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DISTRIBUTION OF HYDROTHERMAL CLAY MINERALS IN THE VALLEY COPPER PORPHYRY DEPOSIT, HIGHLAND VALLEY, BRITISH COLUMBIA

J.L. JAMBOR
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Energy, Mines and Resources Canada
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Abstract

Kaolinite, chlorite, illite, and montmorillonite were determined for the clay (<2 µm) fraction of more than 250 samples from the hydrothermal alteration aureole of the Valley Copper porphyry deposit. Chlorite content in the clay fractions of the samples is low, but the other three minerals are abundant within and beyond the copper zone. In most rocks with extremely intense megascopic argillic alteration, the total of kaolinite plus montmorillonite exceeds 75 per cent of the clay-mineral fraction, and montmorillonite generally predominates. Rocks with this type of intense, "chalky" alteration, are concentrated in the upper, central part of the copper zone, and decrease laterally and with depth. Areas in which kaolinite exceeds illite are irregular, but somewhat elongate in plan, are steep to only slightly inclined in cross-section, and are not restricted to the copper zone. Kaolinite-illite ratios do not seem to vary systematically with depth in the deposit. Neither the intensity of argillic alteration nor the distribution of specific clay minerals seems to be related to sulphide zoning. Pervasive argillization is interpreted to have been a late-stage, post-sulphide alteration.

Résumé

On a déterminé le contenu en kaolinite, chlorite, illite, et montmorillonite pour la fraction argileuse (inférieure à 2 µm) de plus de 250 échantillons provenant de l'auréole d'altération hydrothermale du dépôt porphyrique de Valley Copper. Le contenu en chlorite de la fraction argileuse des échantillons est faible, mais les trois autres minéraux sont abondants dans la zone cuprifère et au-delà. Dans la plupart des roches qui présentent une altération argileuse mégascopique de très forte intensité, le total kaolinite plus montmorillonite dépasse 75 pour cent de la fraction argileuse, et la montmorillonite est en général dominante. Les roches qui présentent ce type d'altération "crayeuse" intense se concentrent dans la partie supérieure et la partie centrale de la zone cuprifère, et elles se raréfient latéralement et en profondeur. Les zones où la kaolinite excède l'illite sont irrégulières, mais légèrement allongées lorsqu'observées dans le plan horizontal, et présentent une inclinaison variable en coupe, très prononcée à légère, et ne se limitent pas à la zone cuprifère. Le rapport kaolinite à illite ne semble pas varier systématiquement avec la profondeur dans le gisement. Ni l'intensité de l'altération argileuse, ni la distribution des minéraux argileux spécifiques ne semblent liés à une zonation des sulfures. On considère que l'argilisation profonde est le résultat d'une altération tardive, ultérieure à la mise en place des sulfures.

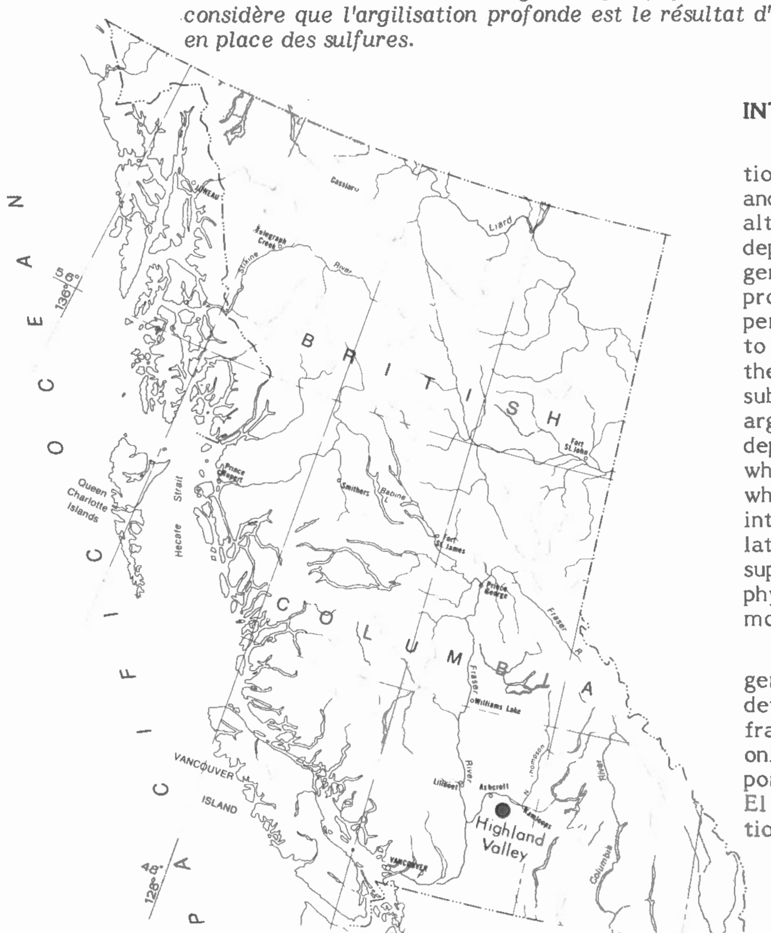

Figure 1. Location map.

INTRODUCTION

Clay minerals are a significant hydrothermal alteration product associated with many types of sulphide deposits and have long been known to constitute a characteristic alteration facies of porphyry copper and molybdenum deposits. Argillization in porphyry hydrothermal systems is generally recognized to be a late-stage, low-temperature product which, in the ideal concentric array of alteration, is peripheral to central potassic and phyllic cores, and gives way to the outermost, lowest grade of alteration represented by the propylitic facies. This idealized porphyry model aside, substantial variations in both the extent and intensity of argillic alteration do occur. Intense argillization in some deposits is so sporadic that the facies is not a mappable unit, whereas in other deposits argillization may be the overwhelming alteration over large areas. This variation in intensity and extent is, in large measure, a reflection of the late-stage appearance of argillization which permits its superimposition and partial obliteration of pre-existing phyllic and potassic alterations, with the latter being the more susceptible to degradation.

Argillic hydrothermal alteration in porphyry deposits is generally mapped on a visual, megascopic scale; only a few detailed laboratory studies have been done on the clay (<2 µm) fractions in these deposits and, to the writers' knowledge, the only three-dimensional analysis of the clay minerals in a porphyry system is that of Gustafson and Hunt (1975) for El Salvador, Chile. Among other past studies of the distribution of individual clay-mineral species in porphyry deposits,

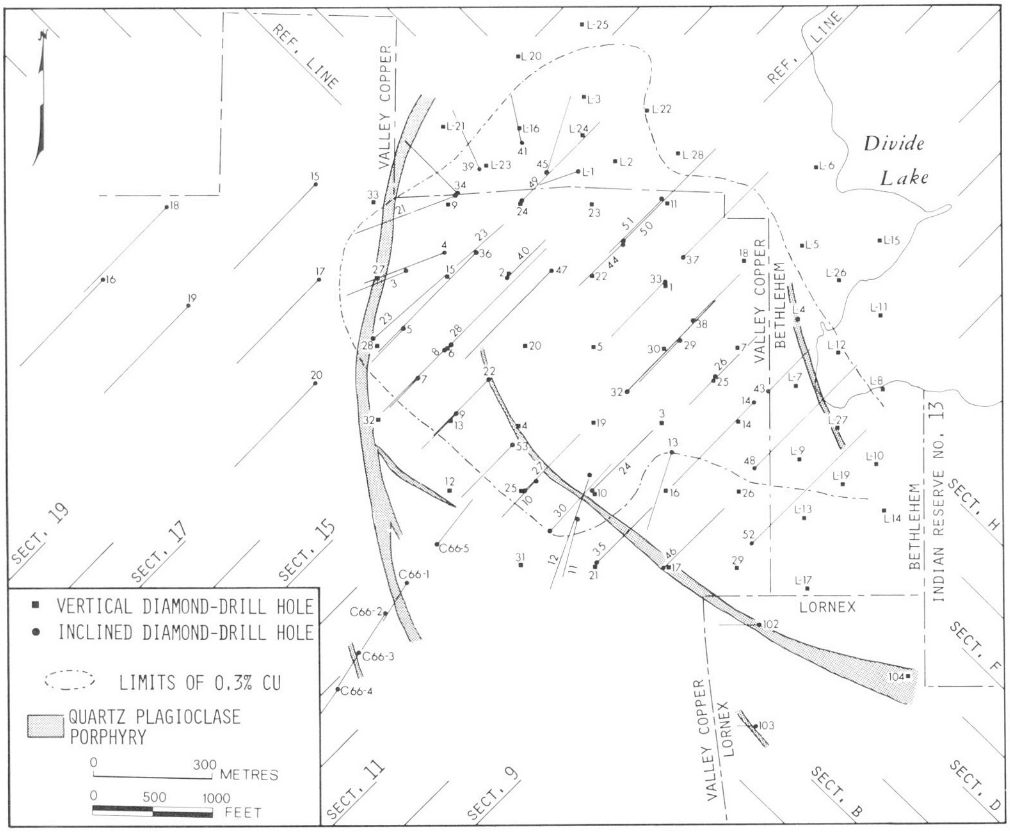

Figure 2

Outline of the Valley Copper deposit, distribution of major porphyritic dykes, and locations of the surface diamond-drill holes dealt with in this study.

Berzina and Sotnikov (1977) reported that Eastern Transbaikalian porphyries have kaolin-group minerals in the inner argillic zone, and montmorillonite, chlorite, and hydromicas in the outer zone. Sheppard et al. (1969) found that in the Santa Rita deposit, New Mexico, the abundance of montmorillonite relative to kaolinite increased with depth. A similar trend at Bell Copper, British Columbia, was found by Jambor and Delabio (1975), who also obtained a more well-defined trend in which kaolinite increased relative to illite with depth. The present writers' search for a similar trend at Valley Copper was initially unsuccessful, and the subsequent analyses of more and more samples eventually culminated in the clay mineral study presented here for the whole of the deposit.

Sample collection and details concerning the distribution of silicification and intense, megascopic argillic alteration are based on field work by the first author (J.L.J.). All surface diamond-drill holes from Valley Copper and many from the Lake Zone were logged, with the total comprising more than 30 000 m of core.

VALLEY COPPER DEPOSIT

Valley Copper is but one of several large porphyry copper-molybdenum deposits clustered in the Highland Valley of south-central British Columbia, about 370 km northeast of Vancouver (121°02'W, 50°29'N; Fig. 1). Valley Copper has been extensively explored by drilling and underground workings, but no date has been set for putting the property into production. Reserves are 790 million tonnes of 0.48 per cent Cu to a depth of 442 m (Osatenko and Jones, 1976). About 80 per cent of these reserves are on ground owned by Valley Copper Mines Limited, which is controlled by Cominco Ltd., and the remainder are on claims held by Bethlehem Copper Corporation (Fig. 2). Bethlehem has named its part of the deposit the Lake Zone.

The discovery of Valley Copper, and its geology and hydrothermal alteration have been discussed by Allen and Richardson (1970), McMillan (1971), Jones (1975), Jambor and McMillan (1976), Reed and Jambor (1976), and Osatenko and Jones (1976). The deposit is almost entirely within quartz monzonite to granodiorite of the Bethsaida phase of the Upper Triassic Guichon Creek batholith. The Bethsaida is medium- to coarse-grained and contains coarse phenocrysts of quartz and biotite. Sparse hornblende is present, but most of the mafic material is biotite which comprises less than 5 volume per cent of the rock. Within the Bethsaida phase are pre-ore quartz feldspar porphyry dykes, up to 35 m wide, which are concentrated along the western side of the deposit (Fig. 2). There are several dykes of felsite porphyry, aplite, and post-ore lamprophyre, but these are volumetrically unimportant. The aplites are pre-ore whereas the felsite porphyry may have been intruded during the waning stages of mineralization (Osatenko and Jones, 1976).

The major zones of hydrothermal alteration at the deposit consist (Osatenko and Jones, 1976) of an elongate central zone of K-feldspar enrichment which is confined almost wholly to rocks containing more than 0.3 per cent copper. Moderately intense alteration consisting of sericitic selvages along veins approximately follows the 0.3 per cent copper isopleth and extends slightly beyond it; areas where this type of atleration is most intense coincide with areas containing more than 0.5 per cent copper. The southeastern part of the deposit contains a stockwork of late-stage, barren quartz veins and associated pervasive silicification which is arched in cross-section (see Sections 12 and 13, Fig. 3). The data of Osatenko and Jones (1976) show that zones with the most intense potassic and sericitic alterations in the deposit, and the zone of 0.3 per cent copper, also are arched or dome-shaped.

The distribution of intense hydrothermal argillic alteration at Valley Copper was given by Jambor and McMillan (1976), and additional data are presented here. The distinction between supergene and hypogene clay alteration is not a problem of major concern. The deepest oxidation is at the southeastern corner of the deposit, where oxide-zone thickness averages 33 m (Osatenko and Jones, 1976). Oxidation depth is otherwise relatively insignificant and averages less than 5 m for most of the deposit.

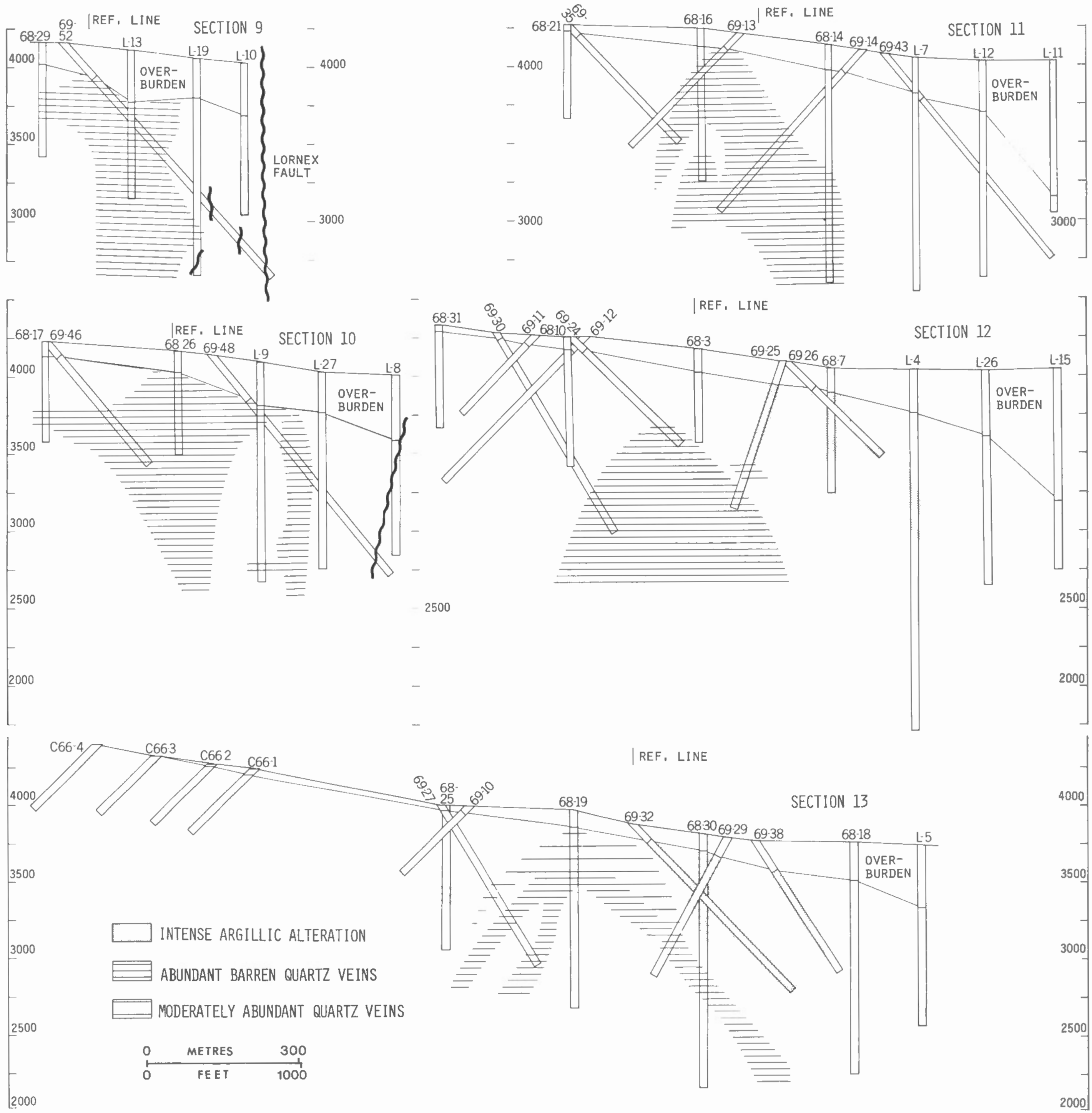

Figure 3. Cross-sections showing the distribution of intense, megascopic argillic alteration and abundant, late-stage, almost barren quartz veins which gradually diminish northwards. Intense argillic alteration is also a local feature near the Lornex fault, which dips 85° west at the nearest part of the Lornex mine, approximately 1800 m to the south. Splays of the Lornex fault are shown schematically in Section 9; the steep westerly dip shown in Section 10 is probably more appropriate as indicated by the presence of a characteristic, black marker gouge near the bottoms of drillholes 69-48 and L-19. Vertical scale is elevation in feet; horizontal and vertical scales are identical.

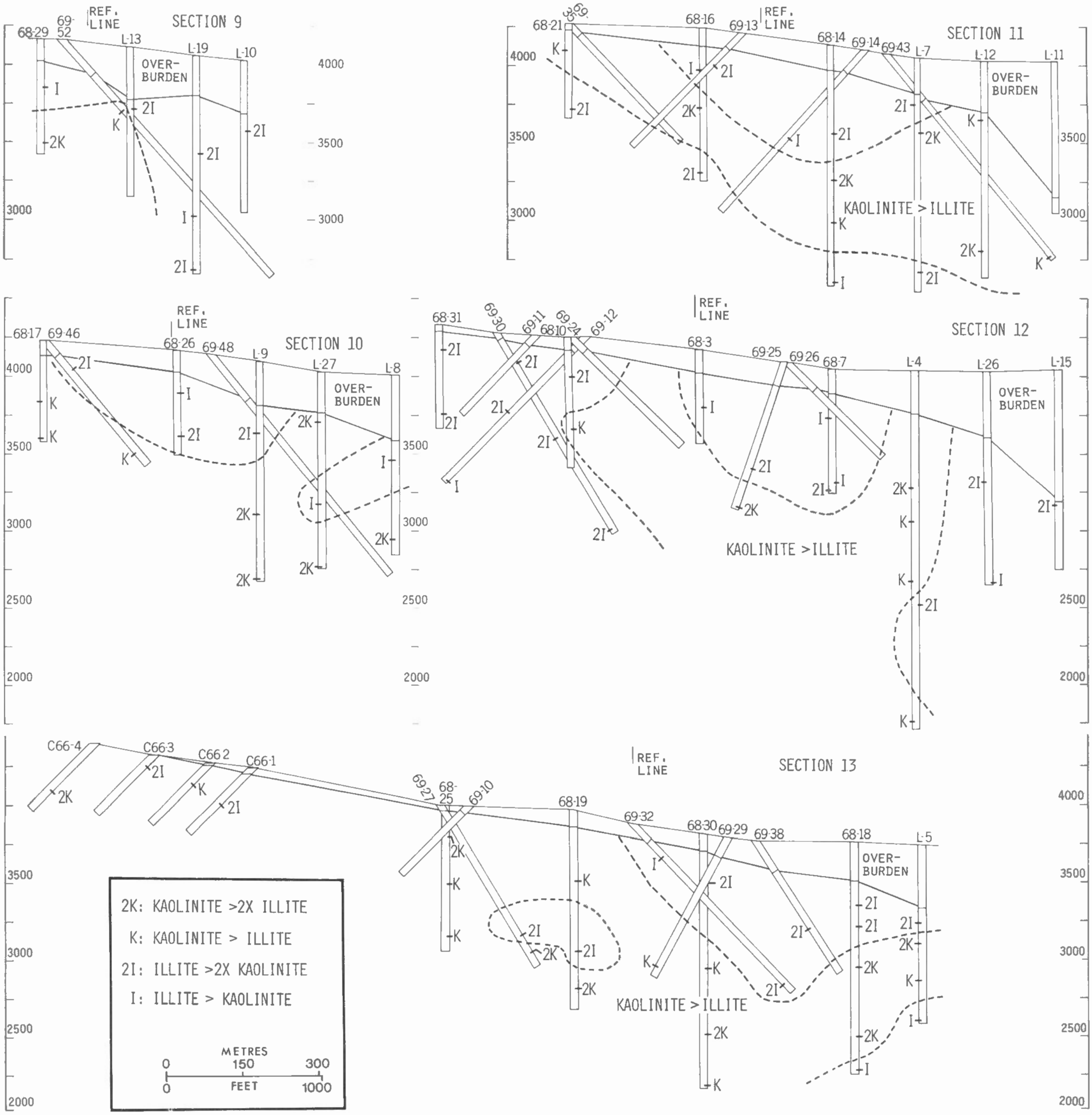

Figure 4. Northeasterly-trending cross-sections (located on Fig. 2) showing kaolinite-illite ratios for samples listed in Appendix 1, and the interpretation of the configuration of the kaolinite-rich and illite-rich zones. Vertical scale is elevation in feet; horizontal and vertical scales are identical.

PROCEDURES

Sample selection

All samples were pieces of drill core from within the Valley Copper hydrothermal aureole (Jambor and Beaulne, in prep.). Most specimens were cut with a diamond saw in order to obtain a better view of the material, to reduce the core to a size appropriate for crushing, and to eliminate veinlets and, in some cases, their altered margins. In the initial stages of the study, samples were selected to provide some degree of lateral and verticle coverage, to test whether the megascopic characterization of the argillic alteration was meaningful, and to determine whether rock types (medium- to coarse-grained Bethsaida, finer porphyritic varieties, and quartz plagioclase porphyry dykes) had a significant effect on results. Thereafter, all specimens were selected only to provide areal coverage of the deposit.

Sample preparation

Drill-core specimens were sawed and crushed to minus 200 mesh. Twenty-gram samples of the fine fraction were bottled and used for the clay determinations.

The procedure outlined below is the standard method used for clay mineral determinations by the Mineralogy Section at the Geological Survey of Canada, Ottawa. The procedure was followed rigorously in order to ensure maximum possible reproducibility, particularly since the determinations were done in separate batches and over a period of more than one year. The elaborate preparation and identification methods are also necessary to ensure the detection of minerals such as montmorillonite. A previous report that montmorillonite abundance is low at Valley Copper (Osatenko and Jones, 1976) is at variance with our results, and may be partly attributable to inadequate sample preparation.

For this study, a 1-2 gram sample from each of the 20-gram vials was placed in a 100 ml Nalgene centrifuge tube and sodium metaphosphate solution (5g/ℓ of distilled water) was added to the marked 10-cm level. The stoppered tubes were agitated with a Vortex Jr. Mixer and then centrifuged four times. Only the residues from the third and fourth runs were combined and used. The procedure is: (1) centrifuge at 750 r.p.m. for 3 minutes and 20 seconds, with timing to start at 200 r.p.m. A stopwatch is used to obtain the necessary accuracy. The supernatant fluid is poured into another set of tubes and set aside, care being taken not to disturb the residue. (2) To the residue from the first run, metaphosphate solution is added to the 10-cm level; the tube is agitated and centrifuged as previously (750 r.p.m for 3 min, 20 s) and set aside. (3) To the supernatant fluid from the first run, metaphosphate solution is added to the 10-cm level and, without agitation, is centrifuged for 5 minutes at maximum r.p.m. (in this case, 2400 r.p.m.). The supernatant fluid is discarded. (4) The supernatant fluid from the second run is carefully decanted onto the residue from the third run, and the level brought to 10 cm. The residue from the second run is discarded. The solution is centrifuged at maximum r.p.m. for 5 minutes and the supernatant fluid is discarded.

Small amounts of the pasty residue from the fourth run were extracted by pipette, smeared on glass slides, and dried at room temperature. Three slides were prepared for each sample. The smear-on-glass technique was adopted because it yields satisfactory precision and accuracy (Gibbs, 1965).

Table 1

Comparison of original and duplicate clay-mineral determinations in samples from Section 15

Code No.	Sample	Date of Analyses orig.	Date of Analyses duplicate	Kaolinite orig.	Kaolinite duplicate	Illite orig.	Illite duplicate	Montmorillonite orig.	Montmorillonite duplicate	Chlorite orig.	Chlorite duplicate	Ratios orig.	Ratios duplicate
				Mineral Ratios									
1	R69-9-266	Apr./76	Mar. 77	8	8	70	61	10	20	12	11	2I	2I
2	68-13-363	Nov./76	"	20	13	25	16	51	71	4	-	I	I
3	-932	Nov./76	"	50	48	11	14	39	35	-	3	2K	2K
4	69-22-395	Mar./76	"	43	42	9	7	44	51	4	-	2K	2K
5	68-20-280	Dec./76	"	9	10	47	51	44	39	-	-	2I	2I
6	-498	Nov./76	"	27	22	19	17	54	61	-	-	K	K
7	-1052	Dec./76	"	7	6	31	37	33	38	29	19	2I	2I
8	-1309	Dec./76	"	10	5	32	37	38	39	20	19	2I	2I
9	-1204	Oct./76	"	32	28	10	8	58	64	-	-	2K	2K
10	68-22-565	Dec./76	"	22	23	10	10	66	67	2	-	2K	2K
11	68-22-1112	Oct./76	May 77	43	32	8	5	44	63	5	-	2K	2K
12	-1467	Nov./76	"	31	22	23	20	46	58	-	-	K	K
13	-1482	Dec./76	"	19	16	51	55	20	23	10	6	2I	2I
14	68-11-344	Oct./76	"	12	6	50	47	38	36	-	11	2I	2I
15	-600	Dec./76	"	28	28	55	53	17	14	-	5	I	I
16	-798	Nov./76	"	69	51	5	3	24	46	2	-	2K	2K
17	-1037	Oct./76	"	27	18	32	37	41	41	-	4	I	2I
18	L-28-487	Oct./76	"	12	13	22	9	66	78	-	-	I	K

Samples 1 to 10 were run on a General Electric XRD-3 diffractometer, and the remainder were run on a Picker Series 3488 Unit.

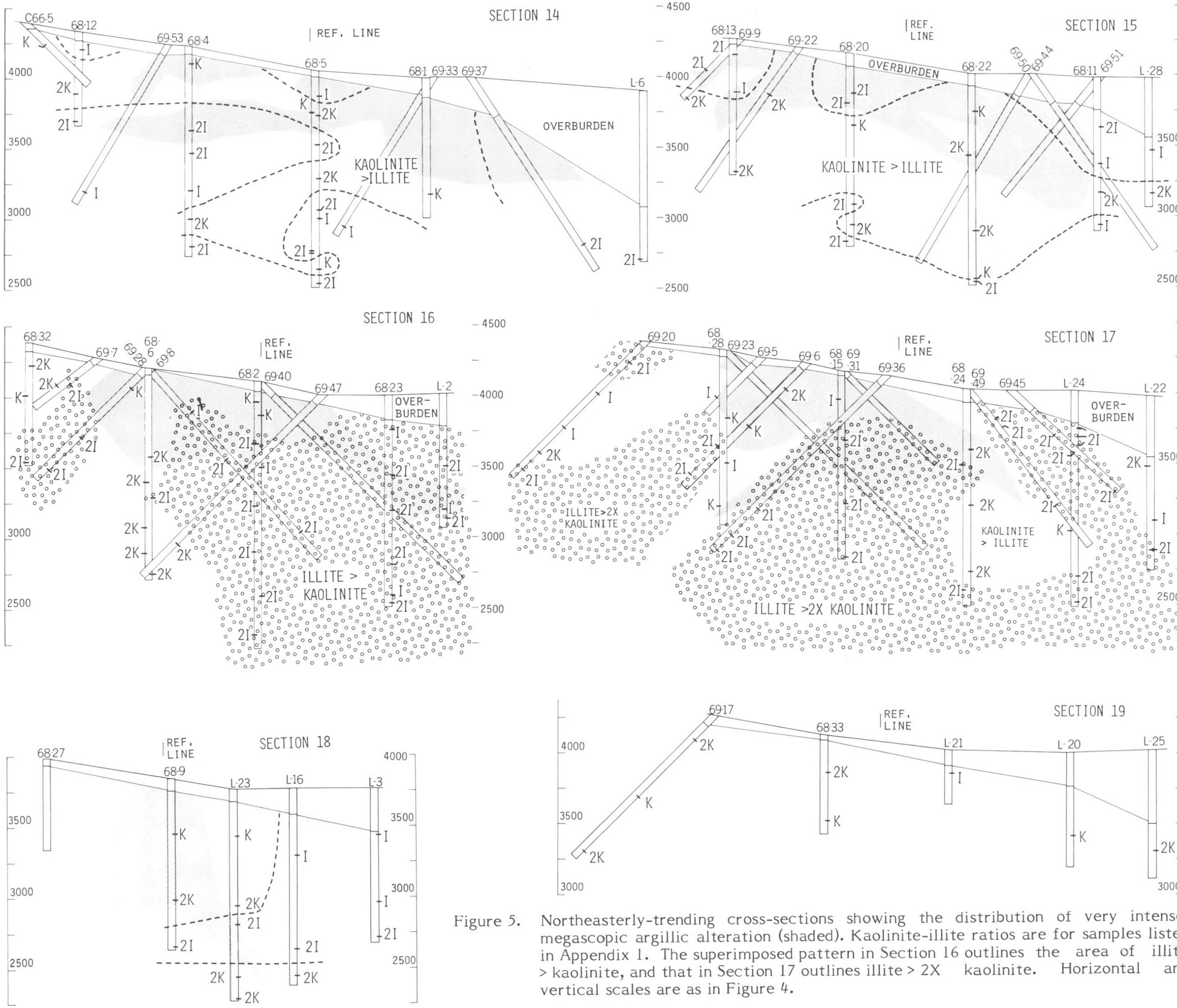

Figure 5. Northeasterly-trending cross-sections showing the distribution of very intense, megascopic argillic alteration (shaded). Kaolinite-illite ratios are for samples listed in Appendix 1. The superimposed pattern in Section 16 outlines the area of illite > kaolinite, and that in Section 17 outlines illite > 2X kaolinite. Horizontal and vertical scales are as in Figure 4.

Table 2

X-ray results for additional samples from Section 11

D.D.H.	Footage	Kaolinite	Chlorite	Illite	Montmorillonite	Megascopic Character
69-35	680	5	-	14	81	biotite fresh; plagioclase slightly creamy; very weak argillic alteration
R69-13	561	45	7	7	41	biotite completely altered; feldspars buff; moderately intense argillic alteration
R69-13	965	23	-	37	52	similar to 69-35 above
R69-14	1146	19	-	32	49	biotite fresh; feldspars greenish buff; weak argillic alteration
R69-14	1335	27	-	27	46	quartz-rich; feldspars white with moderately intense argillic alteration
69-43	561	19	12	69	-	biotite fresh; some feldspar creamy, some greenish; very weak argillic alteration

X-ray determination and interpretation

X-ray charts were obtained with a General Electric XRD-3 diffractometer using copper radiation at 45kV and 16mA, and a scan rate of 2 degrees 2θ per minute for the 2θ range 2 1/2 to 35 degrees. For each of the samples studied, X-ray diffraction patterns were obtained from an air-dried mount, a glycolated mount, and a mount heated in a muffle furnace to 600°C for 15 minutes. The glycolated slides were prepared using the vapour method of Brunton (1955).

The glycolated slides were used to determine the presence of montmorillonite and the heated slides were used to determine the presence of kaolinite. The identification procedures outlined by Carroll (1970) were followed.

Differences in the ratios of clays present in each sample were obtained by measurement of the net peak heights (peak heights minus background) of (001) diffraction lines. For air-dried samples, chlorite, illite, and [kaolinite (001) + chlorite (002)] were measured at approximately 6.2, 8.1, and 12.4°2θ, respectively. Where chlorite was present, its (001) and (002) lines were assigned equal intensities. To obtain kaolinite (001), the combined peak of [kaolintie (001) + chlorite (002)] was reduced by an amount equal to chlorite (001). For montmorillonite abundances, the (001) peak was measured at about 4.9°2θ on glycolated material. When montmorillonite was detected, all clay ratios were determined from the glycolated slide.

For the above adjustment of kaolinite (001) in the presence of chlorite, R.S. Dean of CANMET pointed out (written comm., June 1977) that the assumed equivalence of chlorite (001) and (002) may not be valid for two reasons: chlorite (002) is usually more intense than (001); chlorite (002) is influenced by compositional variations which do not affect (001).

No composition data for Valley Copper chlorites have been obtained but it is likely that substantial variations do occur, as has been noted for other porphyry copper deposits (e.g. Carson and Jambor, 1974). Nevertheless, the principal factor to be dealt with directly is that chlorite (002) is usually more intense than (001). Therefore, the subtraction of chlorite (001) from the kaolinite peak could have been an inadequate compensation for chlorite interference. In other words, the charted kaolinite peak would be erroneously high. As kaolinite-illite ratios are the principal entity used throughout this study, all kaolinite-chlorite assemblages in Appendix 1 were recalculated on the basis that kaolinite should be reduced by a certain percentage of the amount of associated chlorite. It was found that even if kaolinite is reduced by up to 50 per cent of the amount of associated chlorite kaolinite-illite ratios are reversed for only 3 of the 258 samples in Appendix 1. The reversals are as follows:

Sample	Section	K	C	I	New K
69-43-1693	11	6	5	4	3.5
68-5-294	14,E	17	13	15	10.5
69-34-740	E	16	4	15	14

K = kaolinite, C = chlorite, I = illite

Aside from the low number of samples affected and the high percentage of chlorite used in the recalculation, it is also evident that kaolinite-illite ratios are reversed only in samples where K:I is close to 1:1. Thus, it is concluded that the method used to obtain kaolinite (001) does not affect any of the conclusions of the present study.

Reproducibility

Some data for Valley Copper clays were obtained by Jones (1975). From X-ray and thermogravimetric analyses, Jones concluded (Osatenko and Jones, 1976) that kaolinite is the dominant clay mineral species in the deposit, but that some montmorillonite occurs at its western side. These data are not in accord with the results of the present study. Therefore, tests were done to check both the precision of the X-ray results and the interpretation of the configuration of the kaolinite-rich zone in Section 11 (Fig. 7).

Precision was checked by taking splits of 18 of the original samples from Section 15 (Fig. 5). The splits were rebottled, sequentially numbered 1 to 18, and the clay ratios redetermined. The clay analyst (R.N.D.) was unaware of the original sample numbers, the original results, or the relevance of the samples to the present study. The results (Table 1) show that the precision for kaolinite and illite determinations is good. Montmorillonite abundances are more variable, but the results are considered to be acceptable, particularly in terms of ratios to the other clay minerals. Of principal concern in this study is the relative abundance of kaolinite to illite, and, as shown in Table 1, this ratio was changed in only two samples; even more important is the fact that K:I was reversed in only one sample. (Samples 11 to 18, inclusive, were run on a Picker diffractometer because of a malfunction in the original X-ray unit. These were the last X-ray determinations done in this study). For the lone reversed ratio (sample no. 18 in Table 1), the original clay ratio was I > K whereas the new determination gave K > I; the average of the two is I > K. The effect on the configuration of the kaolinite-rich zone is minor because the sample position is at the top of drillhole L-28 in Section 15 (Fig. 5).

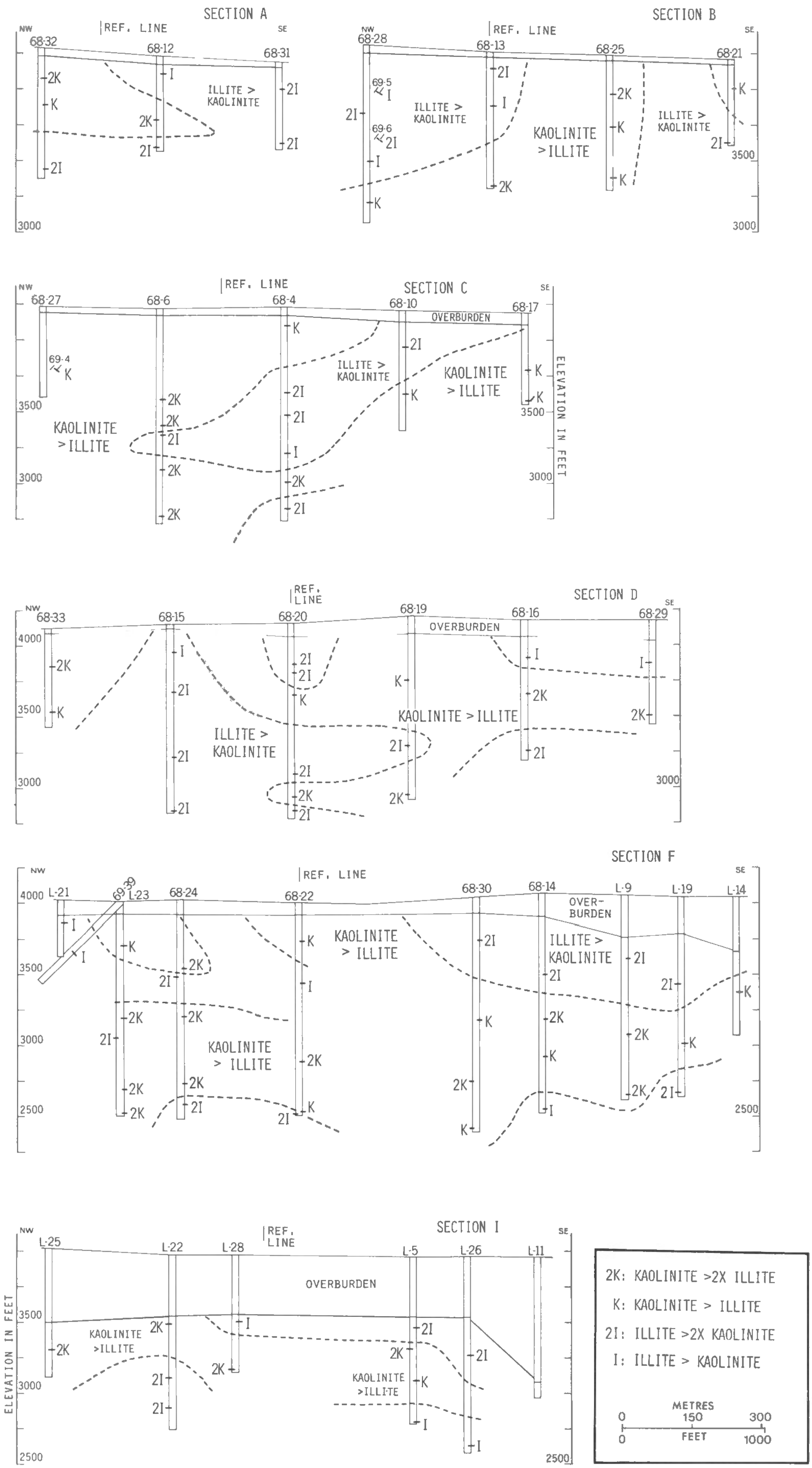

Figure 6.

Northwesterly-trending cross-sections (located on Fig. 2) showing the configurations of the kaolinite-rich and illite-rich zones. Boundaries of the zones are constrained by the results shown in Figures 4 and 5.

Table 2 gives the results obtained from the six new samples which were used to test the shape of the zone of kaolinite > illite in Section 11. The modified configuration (Fig. 7) differs principally in that the kaolinite-rich zone has been divided into two segments. The original single-band configuration could have been retained by projecting a narrower kaolinite-rich zone through drillhole 69-14. However, it is thought that the division into two segments would have been the choice had all data been available for the initial interpretation.

Clay mineral terminology

Sericite is a field term generally used to designate fine grained white mica. The term is used widely, and without grain-size restriction, in descriptions of porphyry copper alteration assemblages (Sutherland Brown, 1976). Sericite in the present study is used to designate the material which is megascopically recognizable as well crystallized white mica and which characteristically occurs as selvages along veinlets. The selvages are typically 1 to 3 cm wide, but masses of completely sericitized host rock, 6 to 7 m wide, also have been noted. Polished thin sections of one massively sericitized sample (D.D.H. 68-25 to 869 feet), and two samples with sericite selvages, were analyzed by microprobe by D.R. Owens of CANMET. (Selvage sample D.D.H. 69-27-569 is in intensely argillized, chalky Bethsaida; sample 68-24-1324 is in Bethsaida with hydrothermal biotite and K-feldspar alteration). Microprobe analyses of five areas in the three sections showed that the compositions of the mica are similar and are close to end-member muscovite. Debye-Scherrer patterns (114 mm camera, Co$K\alpha$ radiation) of two of the analyzed areas indicate that the mica is muscovite-2M. Probably, therefore, most of the mica referred to here as sericite is muscovite.

Among geologists, there is some confusion about the definition of illite versus muscovite. Much of the difficulty may stem from the fact that the name illite originally was proposed (Grim et al., 1937) as a general term for a mica-type mineral in argillaceous sediments rather than as a specific mineral name. Carroll (1970) stated that illite is chemically similar to muscovite, but illite contains less K and more SiO_2 and H_2O; the illite structure may "contain any or all muscovite polytypes", whereas for identification "the diffraction pattern is similar to that of a 1Md muscovite" (Carroll, 1970, p. 19). In contrast, well defined $2M_1$ illite has been described (Gaudette, 1965; Gaudette et al., 1966). A succinct statement by Güven (1972, p. 83) is that "Illites are characterized with (sic) an excess of water and deficiency in K_2O compared to the micas." Variations in compositions of the octahedral layer, and particularly tetrahedral Si/Al, are also well-recognized features of illite. These and other aspects of the term are comprehensively reviewed and discussed by Wentworth (1969). In general, the name illite is used to designate 10Å non-expandible, clay-size layer silicates which have not been categorized as muscovite, biotite, or other specific species. Although muscovite undoubtedly occurs in Valley Copper clay fractions, its presence has not been proved; accordingly, the 10Å non-expandible clay fraciton is referred to as illite.

No attempt was made to establish the composition range of the Valley Copper montmorillonite-group clays. The term montmorillonite is used here without implying compositional restriction. The absence of mixed-layer clays in the identifications may also be noted. Clays with regular mixed layers do not behave as mixtures, but have a new periodicity in which the basal spacing is equal to the sum of those of the two interstratified layers. Clays with irregular mixed layers have no periodicity in their structure and,

Table 3

Average montmorillonite contents and the affinity with kaolinite-rich samples

Cross-section No.	Average montmorillonite content in samples with							
	K > I		2K		I > K		2I	
	Av. mont.	No. of samples	Av. mont.	No. of samples	Av. mont.	No. of samples	Av. mont.	No. of samples
9	65	1	34	1	50	2	41	4
10	46	3	54	5	44	3	41	3
11	71	4	53	4	51	3	30	6
12	45	4	62	2	49	5	34	12
13	52	8	26	8	51	3	27	10
14	55	5	46	4	32	6	27	11
15	58	3	52	8	44	4	32	8
16	48	4	57	8	45	6	23	18
17	47	4	51	6	44	7	27	22
18	64	2	42	5	43	3	45	4
19	56	3	63	4	38	1		
Misc.	55	6	66	4	61	6	30	4
Average montmorillonite	54		50		46		29	
Total no. of samples		47		59		49		102

K > I: samples with more kaolinite than illite
2K: kaolinite content more than twice that of illite
I > K: samples with more illite than kaolinite
2I: illite content more than twice that of kaolinite

therefore, are much more difficult to identify on a routine basis. The presence of regular mixed-layer clays was noted in only a few samples during the present study; where present, these clays were such a small fraction of total clay that their presence was ignored.

Kaolinite-rich samples were checked for dickite by removing the material from non-glycolated X-ray slides of six samples and immersing each in 5N HCl for 35 hours at room temperature. No dickite was detected in any of the residues.

RESULTS

Megascopic silicification and argillization

The pronounced inward deflection of the 0.3 per cent copper isopleth in the southeastern part of the deposit reflects the presence of late-stage, largely barren quartz veins and associated pervasive silicification. The most intensely veined and silicified part of this zone forms an elongate "nose" which extends from near the Lornex fault toward the core of the deposit (Fig. 3). Rocks within the nose commonly consist of up to 50 per cent barren quartz. The contacts of the nose are gradational, and local areas with above-average abundance of barren quartz veins extend well into the centre of the deposit. In the southeastern, most silicified part of the deposit, the quartz nose is dome-shaped in cross-section (Fig. 3).

Megascopic argillic alteration at Valley Copper is variable, but is most intense within the copper zone. Rocks with weak argillization occur in patches throughout the deposit and are abundant at depth. These commonly contain unaltered primary biotite, and the feldspars are cream coloured to slightly greenish but otherwise seem to be well preserved. In rocks with medium-intensity argillization, the feldspars are well outlined and are solidly white to buff coloured. The most intense argillization is described here as "chalky" alteration (Appendix 1). Rocks of this type are white to cream coloured, the feldspar grain boundaries are no longer readily discernible, and the material is sufficiently soft that some can be scratched with a fingernail. Thin section studies indicate that chalky rocks contain 40 to 60 per cent clay (primary quartz accounts for another 30 per cent). Rocks classified as intensely or strongly argillized have at least 25 per cent clay, and moderate or medium-intensity argillic alteration designates a clay content of about 10 to 25 per cent.

Areas in which intense argillic alteration predominates are shown in Figures 3, 5, and 9. These areas are rarely outside of the copper zone, are widest and of maximum intensity in the central part of the deposit, and decrease with depth. The decline with depth is in some cases marked by a transitional zone consisting of potassic alteration with minor areas of intense argillic alteration (Jambor and McMillan, 1976). Below the lower boundary of this transition zone, megascopic pervasive argillic alteration is negligible.

Correlation with X-ray results

Clay ratios of the samples are tabulated in Appendix 1. Kaolinite-illite ratios, summarized in Figures 4 and 5, show that zones with high ratios (K>I) extend throughout the deposit, but are not spatially related to the areas of most-intense argillization. Some cross-sections show clearly that the clay mineral zoning is in irregular bands (Sections 14, 15)

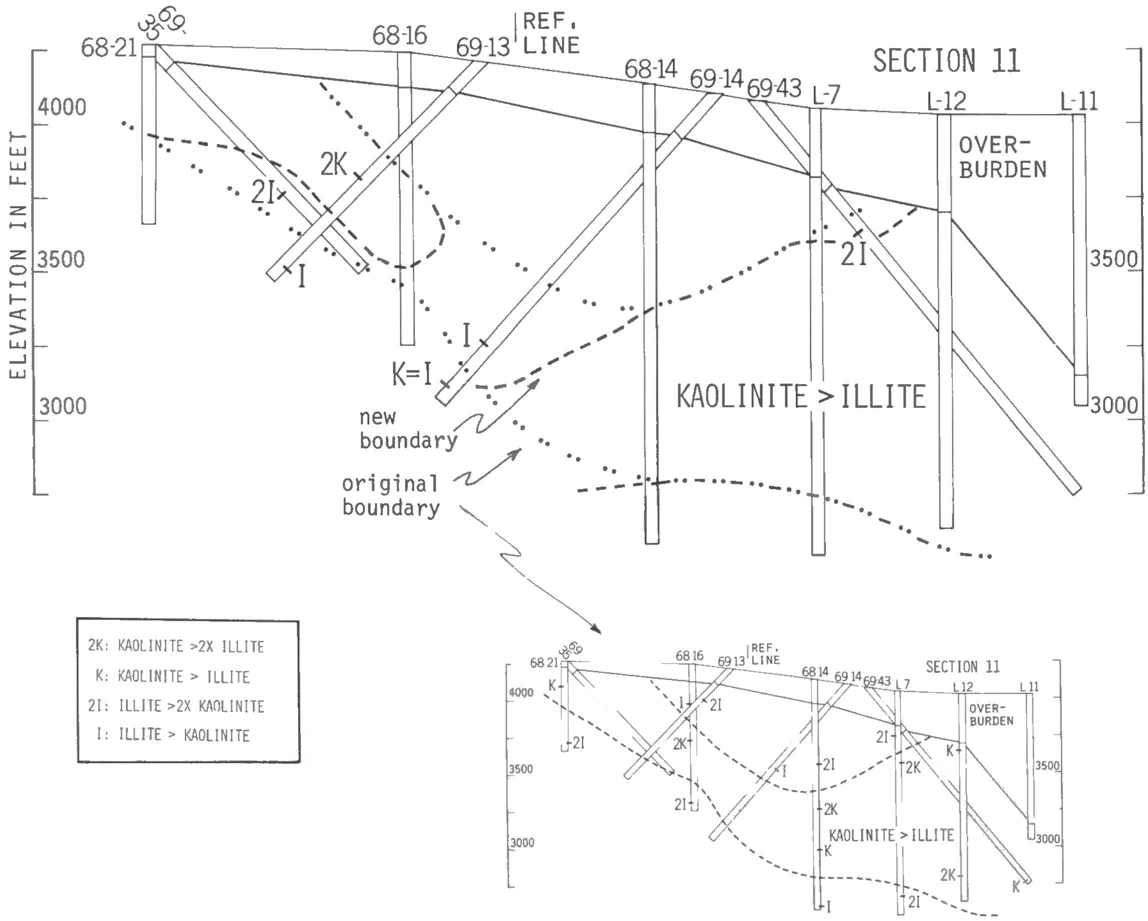

Figure 7. Kaolinite-illite ratios in cross-section 11. Smaller diagram shows the original ratios and interpreted kaolinite-rich zone; upper diagram shows the effect of additional samples on the interpretation of the kaolinite-rich boundary.

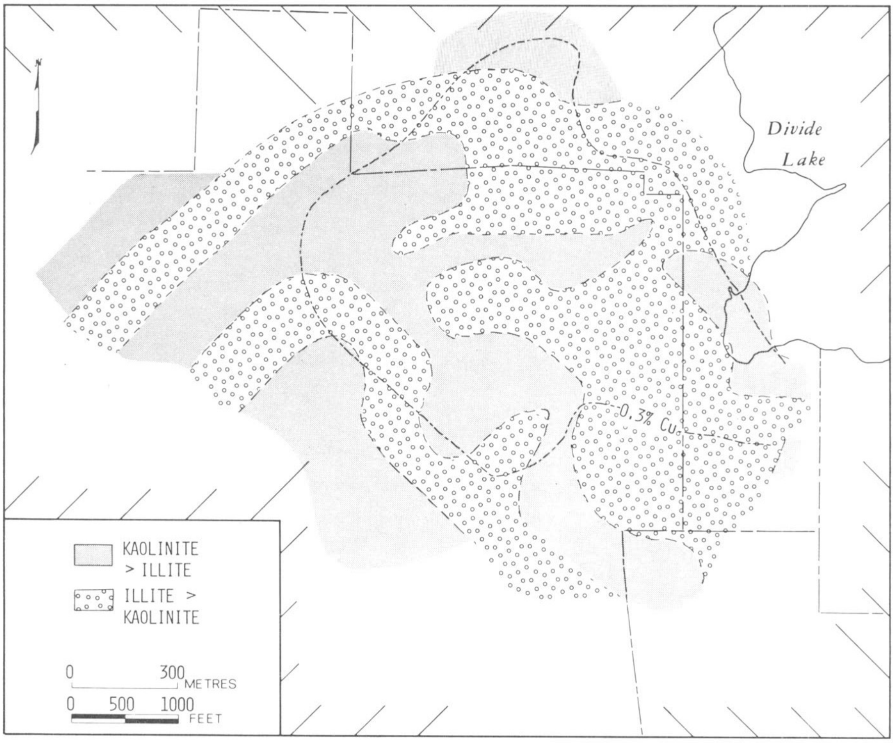

Figure 8

Composite plan of the near-surface distribution of kaolinite-rich and illite-rich zones based on cross-sectional data.

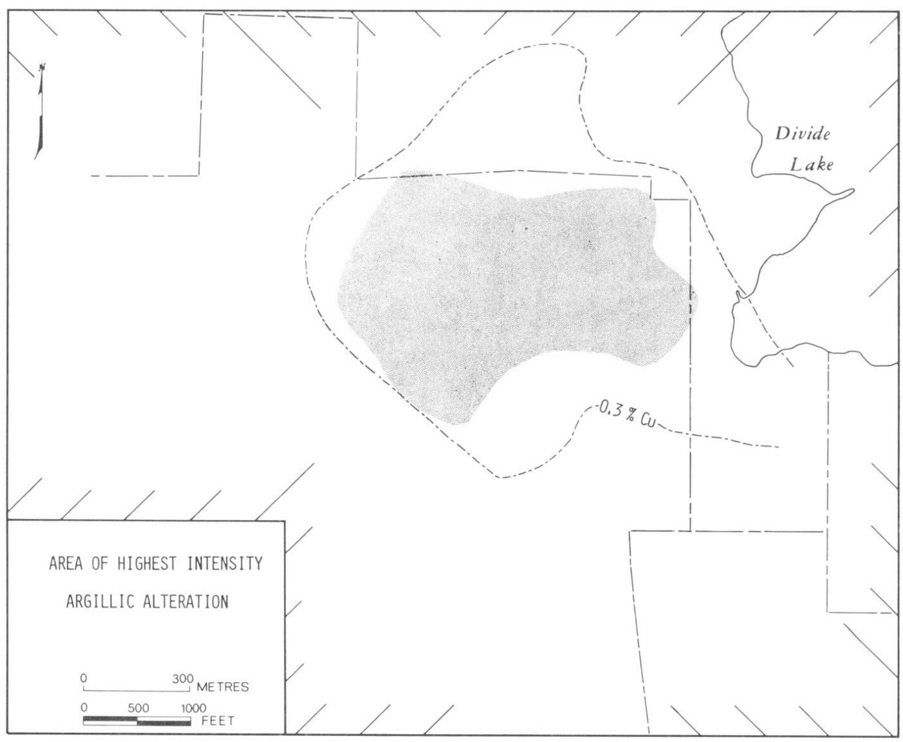

Figure 9

Approximate distribution of near-surface occurrences of very intense megascopic argillic alteration at Valley Copper.

rather than in a vertical zone of argillization. There is no obvious focal point of deep kaolinization, nor is there an obvious association with the copper zone. The latter is particularly evident at the northern part of the copper zone which is beyond possible influence from the quartz-rich nose: the area of kaolinite > illite is relatively small in Sections 16 and 17, but again increases in Section 19 (Fig. 5 and 8).

Because most Valley Copper drillholes are inclined and are parallel to the northeasterly-trending, numerical cross-sections, the fewer results obtainable from northwesterly-trending cross-sections are more difficult to interpret. Some northwesterly sections are shown in Figure 6. Results shown in Figures 4 and 5 in some cases place limits on the positioning of the boundaries of kaolinite-rich zones. A good example of imposed boundaries is evident on the right of Section B, where the steeply dipping illite-rich zone is not evident in the vertical drillholes. Nevertheless, the northwesterly-trending cross-sections yield similar conclusions – the kaolinite-rich zones are irregular and are generally shallow rather than deep and vertical. The irregularity is particularly evident in plan (Fig. 8).

Table 4

Kaolinite and montmorillonite contents of chalky, very intensely argillized samples

Sample No.	Kaolinite	Mont.	Sum
69-46-924*	46	30	76
68-14-883	29	62	91
68-7-302	20	55	75
L-4-1375	36	33	69
69-27-1111	45	34	79
68-30-1306	56	33	89
68-30-1643	33	38	71
68-18-1266	53	31	84
68-12-125	12	75	87
68-4-1223	30	60	92
68-5-320	56	33	89
L-102-570	39	57	96
68-13-363	20	51	71
R-9-570	34	57	91
68-20-498	27	54	81
68-22-265	16	74	90
68-22-1112	43	44	87
68-22-1467	31	46	77
68-11-798	69	24	93
L-28-487	12	66	78
69-28-447	37	18	55
68-6-1130	33	49	82
68-6-1473	55	32	87
68-6-1823	46	35	81
68-2-1214	18	47	65
68-24-473	22	69	81
68-24-812	34	53	87
68-24-1280	62	35	97
L-23-813	19	71	90
L-23-950	11	59	80
Average	35	48	82

K > M: 11 of 30, M > K: 19 of 30

*Drillhole year – number – sample footage.

Each sum is the combined percentage of kaolinite plus montmorillonite determined in the X-ray studies as listed in Appendix 1.

Data for montmorillonite abundances are not plotted on the figures because it was found that most samples with an abundance of this mineral (montmorillonite >50 per cent of the clay-size fraction) fall within or close to the areas outlined for kaolinite > illite. The association of montmorillonite with kaolinite-rich samples is also evident from the summary data in Table 3.

Rock type seems to have had little influence in controlling the formation of a specific clay mineral (Appendix 1). Argillized margins along quartz-sericite-sulphide veinlets are rich in combined kaolinite plus montmorillonite, but neither mineral seems to predominate. Feldspars which are only weakly altered but slightly greenish, and those which are intensely altered to waxy green, contain abundant sericite in thin sections; the clay fractions of these rocks are rich in illite.

Rocks with the most intense argillization, referred to previously as "chalky", have the highest contents of (kaolinite + montmorillonite). For the 30 samples described as chalky (Appendix 1), the average (kaolinite + montmorillonite) is 82 per cent of the clay minerals (Table 4). This does not contradict the previous statement that kaolinite:illite ratios are not correlative with intense argillization. The results indicate that (a) chalky specimens have high contents of kaolinite plus montmorillonite, and illite content is therefore low; (b) in most chalky material, montmorillonite exceeds kaolinite, but the reverse also occurs; (c) despite the association of montmorillonite and chalky argillic alteration, rocks in which alteration is least apparent are also commonly rich in montmorillonite. Other occurrences of this mineral seem to be unpredictable in terms of megascopic alteration.

Relative age of argillic alteration

Jones (1975), Osatenko and Jones (1976), and others have proposed that pervasive sericitic and kaolinitic alteration preceded potassic alteration at Valley Copper. The hydrothermal biotite and K-feldspar alteration represents a high-temperature assemblage for which the formation temperature of 480-500°C proposed by Osatenko and Jones is probably a minimum. Superimposition of this assemblage should have led to widespread destruction of kaolinite-montmorillonite in the area where these minerals are now most abundant.

Jambor and McMillan (1976) and Reed and Jambor (1976) have maintained that argillic alteration was overprinted on the hydrothermal K-feldspar-biotite assemblage. Evidence for late-stage argillization is the widespread replacement and partial to complete destruction of biotite and K-feldspar in argillized zones. Well developed megascopic indications of superimposed argillic alteration also occur in the transition zone which marks the boundary between areas of intense and negligible argillic alteration. In the transition zone, areas and metres-wide seams of locally intense argillic alteration cut through masses of potassic-altered rock. Above the transition zone, the abundance of argillized rocks increases substantially, but areas with residual pervasive potassic alteration can be found in all except the most intensely argillized parts of the deposit. These features are not only in accord with late-stage argillization, but cannot be explained if pervasive argillic alteration were early.

The alternative alteration sequences proposed above also can be evaluated in terms of mineral-stability diagrams which have been investigated experimentally (Hemley and Jones, 1964) and have been utilized extensively in explaining reaction paths in present-day hydrothermal systems (Steiner, 1968; Brown and Ellis, 1970; Ellis 1970). The diagrams show that kaolinite is stabilized at low cation (Na^+, K^+, Ca^{2+})/H^+ ratios; montmorillonite has a similar stability area in terms of K^+/H^+ but requires Na^+/H^+ and Ca^{2+}/H^+ above those of kaolinite. At constant temperature, increased activity of K^+/H^+ leads to the formation of K-mica at the expense of kaolinite and montmorillonite, and with further increase the stability field of K-feldspar is entered. Relatively high pH and high activity of K^+/H^+ which favour K-feldspar stability are incompatible with kaolinite and montmorillonite stability.

Osatenko and Jones (1976) concluded that pervasive kaolinite-sericite alteration at Valley Copper occurred at about a pH of 1.7 and temperature of 260°C; vein sericite formed at a pH of 2.2-3.1 and temperatures of 370-500°C, and K-feldspar alteration formed at about 480°C and a pH of 4.0. Osatenko and Jones proposed that the alterations occurred in the above-listed prograde sequence, that is, early pervasive kaolinite-sericite alteration → vein sericite with the main stage of copper mineralization → K-feldspar. Stability diagrams for these silicate assemblages show that kaolinite and montmorillonite are stabilized at low temperatures and are affected by dehydration reactions as temperature rises towards the muscovite stability field. The upper temperature limit of 400°C established by Hemley and Jones (1964) for kaolinite-bearing assemblages is applicable to Valley Copper. Thus, the mineral associations and their distributions are compatible with a retrograde rather than a prograde alteration sequence.

CONCLUSIONS

The area of most intense argillic alteration at Valley Copper is enclosed within the isopleth for 0.3 per cent copper (Fig. 9). This argillized zone is relatively shallow (Fig. 3, and 5), and throughout it are large volumes of rock which have been altered to a chalky appearance. Such rocks are generally rich in montmorillonite relative to kaolinite, and the sum of montmorillonite plus kaolinite usually exceeds 75 per cent of total clay in a sample. However, this does not indicate that montmorillonite decreases with depth and rocks argillized only weakly are also commonly rich in montmorillonite. Areas in which kaolinite exceeds illite are irregular, somewhat elongate in plan (Fig. 8), and vary from steep to only slightly inclined. The elongation does not coincide with the trends of the most prominent fault and fracture patterns.

All clay determinations in this study were done on material from within the Valley Copper hydrothermal aureole. The potassic halo, as defined by occurrences of hydrothermal biotite, extends well beyond the isopleth for 0.3 per cent copper (Jambor and Beaulne, in prep.), and concentric zoning patterns of pyrite, chalcopyrite, and bornite overlap the area of clay minerals shown in Figure 8. Neither the intensity of argillization nor the distribution of specific clay minerals seems to be related to the sulphide zoning. This lack of correlation is interpreted to reflect the superimposition of argillic alteration at a lower temperature, post-sulphide step in the development of the hydrothermal aureole.

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APPENDIX

Clay Ratios in Valley Copper Samples

D.D.H.	Footage	Section NE	Section NW	Ratios in Clay Fraction Kaolinite	Chlorite	Illite	Montmorillonite	Megascopic Character
68-29	317	9	D	29	-	43	28	intense argillic alteration, almost chalky
	678			52	3	11	34	as above
69-52	595	9		17	6	12	65	very intense argillization
L-13	401	9	E	15	8	59	18	quartz-nose type; pockets of intense argillic alteration
L-19	630	9	F	19	-	44	37	quartz-nose type as above
	1036			16	-	13	71	feldspars pinkish (K-rich?), strongly altered greenish
	1377			15	6	49	30	abundant sericite plus some argillization of moderate intensity
L-10	457	9	G	6	-	16	78	very weak argillization
68-17	397	10	C	19	-	11	70	intense argillic, almost chalky
	632			29	-	25	46	moderately intense argillic alteration
69-46	242	10		12	7	43	38	porphyry; plagioclase creamy, weakly argillized
	924			46	2	30	22	very intense argillization, chalky
68-26	278	10	E	13	11	35	41	pervasively silicified with buff argillic areas
	548			10	-	21	69	quartz-nose type; greenish buff, moderate argillic alteration
L-9	453	10	F	6	-	78	16	feldspars altered buff and greenish; moderately intense argillization
	982			39	-	16	45	greenish buff, moderate argillic alteration
	1416			22	-	8	70	biotite phenos. bleached; rock cohesive compact, with moderately strong argillic alteration
L-27	326	10	G	41	-	20	39	feldspars greenish; moderately intense argillic alteration
	851			23	-	45	32	biotite completely altered; moderately intense argillic alteration
	1265			28	-	10	62	argillization only weak
L-8	547	10	H	15	-	25	60	greenish, weakly altered
	1162			40	-	7	53	moderate to intense argillization
68-21	186	11	B	24	5	20	51	feldspars buff, weak to medium-weak argillization
	560			17	3	63	17	similar, but medium to medium-strong argillization
68-16	278	11	D	26	-	32	42	biotite fresh; plagioclase off-colour to greenish; weak argillic alteration
	529			51	3	19	27	abundant quartz, no biotite; intense argillic alteration
	939			19	3	44	34	quartz-nose type; intense argillic alteration
R69-13	272	11		15	6	38	41	moderately weak, greenish buff alteration of feldspar
68-14	581	11	F	20	3	53	24	intense argillization, almost chalky
	883			29	-	9	62	very intense, chalky alteration
	1153			19	5	11	65	intense, close to chalky
	1539			18	-	33	49	moderately intense argillic; coherent
R69-14	754	11		17	-	20	63	very abundant quartz; pockets of argillized host rock
69-43	1693	11		6	5	4	85	relatively unaltered
L-7	306	11	G	11	-	64	25	feldspars greenish to intensely argillized
	489			20	-	8	72	moderately intense argillization
	1378			-	9	84	7	mafics well-preserved; plagioclase creamy with very weak argillic alteration

D.D.H.	Footage	Section NE	NW	Ratios in Clay Fraction Kaolinite	Chlorite	Illite	Montmorillonite	Megascopic Character
L-12	380	12	H	11	-	7	82	biotite fresh; plagioclase slightly off-colour; very weak argillic alteration
	1221			21	-	10	69	biotite partly altered; weak buff argillization
68-31	163	12	A	2	12	15	71	porphyritic; fresh except that some plagioclase creamy to slightly greenish
	578			16	6	43	35	pinkish; very weak argillization
69-30	234	12		7	32	29	32	not recorded
	763			10	19	44	27	not recorded
	1452			4	8	49	39	K-rich(?) pinkish; very weak argillization
68-10	252	12	C	-	19	37	44	plagioclase slightly creamy to greenish, weakly argillized; some biotite chloritized, some well-preserved
	583			29	5	23	43	dull greenish alteration of feldspars; moderate-intensity argillic alteration
R69-12	683	12		11	-	53	36	intense argillization, almost chalky
	1313			22	5	44	29	dull greenish feldspars; moderate to weak argillic alteration
68-3	378	12	E	6	4	7	83	not greenish; moderate to weak argillic alteration
69-25	718	12		2	20	45	33	relatively fresh with feldspar creamy to slightly greenish
	986			23	5	10	62	almost quartz-nose type with almost chalky patches between quartz
68-7	302	12	G	20	-	25	55	intense argillic; chalky
	732			19	6	33	42	biotite completely altered; abundant sericite and sulphides; moderately intense argillic alteration
	774			2	22	49	27	same as 732
L-4	770	12	H	33	-	5	62	intense, chalky argillic alteration
	984			21	5	11	63	medium to medium-weak argillic alteration
	1375			36	-	31	33	very intense argillic; chalky
	1520			3	17	57	23	negligible argillic alteration
	2277			35	-	24	41	weak argillic alteration
L-26	706	12	I	17	-	68	15	moderate argillic alteration
	1339			32	-	34	34	abundant quartz-sericite-chalcopyrite; moderately intense argillic alteration
L-15	856	12		4	-	64	32	some plagioclase greenish; moderately weak argillic alteration
C66-4	411	13		45	5	20	30	biotite completely altered; buff-coloured, moderate-intensity argillization
C66-3	85	13		3	8	57	32	porphyry; all plagioclase greenish; medium-weak argillic alteration
C66-2	193	13		47	-	26	27	similar to C66-1; porphyry
C66-1	319	13		5	8	52	35	porphyry; plagioclase creamy to greenish; weak to medium-weak argillic alteration
69-27	980	13		19	6	44	31	intense argillic alteration
	1111			45	3	18	34	very intense argillic alteration; chalky
68-25	210	13	B	16	3	5	76	almost chalky, somewhat greenish
	514			23	4	20	53	very intense, slightly greenish argillized margin of quartz-sericite-sulphide vein
	853			52	3	36	9	moderate argillization of pinkish (K-rich?) Bethsaida
68-19	457	13	D	10	4	7	79	biotite altered; intense argillic alteration
	907			13	-	68	19	slightly greenish, moderately intense argillization of plagioclase

D.D.H.	Footage	Section NE	Section NW	Ratios in Clay Fraction Kaolinite	Chlorite	Illite	Montmorillonite	Megascopic Character
	1259			38	-	13	49	pinkish (K-rich?); argillization weak to medium-weak
69-32	281	13		21	-	24	55	intense argillic alteration
	1418			12	2	62	24	biotite completely altered; intense argillic alteration
68-30	298	13	F	10	21	32	37	plagioclase altered to a medium green colour
	868			26	-	24	50	intense argillization of plagioclase
	1306			56	2	9	33	very intense argillic; chalky
	1643			33	-	29	38	same as above (chalky)
69-29	950	13		8	-	18	74	biotite completely altered; very intense argillization
69-38	679	13		14	6	29	51	biotite completely altered; pinkish (K-rich?) with intense argillization
68-18	412	13	H	11	11	42	36	argillic alteration extremely weak
	550			16	3	72	9	moderately intense argillic alteration
	816			61	-	19	20	rich in quartz-sericite, partly chalky
	1266			53	-	16	31	very intense argillic; chalky
	1497			22	3	29	46	intense argillic, but cohesive
L-5	500	13	I	-	-	100	-	quartz-sericite-pyrite-chalcopyrite mass
	634			52	-	12	36	intense argillic, but cohesive
	873			8	-	5	87	same
	1167			18	-	30	52	strong argillic zone bordering sericitic selvage
C66-5	208	14		26	-	21	53	biotite partly fresh; alteration very weak
68-12	125	14	A	12	-	13	75	biotite preserved; feldspars light buff; medium-weak argillic alteration
	440			38	4	11	47	very intense argillic — nearly chalky
	636			6	19	42	33	biotite preserved; feldspars buff and greenish; medium-weak argillic alteration
69-53	1189	14		24	-	39	37	all biotite altered brownish; all feldspar greenish, weakly altered
68-4	126	14	C	19	3	11	67	feldspars greenish buff; moderately intense argillic alteration
	601			9	7	36	48	biotite completely altered; intense buff argillic alteration adjacent to sericite-bornite veinlet 1 cm wide
	748			13	-	80	7	not recorded
	1010			30	20	37	13	very weak sericitization; weak argillic alteration
	1223			32	-	8	60	pinkish (K-rich?); white chalky argillic alteration
	1429			14	25	39	22	fine grained porphyritic; biotite fresh; weak, buff argillic alteration
68-5	189	14	E	23	17	33	27	pinkish with moderately intense argillization
	294			17	13	15	55	biotite completely altered; intense argillization
	320			56	4	7	33	biotite still black, but very intense argillic alteration; crumbly
	529			21	-	48	31	biotite only weakly altered; very weak argillic alteration
	753			31	8	11	50	biotite well-preserved; intense slightly greenish argillic alteration
	975			9	5	42	44	only some biotite completely altered; intense, slightly greenish argillic alteration
	1030			34	9	46	11	K-rich, partly sericitized; weak to medium-weak argillic alteration
	1277			12	5	64	19	moderately intense argillic alteration

D.D.H.	Footage	Section NE	Section NW	Ratios in Clay Fraction Kaolinite	Chlorite	Illite	Montmorillonite	Megascopic Character
	1287			-	-	100	-	weak argillic; sericite and K-feldspar-rich
	1407			30	5	27	38	biotite partly chloritized; intense buff argillization
	1493			3	27	43	27	similar to 1287; very weak argillic alteration
68-1	827	14	G	21	2	16	61	biotite completely altered; very strong argillic, with about 15% sericite from adjacent veinlet
69-33	1232	14		14	-	26	60	biotite fresh; feldspars almost fresh; very weak argillic alteration
69-37	1432	14		5	20	48	27	some biotite preserved; feldspars greenish, moderately altered
L-6	1180	14		5	6	51	38	greenish, weakly altered (propylitic?)
68-13	102	15	B	21	-	53	26	very intense argillization, almost chalky
	363			20	4	25	51	very intense argillization; chalky
	932			50	-	11	39	feldspars buff; intense argillization; cohesive
R69-9	266			8	12	70	10	pervasive sericite-bornite mineralization
	570			34	-	9	57	very intense argillization, chalky
69-22	395	15		43	4	9	44	intense argillization
68-20	280	15	D	9	-	47	44	intense argillization, close to chalky
	350			7	18	32	43	biotite fresh, some grains weakly chloritized; very weak argillic alteration
	498			27	-	19	54	very intense argillic, chalky
	1052			7	29	31	33	biotite fresh; feldspar almost fresh
	1204			32	-	10	58	weak argillic alteration
	1309			10	20	32	38	biotite fresh; feldspar almost fresh
68-22	265	15	F	16	-	10	74	very intense argillic, chalky
	565			22	2	10	66	not recorded
	1112			43	5	8	44	very intense argillic, chalky
	1467			31	-	23	46	very intense argillic, chalky
	1482			19	10	51	20	not recorded
68-11	344	15	H	12	-	50	38	porphyritic Bethsaida(?); almost fresh
	600			28	-	55	17	biotite altered completely; weak argillization parallel to sericitic selvage along vein (sericite removed)
	798			69	2	5	24	very intense argillic, chalky
	1037			27	-	32	41	intense argillic, not quite chalky
L-28	487	15	I	12	-	22	66	some sericite veinlets present; remainder is chalky
	804			15	-	1	84	pinkish (K-rich?); 70% greenish, strong alteration
68-32	214	16	A	8	-	3	89	biotite slightly altered; very weak argillic alteration
	401			22	-	21	57	biotite greenish; plagioclase creamy to buff — weak argillic alteration
	860			16	-	71	13	moderately intense argillization; cohesive, not chalky
R69-7	262	16		10	6	28	56	not recorded
	337			13	4	6	77	biotite altered; some plagioclase only greenish, but most are completely replaced
69-28	447	16		37	-	45	18	very intense argillization, chalky
	864			5	19	43	33	plagioclase creamy, weakly argillized
	1593			20	-	64	16	biotite fresh; alteration potassic; argillic very weak

D.D.H.	Footage	Section NE	Section NW	Ratios in Clay Fraction Kaolinite	Chlorite	Illite	Montmorillonite	Megascopic Character
68-6	633	16	C	42	4	7	47	biotite fresh; argillic very weak
	822			16	-	7	77	not recorded
	886			6	23	39	32	not recorded
	1130			33	3	15	49	intense argillic, chalky
	1323			46	3	16	35	intense argillic, chalky
	1473			55	4	9	32	intense argillic, chalky
69-8	175	16		17	-	16	67	biotite partly preserved; moderate argillization
	663			13	-	64	23	biotite altered; feldspar buff-coloured; moderately intense argillic alteration
	967			1	4	90	5	biotite largely chloritized; plagioclase slightly greenish; very weak argillic alteration
68-2	148	16	E	40	6	28	26	biotite completely altered; intense buff-coloured argillic alteration
	255			30	-	28	42	moderate argillization
	440			7	-	88	5	biotite strongly altered; all plagioclase solidly medium greenish
	587			17	-	21	62	pinkish (K-rich?); medium-weak, buff argillic alteration
	898			8	2	25	65	all plagioclase intensely altered buff
	1214			18	4	31	47	chalky area between quartz-sericite-bornite veinlets
	1492			18	-	59	23	biotite unaltered; weak argillization of feldspars
	1848			16	-	63	21	biotite unaltered; potassic zone; argillization very weak or absent
69-47	1448	16		38	-	10	52	almost chalky area between quartz-sericite-bornite veinlets
68-23	235	16	G	20	-	32	48	not recorded
	581			19	2	74	5	quartz-rich with moderately intense argillization
	818			23	-	65	12	not recorded
	1208			7	2	85	6	feldspars mostly greenish, some buff; alteration weak
	1460			23	-	37	40	pinkish (K-rich?); greenish moderately weak argillization
	1490			-	-	61	39	biotite fresh; weak, buff-coloured argillization
L-2	490	16	H	12	-	82	6	some greenish feldspar; moderate to intense argillization
	812			15	4	28	53	very intense argillization, almost chalky
	872			17	-	74	9	not recorded
R69-20	188	17		2	15	47	36	biotite greenish; alteration of feldspars only very weak
	497			21	-	25	54	biotite altered; moderate-intensity argillic alteration
	838			14	4	25	57	moderately intense, buff argillic margin of sericite-sulphide (py + cp) veinlet
	1086			16	-	4	80	biotite altered; moderate-intensity argillic alteration
	1379			11	3	57	29	same as above
68-28	471	17	B	18	-	69	13	not recorded
	812			28	4	40	28	porphyry; medium-intensity argillization along sericite-chalcopyrite veinlet
	1121			31	-	25	44	similar, but in Bethsaida
R69-5	405	17	B	24	4	25	47	abundant quartz-sericite-bornite; very intense agillization

D.D.H.	Footage	Section NE	Section NW	Ratios in Clay Fraction Kaolinite	Chlorite	Illite	Montmorillonite	Megascopic Character
R69-6	225	17	B	43	3	13	41	very intense argillic alteration
	597			32	4	17	47	very intense argillic alteration
	842			3	-	89	8	greenish feldspars, medium-intensity alteration
	1139			8	3	75	14	weak to medium-weak argillization
68-15	199	17	D	12	-	19	69	pinkish; biotite completely altered; weakly argillized
	481			6	5	72	17	biotite completedly altered; medium-weak argillic alteration
	937			6	8	44	42	biotite completely altered; weak argillic alteration
	1320			-	-	75	25	pinkish feldspar moderately argillized along seritic veinlets
69-36	1310	17		5	-	87	8	porphyry, weakly argillized
	1578			11	-	69	20	no sericite veinlets, but is waxy greenish
	1713			9	-	83	8	feldspars only weakly argillized
68-24	473	17	F	22	-	9	69	very intense argillic, chalky
	530			19	-	56	25	strongly sericitized, bordered by moderately intense argillic alteration
	812			34	-	13	53	chalky
	1280			62	-	3	35	chalky
	1415			11	-	68	21	biotite well-preserved; argillization very weak
69-49	283	17		6	13	35	46	biotite well-preserved; very weak argillic alteration
	346			14	20	39	27	almost fresh
	1035			6	13	46	35	biotite altered; abundant sericite; argillization weak
69-45	437	17		6	18	33	43	relatively unaltered; feldspars slightly greenish
	651			9	20	31	40	not recorded
	1042			17	-	53	30	not recorded
L-24	262	17	H	18	2	61	19	moderate to intense argillization
	321			8	8	48	36	argillization moderate
	405			4	17	42	37	biotite well-preserved; weak argillization
	969			6	4	3	87	similar to above
	1322			15	-	72	13	plagiocalse only slightly greenish
	1497			12	27	61	-	potassic zone, non-argillic
L-22	490	17	I	35	-	16	49	moderately weak argillic; some plagioclase greenish
	872			17	-	74	9	plagioclase altered, greenish
	1083			14	-	33	53	some feldspar greenish, some clayey; averages weak argillic alteration
68-9	381	18	E	35	6	19	40	biotite not completely altered; argillic very intense
	858			42	-	16	42	very intense argillization
	1191			5	-	25	70	pinkish (K-rich?); moderate argillization
L-23	327	18	F	7	-	5	88	moderately weak argillic; some plagioclase greenish; estimated 15% sericite-bornite included
	813			19	3	7	71	chalky argillization along quartz-sericite veinlet
	950			11	-	30	59	similar to above, but no veinlet
	1320			55	5	21	19	partly white chalky, averages intense argillic alteration
	1498			49	-	10	41	moderate to medium-weak argillization

		Section		Ratios in Clay Fraction				
D.D.H.	Footage	NE	NW	Kaolinite	Chlorite	Illite	Montmorillonite	Megascopic Character
L-16	478	18	G	25	7	38	30	biotite completely altered; intense argillization
	1130			8	10	46	36	biotite completely altered; scattered plagioclase grains altered white; very weak argillic alteration
	1328			40	12	12	36	scattered plagioclase grains altered white; very weak argillic alteration
L-3	329	18	H	13	11	18	58	plagioclase creamy, weakly argillized
	795			27	-	33	40	unaltered; no evident argillization
	1049			19	-	67	14	biotite completely altered; moderate to intense argillic alteration
R69-17	212	19		10	-	3	87	weak argillic alteration
	840			17	6	12	65	plagioclase buff to greenish, weakly altered; no veins
	1325			39	4	8	49	intense argillization bordering quartz-chalcopyrite veinlet
68-33	265	19	D	14	-	5	81	only some biotite partly altered; plagioclase very weakly altered
	608			29	-	27	44	not recorded
L-21	162	19	F	21	-	41	38	feldspars greenish to creamy, weakly argillic
L-20	598	19	H	23	-	17	60	some feldspar greenish, with moderate to weak argillic for most
L-25	712	19	I	43	7	16	34	no sericite; only part has intense argillization
R69-15	175	20		3	11	37	49	plagioclases buff and greenish; weak to medium-weak argillic alteration
	912			28	9	30	33	not recorded
R69-16	512	west		28	3	5	64	feldspars slightly buff-coloured; weak argillic alteration
	1137			21	4	2	73	biotite weakly altered; moderately intense, buff-colured argillization
R69-18	100	west		17	-	9	74	weak argillic alteration of feldspar
	609			24	-	15	61	not recorded
	1030			10	12	17	61	feldspars pale buff; close to unaltered
R69-19	216	west		9	-	15	76	biotite greenish; weak sericitization along pyrite veinlet; weak argillic alteration
	450			7	-	70	23	biotite completely altered; pyrite altered; pyrite veinlet with only trace sericite; weak argillic alteration
	755			16	-	25	59	feldspars buff, weakly argillic
R69-4	611		C	31	4	23	42	biotite completely altered; very intense argillic alteration
R69-21	1070	west		18	-	39	43	relatively fresh, no visible argillization
69-34	740		E	16	4	15	65	completely altered; intense argillization
69-39	489		F	10	11	18	61	biotite fresh; feldspars slightly greenish; very weak argillic alteration
L-1	566			25	-	21	54	intense argillic alteration
L-14	658		F	35	4	26	35	not recorded
L-17	520	8		24	3	48	25	quartz-nose type; abundant intense argillic alteration
L102	570	*		39	-	4	57	very intense argillic; chalky
	990			26	3	3	68	feldspars buff; weak to medium-weak argillic alteration
L103	277	*		18	-	77	5	not recorded
	342			9	-	15	76	biotite fresh to weakly chloritized; feldspars creamy; weak argillic alteration

*Lornex claims, bottom right of Figure 1.