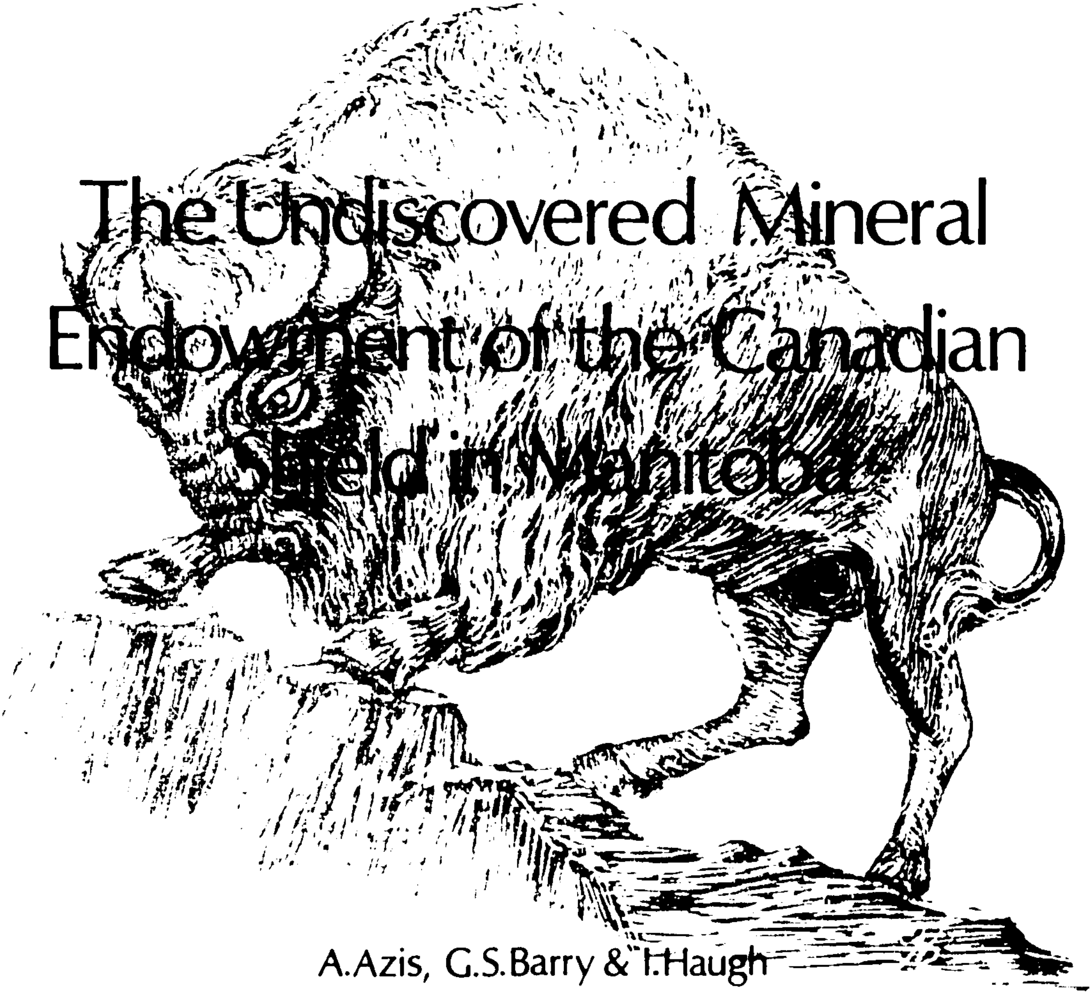
CANADA

1972

The Undiscovered Mineral Endowment of the Canadian Shield in Manitoba



A. Azis, G.S. Barry & I. Haugh

A Federal-Provincial Co-operative Study

Price $3.50

The Undiscovered Mineral Endowment of The Canadian Shield in Manitoba

by

Azman Azis, George S. Barry and Ian Haugh

MINERAL BULLETIN
MR 124

Mineral Resources Branch
Department of Energy
Mines and Resources
Ottawa

PUBLICATION
72-1

Mines Branch
Department of Mines,
Resources and Environmental
Management
Manitoba

Information Canada
Ottawa 1972

Price $3.50 Cat. No. M38-2/124

ABSTRACT

The undiscovered mineral endowment of the (Canadian Shield) area of northern Manitoba was estimated on the basis of geological opinion gathered by means of questionnaires. From selected geologists who are intimately familiar with the area, a response was solicited in terms of probability of occurrence of certain numbers of deposits of various mineral commodities, within given ranges of tonnage and grade. Such judgments were supplied for 480 individual "cells" of one-half degree of longitude and one-quarter degree of latitude.

The individual judgments of the participating geologists were processed by computer to yield an average expectation on mineral occurrences in each cell. These average expectations are depicted in a series of mineral endowment maps of various commodities.

It is emphasized that these endowment estimates do not constitute a forecast of what actually will be found and mined. The results solely represent estimates of the occurrence of undiscovered mineral deposits (down to currently mineable depths), most of which could now be economically exploited; some would currently be sub-economic, but could be expected to become economic within two decades as a result of technological advance in mining efficiency or by better developed infrastructure. The estimate of the magnitude and distribution of undiscovered mineral endowment may be used in focusing private exploration efforts and in public planning for regional economic development.

RÉSUMÉ

Le potentiel minéral non découvert du Bouclier Canadien de la région nord du Manitoba a été estimé à la lumière d'opinions géologiques recueillies à l'aide de questionnaires. Ces opinions d'un groupe de géologues spécialement sélectionnés pour leur connaissance approfondie de cette région furent exprimés en terme de probabilité d'éventualité pour un certain nombre de gisements comprenant plusieurs minéraux individuels et plus spécifiquement en tenant compte de l'étendu du tonnage et de la teneur de chaque gisement. Ces jugements furent rapportés pour 480 "cellules" individuelles mesurant un demi-degré de longitude sur un quart de degré de latitude.

Les jugements individuels des géologues participants furent analysés par ordinateur pour en arriver à une moyenne expectative sur l'ensemble des gisements pour chaque "cellule". Ces moyennes expectatives sont représentées par une série de "cartes de potentiel minéral" pour divers minéraux et métaux.

On doit appuyer sur le fait que ces potentiels estimés ne constituent pas des prévisions de ce qui sera trouvé et mis en exploitation, mais plutôt, que ces résultats représentent uniquement des estimés d'éventualité de la présence de gisements non découverts, qui pour la plupart pourrait être exploités économiquement, soit présentement ou dans une ou deux décades, grâce aux changements technologiques ou par l'avènement d'une infrastructure plus dévelopée. L'estimé de la grandeur et de la distribution du potentiel minéral non découvert peut servir d'indicateur pour l'exploration minière privée et pour une meilleure planification publique en ce qui a trait au développement économique régional.

PREFACE

In 1970, an extensive resource potential survey was concluded for northern British Columbia and the Yukon Territory in connection with a comprehensive analysis by the Ministry of Transport of future rail transportation requirements in that region; the methodology and results of this resource potential survey are described in Mineral Information Bulletin MR 105. Encouraged by the results of this survey, the Mineral Resources Branch of the Department of Energy, Mines and Resources, Ottawa, and the Mines Branch of the Department of Mines, Resources and Environmental Management, Winnipeg, Manitoba, jointly launched a similar study to estimate the undiscovered mineral endowment of the Canadian Shield area in Manitoba and to assess its economic potential. The results can be used in both governmental and private industry planning for the formulation of strategies for mineral development in the study area. This paper covers the first phase of the study, mineral endowment estimation.

Future economic development of the study region, which is mostly in the northern half of Manitoba, depends strongly on the development of its natural resources. Mining in the Canadian Shield area of Manitoba is only in its infancy as compared to that in Ontario and Quebec, which would suggest that the undiscovered mineral endowment of northern Manitoba may be considerable.

Although estimation of mineral endowment is hampered by a great many uncertainties, planning nevertheless requires that a quantitative appraisal of some sort be made in terms of the size and grade distributions of possible mineral deposits. In this study, these distributions were expressed and appraised in terms of probabilities. The results are shown on a series of mineral endowment maps.

While a major working role was played by the computer in processing the data, the crucial ingredient was the basic information that was fed into the study. This was gathered through questionnaires from experienced geologists whose voluntary co-operation formed the foundation of this analysis. All individual responses were kept confidential; only responses in aggregated form are contained in this report.

The results presented in this report serve as an example of a successful co-operative effort by the mining industry, consultants, professional institutes and governments. The research also exemplifies a successful joint venture of provincial and federal governments. Mr. G.S. Barry of the Mineral Resources Branch, Ottawa, and Dr. I. Haugh of the Mines Branch, Winnipeg, initiated and organized this study. Dr. A. Azis (MRB) handled the computerization and interpreted all the obtained results. Dr. J. Zwartendyk (MRB, Resource Potential Evaluation Section) critically reviewed and edited the draft of the authors.

With appreciation for the excellent co-operation from the participating geologists and the organizations they represent, the Mineral Resources Branch and the Mines Branch publish the results of this co-operative study. It is hoped that this publication will foster additional interest in exploration in Manitoba, leading to discovery of a greater part of the impressive estimated mineral endowment here described.

W. Keith Buck
Director
Mineral Resources Branch
Department of Energy, Mines
and Resources
Ottawa

J.S. Roper
Director
Mines Branch
Department of Mines, Resources
and Environmental Management
Manitoba

April 1972

CONTENTS

TABLES

FIGURES

THE UNDISCOVERED MINERAL ENDOWMENT OF THE CANADIAN SHIELD IN MANITOBA

by

Azman Azis, George S. Barry* and Ian Haugh***

INTRODUCTION

Estimating a region's unknown mineral endowment is a difficult undertaking that has to be conducted with a sound realization of the inherent hazards. In effect, such an assessment can be little more than a sophisticated approach to crystal ball gazing. The cardinal assumption made here is that if enough geologists ponder an area's mineral history and apply their knowledge, experience and intuition, we can distil from their judgments a meaningful appraisal of the remaining mineral potential of a given region. A basic requirement is that the judgment of each respondent be expressed in a form that can be analyzed to provide a collective picture of the potential.

The approach used in this project is patterned on a survey done for northern British Columbia and the Yukon Territory (Barry and Freyman, 1970). That study involved a comprehensive analysis of resource potential and possible transportation requirements. The published material represents only a part of the assessment; the overall study also involved the simulation of exploration effort, economic evaluation of deposits that might be discovered, and mine production (Harris, Freyman and Barry, 1970).

Upon analysis of the results of the Northwest study, a joint committee from the Department of Energy, Mines and Resources, Ottawa, and the Department of Mines, Resources and Environmental Management, Manitoba (formerly Mines and Natural Resources), recommended to the respective Ministers in January 1970 that a joint mineral resource study be undertaken, patterned on the Northwest analysis. Such a joint study was approved in principle in March 1970 and initiated during late April 1970.

* Mineral Economists, Mineral Resources Branch, Department of Energy, Mines and Resources, Ottawa.

** Chief Geologist, Mines Branch, Department of Mines, Resources and Environmental Management, Manitoba.

PREVIOUS WORK REGARDING ASSESSMENT OF MINERAL ENDOWMENT*

Qualitative Approaches

There exists a considerable body of literature that illustrates the qualitative approach to assessing the mineral endowment of a region and that describes future expectations of mine development based on such an assessment. Such an approach focuses on the gathering of information on known and potential deposits and on a qualitative evaluation of the relative geological promise of certain tracts of mineralization. Examples are the Royal Commission Report evaluating the proposed railway to Pine Point (Manning, 1960), and the Battelle study on the Pacific Northwest (1961).

Quantitative Approaches

Quantitative approaches to the assessment of mineral endowment, as aids to exploration and regional resource surveys, are a relatively recent development. Allais (1957) did the pioneering work on mining districts in the Sahara; he used a spatial analysis based on the distribution of minerals in a well-developed area to assess the mineral endowment of other areas. Since then, the literature on quantitative methods has been growing rapidly, but most of it applies to petroleum. Among the relatively few developments in the quantitative theory for metallic and nonmetallic minerals, the most significant contribution was made by Harris (1965), who employed multivariate analysis to establish relationships between some geological parameters and the known resources of a thoroughly explored and developed area. Applying probability theory, he used those relationships to infer the probable mineral endowment in a less well developed area.

Comparable experimental methodologies are also being developed by the British Columbia Research Council and by the Geological Survey of Canada. The GSC approach is to estimate the mineral potential of a region by sampling on geological, geochemical and geophysical variables in rather restricted, geologically well defined regions.

Another approach is to use the opinions of geologists who are familiar with the geology of the study area. This method is based primarily on "subjective probability"; a geologist states his expectation of possible mineral occurrences in terms of tonnages, grades and number of deposits. It was used in the study of resource potential and transportation requirements of the Canadian Northwest (Harris, et al., 1970) and is basically the one employed here.

*"Mineral endowment", as used in this report, refers to higher than normal concentrations of minerals present in the earth's crust, as yet unknown, which, when discovered, might be economically exploitable in the coming decades.

DESCRIPTION OF STUDY PROCEDURES

Study Area

The study area is a portion of the Province of Manitoba, lying between latitudes 49°00' and 60°00', and longitudes 91°30' and 102°00'. It covers an area of 161,447.5 square miles, which is about 64 per cent of Manitoba. It includes all of the area of Precambrian rocks of Manitoba, which is divided into the Superior and Churchill provinces and contains the well-known "Nickel Belt". The study area was divided into 480 cells of 300 to 400 square miles depending on latitude. The cells have been grouped into 18 geological regions (Table 1 and Figure 1).

Methodology

The methodology used to estimate the mineral endowment in this study was originally formulated by Harris, Freyman and Barry in their efforts to estimate the mineral endowment of northern British Columbia and the Yukon Territory. It is an application of probability theory to traditional geological analysis: geologists' opinions are expressed in terms of subjective probabilities.

The major operational problem with subjective probabilities is that the stated resource potential of an area is a function of the experience, imagination and attitude of the geologist. In general, he will tend to underestimate the resources; by and large, one might expect that pessimistic

TABLE 1
THE STUDY AREA

	Geological Region	Number of Cells	Area of Region (square miles)
I	West Hawk Lake	14	5,418.6
II	Winnipeg River-Rice Lake	12	4,533.3
III	Lake Winnipeg East	56	20,321.2
IV	Island Lake	14	4,962.3
V	Cross-Oxford-Gods Lakes	79	27,365.3
VI	Fox River	16	5,396.2
VII	Nickel Belt	23	7,834.5
VIII	Flin Flon-Wekusko Lake	10	3,470.0
IX	Sherridon	15	5,133.9
X	Pukatawagan	9	3,047.6
XI	Russell-Mynarski Lakes	15	5,032.4
XII	Lynn Lake-Ruttan Lake	17	5,626.0
XIII	Paskwachi-Southern Indian Lake	20	6,506.5
XIV	Churchill River	37	12,186.7
XV	Brochet-South Knife Lake	50	15,948.4
XVI	Seal River	35	10,771.0
XVII	Munroe Lake	30	9,237.0
XVIII	Thlewiaza River	28	8,656.6
	Total	480	161,447.5

THE STUDY AREA

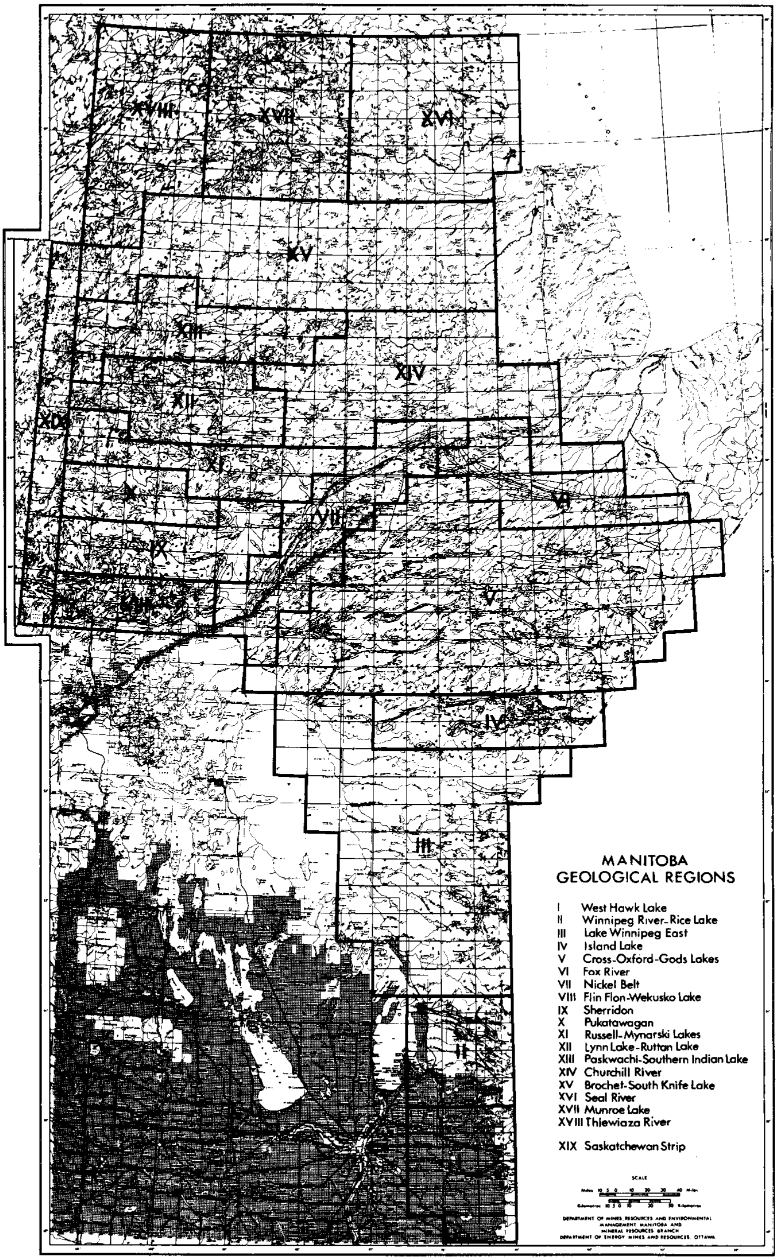


Figure 1

and optimistic attitudes would balance out, but this is apparently not the case since the "average" geologist seems to be somewhat of a pessimist. The study area is a relatively unexplored region whereas the bulk of a geologist's experience has been in areas of active exploration, areas in which he is likely to think the probability for discovery of additional deposits is fairly good. He has no experience relative to what really exists in an unexplored area and tends to be conservative about its potential. This is evident from the distribution of individual responses obtained for "well known" cells and "very poorly known" cells.

The approach used in this study for the evaluation of mineral potential is very similar to that employed in the Canadian Northwest study. A few changes and additions were made in the tonnage and grade classifications and in the number and type of mineral commodities being studied. These changes were necessary to make the method applicable to the study area, which comprises a different geological environment.

Participating Geologists

Seventeen geologists, familiar with the geology of the study area, voluntarily participated in this survey. Eleven of these geologists were from industry and two from the academic field (formerly having worked for industry). The other four geologists were from federal and provincial government offices. The questionnaires completed by these experts served as the basic data for the analysis. The average opinion of these geologists is represented as their estimate of the mineral endowment of Manitoba.

General Geology of the Area

The Canadian Shield of Manitoba is divided into two structural provinces, the older Superior Province and the younger Churchill Province. These geological provinces are separated by the northeast-trending "Nickel Belt".*

The analysis required a generalization of geological units. All rocks were grouped into four categories: volcanic and sedimentary ("greenstone") belts, paragneisses and migmatites, mafic and ultramafic intrusions, and granitoid rocks.

Commodities Investigated

Fifteen commodities, most of them nonferrous metals, were investigated in the survey. These are: copper, zinc, lead, nickel, molybdenum, asbestos, tungsten, uranium, gold (and silver), lithium, tin, beryllium, chromium, columbium and iron.

* For the comparative purposes of this analysis, it is assumed that the Flin Flon-Wekusko greenstone belt and the Lynn Lake greenstone belt are essentially remnants of older Superior rocks within the Churchill Province.

Some of these metals occur together, such as copper and zinc, lead and zinc, and gold and silver. The survey was structured to give an expression of endowment for the "main metal"; other metals associated within the same deposit were counted in terms of "equivalents" of the main metal by conversion through the price ratio.

Mineral fuels (including coal) and nonmetallic minerals were excluded as the survey only covered rocks of the Precambrian Shield.

Tonnage and Grade Classification

The tonnage of ore considered in this study ranges from 0.5 to 200 million tons and was divided into seven classes: .5-1, 1-5, 5-10, 10-25, 25-50, 50-100, 100-200. A large low-grade nickel deposit of 400 million tons would be considered as two deposits.

Three grade categories were used in this survey: Low-Grade, Medium-Grade and High-Grade (Table 2). These grades were defined in consultation with geologists who took part in the pilot survey. The low grade deposits would be uneconomic to exploit at the present time, but if found may be held by a company for development under improved economic conditions.

Prices Used in Analysis

To facilitate a comparison of the results obtained in this study with those from the British Columbia and Yukon Territory mineral endowment study, the same metal prices were employed. These prices are listed in Table 3.

TABLE 2

GRADES CLASSIFICATION

Commodity	Low-Grade	Medium-Grade	High-Grade
Copper-zinc (% Cu)	0.5 - 0.9*	1.0 - 2.9	3.0 - 6.0
Zinc-copper (% Zn)	2.0 - 3.9	4.0 - 7.9	8.0 - 16.0
Lead-zinc (% Pb)	2.0 - 3.9	4.0 - 7.9	8.0 - 16.0
Nickel (% Ni)	0.4 - 0.5	0.6 - 2.5	2.6 - 4.0
Molybdenum (% MoS_2)	0.2 - 0.4	0.5 - 0.9	1.0 - 2.0
Asbestos ($/T)	2.0 - 5.0	6.0 - 15.0	16.0 - 35.0
Tungsten (% WO_3)	0.2 - 0.4	0.5 - 1.9	2.0 - 3.0
Uranium (% U_3O_8)	0.01 - 0.04	0.05 - 0.30	0.40 - 1.00
Gold ($/T)	5.0 - 9.0	10.0 - 41.0	41.0 - 70.0
Lithium (% Li)	1.0 - 1.4	1.5 - 2.4	2.5 - 4.0
Tin (% Sn)	0.3 - 0.5	0.6 - 0.9	1.0 - 2.0
Beryllium (% Be)	0.40 - 0.69	0.70 - 0.99	1.00 - 2.00
Chromite ($/T)	10.0 - 19.0	20.0 - 29.0	30.0 - 60.0
Columbium (% Cb_2O_5)	0.15 - 0.19	0.20 - 0.29	0.30 - 0.60
Iron (% Fe)	15.0 - 25.0	25.0 - 45.0	45.0 - 60.0

* Read 0.999%.

TABLE 3
PRICES USED IN THE ANALYSIS

Commodity	Price ($/lb)
Copper	.50
Zinc	.15
Lead	.15
Nickel	1.30
Molybdenum (MoS_2)	1.70
Tungsten (WO_3)	1.825
Uranium (U_3O_8)	8.00
Lithium	.45
Tin	1.65
Beryllium	.175
Columbium (Cb_2O_5)	.85
Iron	.01

Note:
1. Since ore values of asbestos, gold, and chromite were given in the questionnaire in $/T, no price for these commodities has been listed in Table 3.
2. The price of beryllium is based on the price of ore with a grade of 10-12% at $35-$37/ton.
3. The price of iron is based on the price of ore with average grade 51.5% at $10.55-$10.80/long ton.

Computation Technique

The questionnaire completed by the respondents for each cell is shown in Figure 2. Its design was the result of a compromise between a desire to gather a large amount of information for probability analyses, and the constraint imposed by the time each respondent could be expected to spend on the exercise, in this case, no more than three or four days.

Basically the respondents were asked to complete a form for each cell, according to their best judgment, to provide quantitative responses to three questions, viz. what is:

(i) the most likely total number of deposits, of any minerals studied, that might be found in a cell (a unit area), in size and grade ranges that would now be economic or close to it;

(ii) the most likely distribution of mineral categories (as shown on the questionnaire) in these deposits; and

(iii) the most likely tonnage and grade of each mineral category.

THE QUESTIONNAIRE

LAT & LONG OF N E CORNER OF CELL

COPPER & COPPER – ZINC	GRADE %		
TONS MILLIONS	0.5 → 0.9	1.0 → 2.9	3.0 → 6.0
·50 – 1			
1 – 5			
5 – 10			
10 – 25			
25 – 50			
50 – 100			
100 – 200			

ZINC & ZINC – COPPER	GRADE %		
TONS MILLIONS	2.0 → 3.9	4.0 → 7.9	8.0 → 16.0
·50 – 1			
1 – 5			
5 – 10			
10 – 25			
25 – 50			
50 – 100			
100 – 200			

LEAD – ZINC	GRADE %		
TONS MILLIONS	2.0 → 3.9	4.0 → 7.9	8.0 → 16.0
·50 – 1			
1 – 5			
5 – 10			
10 – 25			
25 – 50			
50 – 100			
100 – 200			

NICKEL	GRADE %		
TONS MILLIONS	·4 → ·5	·6 → 2·5	2.6 → 4·0
·50 – 1			
1 – 5			
5 – 10			
10 – 25			
25 – 50			
50 – 100			
100 – 200			

MOLYBDENUM	GRADE		
TONS MILLIONS	0.2 → 0.4	0.5 → 0.9	1.0 → 2.0
·50 – 1			
1 – 5			
5 – 10			
10 – 25			
25 – 50			
50 – 100			
100 – 200			

ASBESTOS	GRADE $/T		
TONS MILLIONS	2 → 5	6 → 15	16 → 35
·50 – 1			
1 – 5			
5 – 10			
10 – 25			
25 – 50			
50 – 100			
100 – 200			

TUNGSTEN	GRADE		
TONS MILLIONS	0.2 → 0.4	0.5 → ·9	2.0 → 3.0
·50 – 1			
1 – 5			
5 – 10			
10 – 25			
25 – 50			
50 – 100			
100 – 200			

URANIUM	GRADE % U_3O_8		
TONS MILLIONS	·01 → ·04	·05 → ·3	·4 → 1·0
·50 – 1			
1 – 5			
5 – 10			
10 – 25			
25 – 50			
50 – 100			
100 – 200			

GOLD	GRADE $/T		
TONS MILLIONS	5 → 9	10 → 41	41 → 70
·50 – 1			
1 – 5			
5 – 10			
10 – 25			
25 – 50			
50 – 100			
100 – 200			

OTHER	GRADE %		
TONS MILLIONS	↓	↓	↓
·50 – 1			
1 – 5			
5 – 10			
10 – 25			
25 – 50			
50 – 100			
100 – 200			

OTHER	GRADE		
TONS MILLIONS	↓	↓	↓
·50 – 1			
1 – 5			
5 – 10			
10 – 25			
25 – 50			
50 – 100			
100 – 200			

NUMBER OF DEPOSITS	PROBABILITY
0	
1	
2	
3 – 5	
5 – 7	
7 – 9	
9 – 12	
12 – 15	

NOTES:

MINERAL RESOURCES BRANCH
DEPARTMENT OF ENERGY MINES AND RESOURCES

Figure 2

For simplicity, these probabilities were expressed as index numbers. All of these indices were evaluated through a computer program that calculated the average number of deposits, tonnage, grade and metal content for each mineral commodity expected to be present in the cell.

The technique of computation can be summarized as follows:

Let:

p_i = a probability index of the total number of deposits in the cell, where: i = 1, 2, ..., 8 indicates the class of the number of deposits (e.g., 7-9 deposits is class No. 6 on the questionnaire);

q_j = a probability index of the distribution of mineral categories in the cell, where: j = 1, 2, ..., 15 indicates the commodity being studied;

r^j_{kl} = a joint probability index of the average tonnage and grade of commodity j, where: k = 1, 2, ..., 7 and l = 1, 2, 3 represent respectively seven classes of tonnage and three classes of grade (see questionnaire).

Furthermore let:

$$P = \sum_{i=1}^{8} p_i, \quad Q = \sum_{j=1}^{15} q_j, \quad R^j = \sum_{k=1}^{7} \sum_{l=1}^{3} r^j_{kl}$$

Then,

(1) The total number of mineral deposits in the cell:

$$M = \sum_{i=1}^{8} \left\{ (p_i / P) \cdot m_i \right\}$$

where: m_i = midpoints of the classes in the number of deposits.

(2) The number of deposits of commodity j.

$$N^j = (q_j / Q) \cdot M$$

where: j = the commodity index.

(3) The average size (tonnage) of deposit of commodity j:

$$T^j = \sum_{k=1}^{7} \left\{ \left(\sum_{l=1}^{3} r^j_{kl} \Big/ R^j \right) \cdot t^j_k \right\}$$

where: t^j_k = midpoints of tonnage classes for commodity j

(4) The average grade of deposit of commodity j

$$G^j = \sum_{k=1}^{7} \left\{ \sum_{l=1}^{3} (r^j_{kl} \cdot g^j_l) \Big/ \sum_{l=1}^{3} r^j_{kl} \cdot t^j_k \cdot \sum_{l=1}^{3} r^j_{kl} \Big/ R^j \right\} \Big/ T^j$$

where: g^j_l = midpoints of grade classes for commodity j

(5) The total metal content of commodity j in the cell.

$$C^j = N^j \cdot T^j \cdot G^j$$

Based upon this information, a total metal content was allocated to each cell. To derive the average metal content per square mile, the amount of metal in the cell was divided by the area of the cell.

Each respondent's data were processed to produce the individual's expected values. Expected values for the study were arrived at by taking the arithmetic mean of all individual expected values. Statistical procedures were used to test the significance of these figures.

Output of Computer Model

A sample of the computer output is shown in Table 4, for one mineral commodity in cell X. Seventeen respondents were evaluated in this case. This is a relatively small sample; consequently, the results reflect statistical bias.

The average number of deposits in cell X, as computed from the subjective probabilities given by the seventeen respondents, is 2.25 with a standard deviation of 1.43 and a 95% confidence interval of 1.49 to 3.01. The low expectation is no deposits at all, while the high expectation is the occurrence of five or six deposits.

The following formulae were used to compute the standard deviation and 95% confidence interval:

$$S = \sqrt{\frac{\sum_{i=1}^{n} X_i^2}{n-1} - \frac{\left\{\sum_{i=1}^{n} X_i\right\}^2}{n(n-1)}}$$

$$CI_{.95} = \bar{X} \pm t_{.975} (S \sqrt{n-1})$$

where: n = sample size.
S = standard deviation.
X_i = value of observation.

$$\bar{X} = \text{mean of } X_i = \sum_{i=1}^{n} X_i/n$$

$CI_{.95}$ = 95% confidence interval.
$t_{.975}$ = value of student - t distribution at $(n-1)$ degrees of freedom.

Since the questionnaire was designed in a form in which the subjective probabilities for tonnage and grade are interdependent (joint probability) and since the amount of metal content was derived from these figures, only a weighted average may be computed for grade and tonnage per deposit.

In addition to the amount of metal content per square mile, the computer output shows the expected total amount of metal content in the cell (in the lower right hand corner of Table 4).

TABLE 4

A SAMPLE OF COMPUTER OUTPUT FOR CELL X (17 RESPONDENTS)

NICKEL

Geologists	# Deposits	Tonnage per Deposit (million tons)	Grade (%)	Metal Content (tons/sq.mi.)
A	2.67	93.1	2.62	19,140
B	0.00	0.0	0.00	0
C	1.13	8.3	1.78	492
D	1.33	19.0	1.85	1,381
E	2.37	19.7	1.59	2,176
F	4.44	21.4	1.54	4,324
G	1.08	37.1	0.67	794
H	1.94	134.4	1.40	10,753
I	5.40	98.1	0.76	11,834
J	3.30	37.2	2.00	7,245
K	4.00	9.0	1.94	2,058
L	1.18	21.0	1.80	1,309
M	3.25	67.2	1.32	8,493
N	1.84	2.7	1.40	205
O	0.85	20.7	1.70	880
P	1.33	1.5	0.65	39
Q	2.13	18.6	0.58	674
Average	2.25	45.0*	1.42*	4,223
Std. Deviation	1.43	-	-	5,459

Tonnage Class**	Most Likely Tonnage at Grade Range of (%)				Tonnage Class Midpoints**	Most Likely Metal Content (million tons)			
	0.4-0.5	0.6-2.5	2.6-4.0	Total		0.50	1.60	3.30	Total
.5- 1	0.030	0.050	0.0	0.080	0.75	0.00011	0.00060	0.0	0.00071
1 - 5	0.056	0.090	0.007	0.153	3.00	0.00084	0.00433	0.00071	0.00588
5 - 10	0.057	0.187	0.073	0.317	7.50	0.00212	0.02241	0.01814	0.04268
10 - 25	0.143	0.356	0.063	0.562	17.50	0.01249	0.09967	0.03661	0.14876
25 - 50	0.060	0.278	0.050	0.388	37.50	0.01117	0.16693	0.06228	0.24038
50 -100	0.205	0.259	0.049	0.513	75.00	0.07694	0.31093	0.12037	0.50823
100 -200	0.131	0.096	0.010	0.237	150.00	0.09828	0.23091	0.04710	0.37629
Total	0.681	1.316	0.252	2.250	Total	0.20195	0.83578	0.28521	1.32294

* Weighted Average.
** Millions of tons.

In the bottom part of the table, the distributions shown are of tonnage and metal content at various levels; the figures are based on the aggregate subjective probabilities.

RESULTS AND ANALYSES

General

The results of the survey are summarized in Table 5. A series of maps accompanying this report portray the regional distribution of the estimated mineral endowment. The total "place value" of the mineral commodities studied was calculated using the commodity prices shown in Table 3. The expected gross place value of minerals in the study area, is $73.4 billion. The figures in Table 5 are for the whole study area, which covers about 161,447 square miles.

The major points revealed by the survey are as follows:

- On the basis of the replies from the seventeen respondents who participated in the survey, 470 mineral deposits occur in the whole region, exluding deposits of mineral fuels, and nonmetallic and industrial minerals which were not considered in this study.

- The estimate for the total "place value" of the undiscovered mineral endowment in the study area is $73.4 billion. The place value is the nominal value in the ground, before costs of exploration, development, mining, processing and transportation have been considered.

- Of the total ores expected to occur within Manitoba's Canadian Shield, about 19 per cent are in the low-grade or "submarginal" category, 58 per cent are in the medium-grade category, and 23 per cent in the high-grade category. The high- and medium-grade ores are considered to be economic for exploitation at current market prices and production costs.

- The average place value of undiscovered mineral endowment in Manitoba's Precambrian rocks (up to mining depth of about 5,000 ft) is expected to be about $455,000 per square mile. Approximately one undiscovered mineral deposit with an average place value of about $156 million is expected to occur per 344 square miles (about the equivalent of the average cell size).

TABLE 5

THE UNDISCOVERED MINERAL ENDOWMENT OF MANITOBA

The Estimates of Number of Deposits, Tonnages, Place Values and Grades of Mineral Commodities

Commodity	# Deposits	Total Tonnage	Total Place Value	Average per Deposit		Average Grade	
				Tonnage	Place Value		
		(million tons)	(million $)	(million t.)	(million $)	(%)	($/ton)
Copper	176.	740.62	14,185.3	4.21	80.60	1.92	19.15
Zinc	45.	206.84	3,377.9	4.60	75.06	5.44	16.33
Lead	13.	48.73	750.5	3.75	57.73	5.13	15.40
Nickel	81.	1,404.60	41,883.8	17.34	517.08	1.15	29.82
Molybdenum	14.	257.2	4,410.0	18.37	315.00	0.50	17.15
Asbestos	6.	62.1	634.9	10.35	105.82	-	10.22
Tungsten	4.	8.4	307.8	2.10	76.95	1.01	36.64
Uranium	19.	130.7	2,993.4	6.88	157.55	.14	22.90
Gold	92.	189.2	3,439.8	2.06	37.39	-	18.18
Lithium	11.	29.8	433.2	2.71	39.38	1.61	14.54
Tin	1.	5.9	371.5	5.90	371.50	1.92	62.97
Beryllium	0.3	.6	1.3	2.00	4.33	.59	2.17
Chromium	5.	44.1	37.3	8.82	7.46	-	.84
Columbium	-	-	-	-	-	-	-
Iron	3.	117.0	533.3	39.00	184.43	23.6	4.73
TOTAL	470.3		73,380.0				

- Nickel, copper, molybdenum, gold, zinc, and uranium are the principal minerals expected to occur in the region. The aggregate value of these minerals accounts for about 96 per cent of the total place value of the study area (Table 6). However, it should be noted that of the above, molybdenum is expected to occur largely in "submarginal" grades.

TABLE 6

PRINCIPAL MINERALS OF THE STUDY AREA

Commodity	Ore Tonnage (million tons) Subeconomic Grades	Economic Grades	Place Value ($ billion)	(% of total)
Nickel	542	863	41.9	57.1
Copper-zinc	244	497	14.2	19.3
Molybdenum	177	81	4.4	6.0
Gold-silver	92	98	3.4	4.7
Zinc-copper	68	139	3.4	4.6
Uranium			3.0	4.1
Others			3.1	4.2
Total			73.4	100.0

- None of the seventeen geologists expected the occurrence of columbium deposits in the region, while only a few of them indicated probable occurrences of lead, lithium, tungsten (wolframite), asbestos, tin, beryllium, chromium and iron deposits.
- With the exception of nickel deposits in the Nickel Belt, most of the expected deposits are of small size with relatively high grades. The average size of a deposit is generally below 10 million tons and most of the estimated deposit sizes are even below 5 million tons. Only nickel, molybdenum, asbestos and iron are expected to occur in large deposits of over 10 million tons.
- Of the 470 deposits thought to be present, 349 (or 74%) are accounted for by copper-zinc, gold and nickel. The estimates imply that Manitoba could have an additional 176 copper-zinc deposits, 92 gold deposits and 81 nickel deposits. The average tonnage and grade of these deposits are 4.2 million tons at 1.92% Cu (= $19.15/ton) for copper, 2.1 million tons at $18.18/ton for gold, and 17.3 million tons at 1.15% Ni (= $29.82/ton) for nickel.

- Most of the deposits are estimated to have an average grade between $14.50 and $37.00 per ton of ore (Table 5). The expected distribution of certain grade ranges of the undiscovered mineral endowment in Manitoba's Precambrian rocks is shown in Table 7.

TABLE 7

GRADE DISTRIBUTION OF MANITOBA'S MINERAL ENDOWMENT

Grade Range ($/ton)	% of Total Tonnage of Ore
Less than 10	5.0
10 - 20	47.3
20 - 30	47.3
Over 30	.4
Total	100.0

- The aggregate mineral endowment value for the sub-regions in the study area ranges from $46,000 per square mile for the Lake Winnipeg East region to $3,893,000 per square mile for the Nickel Belt.

- The regions of lowest endowment (having an aggregate endowment value of less than $100,000 per square mile) are Region III - Lake Winnipeg East, Region X - Pukatawagan, and Region XV - Brochet-South Knife Lake (Figures 3 and 4). Most of these regions are underlain by granitoid rocks and contain little or no metavolcanic and metasedimentary rocks. Although their average endowment is low, some respondents still consider that a few deposits could still be located in these regions and have portrayed their judgment by "allocating" one deposit to a dozen or more cells within each region.

- The richest regions, which contain more than $800,000 worth of mineral endowment per square mile, are Region VII - Nickel Belt, Region VI - Fox River, Region VIII - Flin Flon-Wekusko Lake, and Region XII - Lynn Lake-Ruttan Lake (Figure 3). Manitoba's production of nickel, copper, zinc, gold and silver has come mainly from these regions. The Nickel Belt and Fox River regions are considered to be predominantly nickel-bearing regions, containing more than 1,400 tons and 300 tons of nickel per square mile respectively.

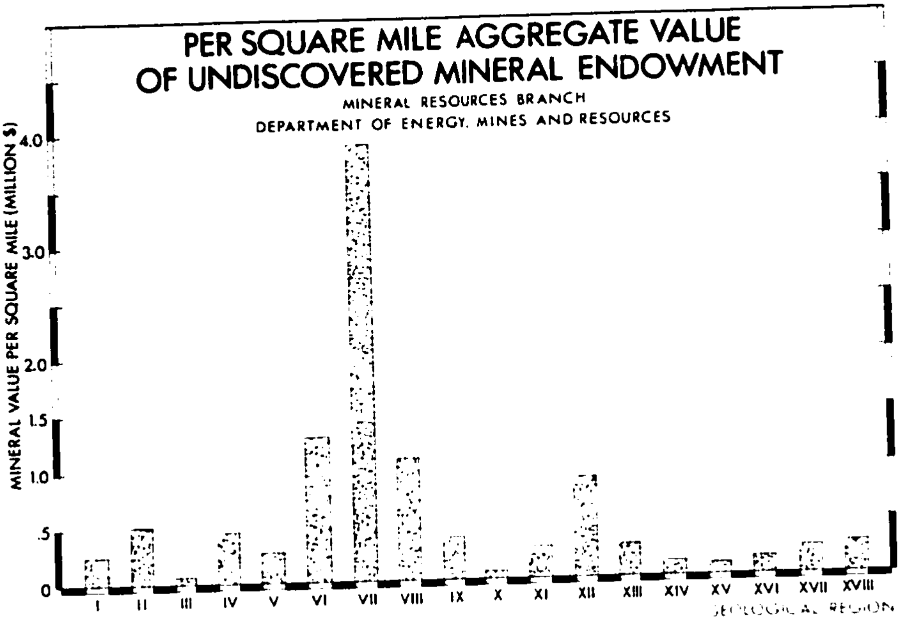


Figure 3

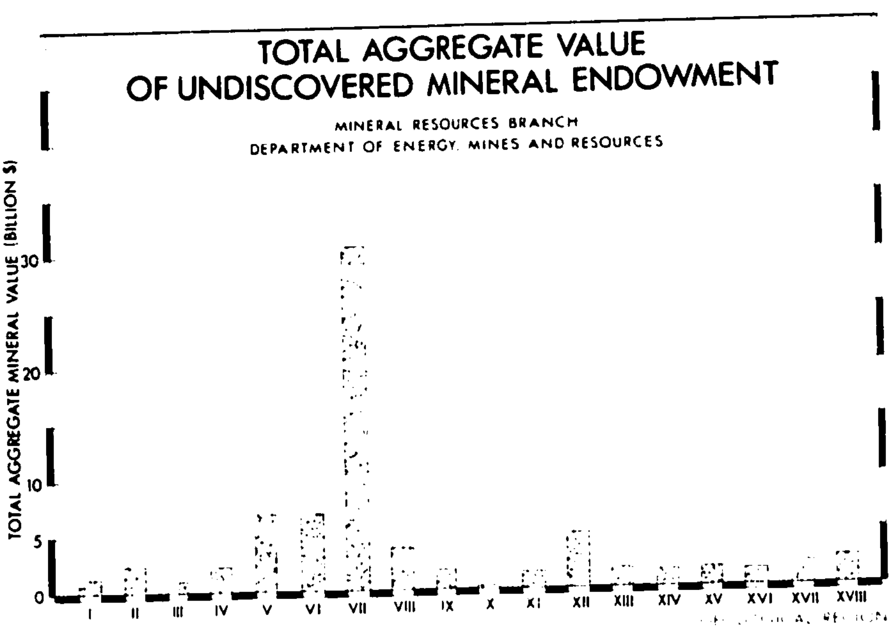


Figure 4

On the other hand, in the Flin Flon-Wekusko Lake and Lynn Lake-Ruttan Lake regions copper and zinc are the predominant minerals. On the average, over 700 tons of combined copper-zinc are expected for every square mile of these regions.

Table 8 and Figure 5 show the principal minerals that are estimated to be present within the richest geological regions of the study area. It is significant that the nickel endowment estimate for the Nickel Belt overshadows other values. The place value of $29.2 billion for nickel in this region corresponds to 40 per cent of the entire endowment estimate for Manitoba.

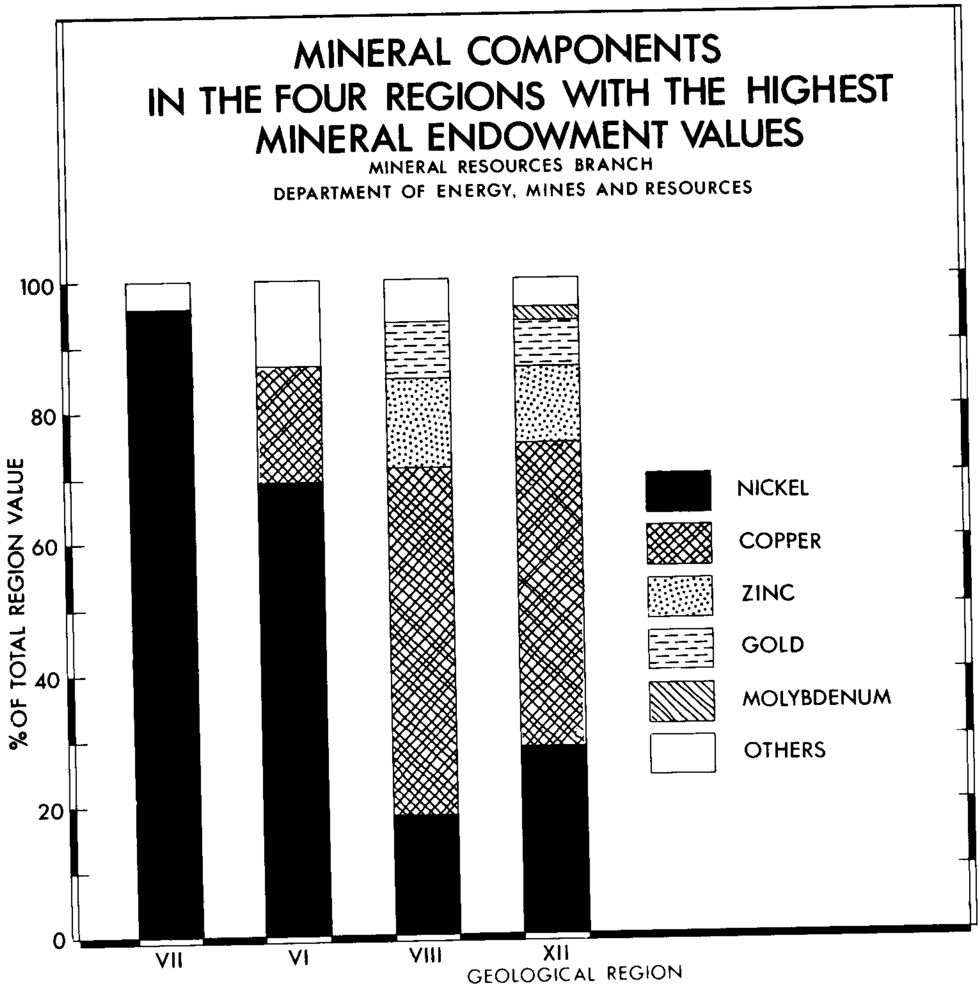


Figure 5

TABLE 8

ENDOWMENT VALUES OF MAJOR METALS
FOR THE FOUR REGIONS WITH THE HIGHEST MINERAL WEALTH

Commodity	Region VII Nickel Belt		Region VI Fox River		Region VIII Flin Flon - Wekusko Lake		Region XII Lynn Lake - Ruttan Lake	
	Value of Endowment	% of Total Value	Value of Endowment	% of Total Value	Value of Endowment	% of Total Value	Value of Endowment	% of Total Value
	(million $)		(million $)		(million $)		(million $)	
Nickel	29,163.1	95.6	4,727.0	69.2	673.5	18.1	1,397.0	28.5
Copper	428.3	1.4	1,186.8	17.4	1,967.5	52.8	2,250.8	46.0
Molybdenum	545.2	1.8	142.3	2.1	24.8	.7	100.1	2.0
Zinc	127.3	.4	77.7	1.1	511.6	13.7	567.2	11.6
Gold	79.8	.3	60.1	.9	331.9	8.9	374.8	7.7
Others	156.3	.5	638.5	9.3	217.7	5.8	207.4	4.2
TOTAL	30,500.0	100.0	6,832.5	100.0	3,727.0	100.0	4,897.3	100.0
Area (sq. mile)	7,834.5		5,396.2		3,470.0		5,626.0	
Aggregate value of mineral endowment per sq. mile (thousand $)	3,893.0		1,266.0		1,074.0		870.0	

- The distributions of nickel, copper, molybdenum, zinc, gold, uranium and lead are shown on the mineral endowment maps. These maps are based on the amount or value of metal content in the cell. They can be used as a guide for exploration for a specific commodity. On the other hand, Map I ("Aggregate") illustrates aggregated values of all minerals studied and can be used as a guide for regional multiresource development planning. The expectations portrayed may also be used in the appraisal of trade-offs that must be considered in resource development projects, and in schemes that would preclude future use of certain resources in a given region.

Comments on Interpretation of Results

At this point, it is important to emphasize that the results of the survey can be interpreted only as an expectation of the mineral potential in the study area. This potential cannot be interpreted as known economic reserves because, for example:

(i) the deposits must still be discovered through exploration, and this involves uncertainty. The major factor that determines the rate of discovery in general is the amount of exploration expenditure, but many other factors influence discovery such as depth and size of deposit, the type of cover and the topographical conditions of the area;

(ii) those deposits that are discovered through exploration will be subjected to an economic evaluation. Some of the low grade deposits included in the endowment would not be economically exploitable under current economic conditions, even though future improvement in technology and expansion of the transportation network are eventually expected to make their exploitation economically feasible.

Many factors must be considered in the economic evaluation, and most of them are subject to change through time. Among these factors are costs associated with, development, operation, transportation, power, capital, depreciation, depletion allowances, federal and provincial taxes, royalties, duties, prices of input factors and product prices.

One of the essential requirements in this type of endowment survey is to avoid taking the results completely at their face value as far as absolute numbers or dollar values are concerned. The results should only be interpreted in the light of their relative values. Thus we can identify, within a large region, numerous subregions (a cell or group of cells) that in a relative sense are expected to be very promising, average, or below average, while some are identified as having little or no mineral potential. Such judgments can be of substantial value to planners if there is an assurance that the collective judgment represents a broad and statistically valid sampling of expert opinion.

We should, however, be able to expect logical relationships between estimated endowment values and what has already been discovered or extracted from a surveyed region and its contiguous areas. We should be able also to compare values obtained in one "geological province" with those of another, and to examine the results in the context of recent metallogenic studies and concepts.

In general it is easy to accept a certain minimum potential but perhaps rather difficult to establish what is a logical ceiling for mineral endowment expectations. From past experience, we find that economic geologists or mineral economists tend to be much too conservative in their estimates. One example of this was seen in the 1952 Paley Commission's Presidential Report (U.S.) which underestimated the continent's ability to greatly increase mineral production. An example closer to home is the recently completed northern British Columbia and Yukon Territory study in which the estimated endowment, although high at first glance, is conservative when compared to some mining districts in the Cordilleran region of the contiguous United States.

As stated earlier, the total estimated undiscovered endowment of Manitoba's Canadian Shield, in terms of gross value, is \$73.4 billion, or \$455,000 per square mile. This is twice as high as the value of \$220,000 per square mile for the Canadian Northwest (minor metals and minerals as well as fossil fuels were not taken into account in either study). But the high value for Manitoba is primarily due to the high expectation of nickel occurrences in the Nickel Belt; if we exclude nickel, the value for other minerals is \$195,000 per square mile.

Map I "Aggregate" shows that 31 per cent of the survey area contains 85 per cent of the total mineral value. This spatial distribution of values predictably centres around the Nickel Belt, Fox River, Flin Flon-Snow Lake-Wekusko Lake, and Lynn Lake-Ruttan Lake regions, characterized mainly by large greenstone belts and nickel-bearing environments. However, the area of influence is much more extensive, reaching into many subregions underlain by schists and gneisses of sedimentary origin as well as into areas of poorly defined geology.

Comments on the Spatial Distribution of Individual Commodities (Maps II to VIII)

Nickel. Nickel is the most important metal in the study area. At the price listed in Table 3 ($1.30/lb Ni) its place value constitutes more than 57 per cent of the total value of mineral endowment in the survey area (40% from Nickel Belt). It is estimated that there are about 1.4 billion tons of undiscovered nickel ore having an equivalent average grade of 1.15% nickel or containing about 16.2 million tons of metal. If we consider only the medium- and high-grade ores (ores with a grade of at least 0.6 per cent nickel), the undiscovered nickel endowment of Manitoba is estimated to be about 862.7 million tons of ore containing 13.5 million tons of nickel (Table 9). This is equivalent to 19 times the cumulative provincial nickel production to 1970 (700,000 tons since 1955).

TABLE 9

ESTIMATED TONNAGES OF NICKEL ORE IN THE STUDY AREA

Ore Classification	Grade (% Ni)	Ore Tonnage (million tons)	(% of total)
Low-Grade	0.4-0.6	541.9	38.6
Medium-Grade	0.6-2.6	726.7	51.7
High-Grade	2.6-4.0	136.0	9.7
Total		1,404.6	100.0

Cells which show a high potential for nickel correspond either with areas of known ultramafic rocks or with areas of known nickel sulphide mineral deposits, or both. The indicated potential for the Nickel Belt and Fox River areas best exemplify this observation. Obviously the prediction of a potential for a given area is only as good as the information available from judging that area. Thus the continued refinement of our present knowledge of the distribution of ultramafic rocks will lead to a substantial re-evaluation of the results of this survey.

The most important nickel region is Region VII - the Nickel Belt (Figure 6) with an estimated endowment of 11.9 million tons of metal representing 73.4 per cent of the provincial total. (Based on tonnage of ore rather than metal content, the percentage is 68.2.)

The Nickel Belt is a complex zone of metamorphic and cataclastic rocks with numerous ultramafic bodies and associated nickel sulphide deposits. The predicted high potential indicated for this area has an obvious correlation.

Thirty-one nickel deposits are estimated to lie undiscovered in the Nickel Belt with an average size of 31 million tons each; six of these would average 68 million tons at 0.96% Ni, and 25 would average 22 million tons at 1.32% Ni.

Against this background, the Mineral Resources Branch of EMR, Ottawa made an independent estimate of total ore for most known deposits within the Manitoba Nickel Belt. Twelve deposits were considered, six with grades of 0.45% to 0.9% Ni: Mystery, Moak, Grass, Bowden, Bucko and Hambone; and six

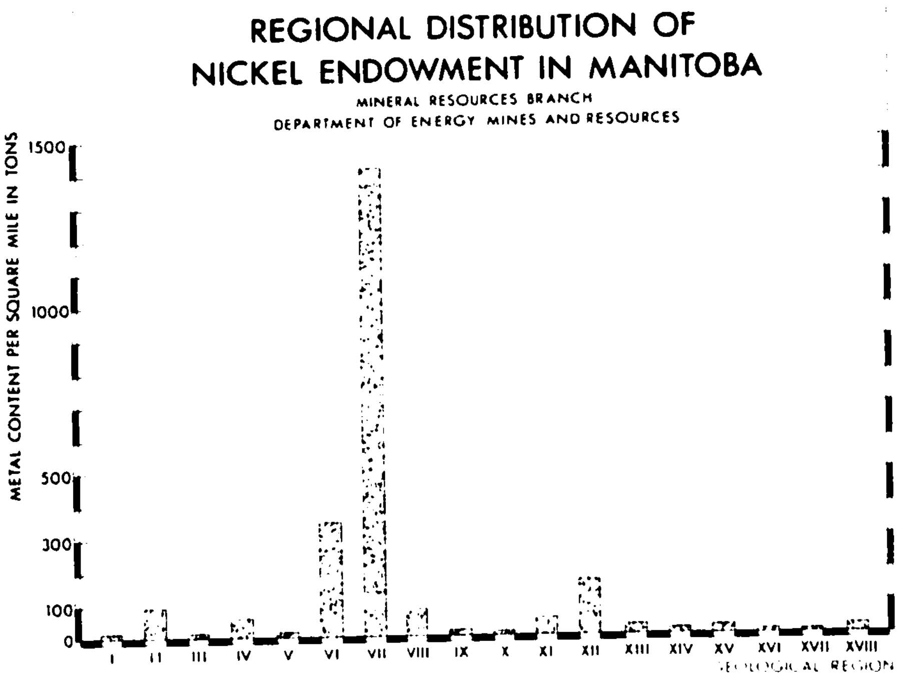


Figure 6

with grades of 1.0% to 2.7% Ni: Pipe, Birch Tree, Soab North, Soab South, Manibridge and Thompson. The estimate of tonnages was based on the geological assumption that mineable grades of ore persist for most deposits to depths of 2,000 to 3,000 feet. Birch Tree and Pipe orebodies were assumed to persist to a depth of 4,000 feet and Thompson to 5,000 feet. The estimated cumulative total is 1,500 million tons of ore containing 13 million tons of nickel, which is several times as much as measured and indicated reserves. This suggests that the estimate of the unknown nickel endowment is realistic and perhaps even on the conservative side.

After the Nickel Belt, next in order of importance are Region VI (Fox River), Region XII (Lynn Lake-Ruttan Lake) and Region IV (Island Lake), which, respectively, contain 11.8 per cent, 2.7 per cent and 2.4 per cent of estimated tonnage.

Seven nickel deposits averaging 24 million tons at 1.10% Ni are expected to occur in the Fox River area (Region VI). The indicated high potential for this area is directly related to the Fox River sill, a differentiated layered ultramafic-mafic body. The body consists of approximately 78% ultramafic rocks and provides an excellent exploration target for potential nickel sulphide deposits. The westernmost half to two thirds of the body is covered by the survey.

The tonnage distributions of nickel deposits in the Nickel Belt and Fox River areas are shown in Table 10.

Analysis of individual responses for the Nickel Belt and Fox River regions reveals a wide divergence in the expectations of each geologist. More than half of the total number of respondents expected the Nickel Belt region to contain in excess of 9 million tons of nickel (metal content); a few of these expected even more than 20 million tons. On the other hand, a third of the respondents expected less than 5 million tons of nickel in the area.

Six deposits of smaller size are expected in Region XII (Lynn Lake-Ruttan Lake). The nickel-copper sulphide deposit contained within the Lynn Lake gabbro and the presence of similar gabbroic bodies in this area result in the indicated high potential.

Region IV (Island Lake) is thought to contain four deposits. The presence of a belt of ultramafic rocks, some with contained nickel sulphide mineralization, is responsible for the potential assigned to this area.

In Region II (Winnipeg River-Rice Lake), the presence of the Dumbarton nickel sulphide deposit, closely associated with rocks of the Bird River sill, is responsible for the indicated potential in the southeastern part of this area. The slightly higher potential indicated for the northwestern part reflects the known association of nickel sulphides with ultramafic rocks of the English Brook area.

TABLE 10

THE PRINCIPAL REGIONS FOR NICKEL

Region		Tonnages of Ore (million tons) Low-Grade (0.4-0.5% Ni)	Medium-Grade (0.6-2.5% Ni)	High-Grade (2.6-4.0% Ni)	Total	Avg. Grade (% Ni)	Avg. Metal Content per sq. mile (tons)	Ore Tonnage as % of Total Manitoba Ore (%)
VII	Nickel Belt	350.7	508.8	98.7	958.3	1.17	1,431	68.2
VI	Fox River	79.5	74.4	11.8	156.6	1.10	337	11.8

For Region VIII (Flin Flon-Wekusko Lake), a generally low potential is indicated. The slightly higher value in the Iskwasum Lake cell (lat. 54° 37', long. 100° 50') reflects the presence of ultramafic rocks in this area.

Copper. Copper is expected to be the second largest contributor to the mineral endowment in the study area. Of the total expected place value of $73.4 billion for all commodities, an estimated $14.2 billion (or 19.3 per cent) is represented by copper. The expected occurrences of copper deposits are more evenly distributed than those of nickel.

The undiscovered copper and copper-zinc* endowment of Manitoba is estimated at more than 740 million tons averaging a computed 1.92% copper; this is about 14.2 million tons of copper. Table 11 shows a breakdown of grade categories. Up to 1970, Manitoba had produced more than 900,000 tons of copper; the estimated endowment is almost 16 times this figure.

TABLE 11

ESTIMATED TONNAGES OF COPPER ORE IN THE STUDY AREA

Ore Classification	Grade (% Cu)	Ore Tonnage (million tons)	Ore Tonnage (% of total)
Low-Grade	0.5-1.0	244.2	33.0
Medium-Grade	1.0-3.0	397.7	53.7
High-Grade	3.0-6.0	98.8	13.3
Total		740.7	100.0

The principal copper areas are Region VIII (Flin Flon-Wekusko Lake) and Region XII (Lynn Lake-Ruttan Lake) (Figure 7), with an average estimate of more than 4.0 tons of metal content per square mile (Table 12). Approximately 22 copper deposits are expected to occur in the Flin Flon-Wekusko Lake region and 17 deposits in the Lynn Lake-Ruttan Lake region. The size distri-

* Most of the Manitoba copper ore contains zinc, which is produced as a coproduct. In such cases, where the zinc component had a lower value than the copper component, zinc was converted to "copper equivalent" in this survey (via the ratio of their prices). For grade categories of combined metals, see Table 2.

TABLE 12

THE PRINCIPAL REGIONS FOR COPPER

	Region	Tonnages of Ore (million tons) Low-Grade (0.5-0.9% Cu)	Medium-Grade (1.0-2.9% Cu)	High-Grade (3.0-6.0% Cu)	Total	Avg. Grade	Avg. Metal Content per sq. mile	Ore Tonnage as % of Total Manitoba Ore
						(% Cu)	(tons)	(%)
VIII	Flin Flon-Wekusko Lake	10.0	42.7	23.8	76.5	2.57	567	10.3
XII	Lynn Lake-Ruttan Lake	24.2	67.3	13.8	105.2	2.14	400	14.2
VI	Fox River	20.5	33.4	7.2	61.1	1.94	220	8.2
IX	Sherridon	10.5	22.8	9.1	42.4	2.15	178	5.7
V	Cross-Oxford-Gods Lakes	38.7	75.3	12.8	126.8	1.88	87	17.1

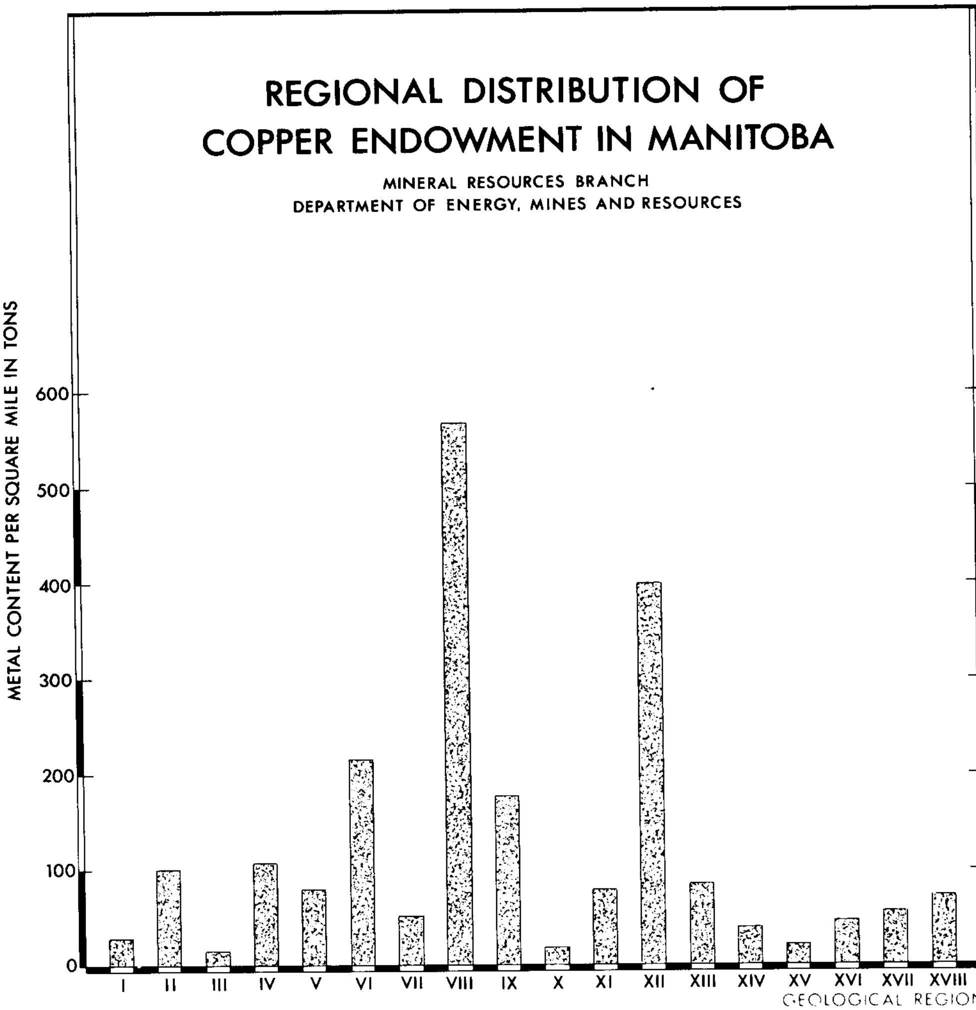


Figure 7

bution, however, indicates that more than two thirds of these deposits contain less than 5 million tons of ore each. The tonnage distributions of the copper endowment in the most important regions are shown in Table 12.

Further analysis of Regions VIII and XII shows that there is a closer agreement among the respondents on the undiscovered endowment of copper than on that of nickel. Of all respondents, about two thirds expected more than 1 million tons of copper (metal content) in Region VIII; almost half expected more than 2 million tons of copper (Table 13). For Region XII, again about two thirds of the respondents expected more than 1 million tons copper; about a quarter of them expected more than 3 million tons. The average expectation of undiscovered copper endowment is 1.97 million tons of metal for Region VIII and 2.25 million tons for Region XII.

TABLE 13

COPPER - ANALYSIS OF RESPONSES

	Number of Respondents		
Million Tons of Metal Content	Region VIII Flin Flon-Wekusko Lake	Region XII Lynn Lake Ruttan Lake	Regions VIII and XII
<1	6	5	2
1-4	9	9	7
>4	2	3	8

The copper endowment estimate shows the expected good correlation of high values with greenstone belts, with the highest cell values found in Regions II, V, VI, VII and XII. While the greatest confidence is revealed in Regions VIII and XII, the two major copper-producing areas of the province, it is significant that the Rice Lake (Region II), Oxford-Knee-Gods Lakes (Region V), Kistigan (Region V), Red Cross (Region V), and Fox River (Region VI) belts in Superior province are all rated exceptionally highly, especially when it is realized that there has been no copper production from these areas, and exploration for copper has been far less than in the established producing regions. Numerous copper showings are present, however, in all these belts. Of particular interest is the high potential assigned to the east end of the Fox River belt, and the small Whitefish Lake greenstone belt to the south (Region VI). Copper associated with nickel sulphide deposits is expressed in "nickel equivalent" so that the high endowment of this area is associated with the greenstones and not the Fox River sill.

The estimated endowment in Churchill Province, while showing the expected close correlation of high values with the Flin Flon-Snow Lake and Lynn Lake-Ruttan Lake greenstone belts, also shows an optimistic outlook for the large areas of metasediments and paragneisses which underlie much of this region. The Sherridon cell (Region IX), where known deposits exist, is exceptionally highly rated, but the rest of the Kissevnew gneisses and their counterparts south of the Lynn Lake greenstone belt, the Southern Indian Lake gneiss belt, and the metasediments and paragneisses north of lat. 58° are all viewed optimistically.

The influence of the Geological Map of Manitoba (Manitoba Mines Branch, 1965) is readily apparent particularly in the lesser known areas. Thus, for example, the high value cell (Region XVI) northwest of the Knife Delta on Hudson Bay is clearly related to the small area of greenstone on the Seal River. Similarly in the far north, higher values are given to cells containing metasediments and metavolcanics (unit 1 on each map) as opposed to paragneisses and granitoid rocks, and little potential is shown for the large drift-covered areas such as those between latitudes 58°00' and 58°30'. An exception to the latter, however, is the area around Buckland Lake, northeast of the Northern Indian Lake, which is one of the least geologically known areas in the province.

Molybdenum. Molybdenum is the third most significant metal expected to occur in the survey area.* The place value for this metal is estimated to be about $4.4 billion. The greater proportion (68%) of the molybdenite ore, however, is anticipated to grade lower than 0.5% MoS_2 (Table 14).

TABLE 14

ESTIMATED TONNAGES OF MOLYBDENUM ORE IN THE STUDY AREA

Ore Classification	Grade	Ore Tonnage	
	(% MoS_2)	(million tons)	(% of total)
Low-Grade	0.2-0.5	176.5	68.6
Medium-Grade	0.5-1.0	68.0	26.4
High-Grade	1.0-2.0	12.7	5.0
Total		257.2	100.0

The estimated molybdenum values show a very sporadic and uneven distribution. This distribution is very probably influenced partly by known occurrences and partly by an unwillingness to write off large areas completely. It is also possible

* The estimates on molybdenum given in this section must be interpreted with caution as they are likely to be much too high. See the last paragraph of this section.

that some cells considered highly favourable by a minority of respondents suffered "dilution" through a lack of similar knowledge on the part of the majority.

Of the six cells showing values of more than 50 thousand tons of metal, only three contain known occurrences as shown on published maps, i.e., High Lake-Falcon Lake, Island Lake, and Marshall Falls (on the Gods River).

Except for the Nickel Belt region, the areas of higher molybdenum endowment do not coincide with regions where major amounts of nickel and copper ores are anticipated (Table 15 and Figure 8). This differs from British Columbia and the Yukon where most of the known molybdenum occurrences are associated with copper or nickel deposits.

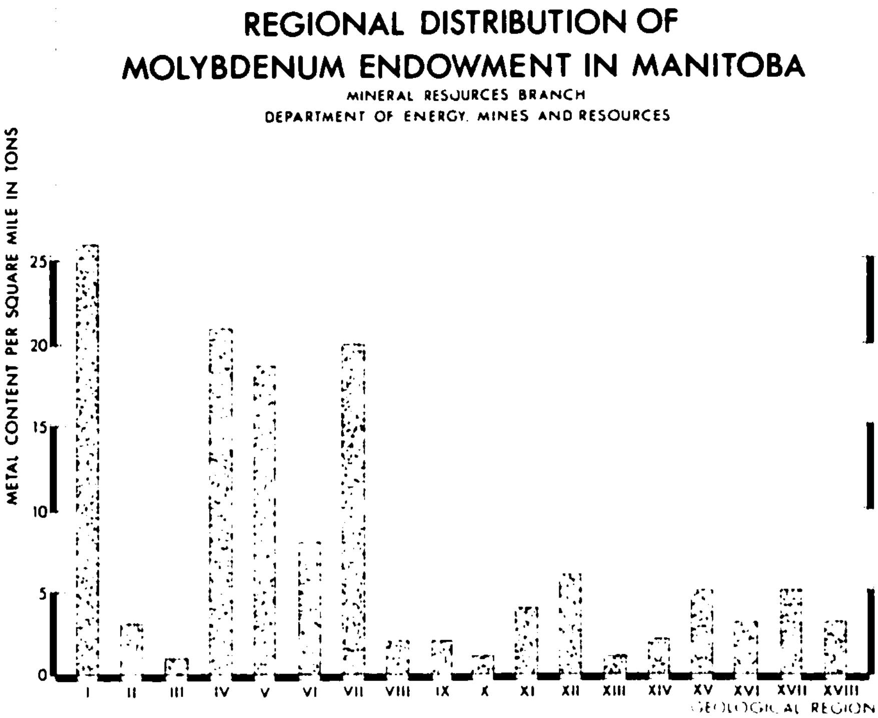


Figure 8

TABLE 15

THE PRINCIPAL REGIONS FOR MOLYBDENUM

Region		Tonnages of Ore (million tons) Low-Grade (0.2-0.4% MoS_2)	Medium-Grade (0.5-0.9% MoS_2)	High-Grade (1.0-2.0% MoS_2)	Total	Avg. Grade (% MoS_2)	Avg. Metal Content per sq. mile (tons)	Ore Tonnage as % of Total Manitoba Ore (%)
I	West Hawk Lake	7.8	4.6	0.3	12.7	1.10	26	4.9
IV	Island Lake	10.1	5.3	2.5	17.9	.57	21	7.0
VII	Nickel Belt	28.4	9.8	0.8	39.0	.41	20	15.1
V	Cross-Oxford-Gods Lakes	78.0	23.7	3.8	105.5	.50	19	41.0

The average expected size of molybdenum deposits in the study area is about 18 million tons with a place value of about $315 million (cf. the smaller copper deposits with an average size of 4.2 million tons and an average place value of $80 million). No molybdenum has been produced in Manitoba up to the present time, but the results of this survey suggest that the future exploration prospect for molybdenum in Manitoba may be good. However, the results obtained for molybdenum must be modified owing to an inappropriate classification of grades on the original questionnaire. Sampling of individual opinion indicated that respondents would most readily consider the possibility of occurrence either of large deposits of low grade material (0.1 to 0.2% MoS_2) or of very small deposits (.05 million tons) of high grade. The questionnaire, however, forced the respondents to enter probability numbers for conceptually higher grades (minimum 0.2% MoS_2) leading to an anomalously high estimate for molybdenum. The writers chose not to completely discount the final results but suggest that the estimates would probably be more realistic if they were halved.

Gold. The place value of gold in the study area is estimated at about $3.4 billion, represented by 189 million tons of ore with an average grade of $18 per ton. About half of the ore would have a grade of better than $10 per ton (Table 16). The gold deposits are expected to be mostly small, averaging about 2 million tons of ore per deposit.

TABLE 16

ESTIMATED TONNAGE OF GOLD ORE IN THE STUDY AREA

Ore Classification	Grade ($/ton)	Ore Tonnage (million tons)	Ore Tonnage (% of total)
Low-Grade	5.0-10.0	91.6	48.4
Medium-Grade	10.0-41.0	84.7	44.8
High-Grade	41.0-70.0	12.9	6.8
Total		189.2	100.0

Most of the expected gold endowment is associated with the greenstone belts of the Superior and Churchill provinces, with sporadic values elsewhere. These scattered values, rather than reflecting a definite knowledge of some potential, probably reveal the respondents' reluctance to totally reject an area. The highest values occur in the Rice Lake (Region II), Gods Lakes-Knee Lake (Region V), Snow Lake (Region VIII) and Lynn Lake (Region XII) cells (all former or potential gold-producing areas) and in the Tod Lake (Region XII), Wass Lake (Region IV), and Meades Lake (Region XVI) cells, where gold occurrences are also known.

Pertinent figures on the principal gold regions are listed in Table 17; the average values of gold per square mile area for each region are shown in Figure 9.

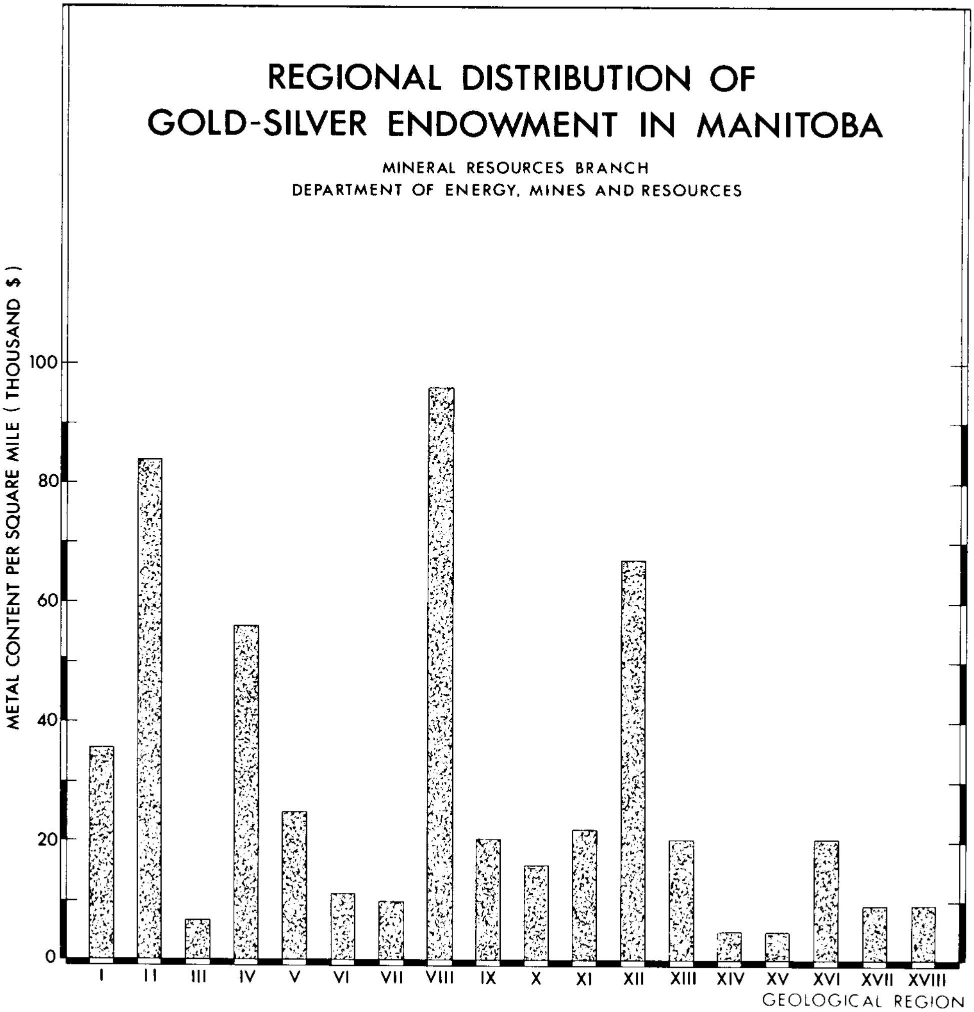


Figure 9

TABLE 17

THE PRINCIPAL REGIONS FOR GOLD-SILVER

Region	Tonnages of Ore (million tons)				Avg. Grade	Avg. Metal Content per sq. mile	Ore Tonnage as % of Total Manitoba Ore
	Low-Grade (5-9 $/T)	Medium-Grade (10-41 $/T)	High-Grade (41-70 $/T)	Total	($/ton)	(000 $)	(%)
VIII Flin Flon-Wekusko Lake	11.2	7.7	1.0	19.9	16.68	96	10.5
II Winnipeg River-Rice Lake	7.3	9.8	1.3	18.4	20.73	84	9.7
XII Lynn Lake-Ruttan Lake	8.8	9.2	1.4	19.4	19.32	67	10.3
IV Island Lake	7.8	7.2	1.0	16.0	17.43	56	8.5
I West Hawk Lake	4.3	4.4	0.9	9.6	20.31	36	5.1
V Cross-Oxford-Gods Lakes	25.0	18.4	2.2	45.6	15.19	25	21.1
XVI Seal River	6.2	4.6	0.7	11.5	18.85	20	6.1

Manitoba has long been a gold producer; up to 1970, cumulative production was more than 4.3 million ounces. The place value of the undiscovered gold endowment of Manitoba, estimated in this survey, is about $3.4 billion, slightly more than 20 times the value (at $35/oz) of all the gold produced in Manitoba up to date.

Zinc. Zinc is estimated to have a total place value of $3.4 billion. The expected average size of deposits is 4.6 million tons, with an average grade of 5.4% zinc. (In zinc-copper deposits, the copper was converted to "zinc-equivalent" by the use of their price ratio, if copper values were on the average lower than zinc values.) This average size is relatively small, but since the grade of many of the deposits is fairly high, many of them would be economic if discovered. The distribution of grade categories is shown in Table 18.

TABLE 18

ESTIMATED TONNAGES OF ZINC ORE IN THE STUDY AREA

Ore Classification	Grade (% Zn)	Ore Tonnage (million tons)	Ore Tonnage (% of total)
Low-Grade	2.0- 4.0	68.4	33.1
Medium-Grade	4.0- 8.0	119.3	57.7
High-Grade	8.0-16.0	19.2	9.2
Total		206.9	100.0

The estimated endowment for zinc shows a distribution similar to that for copper but with generally lower values and more restricted extent. In Superior Province, a good correlation exists between high zinc values and the greenstone belts; similarly, the highest values of all are found in the two major greenstone belts of Churchill Province (Regions VIII and XII) which are the two major zinc producing areas of the province. On the other hand, the belts of metasediments and paragneisses throughout Churchill Province are viewed with considerable optimism and have a relatively higher estimated endowment for zinc than for copper.

Table 19 and Figure 10 provide pertinent data on the expected distribution of the zinc endowment.

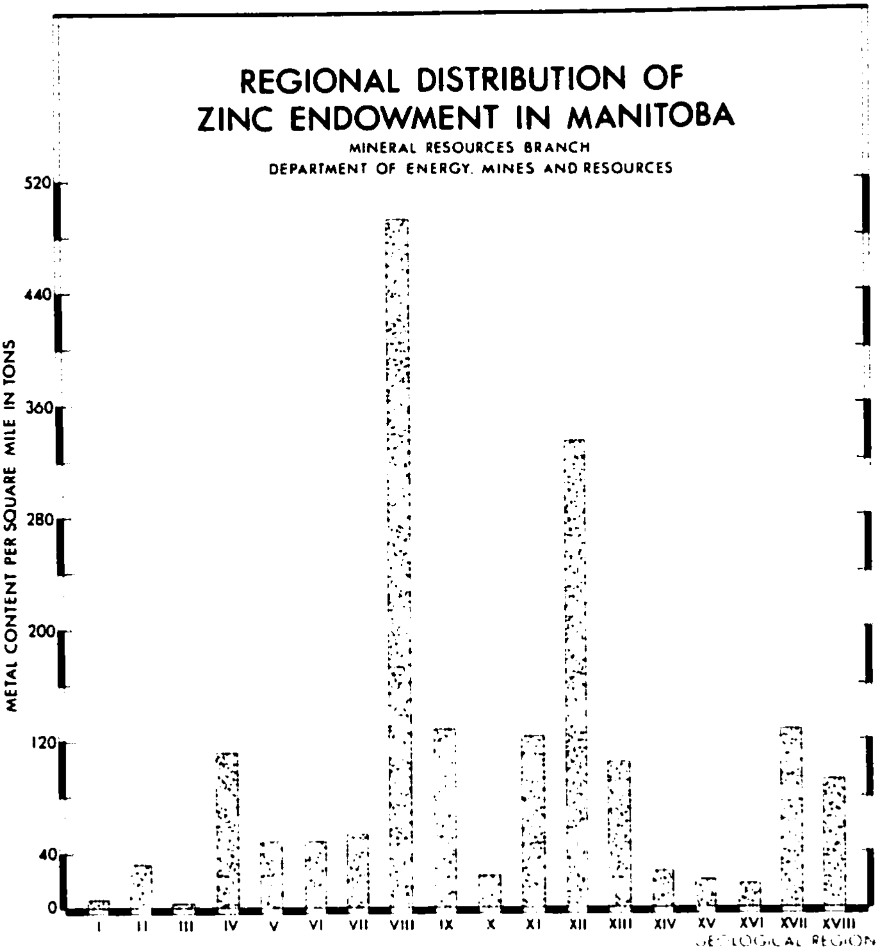


Figure 10

In the metasedimentary and paragneissic belts of the north (Regions XVI, XVII and XVIII), slightly fewer cells in total contain values for zinc than for copper, but the zinc values are generally higher. This is particularly evident in the cells around Stoney and Askey lakes (Region XVII). Regions XIV and XV show a similarly negligible response for zinc as for copper, but in Regions VII, IX, X, XI, XII and XIII, the paragneisses, e.g., north of the Lynn Lake-Ruttan Lake greenstone belt (Region XII) and the Kisseynew gneisses around Nelson House-Rat Lake, etc., (Regions X and XI), show the same generally higher values for zinc than for copper as in the north. The exception to this is

TABLE 19

THE PRINCIPAL REGIONS FOR ZINC

Region		Tonnages of Ore (million tons) Low-Grade (2.0-3.9% Zn)	Medium-Grade (4.0-7.9% Zn)	High-Grade (8.0-16.0% Zn)	Total	Avg. Grade	Avg. Metal Content per sq. mile	Ore Tonnage as % of Total Manitoba Ore
						(% Zn)	(tons)	(%)
VIII	Flin Flon-Wekusko Lake	7.1	17.7	3.7	28.5	5.98	491	13.8
XII	Lynn Lake-Ruttan Lake	9.8	20.0	3.6	33.4	5.66	336	16.1
XVII	Munroe Lake	9.0	14.1	1.4	24.5	4.94	131	11.9
IX	Sherridon	4.4	6.6	1.0	12.0	5.41	126	5.8
XI	Russel-Mynarsky Lakes	4.4	6.7	0.8	11.9	5.20	123	5.8
IV	Island Lake	3.0	6.1	0.9	10.0	5.60	113	4.9
XIII	Paskwachi-Southern Indian Lake	5.1	7.2	0.9	13.2	5.20	106	6.4
XVIII	Thlewiaza River	7.1	8.2	1.1	16.4	4.66	88	7.9
V	Cross-Oxford-Gods Lakes	6.4	13.8	2.6	22.8	5.80	48	11.0

the easterly trending belt of gneisses through Sherridon (Region IX) in which copper is dominant. Zinc values in the two main greenstone belts in Churchill Province (Regions VIII and XII) are generally lower than for copper, with the exception of the Flin Flon cell (Region VIII) and two cells in the Ruttan Lake area (Region XII) which are also three of the four most highly rated cells in the province.

A relatively low zinc endowment is expected for the Nickel Belt (Region VII) but the Kisseynew gneisses flanking the belt to the northwest show a relatively strong response. The very high zinc value in the Split Lake cell (Region VII) appears to be surprisingly high, particularly as neighbouring cells are viewed with considerably less optimism.

A close correlation between estimated zinc endowment and greenstone belts is evident in Regions IV, V and VI with almost invariably lower values for zinc than for copper, and a more restricted distribution. Extremely high zinc values, however, are estimated for the Semmens Lake cell (Region V) and for the cell immediately south of St. Theresa Point on Island Lake (Region IV). In Regions I, II and III, zinc values are consistently lower than those for copper. One "anomalous" value in the Harrop Lake cell (Region III) may reflect an unwillingness on the part of the respondents to write off Region III entirely.

Uranium. A sizeable tonnage of uranium ore is visualized in the study area, although almost half of the deposits are expected to grade lower than 0.05% U_3O_8. The average grade for the study area is 0.14% U_3O_8 and the total estimated tonnage of ore is 130 million (Table 20). The average size of the uranium deposits is estimated to be about 7 million tons with an average value of $157 million. The principal regions for uranium are shown in Table 21.

TABLE 20

ESTIMATED TONNAGES OF URANIUM ORE
IN THE STUDY AREA

Ore Classification	Grade ($\%$ U_3O_8)	Ore Tonnage (million tons)	Ore Tonnage (% of total)
Low-Grade	.01- .05	59.38	45.4
Medium-Grade	.05- .40	53.99	41.3
High-Grade	.40-1.00	17.29	13.2
Total		130.71	100.0

TABLE 21

THE PRINCIPAL REGIONS FOR URANIUM

Region		Tonnages of Ore (million tons) Low-Grade (.01-.05% U_3O_8)	Medium-Grade (.05-.40% U_3O_8)	High-Grade (.40-1.0% U_3O_8)	Total	Avg. Grade	Avg. Metal Content per sq. mile	Ore Tonnage as % of Total Manitoba Ore
						(% U_3O_8)	(tons)	(%)
XVIII	Thlewiaza River	7.8	15.4	4.5	27.7	0.20	7	21.2
XVI	Seal River	3.4	5.8	1.4	10.6	0.24	2	8.1
VI	Fox River	14.6	4.8	0.0	19.5	0.07	2	14.9
I	West Hawk Lake	2.3	2.2	0.7	5.1	0.21	2	3.9
XV	Brochet-South Knife Lake	12.4	8.7	6.5	27.6	0.08	1	21.1

In most parts of the province a low potential for uranium mineralization is indicated, but a few restricted areas have been singled out for more significant endowment. Superior Province is viewed most pessimistically although the Caddy Lake and Rice Lake areas (Region I), where uranium mineralization is known to exist, register about 1,000 short tons. The reason for the optimism shown for the Fox River area (Region VI) in the northern part of Superior Province is not known.

Churchill Province is viewed more favourably with both the Misty-Nicklin lakes belt (Region XVIII) and the continuation of the Wollaston belt (Region XVIII) accountably registering higher values. Recent exploration for uranium has focussed on these sedimentary belts. Significant values are shown in the sedimentary belts further east, with the highest values in this region apparently associated with the Great Island group of sediments (Region XVI). There are no reported occurrences of radioactive minerals from the latter area.

Other commodities. Of the other commodities investigated, namely lead, asbestos, tungsten, lithium, tin, beryllium, chromium, columbium, and iron, relatively small amounts are expected in the study area. Although some of these commodities are expected to occur in one or two sizeable deposits by some of the respondents, the results obtained average to very low values since the dispersion of responses was high. For iron, some respondents did not wish to reply because of lack of expertise; therefore, although three iron deposits of about 39 million tons each with an average grade of 23.6% Fe were suggested as Manitoba's endowment, such an estimate does not reflect any kind of general opinion. This proviso also applies to estimates of six asbestos deposits of 10.4 million tons (or $106 million each) and one tin deposit of 5.9 million tons ($371 million place value) which are expected to occur in the study area.

Lead has not been a prime exploration target in the shield of Manitoba and hence respondents may be less familiar with this commodity. Lead occurrences in Manitoba are generally poorly documented and are generally mentioned *en passant* in association with the other more significant mineralization such as Cu-Zn. Lead sulphide (galena), commonly silver-bearing, is associated with many of the Cu-Zn deposits in Manitoba such as Fox Mine, Ruttan Mine and particularly the Chisel Mine, but it appears to be generally of limited extent and sporadic in distribution (vein/fracture fillings ?). Significant amounts of lead are recovered from the ore at the Chisel Mine. It is surprising that the Chisel Lake cell (Region VIII) has nevertheless been given a relatively low rating, especially as the Ghost Lake deposit (Zn-Cu-Pb-Ag-Au) also lies in this cell.

None of the respondents expected the occurrence of columbium deposits. Several respondents indicated some confidence in occurrences of tantalum, cesium, thallium and other minor metals. However, the computer program used did not have the capacity to process these.

REFERENCES

Allais, M. Method of Appraising Economic Prospects of Mining Exploration Over Large Territories: Algerian Sahara Case Study. *Management Sci.* 3, No. 4 (1957) 285-347.

Barry, G.S., and Freyman, A.J. Mineral Endowment of the Canadian Northwest - A Subjective Probability Assessment. Part B of *Mineral Information Bulletin MR 105*, Mineral Resources Br., Dept. Energy, Mines and Resources, Ottawa (1970) 57-95. Also published in *CIM Bull.* 63, No. 701 (Sept. 1970) 1031-1042.

Battelle Memorial Institute. Transportation Requirements for the Growth of Northwest North America. *U.S. Govt. Printing Office*, Washington, D.C., Vol. 2, 1961.

Harris, D.P. An Application of Multivariate Statistical Analysis to Mineral Exploration. Ph.D. dissertation, Penn. State U., 1965, 261 p.

Harris, D.P., Freyman, A.J., and Barry, G.S. The Methodology Employed to Estimate Potential Mineral Supply of the Canadian Northwest ... An Analysis Based Upon Geologic Opinion and Systems Simulation. Part A of *Mineral Information Bulletin MR 105*, Mineral Resources Br., Dept. Energy, Mines and Resources, Ottawa (1970) 1-56. (Also published as: A Mineral Resource Appraisal of the Canadian Northwest Using Subjective Probabilities and Geological Opinion. In *Proc. Ninth Intern. Symp. Techniques for Decision-Making in the Mineral Industry, Montreal, June 14-19, 1970.* CIM Spec. Vol. 12 (1971) 100-116).

Manning, M.E., *et al. Report of the Royal Commission on the Great Slave Lake Railway.* 2 vol. Information Canada, Ottawa, 1960.