatic trends. High values of MgO in several samples (Fig. 4-2) and generally low values of CaO for the altered samples (Fig. 4-3) account for the scatter of points on Figure 4-1.

The distribution of Na_2O values (Fig. 4-4) within the subalkaline domain, and the quasi-linear relationship between CaO and Na_2O (Fig. 4-5), suggest that spilitization is responsible for the low CaO and high Na_2O contents of some altered samples. However, the consistently very high K_2O (VHK) content of these rocks (Fig. 4-6) was not modified by spilitization. The subalkaline Na_2O and very high K_2O (VHK) content of these rocks results in an alkaline trend (Fig. 4-7) which is a major, diagnostic characteristic of shoshonitic suites (Spence, 1985). Despite weak spilitization, nine of the twelve samples analysed here have K_2O/Na_2O >0.6 for SiO_2 <50 per cent, which is characteristic for shoshonitic suites (Mackenzie and Chappell, 1972).

Contents of other elements are also in ranges that are characteristic of shoshonites (Tables 4-1 and 4-2): Al_2O_3 is variable and unrelated to the total iron, which is constant and low (<11 per cent); TiO_2 is also low (<1 per cent), while the Sr and Ba contents are high. Titanium plots are shown against total ferrous iron (Fig. 4-8), and chromium (Fig. 4-9); these demonstrate unequivocally that Tillicum Mountain volcanism took place in an arc environment.

These basaltic rocks are mafic and classify mainly (10 samples) as absarokite (SiO_2 <50 per cent); one sample is a shoshonite (SiO_2 >50 per cent) and one is an ultramafic pyroxenite with low Al_2O_3 (9 per cent) and high MgO and CaO (both 13 per cent). In conclusion, this geochemical study establishes the shoshonitic and arc character of the Tillicum Mountain basalts.

CORRELATIONS

The age of the Tillicum basalts and associated sedimentary rocks is controversial in the absence of radiometric and fossil data. The metasedimentary and metavolcanic rocks were placed in the Slocan (Triassic to Lower Jurassic) and Rossland (Lower Jurassic) Groups respectively by Little (1960). Hyndman (1968), however, correlated them respectively with the Milford Group (then considered to be Pennsylvanian to Triassic) and the Kaslo Group (then considered to be Triassic). Doubts were cast on Hyndman's correlations after the first analyses of basalts from Tillicum Mountain (Kwong, 1985) and the Milford and Kaslo Groups (Klepacki, pers. comm., 1985) became available. Indeed, basaltic rocks in the Milford Group (now Pennsylvanian) and Kaslo Group (now Permian; Klepacki and Wheeler, 1985) are tholeiites, being lower in K_2O (Fig. 4-6) and falling in the within-plate and ridge domains respectively (Fig. 4-8); shoshonites are absent in these settings.

Arc shoshonites, however, are present in both the Elise Formation of the Lower Jurassic Rossland Group (Beddoe-Stevens, 1982), situated 60 kilometres south of Tillicum Mountain, and in the central belt of the Upper Triassic Nicola Group (Spence, 1985), lying 200 kilometres to the west. Correlation with the Sinemurian to Toarcian Elise Formation is favoured by the authors. The sedimentary rocks are apparently younger than the basalts (Ray, *et al.*, 1985) and may therefore correlate with the Lower and Middle Jurassic Archibald and Hall Formations of the Rossland Group.

The Rossland Group is not an isolated occurrence of Lower Jurassic shoshonitic volcanism. It lies at the southern end of a shoshonitic belt that includes high-K calc-alkaline and alkaline sodic rocks, and extends northward through the Horsefly area into the Toodoggone area (Spence, 1985). Triassic-Jurassic volcanic rocks of the Vernon area may provide the link between the Tillicum Mountain and Horsefly areas.

TABLE 4-1
MAJOR ELEMENT ANALYTICAL RESULTS FOR TILLICUM MOUNTAIN VOLCANIC ROCKS
(All values in per cent)

Lab No.	SiO_2	Al_2O_3	Fe_2O_{3T}*	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	Total
29330	48.05	15.25	10.79	8.35	9.43	9.20	3.23	1.38	0.81	0.190	99.7
29331	48.17	16.53	10.90	8.44	7.76	8.61	3.70	1.30	0.84	0.191	99.5
29332	47.99	14.61	10.76	8.40	10.04	9.02	2.78	1.82	0.82	0.190	100.4
29333	47.53	15.09	10.52	7.73	9.91	9.67	2.71	1.63	0.78	0.164	99.8
29334	49.23	14.31	9.72	8.01	7.31	9.98	2.52	3.29	0.73	0.168	99.6
29335	48.13	16.84	10.60	8.50	6.68	7.73	3.47	3.05	0.82	0.183	100.0
29336	49.32	15.39	10.71	8.38	8.44	8.64	3.01	2.14	0.96	0.244	100.1
29337	51.13	13.01	9.78	7.07	7.47	10.09	2.59	3.92	0.69	0.189	100.7
29338	48.27	16.28	9.82	7.58	7.31	8.44	3.66	2.26	0.75	0.183	99.7
29339	47.18	9.10	9.47	7.57	13.07	13.37	1.32	1.87	0.65	0.189	99.3
29340	49.00	13.67	10.17	8.03	8.99	9.59	2.62	2.72	0.66	0.175	100.2
29341	46.97	15.83	9.74	6.39	8.55	8.84	3.66	1.46	0.73	0.162	99.8

* Total iron expressed as Fe_2O_3.
Major element analysis by Flame AAS with a precision of 0.75% RSD.

TABLE 4-2
TRACE ELEMENT ANALYTICAL RESULTS FOR TILLICUM MOUNTAIN VOLCANIC ROCKS
(All values in ppm)

Lab No.	Zr	Y	Cr	Sr	Rb	Ba
29330	72	6	210	980	27	410
29331	63	8	90	900	45	580
29332	78	3	220	530	69	410
29333	63	2	430	480	39	410
29334	61	1	140	2 420	75	580
29335	54	13	50	1 480	79	780
29336	59	7	200	1 260	70	680
29337	30	13	310	1 250	151	520
29338	51	7	110	1 200	50	610
29339	54	15	790	820	55	220
29340	53	15	320	1 270	88	620
29341	58	5	240	570	57	480

Zr, Y, and Rb analyses by XRF heavy absorber (Borate Fusion).
Cr, Sr, and Ba analyses by Flame AAS (Borate Fusion).

TECTONIC SIGNIFICANCE

Shoshonitic volcanism can be generated at a stage when plate collision results in the steepening and cessation of a subduction zone, which in turn leads to deep melting of mantle rocks in the presence of water enriched in incompatible elements. In recent arcs, two periods of shoshonitic activity have been documented (Kolios, *et al.*, 1980). One is related to an existing but dying subduction zone and is associated with calc-alkaline volcanism; the other is later, occurring after the termination of subduction, and is related to rifting and local extensional movements within areas of large plate convergence.

The Upper Triassic shoshonitic volcanism in central British Columbia occurred during docking of the Stikine, Cache Creek, and Quesnel Terranes in a subduction-related arc which produced tholeiitic, medium-K calc-alkaline, and alkaline sodic sequences. In contrast, the Lower Jurassic shoshonitic volcanism is associated only with high-K calc-alkaline and alkaline sodic volcanism, but was situated east of the contemporaneous calc-alkaline Hazelton (Howson facies) arc (Tipper and Richards, 1976). It is uncertain whether the Lower Jurassic shoshonites represent a late episode of the volcanism initiated in Upper Triassic time, or whether they are related to the destruction of the Hazelton subduction zone at depth.

CONCLUSIONS

This geochemical data establishes the arc shonshonitic (absarokite) character of the Tillicum Mountain basalts. Their composition is incompatible with oceanic-type tholeiites of the Upper Paleozoic Milford and Kaslo Groups to the east. They are best correlated with the shoshonitic Elise Formation of the Rossland Group to the south; they would thus form part of the Lower Jurassic shoshonitic belt which extends northward into the Toodoggone area. This work also suggests that the Rossland Group in general, and the Elise Formation in particular may represent favourable units for hosting other skarn-related precious metal deposits similar to those seen at Tillicum Mountain (Ray, *et al.*, this volume).

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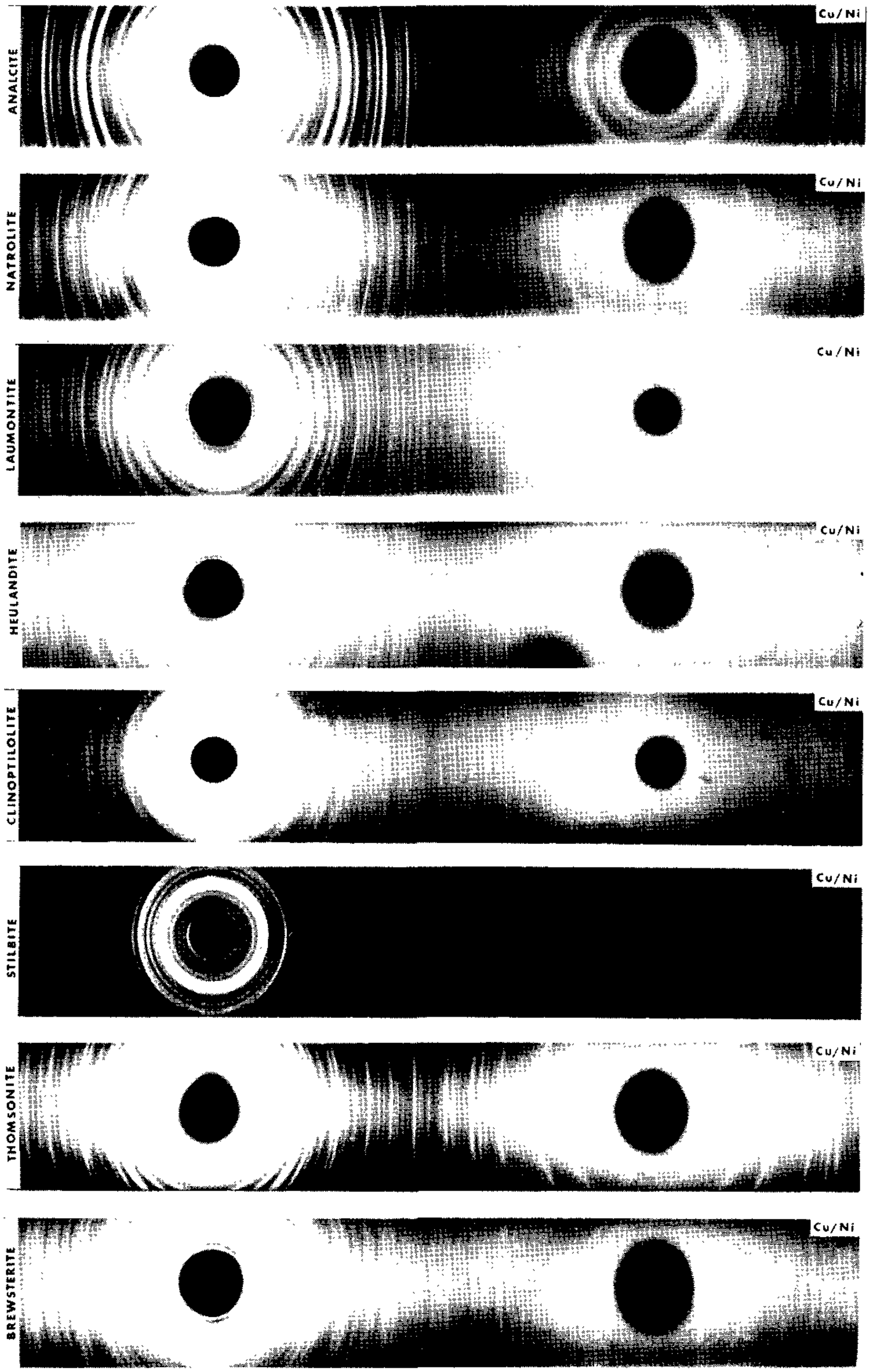

Plate 5-1. X-ray powder diffraction patterns for some common zeolites.