SPATIAL DENSITY OF SILVER-LEAD-ZINC-GOLD VEIN DEPOSITS IN FOUR MINING CAMPS IN SOUTHEASTERN BRITISH COLUMBIA (82F)

By L. B. Goldsmith and A. J. Sinclair
Department of Geological Sciences, University of British Columbia

INTRODUCTION

Spatial density appears to have several practical applications important in resource assessment, *viz.*:

(1) defining limits to mining camps,

(2) providing a systematic basis for comparing mining camps in terms of average deposit density or average metal concentration, and

(3) recognition of systematic variations in spatial density of mineral occurrences within individual mining camps.

Here we examine the potential uses of spatial density applied to clusters of vein deposits.

Sinclair (1979) suggested that contoured spatial density maps of location data (centroids) of mineral deposits might provide a consistent if empirical means of defining boundaries to certain types of mining camps or mineralized centres. In particular, he recommended that a moving average method be used as a basis for contouring 'number of veins per square kilometre' and that the 0.5 density contour be used to define the empirical limits to the Ainsworth vein camp in southeastern British Columbia. The method appears applicable to two-dimensional problems and, of course, suffers the limitation that the 0.5 spatial density contour does not exist as a real entity. Exact locations of some deposits are not always readily attainable from available literature but this problem is restricted largely to small deposits actively explored and/or exploited during the nineteenth century. Uncertain locations in general do not appear to represent problems in contouring spatial density because the uncertainty is generally small relative to the scale of a mining camp.

This study extends the early work by Sinclair (1979) to include four vein camps, Ainsworth, Slocan, Slocan City, and Lardeau (Trout Lake), in southeastern British Columbia (Fig. 87) in an attempt to generalize the approach in relation to vein camps. The data base for three of the mining camps is an updated version of a computer-based producer file established by Orr and Sinclair (1971). Data for the Lardeau (Trout Lake) camp are an edited version of a file established originally by P. B. Read (Read, 1976; Goldsmith, *et al.*, in preparation). The former file (Slocan, Slocan City, and Ainsworth) contains information only for

TABLE 1

AREA MEASUREMENT STATISTICS, AINSWORTH MINING CAMP

Window Size	0.5 DEPOSIT/CELL					1.0 DEPOSIT/CELL				
	Number of Deposits	Miles^2 (4 measurements)		Av Miles^2	Av km^2	Number of Deposits	Miles^2 (4 measurements)		Av Miles^2	Av km^2
25% OVERLAP										
4km x 4km	81	77.70	78.00	77.86	201.67	81	63.66	63.84	63.83	165.31
		77.88	77.88				63.96	63.84		
2km x 2km	80	63.54	36.36	36.35	94.13	80	28.26	27.96	28.08	72.73
		36.18	36.30				28.08	28.02		
1km x 1km	72	13.68	13.00	13.74	35.58	71	10.80	10.80	10.80	27.97
		13.68	13.80				10.80	10.80		
50% OVERLAP	0.5 DEPOSIT/CELL					1.0 DEPOSIT/CELL				
4km x 4km	81	68.10	68.28	68.15	176.50	81	56.22	56.22	56.18	145.49
		67.98	68.22				56.28	55.98		
2km x 2km	75	30.36	30.24	30.30	78.48	75	23.28	23.22	23.24	60.18
		30.24	30.36				23.40	23.04		
1km x 1km	72	13.20	13.26	13.19	34.15	71	10.68	10.74	10.76	27.86
		13.14	13.14				10.62	10.98		
75% OVERLAP	0.5 DEPOSIT/CELL					1.0 DEPOSIT/CELL				
4km x 4km	81	82.20	81.78	81.95	212.24	80	66.60	67.32	67.10	173.78
		81.84	81.96				67.26	67.20		
2km x 2km	74	24.60	24.54	24.59	63.68	72	19.56	19.08	19.31	50.00
		24.60	24.60				19.56	19.08		
1km x 1km	71	11.70	11.76	11.75	30.42	71	9.48	9.42	9.44	24.44
		11.70	11.82				9.48	9.36		

TABLE 2

AREA MEASUREMENT STATISTICS, SLOCAN MINING CAMP

Window Size	0.5 DEPOSIT/CELL					1.0 DEPOSIT/CELL				
	Number of Deposits	Miles^2 (4 measurements)		Av Miles^2	Av km^2	Number of Deposits	Miles^2 (4 measurements)		Av Miles^2	Av km^2
25% OVERLAP										
4km x 4km	176	160.50	160.98	160.53	415.77	176	140.46	140.04	140.36	363.51
		160.32	160.32				140.40	140.52		
2km x 2km	176	108.00	107.46	107.67	278.86	169	73.14	73.20	73.11	189.35
		107.64	107.58				73.08	73.02		
1km x 1km	121	28.65	28.47	28.58	74.02	116	20.37	20.43	20.40	52.84
		28.53	28.65				20.37	20.43		
50% OVERLAP	0.5 DEPOSIT/CELL					1.0 DEPOSIT/CELL				
4km x 4km	176	157.08	156.78	156.59	405.56	175	137.40	137.76	137.75	356.76
		156.24	156.24				137.40	138.42		
2km x 2km	176	102.12	102.36	102.03	264.26	172	72.18	72.06	72.11	186.75
		102.18	101.46				72.12	72.06		
1km x 1km	124	30.60	30.42	30.51	79.02	121	19.50	19.50	19.46	50.39
		30.60	30.42				19.50	19.32		
75% OVERLAP	0.5 DEPOSIT/CELL					1.0 DEPOSIT/CELL				
4km x 4km	176	158.10	158.16	158.02	409.28	175	139.26	138.54	138.75	359.36
		157.74	158.10				139.02	138.18		
2km x 2km	171	90.42	90.00	90.00	233.1	165	54.78	54.66	54.74	141.76
		89.94	89.64				54.66	54.89		
1km x 1km	101	20.10	20.10	20.19	52.79	99	15.18	15.48	15.33	39.77
		20.10	20.46				15.18	15.48		

deposits with a recorded production of at least one short ton of ore. The file for Trout Lake camp contains locations of all publicly recorded deposits irrespective of whether or not they have produced ore.

METHODOLOGY

Consider the problem of depicting spatial density of mineral occurrences to be two-dimensional. An interpolation technique is required to provide spatial density estimates on a regular grid superimposed upon a district containing numerous irregularly located occurrences and/or deposits. The spatial density values for each cell of the grid then can be contoured by simple linear interpolation, either by hand or machine. One procedure used here is to move a (square) window over the field of interest in a regular, periodic fashion, count the number of deposits in the window at each position, and assign each count to the centre of the square for which the count was obtained.

Three parameters can be varied in this procedure: (1) the window shape, (2) the window area, and (3) the proportion of overlap (if any) of adjoining counting cells.

The level of variability in spatial density data that results from these sources must be quantified if spatial density is to be used in a meaningful fashion.

MEASUREMENT OF SPATIAL DENSITY VARIABILITY

We have attempted to evaluate several sources of variability in obtaining spatial density estimates for vein mining camps. In particular, we have examined the effects of:

(1) varying size of counting window, that is, 1 by 1 kilometre, 2 by 2 kilometres, and 4 by 4 kilometres,

(2) defining camp area by two different spatial density contours, that is, 0.5 deposit per cell and 1.0 deposit per cell, and

(3) testing actual reproducibility of camp area estimates by planimeter.

Data from our tests for three mining camps are summarized in Tables 1, 2, and 3 from which several conclusions seem evident. The most obvious feature of the tabulated data is that planimetric measurements in camp areas vary much less than 1 per cent of the area; these errors are negligible.

Estimated camp areas increase dramatically as the size of the counting cell increases, regardless of extent of overlap. This results largely from an ever-increasing zone of no deposits that is included within the camp boundaries as the cell size increases. This effect can be minimized

TABLE 3

AREA MEASUREMENT STATISTICS, SLOCAN CITY MINING CAMP

Window Size	0.5 DEPOSIT/CELL					1.0 DEPOSIT/CELL				
	Number of Deposits	Miles^2 (4 measurements)		Av Miles^2	Av km^2	Number of Deposits	Miles^2 (4 measurements)		Av Miles^2	Av km^2
25% OVERLAP										
4km x 4km	60	111.90	111.30	111.60	289.04	58	82.20	81.95	82.165	212.81
		111.30	111.90				82.32	82.20		
2km x 2km	57	46.62	46.68	45.68	120.90	55	39.00	39.18	39.05	101.13
		46.74	46.68				39.00	39.00		
1km x 1km	57	19.50	19.56	19.55	50.62	37	6.84	6.84	6.84	17.72
		19.50	19.62				6.84	6.84		
50% OVERLAP										
		0.5 DEPOSIT/CELL				1.0 DEPOSIT/CELL				
4km x 4km	59	89.52	89.52	89.48	231.74	59	77.94	77.70	77.78	201.44
		88.45	89.40				77.88	77.58		
2km x 2km	57	44.44	45.18	45.07	116.74	55	37.56	37.20	37.43	96.93
		45.06	45.12				37.50	37.44		
1km x 1km	57	20.34	20.16	20.28	52.53	50	10.17	10.18	10.17	27.38
		20.16	20.46				10.17	10.16		
75% OVERLAP										
		0.5 DEPOSIT/CELL				1.0 DEPOSIT/CELL				
4km x 4km	59	61.74	62.10	62.07	160.76	57	50.94	51.00	51.02	132.13
		62.10	62.34				51.18	50.94		
2km x 2km	57	42.78	43.00	42.87	111.02	55	35.50	34.32	34.43	89.16
		42.90	42.78				34.38	34.50		
1km x 1km	57	17.16	17.40	17.28	44.75	43	7.26	7.26	7.26	18.90
		17.16	17.40				7.26	7.26		

by using a 1.0 rather than a 0.5 deposit-per-cell contour. Nevertheless, window size is a large source of variability in mining camp areas by the method we outline. To counteract this problem we define a mining camp somewhat subjectively on the basis of the smallest window size that results in a high proportion (more than 90 per cent) of known occurrences being contained within a reference contour (for example, 0.5 deposit per cell).

Extent of overlap of adjoining counting windows does not appear to be an important source of variability for smallest cell sizes that produce a cohesive rather than a disaggregated outline. For example, for Slocan camp the 2 by 2-kilometre window produces areas of 121, 117, and 111 square kilometres for overlaps of 25, 50, and 75 per cent respectively.

Our subjective evaluation of these data and the many maps that we viewed (one for each line of information in each table) have led us to conclude that areas of mining camps can be defined usefully and reproducibly, if empirically and subjectively, as follows:

(1) use a 0.5 deposit per cell as the margin contour to define the outer extremity of a mining camp,

(2) use 50 per cent overlap of square counting cells, and

(3) cell size must be selected by trial and error to be that smallest size which retains the large majority of deposits of a subjectively recognized mining camp within the marginal contour.

EXAMPLES OF SPATIAL DENSITY MAPS

Two extreme cases of the application of spatial density procedures applied to mineral deposit location data are: to define boundaries of clusters of vein deposits, and to examine patterns of spatial density contours of mineral deposits within a mining camp.

OUTLINING MINING CAMPS

In a large region containing several mining camps we might wish to develop a reproducible procedure by which we can define boundaries to mining camps and determine an estimate of their individual geographic limits. Such information would be useful for purposes of quantifying the distribution of mineral occurrences in a camp in terms of average spatial density. Similarly the amount of various metals concentrated into veins per unit area in a mining camp could be examined and displayed.

The foregoing objectives require that we know the total number of deposits in a camp and the geographic limits of the camp. Of course a newly found deposit in an old camp or one outside the existing camp limits will bias the parameter we are estimating. As long as we recognize these sources of errors, they need not represent serious problems, and, in fact, are likely minimal in many old, thoroughly explored camps.

Figure 88 is a moving average spatial density contour map for an area including the northern end of the Nelson batholith. A window of 2 by 2 kilometres was used with 50 per cent overlap in the two principal grid directions. Note that in such a case a single deposit will occur in four cells whose centres are in a square with sides half the cell dimension. The 0.5 deposit per 4-square-kilometre contour around an isolated deposit is therefore the same size as the basic counting cell. In a few cases where deposit locations are exactly on the boundary of a counting cell, isolated deposits are surrounded by a rectangular contour with area less than the basic cell area. After some experimentation the artificial contour 0.5 deposit per 4-square-kilometres was selected arbitrarily as setting the outer limit of vein concentrations defining mining camps in the area.

Once an acceptable limit is defined for a mining camp we can calculate average spatial density and average known metal endowment. Our present study is concerned primarily with spatial density of mineral deposits, although the methodology can be extended easily to the presentation of metal endowment using known metal production. Average spatial densities are summarized in Table 4 for Slocan, Slocan City, and Ainsworth mining camps. It is important to realize that the figures quoted in Table 4 are derived only from those deposits lying within the 0.5 deposit per 4-square-kilometre contour.

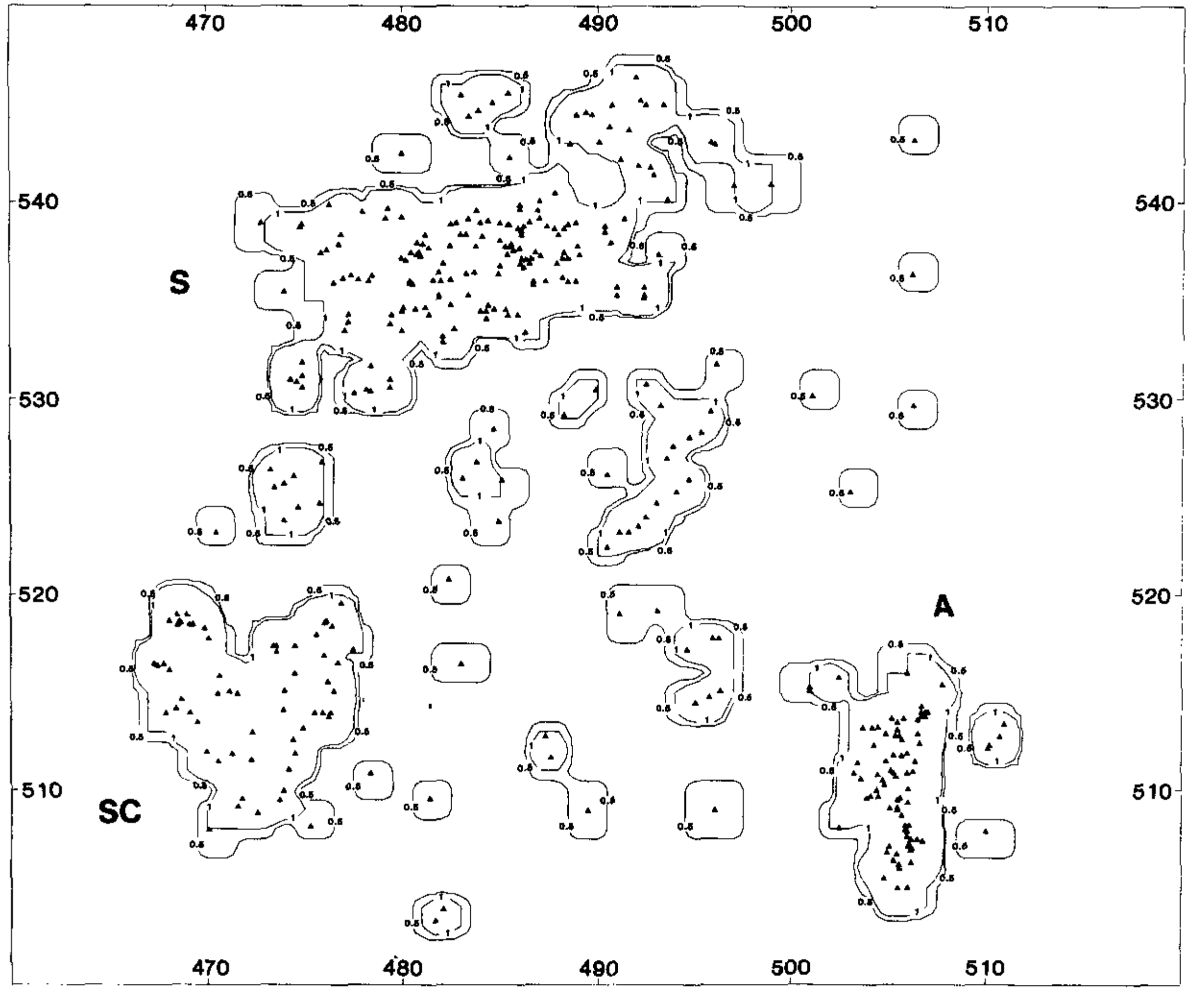

Figure 88. Machine-contoured spatial density contours for vein deposits (number of veins per 4 square kilometres) in and near the northern end of the Nelson batholith. High spatial densities centre on Ainsworth (A), Slocan (S), and Slocan City (SC) mining camps. Contours obtained for a square counting window with 50 per cent overlap of adjacent cells. Individual vein deposits are shown as closed triangles. Marginal numbers are UTM coordinates in kilometres.

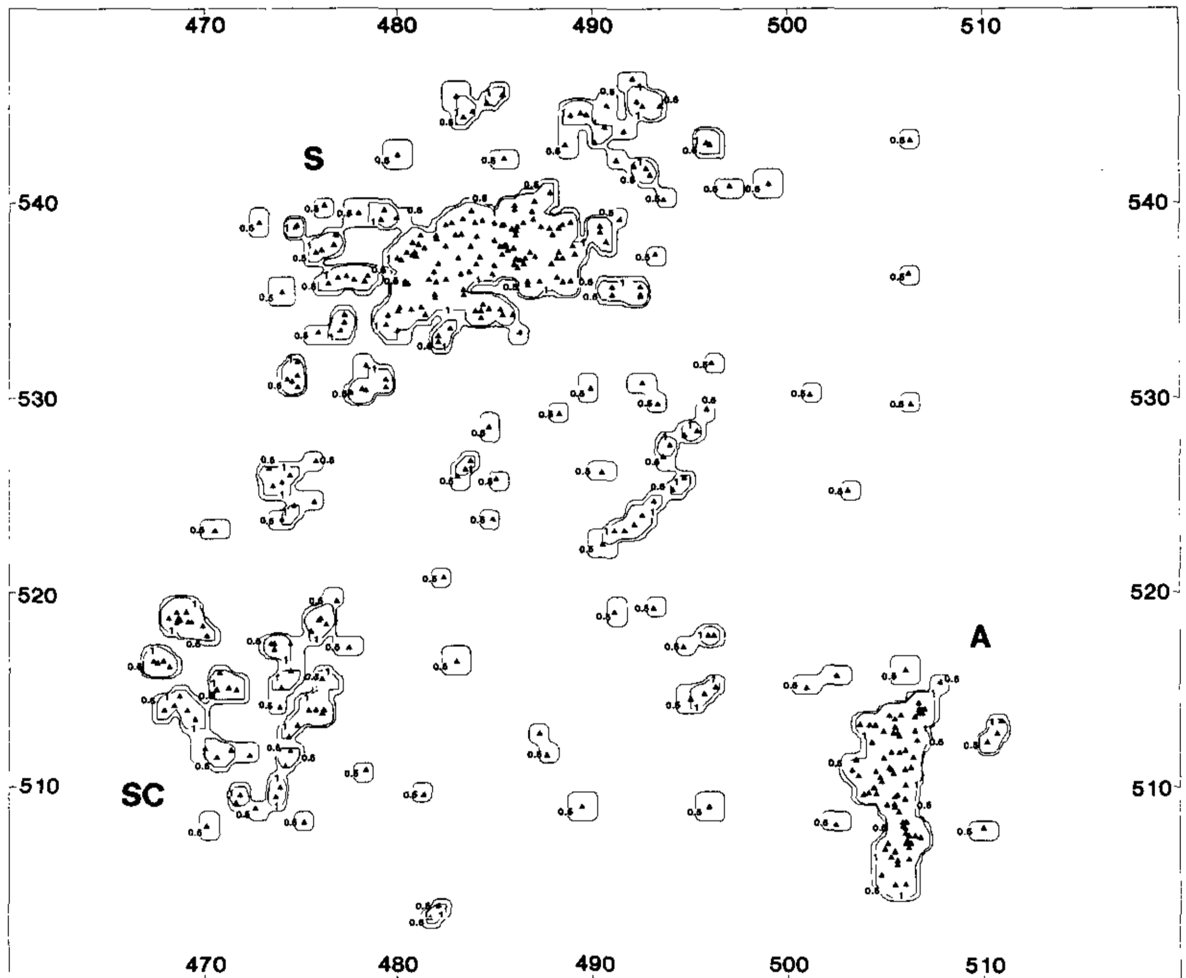

Figure 89. Machine-contoured spatial density contours for vein deposits (number of veins per 1 square kilometre) in and near the northern end of the Nelson batholith. Clusters of high spatial densities centre on Ainsworth (A), Slocan (S), and Slocan City (SC) mining camps. Contours obtained for a square counting window with 50 per cent overlap of adjacent cells. Individual vein deposits are shown as closed triangles. Marginal numbers are UTM coordinates in kilometres.

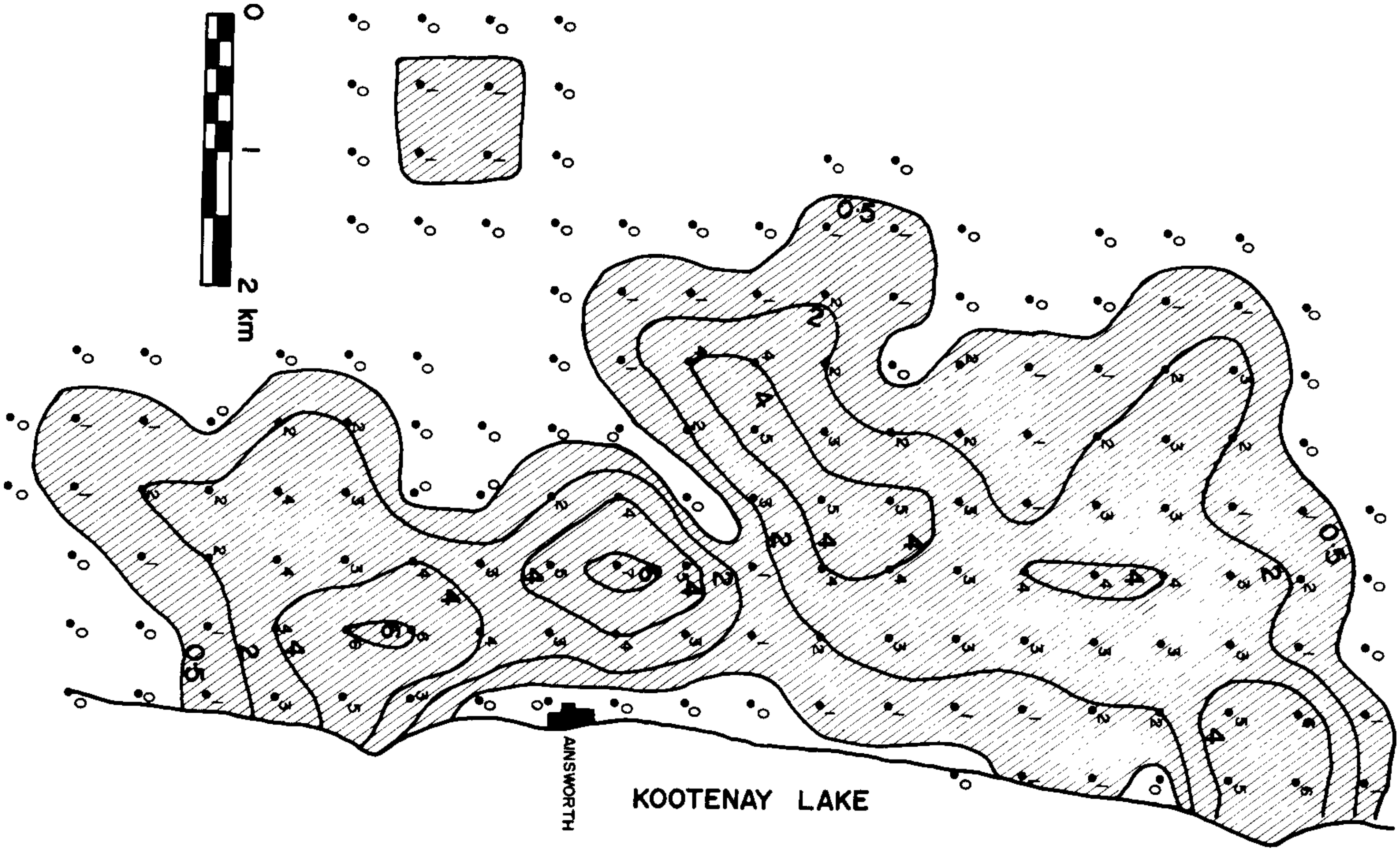

Figure 90. Hand-contoured spatial density map, Ainsworth camp. Counting cell used is 1 by 1 kilometre with 50 per cent overlap. Contours are number of past producers per 1 square kilometre. Modified from Sinclair (1979).

The data of Table 4 are based on the same counting criteria for the entire area. Such a procedure is probably desirable for reasons or practicability. However, different counting criteria may be optimal for different camps. Our experience has shown that counting cell size is particularly critical (*see* Tables 1, 2, and 3) to camp area estimates. A subjective evaluation of the Ainsworth camp, a tightly clustered group of veins in a relatively small area, suggests that a 1 by 1-kilometre counting cell is more appropriate than the 2 by 2-kilometre counting cell used for Figure 88. Spatial contours using a 1 by 1-kilometre counting cell for the equivalent area of Figure 88 are shown on Figure 89. This latter plot also demonstrates how disaggregated a camp appears if too small a counting cell is used as in the case of Slocan and Slocan City camps.

TABLE 4. AVERAGE SPATIAL DENSITIES FOR SOME SOUTHEASTERN BRITISH COLUMBIA MINING CAMPS (BASED ON 2 x 2 km COUNTING CELLS WITH 50 PER CENT OVERLAP)

Camp	Area (km^2)	No. of Deposits	Deposits per km^2
Ainsworth	78.5	71	1.0
Slocan	264.3	172	0.7
Slocan City	116.7	59	0.5

SYSTEMATIC VARIATIONS IN SPATIAL DENSITIES

Spatial density maps of mining camps also are important as a means of examining systematic patterns to deposit clustering within individual mining camps. For such a purpose we are faced with the same problem as in defining camp boundaries, that of selecting an appropriate contouring cell (window) size. If a cell is too small, many irregularities in the contours and 'holes' may obscure general trends. A practical means of selecting an appropriate contouring approach for examining variations in spatial density in a camp is to use a square cell with sides approximately the inverse of the deposit densities of Table 4. Thus, Ainsworth camp can be examined with a 1 by 1-kilometre counting window, Slocan City camp with a 2 by 2-kilometre counting window, and Slocan City midway between the two. Four separate mining camps are described in detail.

AINSWORTH CAMP

Spatial densities for Ainsworth camp (Sinclair, 1979) are shown on Figure 90. Here it is apparent that the camp is well defined as a cohesive unit with only a single nearby outlier, yet local concentrations are apparent within the camp. It is apparent that a single contouring grid will serve both purposes, that is, define general camp limits and average spatial densities, as well as showing local structure to the spatial densities. Average spatial densities calculated in this case for a square contouring grid cell of 1 by 1 kilometre provide an average density of 0.48 deposits per-square-kilometre. This compares with an average density of 1.05 deposits per-square-kilometre grid determined in an earlier section, and provides an indication of the variability of mean spatial density estimates relative to size of contouring grid. As expected, the smaller the grid, the smaller the 'camp area' and, if number of deposits remains constant, the higher will be the average spatial density.

In this particular case it appears that choosing the smallest contouring cell that provides a cohesive camp outline is the optimal empirical approach. Such a procedure, although subjective, provides potential for reproducibility by different operators.

It is interesting to speculate about the importance of the five highs shown in the detailed spatial density contours for Ainsworth camp. A plot of the five largest deposits in the camp shows that all are within the four southernmost spatial density highs. Even without further information one might speculate that the northernmost high, that consists only of small deposits, is an area that warrants investigation. The writers' interpretation for the camp is that 'bedded' veins represent syngenetic deposition in Cambrian time and that some of these bodies were partly mobilized during and/or after emplacement of the Nelson batholith to form numerous small 'transverse' veins. This model is consistent with observed distribution patterns of small (mostly transverse) deposits, relative to large (mostly bedded) deposits. It provides some geological basis for conducting further exploration in the northern spatial density high.

SLOCAN CITY CAMP

Visual examination of the distribution of deposits in Slocan City camp shows that the distribution is asymmetric with a small area of relatively high density and a much larger area mainly to the east, of much lower density (Fig. 88). A grid serving for one part may not serve for the other. However, a grid size controlled by the less dense area will serve, generally at least, for the denser areas. The contoured results of Figure 88 for Slocan City camp based on a 2 by 2-kilometre contouring grid cell cannot be improved significantly by the use of a smaller cell size. High spatial densities form a horseshoe-shaped zone with low values both in the core and surrounding the 'horseshoe.' Considering the 'structural' nature of the camp and known zonal patterns, the 'horseshoe' probably reflects a fundamental attribute of the camp. For example, near-circular fracture patterns on this scale (approximately 4 kilometres diameter) might be produced during emplacement of an underlying hypabyssal intrusion. If such is the case, the 'opening' in the horseshoe may represent an area of exploration interest because a circular pattern could be expected.

SLOCAN CAMP

In Slocan camp it is advantageous to examine spatial densities at two different scales of contouring grids. A large contouring grid cell defines a simple density high along a north-northwest direction and allows for clear definition of the camp. However, the camp contains a very large number of deposits and the possibility of determining some detailed structure to spatial densities exists. An example shown on Figure 91 is based on a counting window cell size of 1 by 1 kilometre and shows clearly separate groups or clusters of past producers. As in other examples, a considerable subjectivity exists in attempting to interpret the spatial density patterns.

TROUT LAKE CAMP

Trout Lake camp represents somewhat different data than do the other three camps considered to this point. Only a small portion of the 180 deposits reported in the camp have produced. Instead of contouring spatial densities of past producers, we have contoured spatial densities of all recorded veins and compared the positions of 45 known producers with the resulting pattern. The results, based on a contouring grid cell of 2 by 2 kilometres, are shown on Figure 92. Clearly, several separate major clusters of deposits are evident. Within each of these clusters are well-defined highs. Plotted positions of producers lie within the high contours. As with the Ainsworth camp, an explanation is not obvious, particularly since here we do not appear to have the possibility of two separate genetic models. Furthermore, there is the possibility that intense exploration in the immediate vicinity of a large deposit will give rise to more small discoveries. In other words, the association of past producers with areas of high spatial densities is self-generating. This latter explanation may be true in part, but it does not appear to provide a total explanation in old camps that have been thoroughly explored over a period of 70 or 80 years.

Spatial density contours clearly define three separate clusters of camps within the Trout Lake area. These separate clusters represent a quantification of previously recognized mineral belts.

Because of the very narrow widths of the mineral belts relative to their lengths, it is not possible to see any structure in the spatial density contours apart from the association of past producers with spatial density highs.

DISCUSSION

Spatial densities of mineral deposits offer problems relating to basic data and interpretation. One problem is illustrated by a major lode along which several different deposits are known -- at what point does an ore shoot along a lode become a separate entity for contouring purposes?

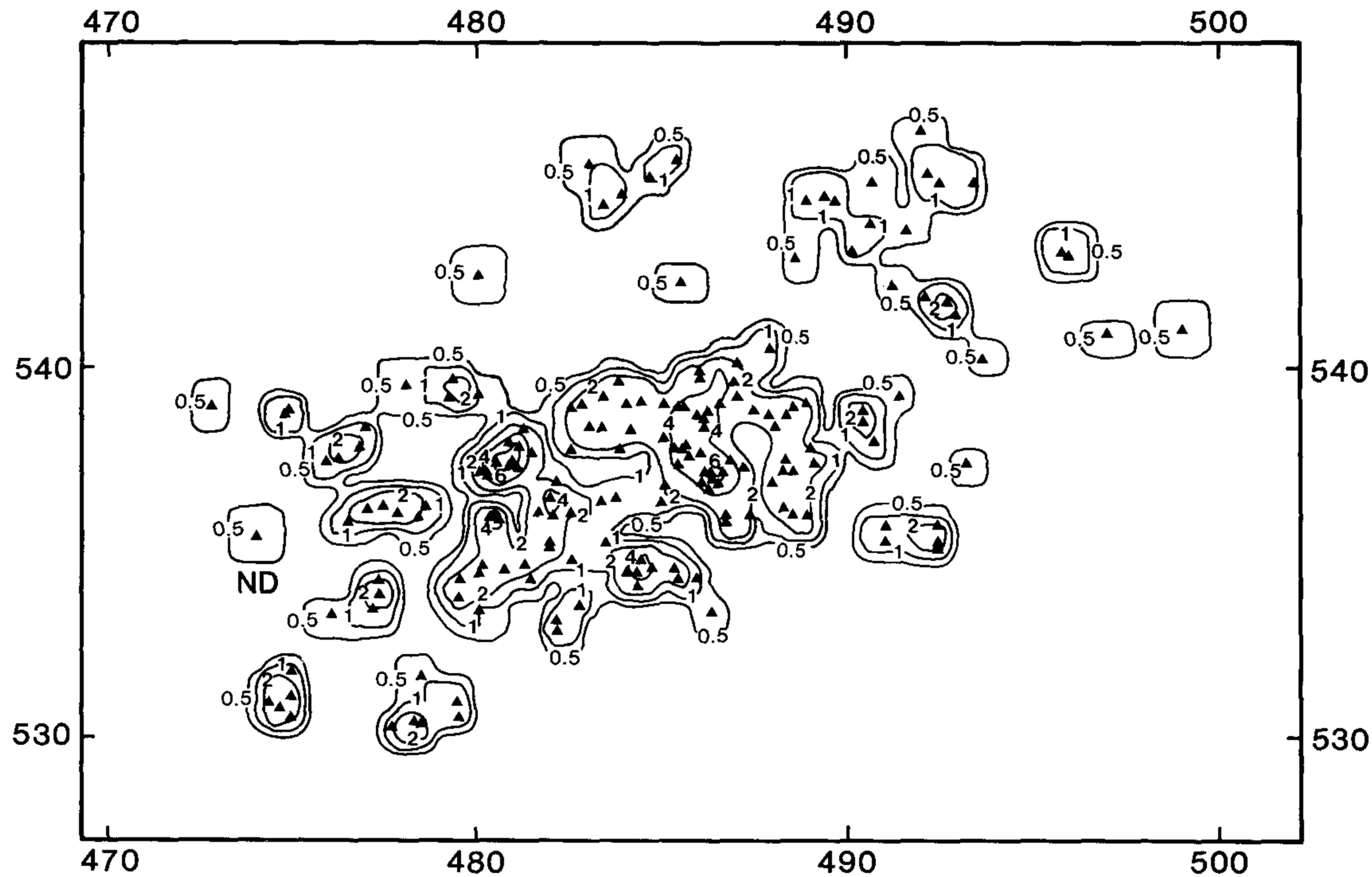

Figure 91. Redraughted machine-contoured map of spatial densities of mineral occurrences in Slocan mining camp based on 1 square kilometre counting cell with 50 per cent overlap of adjacent cells. Filled triangles are deposit locations; marginal figures are UTM coordinates in kilometres. Contour values are number of deposits per square kilometre. ND on the western part of the diagram is centred on New Denver.

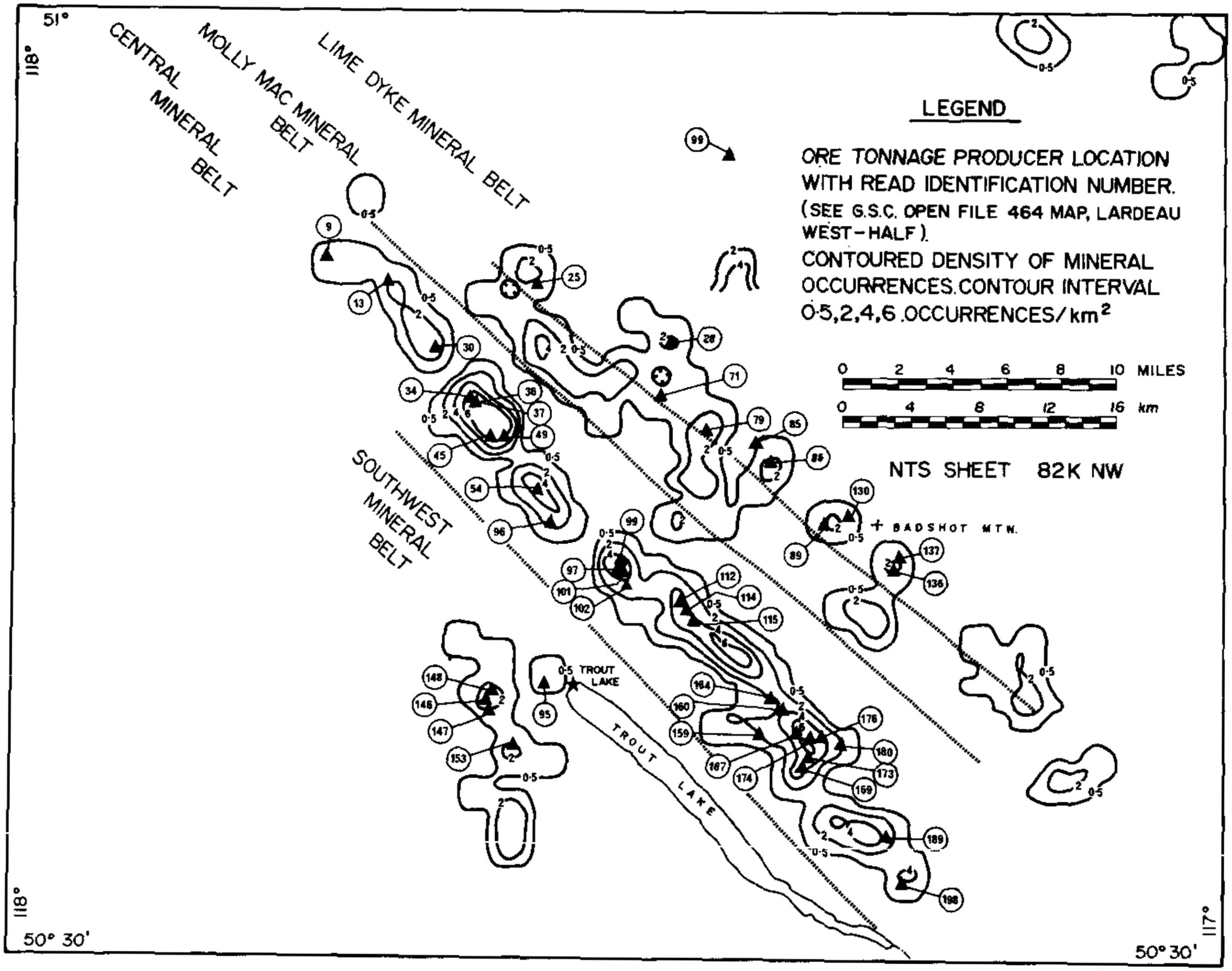

Figure 92. Manually produced spatial density contours (number of occurrences per 2 by 2-kilometre cell) for vein deposits in the Trout Lake area. Contours obtained with square counting window and 50 per cent cell overlap. Filled triangles are known vein occurrences in the camp. Numbers in circles refer to past producers for which geological and production information is tabulated by Read (1976).

We have ignored this question by accepting individual mining properties as individual deposits. Conversely, two separate veins from a single property may have their production data combined in which case spatial density contours will produce an overly smoothed pattern.

Newly found deposits affect spatial density contours derived from a data base of known deposits. Of course, spatial densities become underestimates if new deposits are found within the borders of a camp. It is possible that new deposits will be found outside the margins of a camp and add to the area of a camp. In this latter case it is unlikely that average spatial densities will change greatly. Overall, spatial densities are biased on the low side of reality. In long established camps that have undergone exploration for many decades, such as are studied here, this bias is likely to be slight in terms of mineral occurrences but could be substantial, at least locally, to metal distribution contours.

Average metal endowments of several mining camps can be compared. For example, average silver endowment in Slocan City camp, based on known production and the camp limits shown on Figure 88, is about 1 325 000 grams silver per square kilometre. The comparable figure for Ainsworth camp, based on the camp limits of Figure 90, is about 2 457 000 grams per square kilometre.

The use of metal spatial density contours appears a practical means of generalizing resource (metal) productivity in mining camps where production and/or resources are not concentrated in a few deposits. Even where many deposits exist, metal productivity can change dramatically over short distances and logarithmic values for contours are desirable. Most deposits were found over a few years in the early history of the camps considered here. Modern exploration concepts and methods applied to these camps have not yet resulted in a marked improvement (increase) in the number of finds, as might be expected if existing spatial densities are highly biased. This is an interesting conclusion to emerge from an evaluation of spatial density maps, and some indication of the importance of rates of discovery becomes apparent, as does the need to evaluate recent or new discoveries in the light of their positions relative to known spatial densities.

CONCLUSIONS

(1) Average spatial densities of deposit location and metal endowment data, although biased, represent useful means of comparing vein camps.

(2) In some cases spatial densities have internal patterns that may provide some insight to specific small areas warranting additional exploration or in providing an additional framework for conceptual models of mineralization.

(3) In many cases the large, valuable deposits in a vein camp occur in clusters with many small deposits. It appears that these associations may arise through complicated genetic histories, such as early formed deposits being mobilized to produce younger deposits. In other cases the clustering of large deposits with many smaller ones may be purely a question of clusters of structures, all mineralized at more or less the same time.

(4) The suggestion that spatial densities are highly biased seems unreasonable in the camps examined here. The implication of this statement is that relatively few veins remain to be found within the camps themselves.

ACKNOWLEDGMENTS

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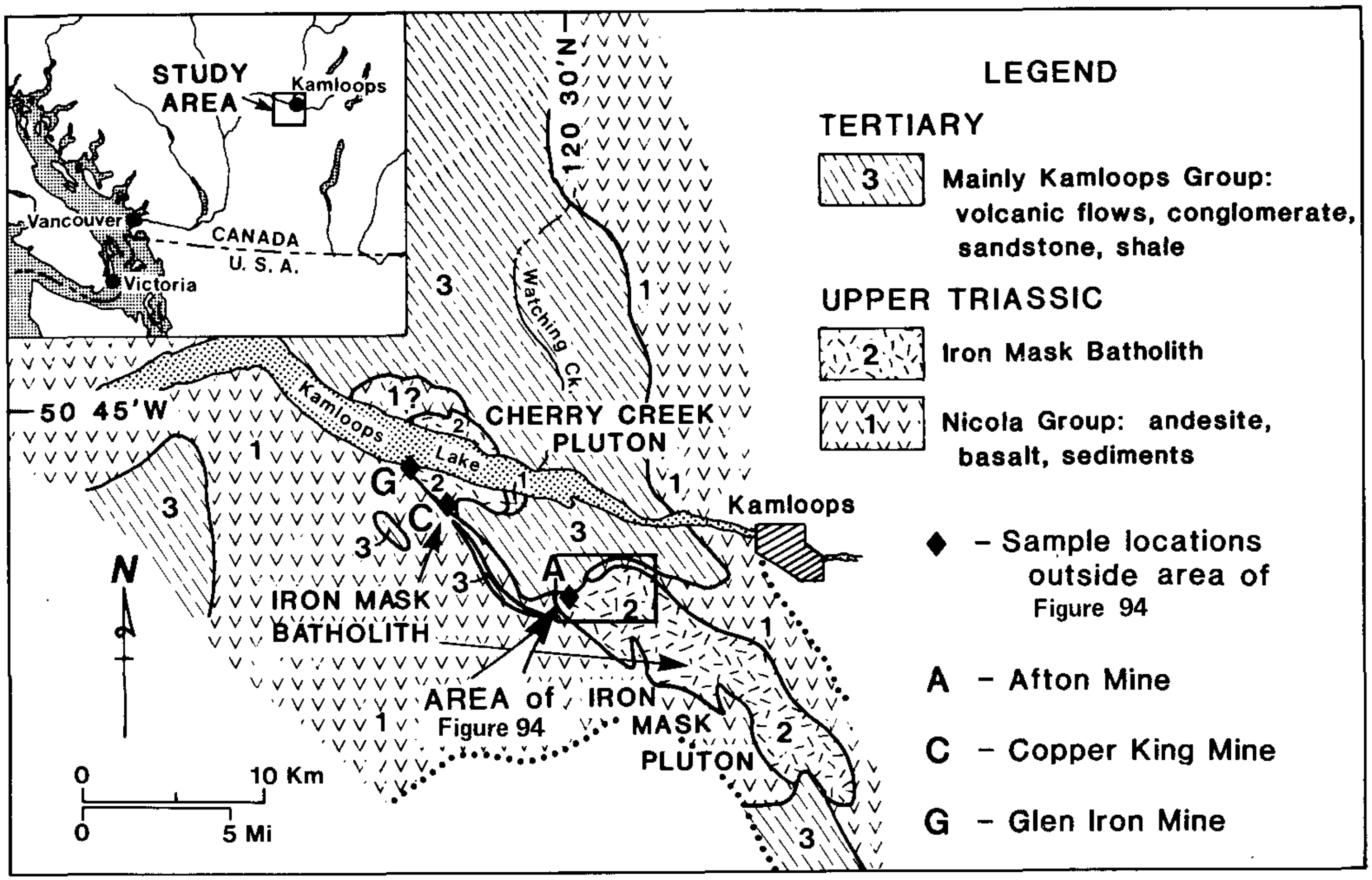

Figure 93. General location of and regional geology around the Iron Mask batholith (after Cockfield, 1948; Northcote, 1977a; Ewing, 1979).