

Quantitative Aspects in the Distribution of Base and  
Precious Metal Deposits of the World.

by

P e t r L á z n i č k a

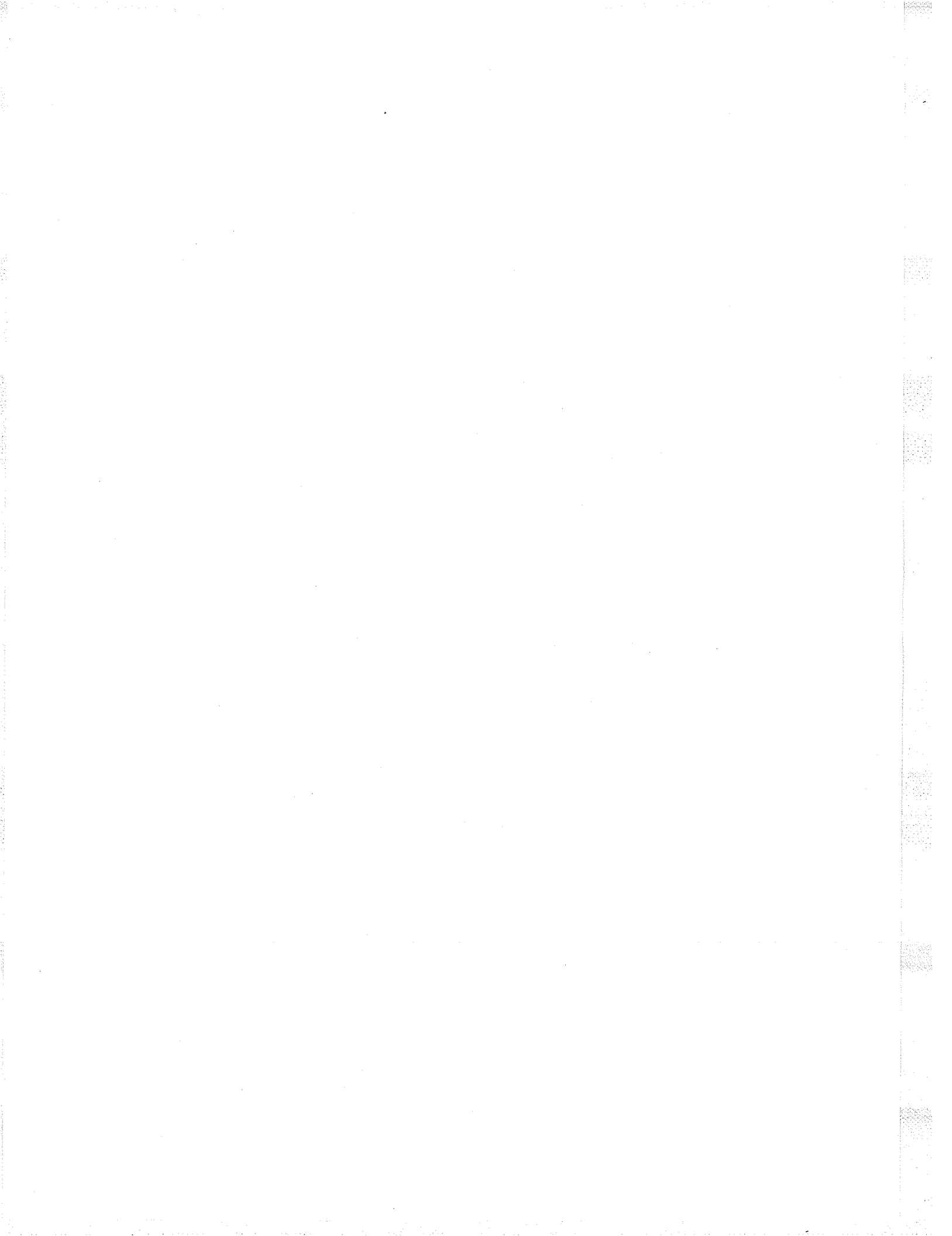
A thesis submitted as a part of the requirements for  
the degree of Doctor of Philosophy.

Department of Earth Sciences,  
University of Manitoba

Winnipeg

1970

© Petr Laznicka 1972



ABSTRACT.

Some aspects of the world-wide distribution of ore deposits of eleven base and precious metals (Au, Ag, Cu, Zn, Pb, Cr, Sn, W, Mo, Sb, Hg) are treated using quantitative data.

PART I. Metal density averages for various divisions of the earth's surface are derived and corrected, using the data of world metal content in ores compiled to include 1967/68, and the sizes of the territories in which the ores occur. Effective and ineffective areas in regard to the presence of ore deposits are distinguished and local effective metal density averages for continents and world principal structures are compared with world dry landmass effective density averages. Precambrian shields have the highest effective metal density of Cr and Au, Paleozoic belts of Zn, Cu, Pb and Hg and Meso-Cenozoic belts of Sn, Mo, Sb, W and Ag which is probably caused by progressive acidization of the earth's crust.

A concept of normative ore (i.e. ore with the world mean grade for each metal) is proposed as a measure of magnitude of ore deposits, districts and areas replacing dollar values. The geochemical index of accumulation results from relating quantities of ores to mean crust content of metals. Both relationships can be expressed by a formula and plotted diagrammatically on a map. The results from this treatment of the data are used to discuss mineral belts of the American Cordillera and some areas with divergent symmetry. Part II. The second part of the thesis consists of a topical manu-

al, describing the content, classification and coding of the computer processible University of Manitoba file of world base and precious metal deposits which has been the basis for the entire thesis work.

PART III is a bibliography,

PART IV are appendices.

Winnipeg, December 1970.

LIST OF CONTENTS

Introduction	1
Acknowledgements	5

PART I : Quantitative aspects in the distribution  
of Base and precious metal deposits of the  
world.

Chapter 1. Content of the eleven base and precious metals in ore deposits of the world.	7
Chapter 2. The density of mineralization.	17
- The application of metal density averages for regional metallogeny.	45
Chapter 3. Distribution of the eleven metals in the principal geotectonic divisions of the dry landmass.	56
- Precambrian shields	65
- Paleozoic folded belts	75
- Mineralized phanerozoic platformic covers	81
- Meso-Cenozoic folded belts	82
Chapter 4. Considerations involving concentrations.	87
- Grade relations	96
- Normative ore	137

- The concentration of metals in ore deposits in relation to their trace content in rocks	147
- The combination of metal density averages with mean crust content values.	160
Chapter 5. The quantitative approach to regional metal- logeny.	164
Chapter 6. Mineral belts of the American Cordillera.	170
-Metal belts	231
- Configuration of the eleven metals in the Cordillera and their geochemical correlation.	256
Chapter 7. Orogenic belts with divergent symmetry.	272
- Possible examples of divergent symmetry in North America	287
Chapter 8. Acidization (continentization) and the deve- lopment of continental crust.	298
- Cyclicity of metals	314

Part II : Topical Manual for the Computer Processible

File of World Deposits of Au,Ag,Cu,Zn,Pb,

Cr,Sn,W,Mo,Sb and Hg.

Chapter 1.	Introduction.	321
Chapter 2.	Record No. 0101 - Identification.	340
Chapter 3.	Record No. 0201 - The metal content in ores.	355
Chapter 4.	Record No. 0301 - References, notes.	369
Chapter 5.	Records No. 0401 - 0403. Geology.	370
Chapter 6.	Record No. 0501 - The mineral deposit proper.	412
	Alphabetical list of codes	439

Part III : Appendices.

Appendix 1.	Tables of the world metal content in ores by countries.	457
Appendix 2.	The world principal geotectonic units and their dry land, "ineffective", "effective" and "human" areas.	547
Appendix 3.	Tables of structural levels and cyc- les for "broader areas" included in the file.	564

Part IV : References and bibliography. 645

LIST OF TABLES.

Table		page
<u>PART I.</u>		
1-1	Value of the world content of metals in ores.	15
1-2	The derivation of metal density averages for various portions of the earth's surface.	21
1-3	The dry continental landmass density averages for the continents and for Canada.	25
1-4	Types of effective and ineffective areas.	30
1-5	The effective density averages for the continents and for Canada.	35
1-6	The ratios of <u>local effective density averages</u> <u>dry landmass effect.dens.avarages</u> for the continents and for Canada.	37
1-7	The "human" density averages for continents and for Canada.	46
1-8	The metal content relationship of the world largest single deposits, districts and groups to the world total metal content in ores.	52
1-9	The metal content in ores of the dry continental landmass of the world and its principal geotectonic divisions.	57
1-10	The effective density averages for Precambrian	



	shields and basement areas of the world.	66
1-11	The ratios of <u>local effective density averages</u> world Precambr. shields dens. av.	
	for Precambrian basement areas of the world.	67
1-12	The effective density averages for some portions of Phanerozoic cover of old platforms.	76
1-13	The ratios of <u>local effective density averages</u> Paleoz. folded belts eff. dens. aver.	
	for the Paleozoic folded belts of the world. Alter- native 2.	77
1-14	The effective density averages for Meso-Cenozoic folded belts of the world.	83
1-15	The ratios of <u>local effective density averages</u> Meso-Cenoz. fold. belts eff. dens. aver.	
	for the Meso-Cenozoic folded belts of the world.	84
1-16	Mean content of eleven metals in rocks, environments and the earth's crust.	92-95
1-17	Frequency distribution of gold grades in world ores.	98-99
1-18	Frequency distribution of silver grades in world ores.	100-102
1-19	Frequency distribution of copper grades in world ores.	103-104
1-20	Frequency distribution of zinc grades in world ores.	105-106
1-21	Frequency distribution of lead grades in world ores.	107-109
1-22	Frequency distribution of chromium grades in world ores.	110-
1-23	Frequency distribution of tin grades in world ores.	111-112
1-24	Frequency distribution of tungsten grades in world	113-114

ores.		
1-25	Frequency distribution of molybdenum grades in world ores.	115-116
1-26	Frequency distribution of antimony grades in world ores.	117-118
1-27	Frequency distribution of mercury grades in world ores.	119-120
1-28	Arithmetic mean grade and other classes of grades for the ores of eleven metals of the world.	136
1-28a	Comparison of Interior and Purcell-Omineca belts of British Columbia using the normative ore concept.	140
1-29	Clarkes of concentration for various classes of ore grades for the eleven metals.	149
1-30	Geochemical indices of accumulation and the deriva- tion of the formula of accumulation for the Bingham, Utah, ore district.	152
1-31	Mean content of eleven metals in rocks, environments and the earth's crust (per cubic meters).	154-155
1-32	Area accumulation indices for the world largest sing- le deposits or districts and belts or groups of the eleven metals.	159
1-33	Relationship of the dry continental landmass effecti- ve density averages to the mean crust content of eleven metals.	162

1-34	Metal contents in ores and relationships in the American Cordillera.	176-202
1-35	Ratios of the <u>rock group trace metal content</u> <u>crust trace metal content</u> for the eleven metals.	240
1-36	Semiquantitative estimate of the degree of accumulation of metals in ores in the longitudinal zones of the American Cordillera.	257
1-37	Pb:Zn and Pb:Ag ratios for some lead-zinc-silver deposits of the Yukon-British Columbia-Northern U.S. section of the Cordillera.	267
1-38	The relationship of chromium, copper and molybdenum in some eugeosynclinal zones of the world.	284-285
1-39	Geochemical relationship of eleven metals in 26 most important ore deposits and districts in the Canadian Maritimes.	290-293
1-40	Comparison of the principal types of petrographic-metallogenetic provinces of the world.	311

PART II.

2-1	Physico-geographic and geotectonic "broader units" of the world.	322
2-2	List of data items.	341-344
2-3	Examples for three Canadian deposits.	345-350
2-4	Metric and non-metric weight equivalents and conversion factors.	357
2-5	Procedures involved in preparation of metal content figures for the porphyry copper deposit of Cananea, Mexico.	361-362
2-6	Comparison of Precambrian and Phanerozoic divisions.	376
2-7	Comparison of some Precambrian and Phanerozoic Geosynclinal development schemes.	378
2-8	Development stages of an average, full-cycle, geosynclinal folded belt.	400
2-9	Development stages of independent basins, platforms and activated areas.	
2-10	List of genetic types.	414-416
2-11	Similarity types of Au, Ag, Cu, Zn, Pb, Cr, Sn, W, Mo, Sb, Hg deposits.	419-429
2-12	Mnemonic codes for minerals, genetically classified.	432-435

LIST OF FIGURES.

figure		page
<u>PART I.</u>		
1-1	Plot of the world metal content in ores against the total metal value in U.S. dollars.	16
1-2	Portioning of the earth's surface for metal density averages.	22
1-3	Map showing the distribution of metallogenically effective and ineffective areas of the world.	23
1-4	Dry continental landmass density averages for continents and for Canada.	26
1-5	The effective metal density averages for continents and for Canada.	36
1-6	Excess/deficiency relationships of eleven metals present in ores on continents.	38
1-7	Excess/deficiency relationships of eleven metals present in Canadian ores.	39
1-8	The relationship of mineral belts and gaps to "effective" and "ineffective" areas in Nevada.	41
1-9	Relationship of the number of Pb and/or Zn occurrences to their size in Bohemia, western part of Czechoslovakia.	50

1-10	Relationship of the world largest single deposits, districts and groups metal content to the world total metal content in ores.	53
1-11	Plot of ratios of <u>metal cont.in single deposit</u> <u>metal content in remaining</u> world deposits.	
1-12	Distribution of the world metal content in ores into principal geotectonic divisions of the world dry landmass. Alternative 1.	60
1-13	The same, alternative 2.	61
1-14	Effective metal density averages for principal geotectonic divisions of the world dry landmass.	62
1-15	The same, alternative 2.	63
1-16	Effective metal density averages for Precambrian shields, blocks and belts of the world.	68
1-17	Effective metal density averages for Afro-Arabian and Australian Precambrian shields.	69
1-18	Excess/deficiency relationship of eleven metals present in the ores of Precambrian shields.	70
1-19	Effective metal density averages for Paleozoic folded belts of the world. Alternative 1.	78
1-20	The same, alternative 2.	79
1-21	Excess/deficiency relationships of eleven metals present in ores of Paleozoic belts. Alternative 2.	80
1-22	Effective metal density averages for the Meso-Geno- zoic belts of the world. Alternative 2.	85

1-23	Excess/deficiency relationships of eleven metals present in ores of Meso-Cenozoic belts of the world, alternative 2.	86
1-24	Plot of trace contents of eleven metals in the earth's crust, rocks and environments.	89-91
1-25	Frequency distribution of grades in world gold ores.	121
1-26	Frequency distribution of grades in world silver ores.	122
1-27	Frequency distribution of grades in world copper ores.	123
1-28	Frequency distribution of grades in world zinc ores.	124
1-29	Frequency distribution of grades in world lead ores.	125
1-30	Frequency distribution of grades in world chromium ores: chromites.	126
1-31	Frequency distribution of grades in world tin ores.	127
1-32	Frequency distribution of grades in world tungsten ores.	128
1-33	Frequency distribution of grades in world molybdenum ores.	129
1-34	Frequency distribution of grades in world antimony ores.	130

- 1-35 Frequency distribution of grades in world mercury ores. 131
- 1-36 Tentative frequency distribution diagram for Au, Cu and Cr content in rocks and ores. 135
- 1-37 The development of computer plotted map symbols for ore deposits, districts and areas. 144-146
- 1-38 Three examples of continuous logarithmic scales for plotting quantities of ore, metal etc. into maps. 147
- 1-38a Relationship of the dry continental landmass effective metal density averages to the mean crust content of the eleven metals. 163
- 1-39 The American Cordillera. Location map of sections, longitudinal belts and the outer limit of the belt. 203-205
- 1-40 The American Cordillera. Plot of main deposits of the eleven metals and the position of the Cu : Pb line. 206-208
- 1-41 The American Cordillera. Location map of main geotectonic units of Meso-Cenozoic and Paleozoic geosynclines. 209-211
- 1-42 The American Cordillera. Statistically derived plot of predominant metallization in longitudinal belts. 214-216
- 1-43 Geochemical excess/deficiency relationships in



	the longitudinal belts of the American Cordillera.	215-217
1-44	Excess/deficiency relationships of the eleven metals in longitudinal belts of the Yukon-British Columbia section of the American Cordillera.	218
1-45	Excess/deficiency relationships of the eleven metals in longitudinal belts of the Oregon-Montana section of the North American Cordillera.	219
1-46	Excess/deficiency relationships of the eleven metals in longitudinal belts of the California-Colorado section of the American Cordillera.	220
1-47	Excess/deficiency relationships of the eleven metals in longitudinal belts of the Bolivia-Puna de Atacama section of the American Cordillera.	221
1-48	Excess-deficiency relationships of the eleven metals in longitudinal belts of the central Chile-Argentina section of the American Cordillera.	222
1-49	Geochemical excess/deficiency relationships in the American Cordillera. Part 1.	223
1-50	The same, part 2.	224
1-51	Effective metal density averages for sections of the American Cordillera.	225
1-52	"Backbones" or axes of maximum accumulation of metals in deposits in the longitudinal belts of the American Cordillera.	226

- 1-53 Variation diagram of the rock group trace met.ct.  
earth crust trace m.c.  
in igneous rocks. 241
- 1-54 Variation diagram of the rock group trace met.c.  
earth crust tr.m.ct.  
for certain rock models of geosynclinal folded  
belts. 242
- 1-55 A schematic, highly simplified diagram illustrating the progressive development of molybdenite deposits by interaction of a hypothetical black shale with a granitizing medium. 249
- 1-56 Semiquantitative estimate of the degree of accumulation of metals in ores in the longitudinal zones of the American Cordillera. 258
- 1-57 Magnesium-zinc relationship in igneous rocks. 269
- 1-58 Preferential accumulation of the eleven metals in zones of a model divergent geosynclinal couple with an eu-ridge in the centre. 276
- 1-59 Preferential accumulation of the eleven metals in zones of a model divergent geosynclinal couple with an eu-furrow in the centre. 277
- 1-60 The relationship of Cu : Pb lines to Auboin's axes of divergent and convergent symmetry in the Italo-Dinaric region of the Mediterranean. 278
- 1-61 Plot of geochemical indices of accumulation of

- Cu, Cr and Mo in ore deposits of some eugeosynclinal zones of the world. 286
- 1-62 The hypothetical divergent symmetry of the Maritime Appalachians. 294
- 1-63 Map of the Canadian Maritime Appalachians showing the geochemical relationships of eleven metals in 26 most important ore deposits and districts. 295-296
- 1-64 Map showing the world distribution of disseminated copper deposits. 308
- 1-65 Map showing the distribution of the principal petrographic-metallogenetic divisions of the effective areas of the world. 312
- 1-66 Map showing the distribution of the world most important areas with "femic" associations predominating. 313
- 1-67 Cyclicity in the formation of ore deposits of eleven metals in the course of progressive acidization of an initial, basic, mantle derived assemblage. 318

P A R T II.

2-1	Physico-geographical and geotectonic "broader units" of the world. A map.	323
2-2	1967/68 data sheet.	324
2-3	1968/69 data sheets	326, 327
2-4	1970 data sheet (used in Australia)	329, 330
2-5	Hierarchy within the "Index number" data item	351
2-6	Map showing the geographic position of "country" mnemonic codes.	354
2-7	Conversion scales for metric to non-metric weights.	358, 359
2-8	Selection of rock group records on two examples from Canada.	372
2-9	Precambrian time scale	379
2-10	Phanerozoic time scale	380
2-11	The relationship among geosynclines, platforms and regions of activation.	388
2-12	The morphological terminology of a simple and complex geosynclines. After Auboin (1965)	392
2-13 to 2-16	Gnetically classified lists of "associated" and "enclosing" rock codes.	404-407
2-17	Similarity types- mutual transitions and relationships.	430

- 2-18 Favourability trend analysis and deposition ages applied to the Carthage lead-zinc district. 438

P A R T III.

- 3-1 Structural levels and cycles of the broader units of the world. 565
- 3-2 Tasman folded belt ("geosyncline")-a map. 619

P A R T IV.

- 4-1 Characteristic geological and metallogenetical division of Canada. 648



## I n t r o d u c t i o n .

This thesis is an intermediate stage of the author's research, done at the University of Manitoba under the supervision of Dr. H. D. B. Wilson the purpose of which has been to use quantitative, production and reserve data of a group of eleven base and precious metal deposits for regional metallogenetic considerations on the world scale.

The first stage of the research, finished in 1968 and presented in the author's M. Sc. thesis, was concerned with relationships of gold, silver, copper, lead and zinc deposit belts, especially with regard to the division lines of predominant metalizations, like Cu:Pb and Cu:Zn lines.

During the second stage a sound basis for quantitative considerations has been completed, in the form of a computer processible file of world deposits of gold, silver, copper, zinc, lead, chromium, tin, tungsten, molybdenum, antimony and mercury, consisting of approximately 4000 stations (deposits, districts and superior areas) and punched on approximately 20,000 cards of the I. B. M. standart format. Due to unexpected delays in the implementation of a program, originally developed at the University of Western Ontario by P. G. Sutterlin and J. de Plancke to the University of Manitoba computer, the file has not become operative during the time of this thesis work so the benefit of the full use of its content

has not yet been attained. Due to this, the use of quantitative data from the file in regional metallogeny is treated methodically on several examples in Part I instead of presenting the final results bearing on the world wide relationships of deposits of the eleven metals and the quantitative comparison of Canadian and world metallogenies as originally planned. Part II concerns methods of building mineral deposits files and with the contents of such files. The thesis serves at the same time as a guidebook and explanation for the University of Manitoba file of world base and precious metal deposits, briefly characterized in the paper of Laznicka and Wilson ( 1970, in press ).

In the third, post-doctorate stage, it is hoped the same considerations given in this thesis to local areas and to selected subjects will be considered more fully on the world wide scale.

The cardinal problem with which the writer has been confronted during the work was the presentation of the data and information related to mineral deposits and their geology, to the computer. Written word gives geologists freedom to express their thoughts, list exceptions, quote sources, ideas and examples, label their statements with "perhaps", "possibly", "according to", arrange the length of an article according to the complexity of a problem and they can avoid touching problems for which there is no answer. Moreover, an average geological paper is a mixture of geologist's observations and subjective interpretations and very often mere