A QUANTITATIVE APPROACH TO REGIONAL METALLOGENY IN THE VANCOUVER–HOPE MAP–AREAS (92 G, H, I, J)

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INTRODUCTION

Regional metallogeny deals with broad aspects of the genesis of mineral deposits, particularly their distribution in time and space. Here we are concerned with such a study of a 28 700-square-kilometre area in the southwestern corner of British Columbia, including much of the Vancouver and Hope map-areas (NTS 92 G and H) and small parts of the adjoining map-areas to the north (NTS 92 J and I)

This region is of interest because it contains two large past producers and one present producer; as well, many mineral occurrences are known in the area. Geologically the area is complex and is centred on the intersection of three major tectonic belts (Fig. 58). The Coast Crystalline Belt forms the northwestern part of the area, the Intermontane Belt underlies the eastern part, and the Cascade Belt forms the south-central part. For purposes of the following discussion the Intermontane Belt has been further subdivided from *east to west into the Eagle Plutonic Belt, Hozameen Trough, Ladner Basin, and Spuzzum Plutonic Belt.* Tectonic history of the area is summarized briefly in Table 1 (for tables and figures, *see* pages 169-177).

METHOD OF DATA ACCUMULATION

Mineral deposit data were compiled from the literature for 258 metal occurrences. Some deposits were examined in the field, and, in many cases, information was discussed with exploration personnel who had greater familiarity with some areas than the authors. Eventually, verified information was coded in the MINDEP system and entered into a computer file for storage and retrieved in a variety of forms. A simple example is illustrated in Table 2 which summarizes general information for the major deposits in the area.

A classification of deposit types was required for our study and, because of limitations of published descriptions, we adopted the following rudimentary categories as a basis for data collection and subsequent *data analysis.*

(1) Magmatic – nickel-copper sulphides, for example, Giant Mascot.
(2) Porphyry-type – large, low-grade accumulations of copper and/or molybdenum sulphides commonly in or near felsic to intermediate intrusions, for example, Canam.
(3) Skarn – calc-silicate and ore-mineral assemblages produced by replacement at contacts of intrusions.
(4) Volcanogenic – tabular sheets of syn-sediment sulphides within volcanic sequences, for example, Britannia.
(5) Vein – tabular discordant zones of epigenetic, hydrothermal origin, for example, Aurum.
(6) Shear – coatings of minerals on shear surfaces.
(7) Disseminated – sparsely distributed grains or aggregates of ore minerals.
(8) Massive – pods of massive ore minerals of uncertain origin.

The detailed structure of the MINDEP file is included elsewhere (Wynne-Edwards and Sinclair, 1978). In general, for each deposit we recorded information on commodities, location, physiography, classification, tectonic setting, geological attributes of host rocks, geological features of the deposits themselves, grade, and production information. Of course, information on all these topics was not available for every deposit. These data formed the basis for a variety of retrievals designed to aid in a metallogenic interpretation for the area.

DATA ANALYSIS

It is not possible to reproduce all the tabulations of data derived from the computer file of mineral deposits in the Vancouver-Hope area, these are shown by Ditson (1978). Some of the more important results are summarized diagrammatically on Figures 59 to 63 and most of what follows can be derived from the numerical information in Table 3. Of the 258 deposits considered in this study, deposit classification could be determined for only 228. For reasons emphasized by Sinclair, *et al.* (1978) we do not distinguish deposits and occurrences on the basis of size except to indicate in some of the diagrams where past producers plot relative to the total number of known occurrences.

Figure 59 shows the number of cases in which various commodities were recognized in each deposit class. If we arbitrarily consider that only counts greater than 10 are significant, the list of commodity associations as a function of deposit type is clearly demonstrated (Table 4). Magmatic and porphyry-type categories contain traditional commodities. Vein, disseminated, volcanogenic, and shear categories have much in common. Gold is particularly prominent in vein deposits, but the polymetallic character of these classes is evident. Massive deposits are omitted because of lack of data. Skarn deposits represent a mixture of several mineral associations.

Spatial density of commodity occurrences can be determined from the data of Table 3 and, compared with figures for the Coast Crystalline Complex as a whole, spatial densities in the study area range from 1 to 13 times average values for the Coast Crystalline Belt. The area is particularly enriched in zinc, nickel, arsenic, lead, silver, and cobalt relative to the Coast Crystalline Belt. It is of interest to note that gold is economically important and is present in many deposits but it generally has other commodities associated with it and does not appear as the commodity of principal importance in many cases. In summary, the area has above-average spatial densities of many principal commodities and gold is a common associate in these occurrences. Higher than average values occur because much of the area is underlain by transitional or contact zones at the margins of crystalline complexes (Sinclair, *et al.*, 1978).

Relative spatial densities of occurrences of some of the more important commodities are shown on Figure 60. It is evident that large differences exist from one tectonic environment to another. Tectonic units consisting largely of plutonic intrusive rocks have few mineral occurrences. The Hozameen Trough, Ladner Basin, and pendants within the Coast Crystalline Belt stand out as having much higher relative densities of mineral occurrences. These three tectonic subdivisions are dominated by sedimentary and/or volcanic rocks close to large complexes of intrusive rocks. The probability of success in finding new mineral occurrences is relatively high in such an environment.

Mineral deposit types are also unevenly distributed in the various tectonic environments. Pendants in the Coast Crystalline Belt have greatest diversity of deposit types with high proportions of skarn, volcanogenic, shear, and disseminated deposits; the Spuzzum Plutonic Belt intrusions contain most of the magmatic sulphide deposits; the Cascade Belt has relatively more abundant skarn occurrences; the Hozameen Trough encompasses higher than average numbers of magmatic, skarn, disseminated, and massive occurrences; and the Ladner Basin contains a large proportion of vein and shear occurrences.

In a general way host rock exerts considerable influence on ore-rock associations (Stanton, 1972). In our study of spatial densities, rock type can be considered in several ways. For example, the distributions of deposit types of commodities can be examined as a function of host rock type (Figs. 61, 62, and 63). Veins are abundant in all three broad rock categories considered here (intrusive, sedimentary, and volcanic). Porphyry-type and magmatic deposits are almost exclusively in intrusive rocks, skarn deposits are mainly in sedimentary rocks, and other categories (disseminated, shear, massive, volcanogenic) are usually in volcanic units. The distinction between volcanic and sedimentary is important; in our usage 'volcanic' includes volcaniclastic rocks. As is stated previously, some deposit types differ dramatically among rock types. In view of the relatively large proportion of the area underlain by intrusive rocks and the correspondingly small proportion of the area underlain by intrusive rocks and the correspondingly small proportion underlain by volcanic rocks, the number of volcanic-hosted deposits is striking. Of the 245 deposits for which host rock type is known, 85 are in volcanic rocks, 88 are in intrusive rocks, and 72 are in sedimentary rocks.

Principal commodities are plotted against rock type on Figures 61, 62, and 63. Copper is common in *deposits in all rock types and, as shown earlier, is a common constituent of many deposit types. Gold and* silver are less abundant but similarly both are also fairly evenly distributed among main rock categories.

In contrast, zinc and lead-bearing deposits are most common in volcanic rocks, and molybdenum and nickel are most abundant in intrusive rocks (albeit of different character).

Mineral deposits of all types and in a variety of volcanic sequences (greenstones, acid volcanic rocks, volcaniclastic, and unclassified) are all characterized by the metal association copper-zinc-gold-silver-lead. Volcanic-sedimentary deposits throughout the world commonly have this association, presumably because the metals are derived principally from the volcanic rocks themselves. Perhaps many so-called shear, disseminated, and massive deposits with the same metal association also derived their metals from the subjacent volcanic pile.

In clastic sedimentary rocks the dominant association is gold-silver-copper (in decreasing order of frequency) whereas in limestones the association is copper-silver-gold. In general, precious metals predominate in a sedimentary environment and base metals predominate in a volcanic environment. Perhaps, in part, this reflects contribution of metals from wallrocks to the mineralizing solutions.

CONCLUSIONS

The preparation of a mineral deposit computer file results in a rigorous approach to data accumulation and provides quantitative information for calculating spatial densities and quantitatively study the various *relationships between commodities, deposit type, and rock type as well as other variables not considered* here.

For the Vancouver-Hope map-area several obvious relationships and less obvious metallogenic implications are as follows:

(1) Tectonic belts consisting dominantly of intermediate intrusive plutons have relatively few mineral occurrences.

(2) Volcanic or sedimentary terranes, with or without associated plutonic rocks, are favoured environments for mineral occurrences.
(3) Sedimentary rocks are characterized by deposits containing gold and silver.
(4) Volcanic rocks are characterized by deposits with a polymetallic assemblage containing silver, gold, zinc, lead, and copper.
(5) The distinctive commodity associations in volcanic and sedimentary terranes are consistent with the concept of rock-ore associations expounded by Stanton (1972). There appears to be a genetic relationship between principal commodities and host-rock lithology. For volcanogenic deposits, and perhaps other deposits types in the same lithologic terranes, the polymetallic assemblages are apparently derived from the subjacent volcanic pile. By analogy the predominance of gold and silver in sedimentary rocks may result from derivation of these metals from the volcanic rocks themselves.

ACKNOWLEDGMENTS

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TABLE 1. SUMMARY OF TECTONIC HISTORY

	TIME SPAN	EVENTS	UNITS INVOLVED
I.	Pre-Devonian	Formation of basement	YA in C-2
II.	*Upper Paleozoic/Lower and Middle Triassic*	*Marine eugeosynclinal deposition in a basin which shallows westward (or, if right-lateral offset is considered, shallows to the south).*	*CH, HZ (TI?, BI?, YA in C-4?)*
III.	Permian/Triassic	Deformation.	YA in C-4 (TI?, BI?)
IV.	Lower and Middle Jurassic	Volcanism in the Coast Plutonic Belt and extensive volcanism east of the study area forms the *Intermontane Belt. Deposition of marine turbidites begins in the southern section.*	PI, N *C*
V.	Lower and Middle Jurassic	Deep-water deposition in the Ladner Trough begins from a high source area to the east. Deposition continues in the south, and a burst of acidic volcanism occurs on the eastern edge of the Coast Plutonic Belt, followed by deposition in local basins of varying relief.	L C, D HL, BME
VI.	Upper Jurassic	Plutonism of unknown extent in the Coast Plutonic Belt, deformation and metamorphism begins along a north-south axis in the Spuzzum and Cascade Belts. Deposition of trench-like sediments along this axis beings Shallow-water deposition of more easterly derived sediments in the Ladner Trough and possible intrusion of the Eagle Complex.	CR, FL (AP?, K?) SS, Custer Gneiss D DC Eagle ?
VII.	Lower Cretaceous	Considerable marine volcanism and sedimentation in the Coast Plutonic Belt along with the beginning of intense plutonism and/or cooling of plutons to the point where they have begun to retain argon. Axial deformation continues, and the Giant Mascot ultramafic body has also cooled below argon retention temperature. Trench-like deposition along the metamorphic axis ceases by mid-Lower Cretaceous. Easterly derived marine deposition continues in the Ladner Trough, but becomes westerly derived and nonmarine by the close of Albian time, indicating considerable uplift to the west, presumably of the Coast Plutonic Complex. The Eagle Complex is also shedding debris into the Ladner Belt by Albian.	G, CEH, FL, PN, BH CR SS, Custer Gneiss D um NK JM, P
VIII.	Mid-Cretaceous (limits undefined)	Major thrusting directed away from the central metamorphic axis brings up mantle-derived (?) ultramafic rocks and basement material. Genetically related folding accompanies thrusting in the Cascade Belt, Hozameen Basin, and Ladner Trough. Uplift of the Eagle Plutonic Belt occurs.	Shuksan, Church Mountain, Hozameen, Pasayten Faults um Eagle
IX.	Upper Cretaceous	The majority of the Coast Plutonic Complex (and Spuzzum) K/Ar dates are clustered in this period, but by the end of Cretaceous time large-scale plutonism had ceased. Major deformation and thrusting in all areas also ceased by latest Cretaceous.	CR, Spuzzum, Scuzzy
X.	Tertiary	The Coast Plutonic Belt records volcanism and sedimentation which began in latest Cretaceous, uplift and erosion continue in the Coast Mountains. One K/Ar date records late cooling/intrusion of plutonic rocks. Major right-lateral-movement along the Straight Creek — Fraser River fault zones and related (?) sedimentation and intrusion occurred before Oligocene. *High-level plutons are concentrated in the Cascade Belt, but are also scattered throughout the area;* coeval volcanic rocks were extruded.	s, bv, CR Straight Creek — Fraser River Zone, CK, Yale Intrusions Hell's Gate, Silver Creek, *Chilliwack, Mount Barr, Needle Peak* av, SK, CQ
XI.	Pleistocene	Calc-alkaline volcanism in the Coast Plutonic Belt.	GB

ABBREVIATIONS USED TO IDENTIFY UNITS IN TABLE 1

[Units are arranged alphabetically within tectonic belts; *see* text for description and ages.]

I. Eagle Plutonic Belt

CQ	Coquihalla Group
N	Nicola Group

II. Ladner Trough

CQ	Coquihalla Group
CR	Coast Plutonic Complex
DC	Dewdney Creek Group
JM	Jackass Mountain Group
L	Ladner Group
P	*Pasayten Group*

III. Hozameen Basin

CR	Coast Plutonic Complex
HZ	Hozameen Group
Qs	Quaternary sediments

IV. Cascade Belt

C	Cultus Formation
CH	Chilliwack Group
CK	Chuckanut Formation

IV. Cascade Belt—*Continued*

CR	Coast Plutonic Complex
D	Darrington Phyllite
NK	Nooksack Group
QS	Quaternary sediments
SK	*Skagit Formation*
YA	Yellow Aster Crystalline Complex

V. Spuzzum Plutonic Belt

av	acid volcanic rocks
CR	*Coast Plutonic Complex*
gn	gneiss
ms	metasedimentary rocks
Qs	Quaternary sediments
SS	Settler Schist

VI. Coast Plutonic Belt

AP	Agassiz Prairie Formation
av	acid volcanic rocks
BH	Brokenback Hill Formation
BI	Bowen Island Group

VI. Coast Plutonic Belt—*Continued*

BME	Billhook Creek Formation Mysterious Creek Formation Echo Island Formation
bv	basic volcanic rocks
CEH	*Cheakamus Formation* Empetrum Formation Helm Formation
CR	Coast Plutonic Complex
FL	Fire Lake Group
G	Gambier Group
GB	*Garibaldi Group*
gn	gneiss
HL	Harrison Lake Formation
K	Kent Formation
m	metamorphic rocks
ms	metasedimentary rocks
PI	Pioneer Formation
PN	Peninsula Formation
Qs	Quaternary sediments
s	sedimentary rocks
TI	Twin Islands Group

TABLE 2. GRADE AND TONNAGE OF MAJOR DEPOSITS*

	Cu *per cent*	Pb *per cent*	Zn *per cent*	Au *per cent*	Ag *oz/ton*	Ni *per cent*	Production *tons*	Total Resources *tons*
Britannia G-3	1.1		.65	.02	.20		52,783,964	
Giant Mascot HSW-4	.33					.77	6,081,133	7,577,000
Northair J-130		2.7	4.0	.40	4.60			330,637
Canam HSW-1	.61							8,000,000
Aurum HNW-3				.098				3,000,000

*Sources of information are documented by Ditson, 1978.

TABLE 4. PRINCIPAL COMMODITIES VERSUS DEPOSIT TYPE

Deposit	N	Commodities Recognized in 10 or More Deposits*				
Vein	78	Au	Cu	Ag	Pb	Zn
Porphyry	41	Cu	Mo	Ag		
Disseminated	39	Cu	Zn	Ag	Au	
Skarn	22	Cu	Ag	Au	Fe	
Shear	24	Cu	Ag	Zn		
Magmatic	15	Ni	Cu			
Volcanogenic*	4	Au	Zn	Pb	Ag	Cu

*Total abundance of volcanogenic deposits is 4.

TABLE 3. NUMBER OF COMMODITY OCCURRENCES AND DEPOSIT TYPES
EACH TECTONIC BELT OR BELT SUBDIVISION IN THE STUDY AREA*

	Iron	Cobalt	Nickel	Copper	Zinc	Arsenic	Molybdenum	Silver	Cadmium	Antimony	Tungsten	Gold	Lead	Bismuth	Uranium	Magmatic	Porphyry	Skarn	Volcanogenic	Vein	Shear	Disseminated	Massive	Total
Coast Plutonic Belt Intrusions 10 186 km^2	2		1	32 (3)	5 (1)		19 (1)	9 (3)				7 (2)	1			1	21 (1)			8 (1)	1	4		35 (2)
Coast Plutonic Belt Pendants 2 652 km^2	10 (3)			59 (9)	32 (7)		4 (1)	30 (9)		1 (1)	3 (3)	25 (9)	15 (6)	1			7	9 (2)	2 (2)	13 (5)	14 (2)	19 (1)	1	65 (12)
Spuzzum Plutonic Belt Intrusions 3 097 km^2		1	10 (1)	11 (1)	1		2	1		1	1	3	1	1		8 (1)	2			2	1	1		14 (1)
Spuzzum Plutonic Belt Pendants 1 145 km^2		1	1	4 (1)		1 (1)		4 (1)				3 (1)						1		4 (1)		1		6 (1)
Cascade Belt 1 619 km^2	3 (1)		2	15 (3)	6		6 (1)	14 (3)			1	9	7 (1)			1 1	4	7 (2)		7 (1)	1	3		23 (3)
Hozameen Basin 1 111 km^2	3		3	16 (1)	10 (1)	1	3	15 (1)		3	1	17 (1)	8 (1)			2	1	4		5 (1)		7		23 (1)
Ladner Trough 1 875 km^2	1 (1)		1	21 (7)	17 (5)	1	2 (1)	22 (9)		2		37 (11)	15 (6)		1 (1)	1	1 (1)			34 (10)	7	2		45 (11)
Eagle Plutonic Belt 1 787 km^2	1		1	18	6		5	9				10	6			1	5	2		7		2		17
Total 23 473 km^2	20 (5)	2	19 (1)	176 (25)	77 (14)	3 (1)	41 (2)	104 (26)	1	7 (1)	6 (3)	111 (24)	53 (14)	2	1 (1)	14 (1)	41 (2)	23 (4)	2 (2)	80 (19)	24 (2)	39 (1)	5	228 (31)

*The lower number in parentheses is the number of deposits with production records; this number is *included in the total count above it.*
Area represented included below each division name.

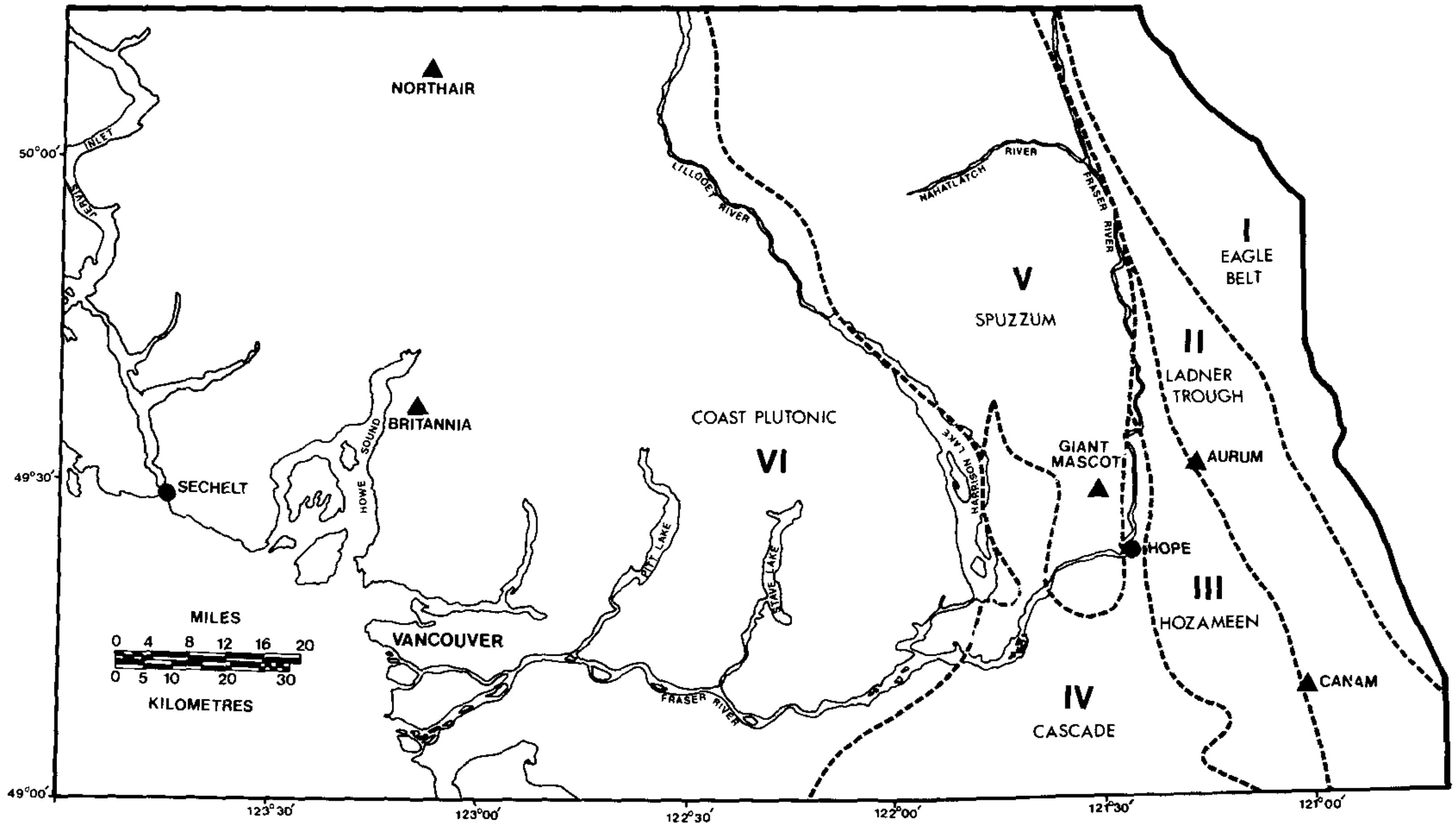

Figure 58. Location map and major tectonic subdivisions, Vancouver-Hope map-area. I – Eagle Plutonic Belt; II – Ladner Trough; III – Hozameen Basin; IV – Cascade Belt; V – Spuzzum Plutonic Belt; VI – Coast Plutonic Belt. Five important mineral deposits are located.

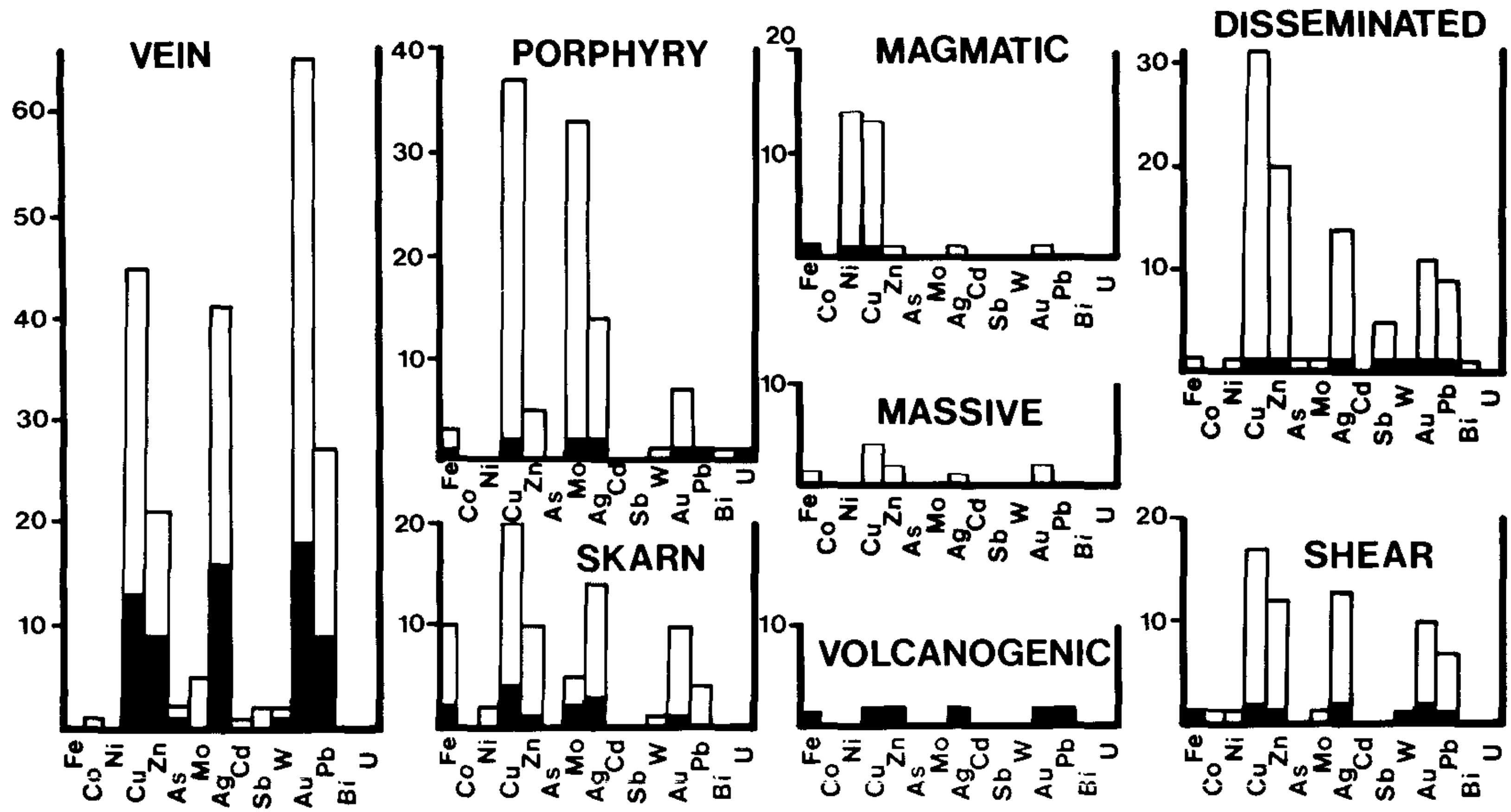

Figure 59. Distribution of commodities as a function of deposit type. Black bars indicate past producers; blank bars are nonproducers.

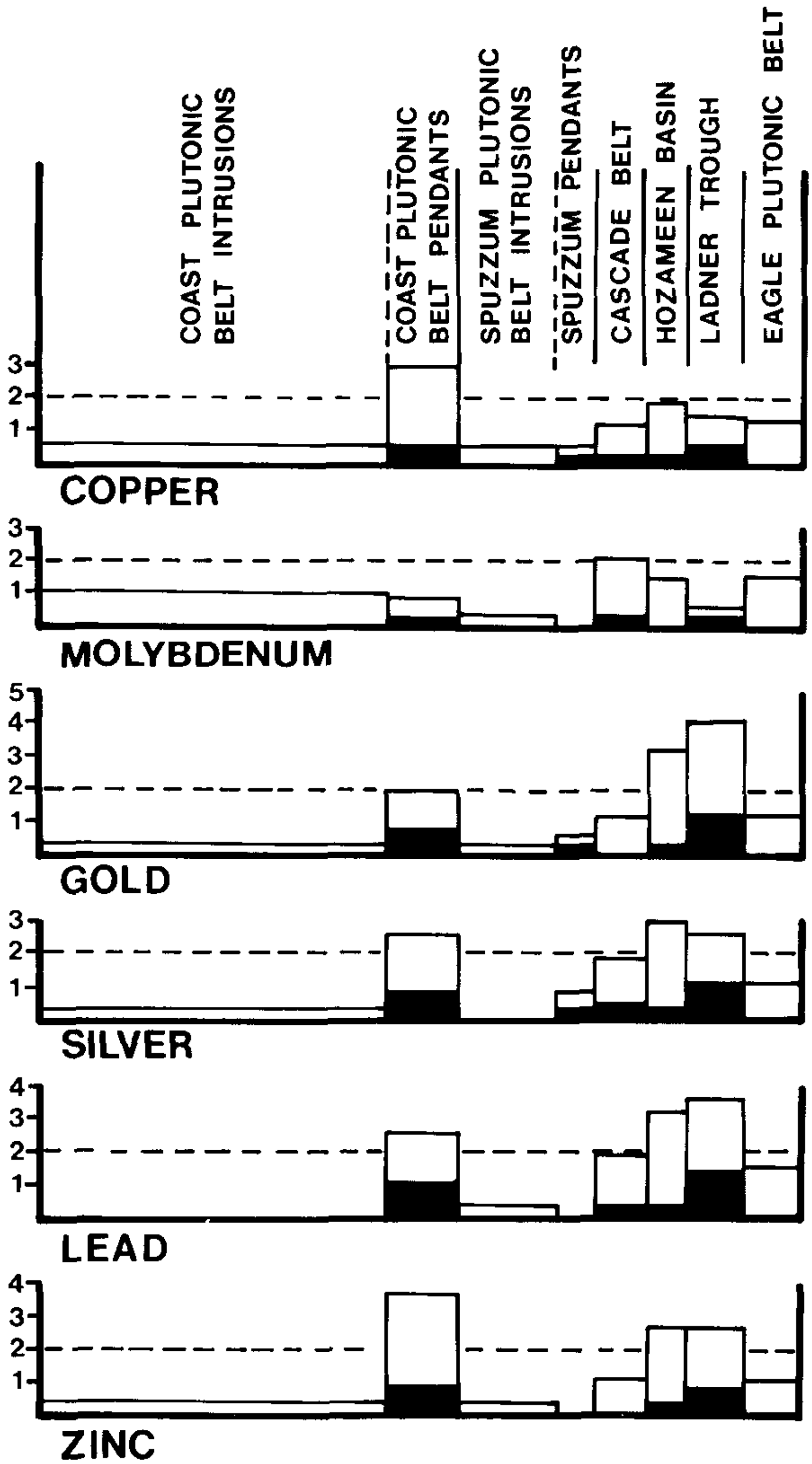

Figure 60. Relative spatial densities of commodity occurrences as a function of tectonic unit. Black bars represent past producers; blank bars are nonproducers.

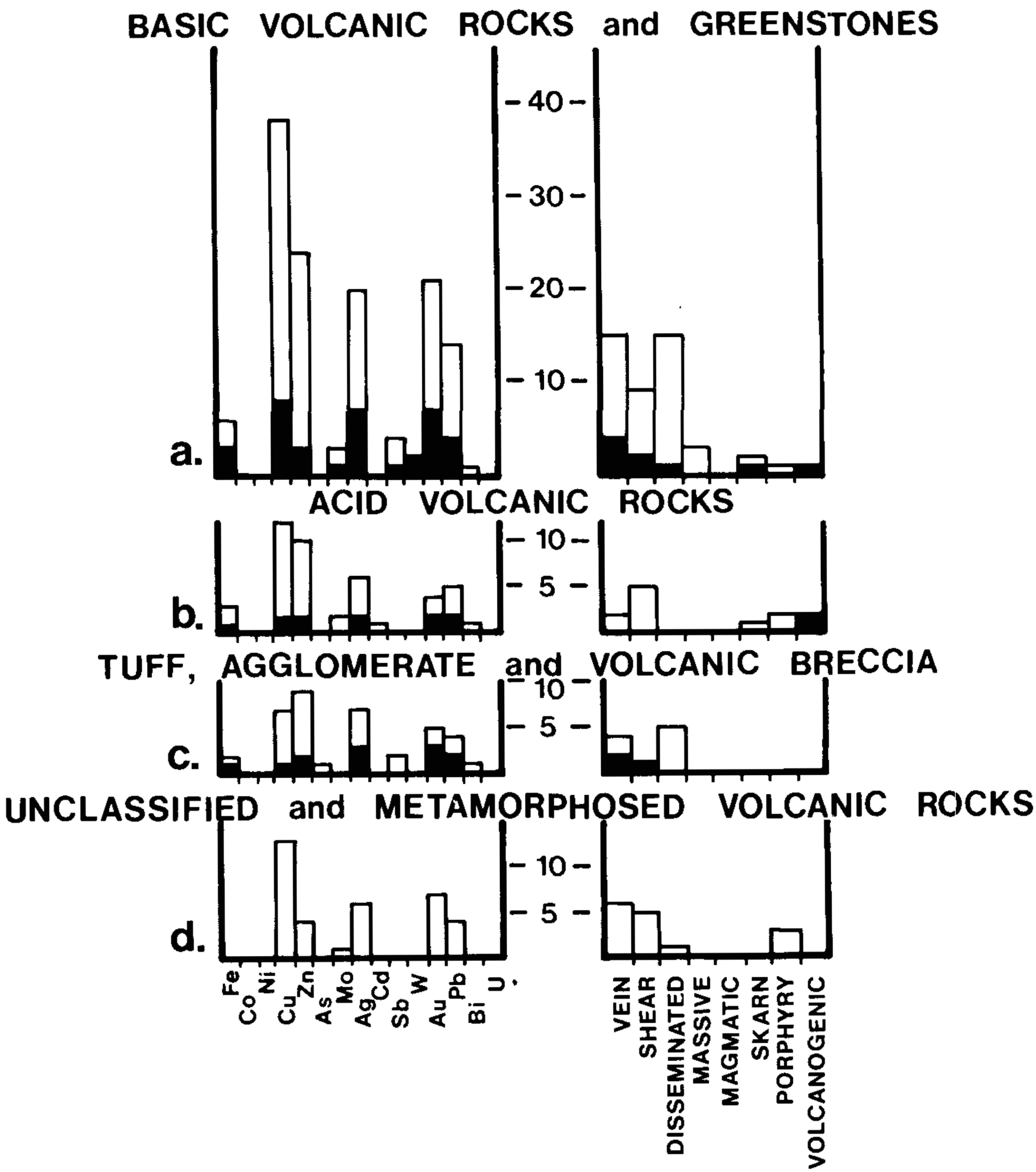

Figure 61. Frequency of deposit occurrences as a function of commodities and deposit type for mineral occurrences in volcanic rocks, Vancouver Island.

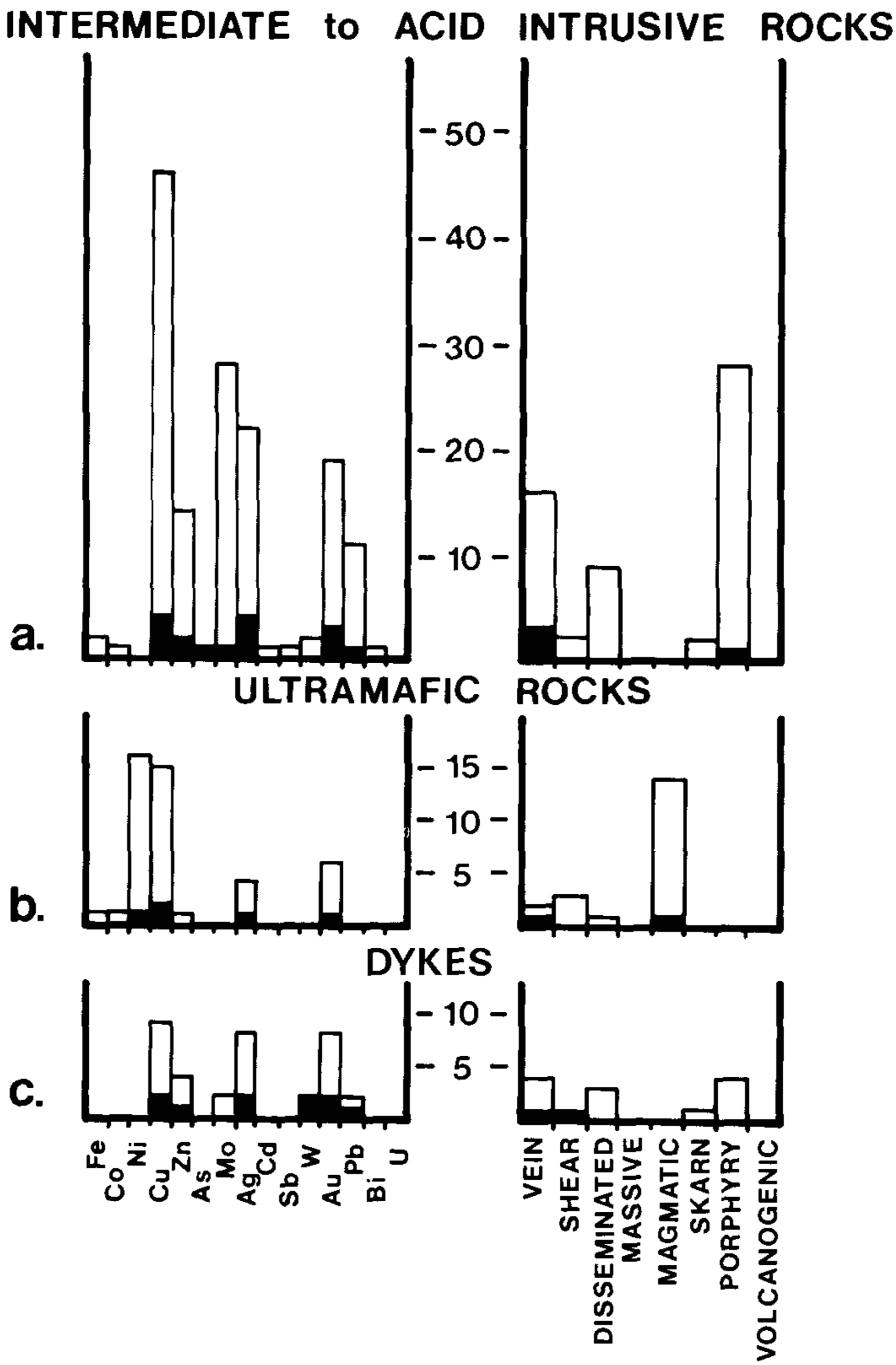

Figure 62. Frequency of deposit occurrences as a function of commodities and deposit types for mineral occurrences in intermediate to acid intrusive rocks, Vancouver-Hope map-area.

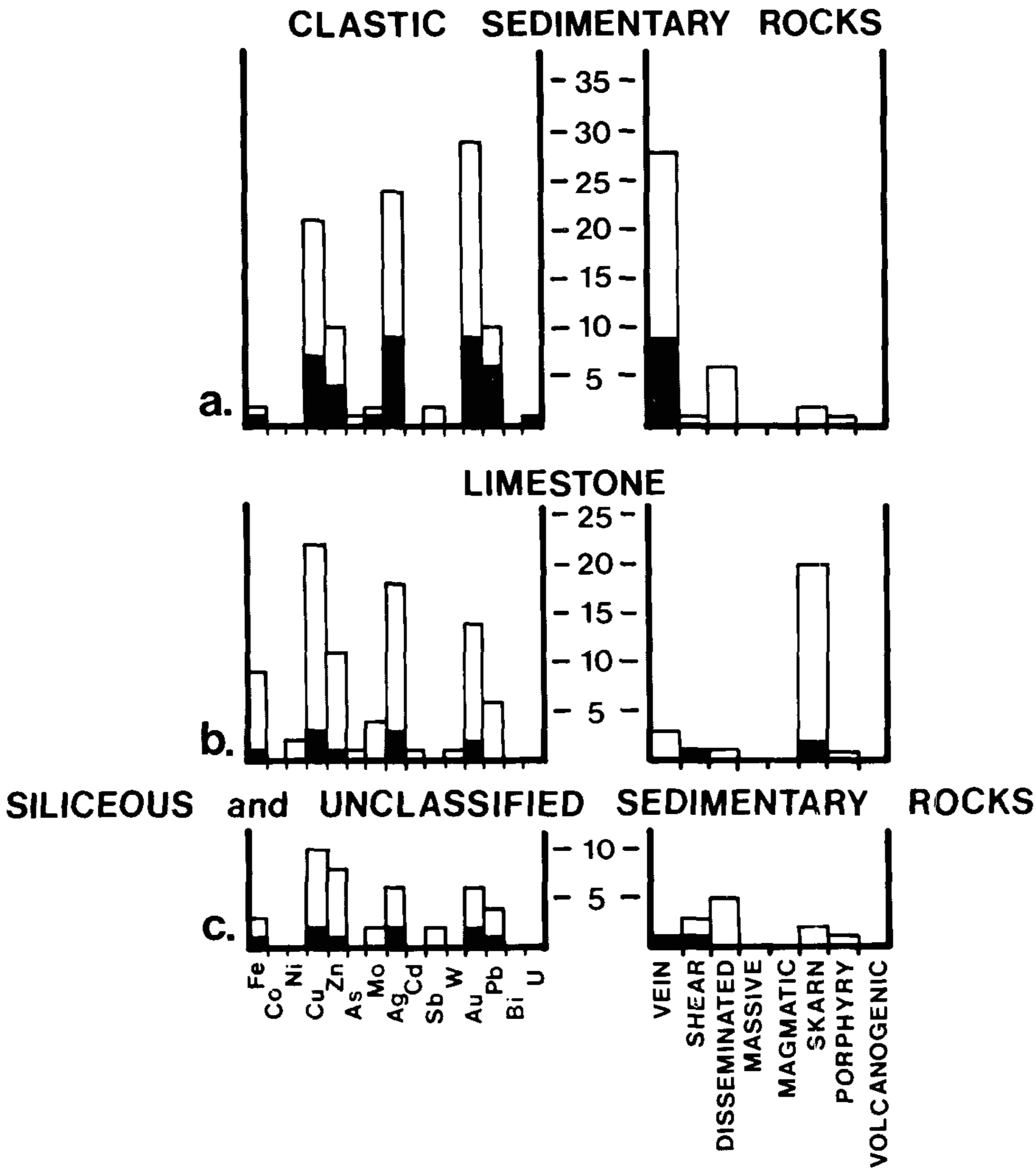

Figure 63. Frequency of deposit occurrences as a function of commodities and deposit types for mineral occurrences in sedimentary rocks, Vancouver-Hope map-area.

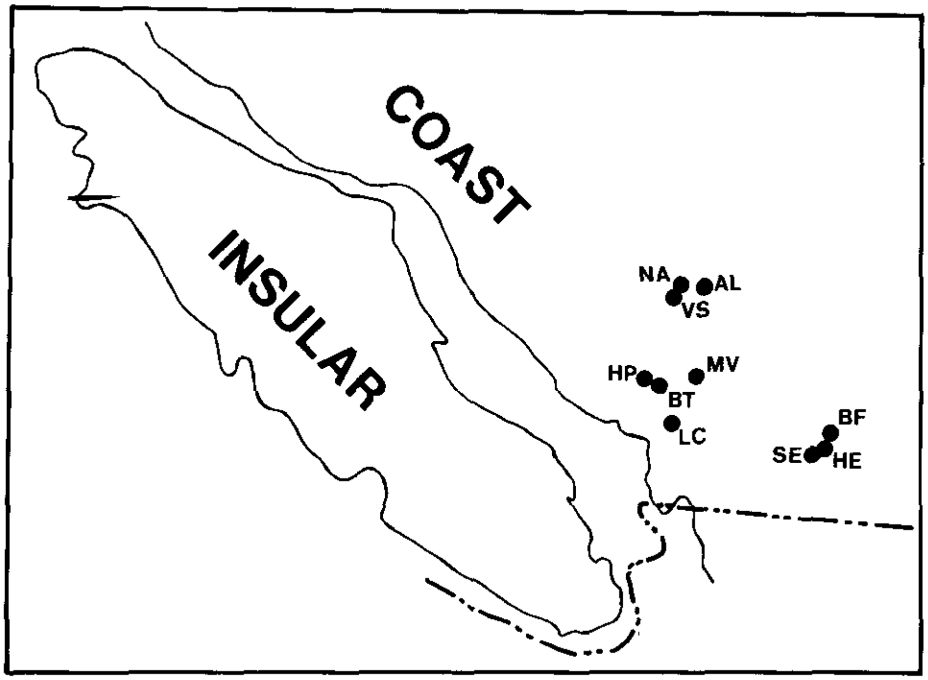

Figure 64. Location of mineral deposits in the southern Coast Crystalline Belt for which lead isotope data were presented by Godwin, *et al.* (1980). *See* Table 1 for abbreviations.

TABLE 1. GENERAL DESCRIPTION OF SOME MINERAL DEPOSITS IN THE SOUTHERN COAST CRYSTALLINE BELT

Deposit	Symbol	
Northair	NA	Layered sulphides (galena-sphalerite-pyrite) intercolated with carbonate in acidic pyroclastic rocks of Early Cretaceous age; cut by sulphide-bearing carbonate veins (Miller and Sinclair, 1979).
Britannia	BT	Volcanogenic polymetallic sulphide deposits with associated barite in acidic pyroclastic sequence of Early Cretaceous age (Payne, *et al.*, 1980).
Alta Lake	AL	Large stringer zone containing chalcopyrite, sphalerite, and galena in metamorphosed rocks of Alta Lake pendant (*B.C. Ministry of Energy, Mines & Pet. Res.*, internal report).
Van Silver	VS	Several small polymetallic sulphide deposits in Callaghan Creek pendant with apparent volcanogenic affiliations (Miller and Sinclair, 1979).
Seneca	SE	Exhalative sphalerite-galena-barite in layered sheet within acid to intermediate volcaniclastic rocks of Middle Jurassic Harrison Lake Formation; copper-bearing siliceous stringer zone also present (Pride, 1973).
Harrison Lake Gold	HE	'Pipe' zone in Jurassic volcanic rocks.
Lynne Creek	LC	Layered and massive sulphides (sphalerite and galena) in carbonate within a small pendant of predominantly pyroclastic rocks.
Hopkins Landing	HP	Massive sulphide volcanogenic deposit in acidic volcaniclastic rocks probably equivalent to Gambier Group.
Big Foot	BF	Sphalerite, chalcopyrite, galena, and barite occur in quartz-carbonate veins confined to a band of strongly altered lapilli tuff.
McVicar	MV	Pyrite and chalcopyrite occur as irregular masses, stringers, disseminations, and quartz-filled fractures within greenstone of the Goat Mountain Formation (Triassic) near its contact with the Coast Range batholith. Sphalerite and galena occur in alternating bands.