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Full Name of Author — Nom complet de l'auteur

Árpád Füstös

Date of Birth — Date de naissance

May 9, 1926

Country of Birth — Lieu de naissance

Hungary

Permanent Address — Résidence fixe

35 Quinpool Crescent
Ottawa, Ontario
K2H 6H9

Title of Thesis — Titre de la thèse

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Dr. William Tupper

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COMPARATIVE STATISTICAL ANALYSIS
OF THE
URANIUM AND THORIUM CONTENT DISTRIBUTION
IN THE
DENISON MAIN REEF, ELLIOT LAKE SYNCLINE

ELLIOT LAKE, ONTARIO

BY

© ÁRPÁD FÜSTÖS, B.S.F./F.E., B.Sc.

A THESIS SUBMITTED TO THE FACULTY OF
GRADUATE STUDIES AND RESEARCH IN PARTIAL
FULFILMENT OF THE REQUIREMENTS FOR THE
DEGREE OF MASTER OF SCIENCE

CARLETON UNIVERSITY
OTTAWA, ONTARIO
DECEMBER, 1982

The undersigned hereby recommend to the Faculty of
Graduate Studies and Research acceptance of this thesis,
submitted by Árpád Füstös, B.S.F./F.E., B.Sc., in partial
fulfillment of the requirements for the degree of
Master of Science.

David H. Walison

Chairman, Department of Geology

Wm M. Lippert

Supervisor

ABSTRACT

The genesis of the uranium in the quartz pebble conglomerates has been explained by the Modified Placer Hypothesis. According to it the uranium was deposited as solid detritus, because the earth's atmosphere is postulated not to have contained free oxygen at the time of deposition.

A statistical null hypothesis was set up, based on two a priori assumptions. The detrital origin of uranium is acceptable if the distribution patterns of uranium and thorium are analogous in the Reef.

The acceptability was tested by applying a statistical hypothesis testing exercise to 5556 uranium and 3264 thorium assays from Denison Mines Ltd.

Four independent statistical test sequences produced identical results. The distribution patterns of uranium and thorium were found to be different.

The statistical hypothesis testing methods found the postulated detrital origin of uranium in the Denison Main Reef unacceptable.

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I wish to express my appreciation to my supervisor, Dr. W.M. Tupper, for his advice and guidance, without which an initially strictly statistical analysis of an ore genetic hypothesis could not have been integrated into the geological framework presented here. Thanks are also extended to Drs. D.H. Watkinson and G. Ranalli for reading drafts and progress reports during the preparation of the thesis.

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Last, but not least, I wish to thank Dr. A.J. Sinclair, my former faculty advisor during my long past undergraduate years at the University of British Columbia, who at every occasion when we met patiently sacrificed his time and gave advice to the preparation of this project.

INTRODUCTION

"In reconstructing more precisely the Earth's past based on geophysical measurements and geochemical analyses of rock samples, the geologist will need to perform statistical analyses in order that more exact inferences may be drawn from the data."

R.B. McCammon

Concepts in Geostatistics, 1975

LOCATION

Oligomictic quartz-pebble conglomerates in the Elliot Lake Syncline, at the base of the Huronian Supergroup of Proterozoic clastic sediments, are the host rocks of Canada's largest producing uranium deposits. They are located in the vicinity of Elliot Lake, Ontario. Elliot Lake lies about 20 km northeast of Blind River which in turn is located halfway between Sudbury and Sault Ste. Marie, on the North Shore of Lake Huron (Fig. 1).

The uranium-bearing horizons - commonly referred to as "reefs" - of the Elliot Lake Syncline were or are exploited on both limbs of the syncline (Lang and others, 1962). The north limb is subjected to the most extensive mining, where production of uranium has been continuous since 1955. Two companies, Denison Mines Limited and Rio Algom Mines Limited, own the mines currently in production. The data, in this paper, originates from Denison Mines Limited.

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INTRODUCTION

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REGIONAL LOCATION MAP

FIGURE 1

PURPOSE

The mode of deposition of uranium in the "reefs" - one of the major geological controversies of the present century - is still actively debated. The so-called "Modified Placer Hypothesis" enjoys currently the greatest popularity among the geological fraternity (Stanton, 1972). This hypothesis is based partly on geochemical and mineralogical investigations on both the Elliot Lake ores (Robertson, 1981) and those from the Witwatersrand system in the Republic of South Africa, (Pretorius, 1974), and partly on the consideration of a proposed hypothetical reducing atmosphere which is postulated to exist at the time of deposition of uranium in the "reefs". The "Modified Placer Hypothesis" proposes that the uranium content was deposited syngenetically with the "reef" - forming sediments in the form of solid detritus (Roscoe, 1969). The hypothesis, despite the time-enduring actuality of the question which it attempted to answer, is still not accepted unanimously. Its validity however, to the writer's knowledge, has not been subjected to quantitative statistical tests which utilize a large data base. The need for such investigations was suggested a long time ago (Roscoe, 1957).

Collection of uranium assay information commenced on a Canada-wide scale in 1974 to facilitate the establishment of dependable ore reserve estimates for the whole country. The writer, actively participating in this exercise since its beginning as Senior Geologist of EMR/CANMET's Mine Evaluation Group, realized at an early stage that the established extensive uranium assay data files offered a unique opportunity to carry out a large scale quantitative testing exercise whose results would significantly contribute to the

study of those ore-genetic processes which regulated the deposition of uranium in ancient conglomerates, provided the highly confidential data base of the concerned mining companies could be released for such a purpose. Due to the generosity of the management of Denison Mines Limited a restricted release for such purpose was secured. The restriction on the release specified that actual uranium or thorium contents cannot be shown in the text.

Denison Mines Limited maintained large uranium and thorium assay data files since the early 1950's. These data files are segregable into partial subfiles, according to stratigraphy and lithology. Comparison of the results of the statistical analyses, executed on the different partial subfiles, offers a way to describe the mineral content distributions over the whole reef, or any part of it, in a quantitative mode, derived by inductive reasoning. Furthermore, the dependability of the derived results will be measurable on a relative, probabilistic scale (Krumbein, 1960). Concisely expressed: Statistical analyses of these large data files have a potential to reveal a definite, quantitative model of the uranium and thorium distribution both over the entire main reef and in any part of it.

The purpose of this thesis is to design a statistical experiment - based on the analysis of the Denison files - which will quantitatively test one aspect of the validity of the Modified Placer Hypothesis, i.e. the detrital mode of the uranium deposition. The design of the statistical experiment requires two a priori assumptions, namely:

1. The thorium content was deposited syngenetically with the "reef" - forming sediments in the form of solid detritus (Adams and others, 1959, Gabelman, 1977).
2. The presently existing distribution patterns of both uranium and thorium in the reef were produced by the depositional processes of the two elements (Holland and Petersen 1979).

The object is, upon the acceptance of these two a priori assumptions, to compare the uranium and thorium distribution patterns in the Denison Main Reef, in the frame of a statistical hypothesis testing procedure. If a comparison of the uranium distribution pattern with the thorium distribution pattern discloses that the two patterns are analogous, then the detrital mode of deposition of uranium - which the Modified Placer Hypothesis proposes - must be accepted. This would strengthen the tenability of the Modified Placer Hypothesis.

If, on the other hand, the two distribution patterns are dissimilar, the proposed detrital depositional mode of uranium would be rejected by the results of the statistical tests. This eventuality would weaken the tenability of the Modified Placer Hypothesis.

METHODS

The methods utilized in the present exercise are rooted in three closely related but nevertheless distinct fields of scientific inquiry. These, in sequence of their application to the present case, are:

- 1) Sampling theory.
- 2) Geological data analysis with the application of the computer.
- 3) Statistical inference.

(1) Sampling theory

Sampling theory deals with the art of drawing a representative batch of elementary units, called a "sample", from an infinitely large accumulation of the same units, called a "universe" or "population". The "sample" will serve as a model of the "population". The sample will be subjected to investigations to confirm or reject surmised regular relationships within the model. If the existence of such relationships are experimentally established within the "sample", they can be extrapolated over the parent "population" with the concomitant quantitative expression of the dependability of the extrapolation on a probabilistic scale.

Sampling theory is a collection of tenets or rules according to which a "sample" must be drawn, in order to make it representative of its parent "population" (Visman & Picard, 1970; Gy, 1979).

(2) Geological data analysis with the application of the computer

Geological research is affected by the use of the computer as much, or more, than any other scientific endeavour.

Natural science in its infancy practised a deductive approach. It attempted to explain any observed natural phenomenon on

the basis of a priori established axioms, formulated by metaphysical "reasoning". Technological development of observing and measuring methods made all aspects of natural science more and more inductive but at different rates. Those scientific endeavours which dealt with natural phenomena repeatable in a controlled laboratory environment (i.e., physics, chemistry), became more rapidly inductive or, more explicitly, quantitative than geology which was restrained to passive observation of natural phenomena in its sector of inquiry due to the largeness and non-reproducibility of the phenomena on a laboratory scale.

Quantitative evaluation of numerical data, reproducible in a controlled laboratory environment, was solvable by manual methods because accumulated data bases of limited extent satisfied the required scientific rigor. Geology, due to the passive data collecting method, to which it is inherently restricted, must accumulate extremely large data bases for its quantitative evaluations to achieve results with a level of confidence comparable to the results produced by the more laboratory based natural sciences (Krumbein, 1960). Such extremely large data bases are unmanageable by manual methods. The computer eliminates this restriction (Loudon, 1979). Its extreme calculating speed and capability to store and maintain in evidence, by human standards, a colossal amount of numerical data did more to quantitize geology than many of its sister sciences. The computer based evaluation of extremely large data bases are repeatable and reliable, whereas deductive, qualitative methods, or even inductive methods if they are manual, are not. This contrast illustrates most markedly the advantage which geology gained by the introduction of the computer into its armoury (Merriam, 1970, 1982).

(3) Statistical Inference

Statistics is the science of collecting and tabulating numerical data to form a "sample" and using this "sample" to draw conclusions from it with the help of well established techniques. The drawn conclusions subsequently can be generalized over the parent "population" of the "sample". Although the conclusions, in their generalized form, will not have an absolute certainty, the degree of validity will be numerically expressible on a relative scale of probability. The collecting and tabulating of data and the calculation of various "statistics" from the tabulated data is an activity called descriptive statistics. The conclusion-drawing and subsequent generalization of the drawn conclusions is statistical inference. Geologists, when they examine and analyze individual rock specimens, are really interested in the nature and formation of a considerably larger part of the earth's crust, from which the examined rock specimens originated (Krumbein, 1960). They subsequently extrapolate the results of their examinations and experimentations over this larger part of the earth's crust. This exercise is called statistical inference from "sample" to "population" in the geological sense (Li, 1964).

In the context of the present work from the arsenal of statistical inference the procedure of "hypothesis testing" is utilized and the actual tool applied is known as "analysis of variance" in statistical parlance.

Hypothesis testing

Experimental data are collected in many situations to test the validity of some pre-conceived concept about the parent "population" from which the experimental data, or "sample", were drawn. The pre-conceived concept is a hypothesis, usually arrived at by deductive reasoning. The "hypothesis testing" procedure is in essence a comparison between the pre-conceived concept about the parent "population" and the objectively collected facts, implicitly present in the "sample". The hypothesis is either accepted or rejected depending on the agreement or contradiction between it and the collected facts. Here however a double caveat must be stated. The first is inherent in the basic concept of statistics, the second is in the nature of geological data.

Statistical procedures are of stochastic nature. The answers, arrived at by them, are not absolute, only most likely. Consequently, acceptance or rejection of a contention by hypothesis testing should not be considered absolute. On the other hand, it must be said that it will always be possible to express the likelihood of the decision in quantitative terms (Li, 1964; Bennett & Franklin, 1954).

All quantitative geological data, when submitted to statistical procedures, will produce only "quasi-statistical" or "proto-statistical" results in the strictest sense (Davis, 1973). The reason for it is that the entire theory of statistics is built on the assumption that the examined data in the "sample" was collected randomly and the parent "population" was distributed according to the so-called "normal" or Gaussian function, or transformable into the

same. Geological data can not be collected perfectly randomly and its parent population is rarely distributed in a completely normal manner.

Unfortunately while the statistical uncertainty can be quantitized, the uncertainty rooted in the nature of the geological data will be expressible only qualitatively until an adequate general theory will be established about the statistical behaviour of geological data "populations" (Davis, 1973).

Analysis of Variance

An internationally known statistician once called analysis of variance one of the most elegant, powerful and useful techniques in modern statistical methodology (Moroney, 1956). Analysis of variance uses the two most commonly calculated "statistics" of a statistical sample: the arithmetic mean and the variance. The first is a central value of a distribution, the second is the measure of the variability of all individual values around the central value in the distribution. If two or more statistical samples are compared, to decide whether they originate from the same population or not, and their means as well as their variances differ, the analysis of variance technique is employed to discover whether or not the existing differences are significant in the statistical sense (Li, 1964; Pollard, 1977). The technique provides the way to calculate the odds that the observed differences are the products of pure chance or the consequences of the fact that the examined samples were drawn from different populations. If the differences are large there is a certainty that the two samples are heterogeneous, but if the differences are small they do not prove beyond doubt that the

two samples have a common origin. Therefore, when the analysis of variance technique is applied in a hypothesis testing exercise, it can only disprove the tested hypothesis. Proving the validity of the hypothesis, i.e., that there are no differences between the parent populations of the compared samples, is beyond the capability of the analysis of variance technique. Consequently, one of the most important parts of a hypothesis testing exercise, with the application of the analysis of variance technique, is the proper statistical formulation of the hypothesis under scrutiny (Visman & Picard, 1970).

The analysis of variance technique, as described above, was discussed in the context of classical or "parametric" statistics. Consequently it is subject to the second caveat, raised in the previous section, because classical statistics requires the a priori assumption that the compared parent populations have an approximately "normal" distribution. If this assumption cannot be made with absolute certainty, the results of the analysis of variance tests could be questionable.

There are two approaches to circumvent this restriction. One could transform the examined sample values into one of their higher mathematical functions. The weakness of this approach is that transformations tend to obscure the nature of the compared variables (Li, 1964). The other approach utilizes methods developed by a younger branch of statistical science, called distribution-free or "non-parametric" statistics (Siegel, 1956). This discipline does not require the fulfilment of any a priori assumption about the distribution of the investigated parent populations.

In order to reinforce the dependability of the conclusions, arrived at by the present analysis, all analysis of variance tests were carried out according to the rules of both classical and distribution-free statistics. The results, produced by the two methods, have led to the same conclusions in the present exercise.

There are specific geological reasons also for the choice of the analysis of variance technique in the present exercise, since there are other techniques to compare samples in order to clarify the question of their possible common parentage (Krumbein, 1960). It was pointed out more than a decade ago in the geological literature that in investigations of sedimentary genetic problems the analysis of variance technique is superior to many others (Nagy, 1969). In addition, the analysis of variance technique proved its mettle in a well publicized application of statistical methodology to a geological problem concerned with metallic element behaviour (Koch & Link, 1963, 1970, 1980). In that case, the questions asked were very similar to the central question of the present exercise.

GEOLOGICAL SETTING

GENERAL

The Quirke Lake Syncline is on the northern edge of the Southern Province, where the latter borders the Superior Province of the Canadian Shield.

The Archean rocks toward the north: greenstones, Algoman-type granites and minor mafic intrusions, extend southward below the Proterozoic sediments of the syncline, forming its basement (Pienaar, 1963; Robertson, 1981). The same rocks, at least the felsic ones, are the progenitors of the syncline-filling sediments. Several investigators have suggested that these rocks also supplied the uranium and thorium minerals in the ore bodies in the Blind River - Elliot lake area (Roscoe, 1964; Charbonneau, 1982).

The Archean rocks were all affected by the Kenoran Orogeny (2.5 b.y.) (Little and others, 1972). The eastern part of the syncline has a basement composed of massive and pillow lavas as well as sedimentary iron formations which strike to the northwest and dip to the southeast. These rocks have a structural fabric which is a product of the Kenoran orogeny (Robertson, 1981). Basement rocks are metamorphosed to the chlorite grade. Metamorphism rises to the greenschist facies at locations where the greenstones are in contact with the intruding Algoman granite. These latter rocks occur in two phases: a generally gray, gneissic to massive heterogeneous granodiorite and a red, massive more homogenous quartz monzonite (Robertson, 1981). Locally the quartz monzonite is in unconformable contact with the uranium hosting Proterozoic sediments along and under

the northern rim of the Elliot Lake Syncline. Northward, where the quartz monzonite is exposed on the surface or covered only with a relatively thin veneer of Pleistocene sediments it was found to be enriched with radioactive minerals by the airborne scintillometer/magnetometer surveys of Ontario Department of Mines in 1955 and later by the spectrometric surveys of the Federal-provincial uranium reconnaissance program (Darnley and Grasty, 1971).

In the late stages of the Kenoran Orogeny, the Archean rocks were intruded by diabase dikes. This final event was followed by a long period of weathering and peneplanation. The topography developed was probably related to the structural pattern of the greenstones. Drainage patterns developed on topographic lows and, after their full development, regulated the sedimentation at the beginning of the Proterozoic Eon. The weathering process affecting the basement rocks must have been both intensive and of long duration because mine workings and diamond drill holes at many places over granitoid rocks intersected up to 50 feet of altered rock apparently of regolithic origin (Elenaar, 1963; Roscoe 1957). Similar, but much thinner, altered zones have been reported over pre-Huronian volcanic rocks by several investigators.

The Elliot Lake Syncline, whose axis strikes slightly north of west and plunges gently to the west, is structurally limited between the Flack Lake Fault on the north and the Chilbow Anticline in the south. The syncline is a consequence of the Penokean orogeny (1.75 b.y.). It developed after the deposition of the sedimentary rocks which are filling it at the present time. Its structural

pattern was produced by north-south compression which caused gentle deformation, bedding plane lineations, thrust faults and minor vertical faulting, all parallel to the synclinal axis in the syncline-filling thick sedimentary sequence.

The sedimentary rocks, which fill the ~~Elliot~~ Lake Syncline, are part of a belt, nearly 200 miles long and 50 miles wide which extends from Sault Ste. Marie in the west to the Grenville Front in the east along the northern border of the Southern Province of the Canadian Shield. They are the products of the earliest known platform-type sedimentation on the earth; a result of increased crustal thickening produced by the Kenoran Orogeny (2.5 b.y.). The age of the sedimentary rocks falls between the age of the Archean basement, 2.7-2.5 b.y. and the age of the Nipissing diabase dykes and sills, 2.1 b.y., which intrude and transect them. The sedimentary rocks belong to the Huronian Supergroup. Their maximum thickness is over 40,000 feet on the south but they wedge out northward. They are dominantly terrigenous clastic sedimentary sequences, originated from the Archean terrane toward the north. The sediments were deposited in regressive marine cycles. Each regressive cycle however was transgressed northwards by the subsequent regressive cycle. The contact between the Huronian and Archean rocks is an angular unconformity on the north. To the south, the Huronian is overlain unconformably by Cambrian and Ordovician sediments. The Elliot Lake Syncline itself however - at least its eastern lobe - is in part an outlier, bordered on the south also by Archean basement rocks (Figure 2).

The Huronian Supergroup consists of four groups. In an upward sequence these are the Elliot Lake Group, the Hough Lake Group, the Quirke Lake Group and the Cobalt Group. The Elliot Lake Group has two sedimentary formations: the Matinenda Formation which grades upward and laterally into the McKim Formation. The subject of the present study, the Denison Main Reef, is in the lower part of the Matinenda Formation, in the northern limb of the Elliot Lake Syncline. (See Table of Formations I).

URANIUM ORE ZONES IN THE ELLIOT LAKE SYNCLINE

LEGEND

	Ore zones		Mines on North Limb
	Extent of Huronian group on present surface		Denison
Basement			New Quirke
			Panel
			Spanish American
			Greenstone
			Iron formation

FIGURE 2

TABLE OF FORMATIONS, ELLIOT LAKE DISTRICT

After Robertson et al, 1969

PHANEROZOIC		
PALEOZOIC		
ORDOVICIAN	Limestone	
PRECAMBRIAN		
PROTEROZOIC		
SUDBURY DIKES	Olivine diabase	1,225 m.y.
Intrusive Contact		
CROKER ISLAND COMPLEX	Gabbro, granite	1,445 m.y.
CUTLER BATHOLITH	Granite	1,750 m.y.
Intrusive Contact		
NIPissing	Quartz diabase, diorite	2,155 m.y.
Intrusive Contact		
HURONIAN SUPERGROUP		
COBALT GROUP		
BAR RIVER	Quartzite	
GORDON LAKE	Siltstone	
LORRAIN	Quartzite, conglomerate	
GOWGANDA	Conglomerate, quartzite	
Unconformity-Disconformity		
QUIRKE LAKE GROUP		
SERPENT	Quartzite	
ESPANOLA	Limestone, siltstone	
BRUCE	Conglomerate	
Local Disconformity		
HOUGH LAKE GROUP		
MISSISSAGI	Quartzite	
PECORS	Argillite	
RAMSAY LAKE	Conglomerate	
Local Disconformity		
ELLIOT LAKE GROUP		
McKIM	Argillite	
MATINENDA	Quartzite, ± U-conglomerate	
	Conglomerate	
	Arkose ± U-conglomerate	
Unconformity (locally marked by a regolith)	Volcanic rocks	
Unconformity		
ARCHEAN		
KENORAN (ALGOMAN)	Granite	2,500 m.y.
Intrusive Contact		
	Volcanic and sedimentary rocks	

TABLE OF FORMATIONS I

MATINENDA FORMATION

The Matinenda Formation is the oldest formation of the Huronian Supergroup at the part of the Elliot Lake Syncline under consideration (Robertson, 1981). It unconformably overlies Archean greenstones of Keewatin age and Algonian-type granites, which are covered by a regolith zone. Minor basal Huronian mafic volcanic flows are present on the north limb of the syncline to the west of the study area. The presence of similar volcanic rocks is being investigated at present (1982) in the underground workings of the Rio Algom Ltd. Panel mine, immediately east of the Denison mine. The Matinenda Formation hosts not only the Denison Main Reef but all the other known economically significant uranium bearing conglomerate reefs of the Elliot Lake uranium district. The Formation consists of sericitic arkoses and quartzites deposited in a near-shore deltaic environment. Their structure, texture and degree of sorting varies both parallel to the depositional surfaces and perpendicular to them (Pienaar, 1963). The conglomerate reefs, which form in essence the economic uranium ore zones, are fluvio-deltaic detrital deposits intercalated in a quartzitic-subarkosic sedimentary sequence deposited, and in some areas reworked, by a northward transgressing shallow sea. The Matinenda Formation is about 300 feet thick on the Denison property.

Geological descriptions on the north limb of the syncline generally classify the Matinenda Formation as a thick pebbly grit sequence, containing numerous quartz pebble beds or lenses elongated in a northwest-southeast direction. The orientation of these lenses seems to reflect the underlying basement topography (Robertson,

1981). The economic uranium content is concentrated in five major and several intercalated minor pyritic, oligomictic conglomerate zones, separated from each other by quartzitic or arkosic beds which are also almost without exception more or less radioactive. (See Table of Formations, II). The conglomerates are variable from tightly packed ortho-conglomerates to pebbly quartzites, reflecting by their composition the dynamic variation of the depositing agents. The pebbles are almost exclusively quartz; they are well rounded and their size-sorting is also the consequence of the deposition. The matrix between the pebbles is allogenic and originates probably from the same source area as the pebbles, the granitic terrain immediately north of the Elliot Lake Syncline.

The strike of the conglomerate ore zones is southeasterly with a gentle rake of five to seven degrees and a south-south-westerly dip of 15 to 20 degrees. Low angle regional thrustfaults, parallel to the synclinal axis repeated some of the conglomerate zones. The thrustfaults, as well as "rolls" - the latter occasionally double the regional dip angle of the bedding, cause local flattening or even reverse dips - are the consequences of the syncline - forming tectonic activity. Old steep-angle faults in the basement were rejuvenated after the deposition of the sediments and localized the intrusions of east-west striking regional Nipissing diabase dikes which transsected the entire Huronian sequence before the formation of the syncline.

Metasomatism of the sediments is restricted to the immediate vicinity of the diabase dikes and manifests itself as a narrow chloritized halo along them. Within this alteration halo minor re-

mobilization and local enrichment of the uranium mineralization is locally observable.

DENISON MAIN REEF

The Denison Main Reef, in which the uranium and thorium content distributions were investigated, underlies continuously almost the entire Denison property and to the west, south and east extends beyond the company's boundary (Figure 2). It is missing only in the central north area where it was truncated by an erosional surface. On this erosional surface and on local basement highs the basal member of the Hough Lake Group, the Ramsay Lake Formation and/or Pecors Formation is deposited unconformably. The McKim Formation, which follows the Matinenda Formation in the Elliot Lake Group, is missing in this area. (See Tables of Formations I & II, Fig. 3)

The Denison Main Reef is essentially a tripartite complex in which two mainly conglomeratic units enclose between them a mainly quartzitic unit. The hanging and the foot walls of the quartzitic unit are intrinsic dividing surfaces. The hanging wall of the upper conglomeratic unit is an economic limit, varying locally, from time to time, in terms of the momentarily feasible mining cutoff grade. The footwall of the lower conglomeratic unit is mainly defined in the same way but in some areas, where basement highs approach or encroach this unit, it is a natural limiting surface. (See Table of Formations II).

In the present exercise all three units are designated as reefs; the upper unit is the "A" reef, the middle unit is the "I.Q"

reef - from the company's everyday nomenclature, i.e., "intercalated quartzite" - and the lower unit is the "B" reef. The lithologies of "A" and "B" reefs are dominated by conglomeratic units, the "I.Q" reef by quartzitic ones. In the routine daily sampling the sampled intersections are described lithologically as "conglomerate", "pebble quartzite" and "quartzite". The relative coarse and fine grained components of the "pebble quartzite" are not described quantitatively at every instance, consequently "pebble quartzite" could mean anything from a loosely packed conglomerate to a fine grained layer with a few pebbles in it. The thickness of the "I.Q" reef varies between less than one foot and six feet, with local extremes reaching to ten feet. The thickness of "A" and "B" reefs are defined by the utilized economic cutoff grades, mining techniques, or both of these factors from time to time and from place to place.

The uranium content usually, but not unfailingly, reaches its highest level in the conglomeratic units, which form intertonguing lenses elongated in a southeasterly direction, reflecting the depositional morphology of braided gravel beds in an essentially deltaic environment, both in "A" and "B" reefs. The morphology of "I.Q" reef in contrast suggests deposition along the shorelines of a transgressing sea, active between two successive fluvio-deltaic regimes, although minor conglomeratic units are not entirely absent from this reef.

The radioactive minerals in the reefs consist of uraninite, "brannerite", uranothorite, thorite, monazite and zircon. This mineral assemblage has been described by several authors but for the present exercise the descriptions of Theis (1979) were followed as

a general guide line because, to the writer's knowledge, this study is not only the most recent work, but also because it is the most intimately connected with the Denison Main Reef.

CORRELATION OF QUARTZ-PEBBLE CONGLOMERATE REEFS, NORTH LIMB

After J.A. Robertson, 1976

QUIRKE 1 & 2 (Rio Algom Mines) Ramsay Lake Formation		DENISON Denison Mines Ltd. Ramsay Lake Formation		STANROCK Denison Mines Ltd.	
Quartzite	Quartzite	Quartzite			
Upper _____	F				
Quartzite	Quartzite				
A (Quirke 1) _____	E				
Quartzite	Quartzite				
B _____	D				
Quartzite	Quartzite				
C-L _____	Floater reef(s)				
Quartzite	Quartzite				
C (Quirke 2) _____ ?	A ₁ Quartzite				Quartzite
Quartzite	A ₂ _____				St ₁
	I.Q. (Interbedded quartzite)				Quartzite
	B _____				St ₂
	Quartzite				Quartzite
FWC (Scraps) _____ ?	Scraps				St ₃
Quartzite	Quartzite				Quartzite
Basement	Basement				Basement

Matinenda Formation

TABLE OF FORMATIONS II

GENERALIZED GEOLOGICAL CROSS SECTION
(after Denison Mines Limited)

FIGURE 3

Uraninite

Uraninite occurs in individual grains whose size ranges between 50 to 200 microns. The grains seem to concentrate preferentially in the basal area of their individual host layer. The lower part of the perimeter of pebbles and pyrite grains may also have above average uraninite grain accumulations. This relationship between uraninite grains and quartz pebbles was investigated by Theis quantitatively and he demonstrated good correlation between increasing pebble size and uraninite concentration around pebbles. The shape of the grains are generally subangular although shapes from euhedral to well rounded were observed by different investigators. Theis analysed the chemical composition of the uraninite grains and as a result of this analysis he quoted the following "approximate partial analysis" result: 65% UO_2 ; 6.5% ThO_2 ; 18% PbO and 2.5% Y_2O_3 . He did not indicate whether this result is a mode; a median or one of the several types of possibly calculable means. Neither did he elaborate on the location, size, distribution or relative representativeness of the sample which possibly could have produced the above quoted chemical composition. Despite these shortcomings from the sampling theory point of view, his analytical results should be considered the most up-to-date and probably the best, simply because no better published data are known.

"Brannerite"

This mineral was identified by X-ray diffraction in the Elliot Lake ores relatively early in the explorational history of the

district (1954). The material examined, being metamict, required heating before it produced a definite X-ray pattern. It was suggested that the examined mineral became brannerite due to the applied heat treatment; originally perhaps it was something else. Although the issue was not resolved satisfactorily it had become an accepted practice to call any occurrence of uranium-titanium oxide "brannerite" in quotation marks, perhaps merely for sake of convenience.

Thies described three types of uranium-titanium minerals, loosely called "brannerite" but he did not produce adequate statistical data which one could use to decide which, if any, of his painstakingly analysed and described occurrences would qualify as a representative sample, or are they merely interesting specimens.

Various students of the Elliot Lake conglomerates described the origin of the "brannerite" as detrital material. Others suggested a metamorphic origin, and/or a product of local mobilization and redistribution of uranium. The questions about the identity and formational mode of this material, called "brannerite", will remain unanswered until somebody makes the painstaking mineralogical investigations with a systematic and representative sample collecting program. As long as such a project is not completed, the unquestionably very valuable mineralogical investigations, done to date, will not become correlatable and generalizable. "Brannerite" till then must remain in quotation marks.

Miscellaneous Radioactive Minerals

The dominant radioactive ore minerals in the conglomerates of the Elliot Lake uranium district are uraninite and "brannerite". Their ratio to each other is variable not only between reefs but even between areas of the same reef, according to the geologists of the local mining companies.

The occurrences of the following miscellaneous radioactive minerals were reported from the Elliot Lake mining district in general, and from the Denison Main Reef in particular.

Roscoe (1969), based on both his own extensive investigations and published reports of other authors, listed and discussed, besides uraninite and "brannerite", monazite, zircon, thucholite, rutile and anatase.

Theis (1979) reported monazite and zircon, as well as the "expected presence" of thorite and uranothorite. He based his expectations on geochemically anomalous thorium concentrations. If one considers the all-prevalent presence of thorium in systematic company sampling and used in the numerical analysis, which is the essence of the hereunder presented exercise, Theis's expectations about the thorium minerals were fully justified. His later investigations substantiated it also. He noted that metamict uranothorite was recognizable in his polished thin sections.

Robertson (1981) recapitulated the findings of the above investigators, together with several others and enriched this summarization with his very intimate personal knowledge of the Elliot Lake district. He listed several subtypes of monazites, discussed the substitutional relationships of thorium in uranium minerals and the

morphologies of various radioactive mineral grains.

Stanton (1972), in a comparative discussion of the Witwatersrand, Blind River and the Brazilian Jacobina deposits - the three classic locations of early Proterozoic uranium-bearing conglomerate deposits on the earth - emphasized the ubiquitous presence of thucholites, - uranium-bearing hydrocarbons - in the Witwatersrand and their relative scarcity in the Elliot Lake area. He also mentioned a reverse relationship between thorium minerals from the two districts, i.e. comparative abundance in Elliot Lake and scarcity in the Witwatersrand, but unfortunately did not elaborate on the respective mineralogical parentages of the quoted thorium occurrences.

Pyrite, though not radioactive, is very intimately and ubiquitously associated with uranium minerals. No discussion of the Elliot Lake deposits would be satisfactory without some remarks about the pyrite.

Pyrite

The early Proterozoic conglomerate deposits of the Elliot Lake area, as well as those in the Witwatersrand in South Africa, contain unusually large amounts of pyrite. The uranium minerals are practically invisible in the deposits and the primary mineral commodity in the Witwatersrand, gold, is also very fine grained. The highly visible pyrite content always attracted the attention of investigators because geochemical and ore genesis considerations suggested causative relationships between the gold, uranium and pyrite in these deposits.

The pyrite content of the deposits in Elliot Lake generally averages around 15% with local concentrations of 25% in the matrix of well packed conglomerates. If one considers that the quoted pyrite percentages are usually volumetric percentages, based on visual estimations, and that specific gravity of pyrite ranges between 4.9 and 5.2 (Betekhtin, 1964), while the specific gravity of arkosic sediments is routinely estimated by the operating mines as 2.7, therefore one quarter of the mass of the average unit volume of rock is pyrite. Pyrite in the uraniferous conglomerates of the Elliot Lake area is thus a major rock forming mineral, which exercises a very significant influence on the character of the ore. The continuing interest in pyrite by the students of these deposits is well justified.

Stanton (1972), in his comparative study of the early Proterozoic gold and uranium bearing conglomeratic deposits, called pyrite the most conspicuous mineral of these deposits after feldspar and quartz. He listed it as a constituent of the sedimentary beds and of the cross-cutting inlets in the form of euhedral, subhedral and rounded grains.

Roscoe (1969) in his study of uraniferous Canadian conglomerates noted the heterogeneous morphology of the pyrite and classified it according to grain shape and appearance in seven different types. According to the variety of the grain characters he suggested different possible origins for them. All of his genetic suggestions were obviously rooted in his commitment to the "Modified Detrital Hypothesis". In his further investigations - true to his beliefs that the pyrite is the erosional product of the Archean ter-

rane, north of the Elliot Lake Syncline - he compared the pyrite of the deposits with the pyrite of the Archean sulphide deposits of the Superior Province. His examinations led him to accept that at least some of the pyrite could be of diagenetic origin.

Theis (1979) also examined the morphology of the pyrite grains, but concluded that the origin of pyrite cannot be deciphered from grain-morphology. He suggested a twofold division of the pyrite grains, as observed by him in polished thin sections. His first division is the collective accumulation of all grains which are relatively small and show signs of in situ growth, partly by outline, partly by location, i.e., euhedral or located in fractures. His second division is a catch-all group, containing all pyrite which does not fit into the first. He postulated that there is no genetic relationship between the two divisions, but did not propose any explicit hypothesis about the origin of the pyrite grains which belong to his second division. One has the suspicion that Theis intended to suggest in an implicit way that the pyrite in his second division could be at least partly of detrital origin.

Robertson (1981) noted that pyrite is concentrated in the matrix of the conglomerates. According to him replacement and fracture filling with pyrite occur only rarely. He found the shape of the pyrite grains mainly round or subhedral. Reiterating the old concept that pyrite in the conglomerates could be the product of sulphidization of detrital magnetite grains, Robertson suggested that the necessary sulphur for such a process could have been derived from the Lower Huronian volcanic rocks.

Many investigators concentrated their attention on the pyrite content of the conglomerates both in the Elliot Lake district and elsewhere (Witwatersrand, Jacobina), but the universal shortcoming of all their cumulative effort is that the examined specimens were in every case only "specimens" and not "samples" produced by systematic sampling projects. As long as such a systematically collected sample is not examined, dependable generalizations about the distribution and origin of the pyrite in conglomerates cannot be established.

GENETIC HYPOTHESES

Efforts to develop and substantiate an acceptable genetic model for both the gold-uranium-pyrite ores of the Witwatersrand and the uranium-pyrite ores of the Elliot Lake district not only created some of the most elegant examples of deductive geological reasoning but triggered also one of the most prominent controversies of geology in the present century. The proposed genetic hypotheses and their variations are numerous. The debates over their relative merits and shortcomings were widespread, but to date have not produced an acceptable consensus.

Three hypothetical genetic models play the principal roles in the controversy. Their outline, according to their principal advocates as well as proposed considerations which contradict their feasibility are summarized in the following paragraphs.

Placer Hypothesis

The earliest, most simplistic but today somewhat stale genetic hypothesis is based on the similarity between recent auriferous placers and the discussed Proterozoic conglomerates. As far as the hostrocks of these two deposit types are concerned the analogy is correct and unequivocal. Deposition of modern gravelbeds are observable where a dynamic, detritus-loaded stream leaves its mountainous source area, enters the flat foreland at the base of the mountains, loses its competence and drops its coarse load in the form of sinuous placers. If the source area of the stream is enriched with gold, it will be eroded together with the rock material and will be deposited together with the gravel-bed-forming cobbles and pebbles as an auriferous placer. Such deposits were discovered and formed the famous bonanzas in California and in the Yukon at the time when the Witwatersrand was discovered. It is understandable that the earliest interpreters, finding the only difference between the two types of the deposits the complete lithification of the Witwatersrand rocks, attributed this aspect to their greater age and called those deposits auriferous fossil placers. With the continuous and intensive exploitation of the Witwatersrand the mass of observational facts rapidly increased and contradictory evidence had begun to build up against the placer hypothesis. Perhaps the first serious misgiving was the complete lack of coarse gold in the Witwatersrand in contrast with modern placers, in which the gold is present in a wide range of particle sizes from coarse "nuggets" to barely visible "colours". Another drastic contrast between the Rand and modern auriferous placers is the dominating presence of pyrite

and conspicuous absence of magnetite in the former versus the exact opposite situation in the latter. The discovery of significant amounts of uranium in the Witwatersrand ores raised the final contradiction against a simple placer hypothesis because the geochemical peculiarities of this element may completely negate the possibility of its large scale movement in detrital form.

Attempts to maintain the validity of the placer hypothesis were modulated by the development of hypotheses about the early atmosphere of the earth at the time when the great age of the Witwatersrand deposits was realized. Considerations about a reducing early atmosphere of the earth, which was popularized by the experiments of H. Urey and S.L. Miller in 1953 at the University of Chicago and coincided with the first world-wide uranium exploration boom, led to modification of the postulated depositional environment of the Rand deposits instead of change of their hypothetical genetic model. In a reducing atmosphere both uranium and pyrite would survive as detritus, accumulated, transported and deposited by streams and rivers. Consequently the placer hypothesis is acceptable for pyritic uranium-bearing conglomerates, provided that they are old enough to have been developed while the earth's atmosphere was still reducing.

This is the present status of the placer hypothesis. Today it has few adherents for two reasons. First because the experiments of Urey and Miller, which produced amino acids - the possible precursors of life on earth - in a closed system of water vapour, carbon dioxide, hydrogen, ammonia and methane, dominated by the last two, was found to be repeatable in another artificial atmosphere

which consisted mainly of carbon dioxide, nitrogen, water vapour and only traces of ammonia (Gribbin, 1982). Consequently the earth did not need a reducing atmosphere to develop life. Second, because of the argumentation against it by one of the giants of modern geology, C.F. Davidson who was committed to a hydrothermal genetic model.

Hydrothermal Hypothesis

The genetic hypothesis, according to which the uranium mineralization in the Elliot Lake Syncline and the gold-cum-uranium mineralization of the Witwatersrand is the consequence of hydrothermal-hypothermal processes, was explicitly outlined by C.F. Davidson (1957). Davidson, (1) detailed the factual evidence collected at the time of his writing (2) argued against the use of this evidence as support of the detrital school of thought; and (3) elaborated on his arguments in favour of an epigenetic-hydrothermal mode of emplacement of the gold and uranium in the conglomerates. Stanton (1972) recapitulated and summarized Davidson's and other hydrothermalists arguments. Following these two sources, the epigenetic hypothesis rests upon the following points:

1. The arenaceous parts of the host formation are more radioactive than the argillaceous parts, indicating a reverse situation from that which would be expected in "normal" sedimentary rocks.
2. The gold and or pyrite content of the quartzites, as well as their uranium content is of an anomalously high level, compared with quartzites elsewhere.

3. The mineralization, accumulated in the conglomerate "reefs" in the bottom of the total overlying sedimentary rock column, is more than the amount which could have originated from these rocks.

These three arguments indicate according to Davidson that the mineralization originated from a hydrothermal source younger in age. Stanton (1972) adds to these points the following hydrothermal origin - indicating concepts:

1. The conglomerate zones are merely permeable conduits which the hydrothermal solutions used as preferable natural pathways for lateral movement.
2. The mineralization is located at various levels of the conglomerate beds, not concentrated at their bases which would be the case in normal detrital deposition processes.
3. The rounded uraninite grains suggest colloidal origin not attritional tear and wear.
4. Both uraninite and pyrite would have been dissolved at or near their original location as soon as they had been exposed to atmospheric conditions by erosion, unless the atmosphere at the time of their erosion and transportation was reducing.

It is worthy to note, in connection with this last point, that the postulated reducing atmosphere at the time of deposition is the cardinal argument of the "modified placerists" too and this proposition was accepted until the present decade in the scientific community. Very recent propositions however raised weighty and ser-

ious arguments against it (Dimroth and Kimberley, 1976; Dimroth, 1979; Henderson-Sellers, Benlow and Meadows, 1980; McLennan and Taylor, 1980; Gribbin, 1982).

5. The lack of titaniferous iron minerals in the uranium and uranium-gold bearing sediments indicate that the mineralization is not of alluvial origin.
6. While modern gold placers contain thorium minerals and uraninite is virtually absent from them, in the discussed deposits the uranium content equals or dominates the thorium content. (Preliminary calculations, completed during the preparation of the present exercise, bear this statement out. The ratio between the weighted averages of 11297 samples of U_3O_8 and ThO_2 assays is 2.300)
7. Gold-silver ratios in placers are usually high near the top of the deposits and lower at the bottom, due to the leaching action of groundwater on the silver content. In the Witwatersrand reefs the situation is exactly the opposite.

Stanton, in his final conclusions, negated the plausibility of both the placer and hydrothermal genetic hypotheses and committed himself to the "Modified Placer Hypothesis" but his commitment was not absolute. He left a door open toward the final decision, which according to him, will depend on conclusions drawn from further lengthy examination and evaluation of existing, and yet to be found, evidence. The necessity of such projects was voiced by virtually all of the students of the early Proterozoic sedimentary uranium and gold deposits.

Modified Placer Hypothesis

The most recent and most widely accepted model for the genesis of the uranium ore in the Elliot Lake Syncline and the gold-uranium ores of the Witwatersrand is the "Modified Placer Hypothesis". Supporting mineralogical, geochemical, paleo-environmental and other arguments both for its validity and against the above discussed alternative models were and are the subjects of many publications. To delve into the relative merits of these arguments is not the task of the present thesis. An outline of the "Modified Placer Hypothesis" is presented below as a straight quotation from J.A.

Robertson (1981) as published in his summary description of the uranium deposits in the Elliot Lake area. Robertson, taking into account the published evidence of many investigators to date, defines the hypothesis in the following way:

"This hypothesis proposes that the deposits were derived from Archean terrain to the north and northwest, transported by rapidly moving water, and deposited in a near shore fluvial environment under cold, possibly frigid, reducing conditions about 2500 my ago. Mafic volcanic rocks were simultaneously accumulating in the basin. The uranium deposits were later subjected to diagenesis and to minor alteration during subsequent intrusive, metamorphic, and tectonic events, but were not subjected to erosion or leaching".

According to this definition the uranium minerals in the deposits are of detrital origin and reached their present place as solid fragments, carried by water, as it was proposed for the gold in the Witwatersrand by the early "pure" placerists. Subsequent minor alteration, in restricted localities, did not change their postulated detrital nature. The writer is indebted to J.A. Robert-

son for pointing out a curious semantic obscurity which prevails in the published accounts of the "Modified Placer Hypothesis". Does the word "modified" in the name refer to the hypothesis or to the deposits themselves? Re-reading the many publications, in the writer's judgment it refers to both by nearly all authors, but with differing orders and importances.

If the hypothesis itself is modified, it means an attempt to circumvent the obvious contradiction to the "pure" placerist proposal, formed by the presence of uranium in the deposits. Uranium is perhaps the most unstable element when exposed to atmospheric conditions existing on the earth. It oxidizes rapidly and enters into solutions faster than most elements of the periodic table. When the simple placerist mode of deposition of the Witwatersrand deposits was first proposed the presence of uranium was not known, or at least not seriously considered in those deposits. Its presence was noted in the Rand deposits and it was subsequently discovered as not only the dominant, but nearly the sole economic component in the Elliot Lake deposits, precisely because of the search for it. The deciphering of its geochemical behaviour raised the first serious arguments against the placerist mode of its emplacement in the deposits. The nearly concurrent work of Urey, about the origin and early development of life on the earth - mentioned previously -, led to the modification of the hypothesis. The contradiction between uranium's geochemical behaviour and its mode of detrital emplacement was resolved by the proposal of a reducing early atmosphere on the earth. The hypothesis had become "modified" in this case. In my

opinion S.M. Roscoe (1969) is the leading advocate of the "Modified Placer Hypothesis" for the Elliot Lake deposits in Canada in this sense. In his work, entitled: "Huronian Rocks and Uraniferous Conglomerates in the Canadian Shield" (1969) he discusses extensively the early atmospheric evolution of the earth.

Increasing knowledge and numerous intensive mineralogical and petrological investigations of the ores in the Rand and in the Elliot Lake area led to the proposition of modifications of the deposits. Various experimental results suggest that the originally detritally deposited uranium bearing minerals underwent solution, redistribution and subsequent re-precipitation "in situ" after their deposition. The degree and extent of this type of suggested modification is different according to different authors. The comparison of different lines of thought is not the purpose of the present thesis, so only one example is cited here. This example is called the "Pronto-Reaction" by P. Ramdohr, its proposer (1957). According to him "brannerite", one of the main uranium ore minerals in the Elliot Lake area mines, was formed "in situ" and was not transported as detrital material to its present place. The process which had led to its formation is based on the chemical reaction between detrital rutile and uranium bearing solutions which were the products of dissolution of uraninite grains in the deposits. Ramdohr's proposal has been questioned because of the lack of demonstrable temperature level in the deposits for such a reaction. Here it is merely used as an illustration for the "modification" of the deposit in contrast to the "modification" of the hypothesis.

As it was said before the two types of "modification" exist almost in every discussion of the genetic mode of the Elliot Lake deposits when it was written by a proponent of the "Modified Placer Hypothesis". The order and degree of importance however is different in practically every discussion. In the formalized statement of the "Modified Placer Hypothesis" - quoted above - the emphasis is implicitly on the postulated reducing atmospheric conditions, which enabled uranium minerals to weather out, travel and be deposited in a detrital form. "In situ" modification played but a minor role in Robertson's model. It was restricted to the vicinity of the transecting post-Matinenda diabase dykes and consisted of minor hydrothermal redistribution of the uranium.

In conclusion it must be again stated - perhaps somewhat repetitiously - that the discussion of different depositional hypotheses in this thesis is not intended to be an evaluative exercise. It was done merely to recapitulate and outline the three most dominant schools of thought. The exercise was necessary because the present thesis is centred on the "Modified Placer Hypothesis". This hypothesis was formulated into a statistical "null hypothesis" whose validity in turn can be investigated in an unbiased way with the help of statistical inference. The formulation of the statistical "null hypothesis" involved the consideration of certain geochemical concepts which are summarized in the following chapter.

PERTINENT ASPECTS OF THE GEOCHEMISTRY OF URANIUM AND THORIUM

In the Denison Main Reef both the uranium and thorium contents are highly anomalous. From a commercial point of view however, only the uranium content is significant because the economic role of thorium is negligible due to the very limited commercial demand for it. The exercise, described in the present thesis, utilized the available numerical data on both elements to examine the plausibility of the currently most popular hypothesis about the mode of emplacement of uranium in the Denison Main Reef, i.e., the Modified Placer Hypothesis. This genetic hypothesis postulates the existence of a prevailing atmosphere on the earth at the time of the formation of the deposit which was drastically different from the presently existing one. In the postulated atmospheric model free oxygen was supposed to have been either totally absent or present only in insignificant traces. In such conditions uranium and thorium would behave the same way in the upper, weathering zone of the earth's crust. Their erosion, transport and deposition would follow the same patterns.

Uranium and thorium are very closely related elements. Both belong to the actinide series. In fact they are the only two actinides whose presence in the earth's crust is permanent since the formation of our planet. The other two naturally occurring actinides, actinium and protactinium, have such short radioactive half-lives that their existence is only transitory, merely a consequence of the radioactive decay of their respective parent elements.

The close relationship of uranium and thorium is explainable by their very similar atomic structure. Both their atomic number and atomic weight differs less than three percent from each other. They have a similar coordination number (8) with respect to oxygen, with which they form their primary minerals, uraninite and thorianite respectively. Both elements are able to proxy in the primary oxide of the other in a continuous isomorphic substitution, crystallizing in the cubic system. The above mentioned minerals are the dominant form of occurrence of the two elements in the deeper regions of the earth's crust. In these minerals both elements, at least initially, are in the tetravalent state. The chemical bonding of the two elements with oxygen is ionic to the same degree, about 67%. Uraninite and thorianite resists chemical alteration in the absence of free oxygen and their physical properties are very similar. If exposed to purely physical weathering forces they suffer simple attrition and comminution roughly at the same rate.

From the geochemical aspect the significant difference between the two elements is the presence of the two extra electrons in the slightly heavier uranium atom. Although these two electrons are located in an internal electron shell of the uranium atom, leaving its outermost electron shell identical to the thorium atom, the two additional electrons are able to act as valence electrons if the uranium atom comes into contact with available free oxygen atoms. When the two additional electrons become activated as valence electrons uranium changes into the hexavalent state.

Tetravalent uranium, when it is oxidizing in the presence of free oxygen and becoming hexavalent, will form the very soluble uranyl ion. Uranyl ions dissolve in water and are transported away from their place of formation in solutions. This is the only geochemically possible mode of movement of uranium in the zone of weathering on or near the earth's surface (Gabelman, 1977). In stark contrast to uranium, tetravalent thorium, due to the lack of the two additional electrons with valence potential, cannot oxidize into a hexavalent form analogous to the uranyl ion, even if oxygen is available for such reaction. Not being able to oxidize, thorium does not become soluble in water (Rosholt and others, 1971). Remaining in resistate form, thorium will be transported away in the weathering zone from its place of origin as solid detritus (Gabelman, 1977). The different behaviour of the two elements during their transportation was documented, based on theoretical geochemical considerations by Adams and others (1959). The phenomenon was analytically demonstrated by Rosholt and others (1971). Gabelman (1977) extensively discussed the two elements' behaviour in surface conditions in the context of its exploration significance. The evidence, offered by the above investigators, is the basis for the first assumption in this thesis (see page 5), according to which:

"The thorium content was deposited syngenetically with the "reef" - forming sediments in the form of solid detritus."

Surface waters, as well as oxidized ground waters, mainly due to the abundantly present carbonate ions in them will accumulate and transport uranium as a solute. The solution and transportation of uranium in oxygenated surface and groundwaters drastically increases the duration of time during which uranium will suffer chemical weathering and transportation as well as the continuity of supply at its eventual place of deposition. Under the regime of our present oxidising atmosphere this is the almost exclusive mode of movement of uranium on the surface and in the zone of weathering of the earth's crust. This type of movement of uranium, i.e. as a solute in water, is drastically different from the inert resistate - type behaviour of thorium. Uranium will not only separate from its sister element both in space and time, even if their place of primary origin is common, but will demonstrate a completely different pattern of distribution at its place of deposition, even if intermittently transporting surface waters will deposit thorium, transported as physical detritus, at the same location.

THE GENETIC HYPOTHESIS AS NULL HYPOTHESIS

The essence of the exercise, discussed in this thesis, is the statistical testing of the acceptability of the Modified Placer Hypothesis. To do the testing Statistical Inference was used. Statistical Inference is a quantitative and inductive reasoning method. In contrast, the Modified Placer Hypothesis was formulated essential-

ly by qualitative and deductive reasoning. To test the acceptability of a hypothesis derived by deductive reasoning with the application of Statistical Inference it is necessary to state it as a "null hypothesis". The term "null hypothesis" means that an initial, deductively arrived at, statement about some observed phenomenon is reformulated in such a way that it becomes subjectible to statistical testing procedures. Due to the probabilistic nature of statistical reasoning the initial statement must be reformulated in such a way that its "likeliness" will be quantitatively calculable. It means that instead of its original qualitative form the initial hypothesis needs to be changed into some of its quantitatively expressible form, measurable in the same measuring units as the data base which was used in the testing calculations. The data base in the present exercise consist of numerical uranium and thorium content statements, consequently the Modified Placer Hypothesis must be stated in the same terms.

According to the Modified Placer Hypothesis the uranium was carried to and deposited in the Denison Main Reef by surface waters as solid mineral fragments at the same time as the reef itself was deposited. In short, the uranium mineralization is detrital and syngenetic. To justify the hypothetical detrital origin of the uranium, which is contrary to the geochemical nature of this element in presently existing atmospheric conditions, an explanatory sub-hypothesis was added which proposed an atmospheric model at the time of ore genesis, that is chemically different from the present one. Based on the geochemical nature of thorium, (Adams and others, 1959), occur-

ing together with uranium in the hostrock, it can be stated that this element was unquestionably deposited syngenetically as water transported detritus in the Denison Main Reef (Gabelman 1977). An atmosphere different from a presently existing one would not have changed the essentially insoluble behaviour of thorium. Considering the many similarities between uranium and thorium, together with the proposed atmospheric model at the time of their co-deposition in the Denison Main Reef it is plausible that both elements were deposited and are distributed in the same pattern both in time and space dimensions. The Denison Main Reef is classifiable in the time dimension according to its stratigraphy and in space according to its lithology. The individual uranium and thorium contents of the data base are groupable in the same way. Statistical methodologies allow us to measure the distribution patterns of both elements in a quantitative way. In other words it is possible to express the degree of likeliness of the proposition that the distribution of the uranium content and thorium content in the Reef and in its time and space subunits are similar to each other.

Based on the above detailed reasoning the Modified Placer Hypothesis as "null hypothesis " is stated the following way:

"The distribution of uranium and thorium contents both in the Denison Main Reef and in its stratigraphic and lithologic components are analogous and resemble each other in their pattern and style".

Statistical testing techniques, applied to the data base, i.e. Analyses of Variance and non-parametric Mann-Whitney Tests,

made it possible to calculate the degree of plausibility of the Modified Placer Hypothesis expressed in this way as a "null hypothesis".

It is noteworthy that in this way the magnitude of neither thorium contents nor uranium contents were considered. Uranium and thorium concentrations are a function of mineral supply and not of depositional mode.

MINE DATA BASE

The Denison Main Reef has been systematically sampled since the beginning of mining operations. The continuous daily sampling program is organized, supervised and evaluated by the geology department of the mine. The data, accumulated by the sampling, is used primarily for ore reserve estimation and production grade control but it also serves as a basis for both daily and long range mine planning. The sample collecting technique, which yielded and yields continuously the mine data base, employs two distinctly different sampling methods, diamond drilling and chip sampling (Fig 4, Table 1).

Typical Underground Section

Showing: Sample collection method (D.D.H. or "FACE")
Reefs and Rocktypes

SCALE: 1" = 5'

Key:

UR = Upper or "A" Reef
IQ = Intercalated Quartzite
LR = Lower or "B" Reef

Legend:

Quartzite
Pebble Quartzite
Conglomerate

FIGURE 4

TYPICAL UNDERGROUND SECTION

(Assay data fictive, for illustrative purpose only!)

#	Reef	Rock Type	Width ft.	U ₃ O ₈ lbs/ton	ThO ₂ lbs/ton
1	A	Quartzite	0.4	0.01	0.01
2	A	Pebble quartzite	2.7	0.60	2.60
3	A	Conglomerate	3.2	24.30	6.00
4	A	Quartzite	0.8	0.30	0.01
5	A	Pebble quartzite	0.3	1.00	0.70
6	A	Quartzite	0.7	0.20	0.60
7	A	Pebble quartzite	4.1	0.10	0.01
8	IQ	Quartzite	0.7	0.50	0.80
9	IQ	Pebble quartzite	0.3	0.50	0.01
10	IQ	Quartzite	0.4	0.70	0.70
11	IQ	Pebble quartzite	0.2	6.30	3.20
12	IQ	Quartzite	0.9	0.40	0.01
13	B	Conglomerate	1.5	0.80	0.02
14	B	Quartzite	0.3	0.90	0.01
15	B	Pebble quartzite	2.5	0.70	1.40
16	B	Quartzite	0.2	0.15	0.25
17	B	Pebble quartzite	3.0	1.40	0.85
18	B	Quartzite	0.5	0.60	0.01

TABLE 1

Diamond drill sampling is done in all development headings by vertically upward and downward drilled holes. Small, extremely portable, so-called "packsack" diamond drills are employed to collect continuous drill cores whose diameter is somewhat less than one inch. The core is used both for geological examination of the rock above and below the development headings, and for the laboratory analyses to determine their uranium and thorium contents. Locations of the drill holes are determined by the geologist who is in charge of the mine section or "beat" where the drilling is done. The driller, who does the actual drilling, is responsible for the immediate transfer of the produced drill core to the surface, where the same geologist who determined the location of the hole, logs the drill core. The logging subdivides the core according to a uniformized and simplified lithologic terminology into segments. This terminology allows the classification of the accumulated lithological data to be as free from individual and personal bias as is possible in situations where qualitative and visually establishable parameters are utilized in a classification system. The core segments of uniform lithology, or their subsegments, - if the geologist feels that the too great length of a segment with uniform lithology demands such subdivisions - are measured for their length and forwarded to the mine assay office. The diamond drill hole logs, which the geologist prepares during core logging, tabulate the number of the drill hole, its attitude and the lithological description of the drill core according to the length of the individual uniform core segments. The exact location of the drill hole is established by mine surveyors who use chain and transit

methods in their work. The results of the survey, latitude, departure and elevation of the drill hole collars, are entered into the logs of the drill holes.

Between the upward and downward drilled diamond drill holes the wall of the development heading is sampled by chip sampling. The chip samples are collected by sampling crews who were trained and are continuously supervised by the "beat" geologists in their work. They subdivide the wall along a vertical line between the two drill hole collars according to the same simplified lithological classification which is used for core logging. The length of the individual chip sample segments, together with their lithological description, are entered into a "chip sample log" and the collected samples are forwarded to the mine assay office for analytical determination of their uranium content and thorium content.

The three logs, upward hole, chip samples and downward hole, form a complete quantitative description of a vertical stratigraphic section which extends well beyond the economically mineable upper and lower limits of the reef. The stratigraphy of the sections are determined by the "beat" geologists whose intimate, continuous contact with the mine workings enables them to define the exact locations of the hangingwall and the footwall of the Intercalated Quartzite in each individual stratigraphic section. As was mentioned previously, these two points are the only natural dividing points in the stratigraphic sections since the hanging-wall of the "upper" or "A" reef and the footwall of the "lower" or "B" reef varies according to the momentarily utilized cutoff grade. The cutoff grade is the function

of the economic atmosphere, mainly the product of mining costs and metal prices, which prevail at the time when actual mining is carried out in the vicinity of the respective stratigraphic sections.

The individual drill core segments and chip sample segments, which were sent to the mine assay office to determine their uranium and thorium contents, were or are analyzed during the lifetime of the mine by different methods. Initially chemical assaying methods were employed. Uranium was determined by a fluorimetric method while thorium was determined by a colorimetric method. Several years ago the company discontinued the use of chemical assaying methods and since then uranium and thorium contents are determined by X-ray fluorescence. The metal contents are determined in pounds of metal oxide per short tons of ore, i.e., U_3O_8 lbs/s.t. and ThO_2 lbs/s.t. The uranium and thorium contents of the individual core and chip sample segments are tabulated by the mine assay office and returned to the geology department where they are entered into their respective drill and chip sample logs.

When the data base for the present thesis was extracted from the accumulated mine assay files the latter consisted of over ten thousand triads - upward hole, chip sample and downward hole logs - with a cumulative total of over half million uranium and thorium assay determinations. As mentioned above, each triad represents a vertical stratigraphic section which covers the entire reef complex, not only the economically mineable part of it. Although the stratigraphic sections are not drilled on a perfectly rectangular grid, on the average each vertical section represents a horizontal area of some-

what less than four thousand square feet. It means that no information, gained from any of the stratigraphic sections, is extrapolated on the average more than forty-five feet laterally.

It is necessary to mention here that the mine employed and employs two additional sampling methods, the results of which at one time or other in the past were incorporated in the mine data base.

For several years instead of collecting chip samples from the development heading walls a radiometric instrument, the "scanner", was used to determine the uranium content of the individual chip sample segments in those places. The "scanner" was essentially a multiple tube Geiger counter, able to measure the total amount of gamma radiation, but it could not differentiate between different radiation emitting radioactive sources. The readings, taken by this instrument, were adjusted to "net uranium content" with the application of generalized uranium to thorium ratios. The instrument was not considered worthy to determine the usually lower thorium content, consequently in the mine data base where uranium determinations by "scanner" were recorded the corresponding thorium content entry is missing. The "scanners" were several years ago replaced by spectrometers which are able to differentiate between uranium and thorium because they not only sense the total amount of radiation but the different energy levels of each of its components too. The spectrometers are not used, despite their improved capability, to collect data for the mine data base because the presently used XRF assaying technique is so efficient for both uranium and thorium analyses that the mine geology department finds it worthwhile to use the chip sam-

pling method for the development heading wall sampling. The spectrometers are used at the present time mainly for production grade control purposes.

MEG COMPUTER DATA FILE

In 1974 the Government of Canada established the Uranium Resource Appraisal Group (URAG) as a part of the Department of Energy, Mines and Resources (EMR) to develop and maintain an inventory of the country's nuclear resources. The task to evaluate the Reasonably Assured Resources - in mining parlance proven and probable or measured and indicated ore reserves - was assigned to the Mine Evaluation Group (MEG) which is part of Canada Mineral and Energy Technology (CANMET). For the sake of clarity it is necessary to define Reasonably Assured Resources as ore reserves within the developed and thoroughly sampled part of a mineral deposit. This definition is an oversimplification but it will suffice for the present purpose. Since mining companies calculate their ore reserves according to the economic conditions within which they operate, the validity of their ore reserve inventories is bound to those conditions. Drastic changes in the economic climate will invalidate these inventories and will demand the recalculation of ore reserves which is a time consuming major engineering project. The Mine Evaluation Group, entrusted with the task to establish a country-wide ore reserve inventory whose validity will not diminish with time, was forced to develop a mechanism through which ore reserve inventories could be revised and updated

in relatively short time. For this purpose the individual mining company assay data files were "translated" by MEG into a form to which electronic data processing methodologies are applicable. In short: mine data bases or representative parts from them were computer coded.

The Denison Main Reef, as stated in the previous chapter, is documented in a Mine Data Base whose size is so large that to transcribe it into a computer processible form was prohibitive due to time limitations. To solve the dilemma the writer devised a method which secures the extraction of a manageable part from the Mine Data Base in such a way that the extracted part will represent the whole without any bias. The method works on the following way:

The geology department of Denison Mines Ltd. maintains a general drill map on which the locations of all sampled stratigraphic columns (drill hole - chip sample - drill hole triads) are plotted. Over this general drill map a 200 x 200 feet square selector grid was placed, parallel to the existing mine co-ordinate system. The grid facilitates the collection of a random stratified sample from the Mine Data Base. From each grid square one stratigraphic column was selected, with the requirement that the selected stratigraphic column should be the closest from all selectable columns to the geometric center of the grid square. The selected stratigraphic columns were transcribed from the Mine Data Base to the MEG Computer Data File. This latter file contains 1049 stratigraphic columns, slightly more than ten per cent of the Mine Data Base. All information maintained about these stratigraphic columns in the Mine Data Base is now electronic data processible. The spatial distribution of the MEG Computer Data File is illustrated on Figure 5.

SPATIAL DISTRIBUTION OF THE MEG COMPUTER DATA FILE OVER THE DENISON MAIN REEF

FIGURE 5

THE THESIS DATA BASE, A GENERAL FILE

The essence of the present thesis is the comparative statistical analysis of the uranium and thorium content distributions. To carry the statistical analysis to a meaningful conclusion it is necessary to develop a thesis data base which satisfies the requirements imposed by the rules of statistical inference. This thesis data base is a General File, which was extracted from the previously described MEG Computer Data File.

The General File contains all stratigraphic sections from the MEG Computer Data File whose core and chip sample segments were assayed for both uranium and thorium. There are 589 stratigraphic sections in the file. The number of assayed core and chip sample segments in it is 11,297. The cumulative length of these segments is 18,348.1 feet or 3.475 miles. The spatial distribution of the stratigraphic sections over the Denison Main Reef is shown on Figure 6.

The General File contains the following relevant information about the stratigraphic sections and the sample segments:

1. The serial number of the stratigraphic section.
2. The length of the stratigraphic section.
3. The number of sample segments in the section.
4. The latitude, departure and elevation of the top of the section.
5. The serial numbers of the sample segments within each section.
6. The length of each sample segment.

SPATIAL DISTRIBUTION OF THE THESIS DATA BASE OVER THE DENISON MAIN REEF

FIGURE 6

7. The stratigraphic classification of each sample segment.
8. The lithologic classification of each sample segment.
9. The uranium content of each sample segment.
10. The thorium content of each sample segment.

In addition there are numerous other items of information about the stratigraphic sections and their sample segments in the General File but those items serve data management purposes only. These latter items are not pertinent to the statistical analyses, performed in this thesis.

During the preparation of the General File it was necessary to treat it by several selective computer programs to make it suitable for statistical analyses. The purpose of these programs are listed here in the sequence of their application:

1. Elimination of sample segments with indeterminate low uranium and thorium concentrations.
2. Elimination of all sample segments, which were lithologically classified as "pebble quartzites".
3. Segregation of the General File into subfiles according to stratigraphy and lithology; classification of the sample segments according to their length (thickness) in the developed subfiles.
4. Application of a random selection process to distribute the sample segments in statistical samples which satisfy the requirements of the subfiles. ▽

1. Elimination of sample segments with indeterminate low uranium and thorium concentrations

When a rock sample is assayed for its elemental content in an analytical laboratory generally one of two types of approaches are followed in the mining industry. The sample is either analysed for its total composition, in which case the dominant five, ten or twenty-five constituent elements are determined in terms of their oxide percentages, or only the presence of the sought after elements are measured as oxides or elemental substances, depending on the analytical method. The first approach is restricted to the initial exploratory stages of mining. It usually employs spectroscopic techniques and the produced analytical results are generally only semi-quantitative. The second approach is used almost exclusively during the development and subsequent mining of an already known mineral deposit. Its applied methods, whether they are chemical or physical, are completely quantitative within narrow precision tolerance limits. To maintain these rigid requirements the applied analytical method must be calibrated on a relatively narrow "window", whose center is usually the tenor of the ore of the entire mineral deposit. If the determined element content of the assayed rock sample turns out to be outside of the applied methods' calibration "window", the precision and accuracy of the content determination will be questionable. In practice it means that if an analysis of a rock sample indicates unusually high concentration of the sought after element, the analysis will be repeated after the applied method is recalibrated on a "window" with a higher centered range. On the other hand, if the analysis of the sample indicates a very low

value, the presence of the sought after element is established but its quantity cannot be exactly measured with the applied analytical technique. In such a case the analysis will not be repeated with a recalibrated approach. The elements presence in such a case will be simply stated as "trace" in the assay record. "Trace" is not a quantitative statement. The computer is not able to manipulate such a statement together with the other quantitative content determinations. To avoid this electronic data processing difficulty, when the Mine Data Base was transcribed into the MEG Computer Data File, all "trace" values were entered as 0.01 lbs/s.t., which are quantitative statements. This definite value is between zero and the lower limit of the "window" of the utilized analytical technique. The solution neatly bypassed the difficulty posed by any nonquantitative value in the list of quantitative statements, but endangered in advance the validity of results of certain subsequent statistical analyses. To protect the present exercise from such danger the General File was stripped from all uranium and thorium content entries less than 0.02 lbs/s.t. After this step all uranium and thorium content statements remaining in the General File were on equal level of dependability.

2. Elimination of all sample segments, which were lithologically classified as "pebble quartzites"

In the Mine Data Base, and the mentioned computerized derivations of it, those sample segments which are autogenic parts of the Denison Main Reef were classified according to their lithology as belonging to one of the following three types:

conglomerates

or

pebble quartzites

or

quartzites

These three textural types are all parts of a continuous series in which the two end members are of definite composition, i.e., the conglomerates consist completely of pebbles and the quartzites consist completely of sand or smaller-size particles. In the pebble quartzite type however the ratio between coarse and fine particles is variable and undefined. All three lithological types are reflections of the sedimentary environment which dominated their deposition. Since pebble quartzites are the products of two slightly different sedimentary environments, the order of importance of the two could be expressed only if the coarse-fine ratio of the textural constituents would be spelled out quantitatively. In the present case it cannot be done, consequently all sample segments classified as pebble quartzites must be considered as hybrids, whose "parentage" was dominated by one or the other sedimentary environment to a varia-

ble degree. This circumstance diminishes their value as objects of a statistical analysis, whose purpose is to investigate distribution patterns of uranium and thorium contents in them, since those distribution patterns themselves were postulated as products of the same sedimentary environments. Because of this consideration all sample segments which were lithologically typed as pebble quartzites were scrapped from the General File.

3. Segregation of the General File into subfiles according to stratigraphy and lithology; classification of the sample segments according to their length (thickness) in the developed subfiles

~~Dependable~~ statistical inference can be drawn only from the results of such statistical analyses which were carried out on statistical samples whose homogeneity for the purpose of the strived for inference can be safely assumed (Krumbein, 1960). To satisfy this fundamental statistical prerequisite it was necessary to subdivide the heterogenous statistical sample, contained in the General File into subfiles in which the statistical samples are homogeneous for the purpose of the intended statistical inference.

According to the Null Hypothesis, formulated in order to infer its acceptability from the results of statistical analyses: "The distribution of the uranium and thorium contents in the Denison Main Reef as a whole, and in its stratigraphic and lithologic components, are analogous and resemble each other in pattern and style". The detrital origin and depositional mode of the thorium contents are accepted as factual, both for the purpose of the present exercise and in general geological and geochemical thinking. The detrital origin

and depositional mode of the hostrocks, which form the stratigraphic and lithologic components of the Denison Main Reef, is beyond dispute. The object of the present thesis is to compare the distribution patterns and styles of the uranium and thorium contents in the Denison Main Reef to find out whether they are analogous or not. To make the data satisfactory to the requirements of the exercise, the General File was made divisible into statistically homogeneous subfiles according to the following categories:

The stratigraphic classification of every sample segment was used to delineate three first order subfiles containing a uranium content and a thorium content version in all three instances. These are the following:

"A" reef uranium subfile

"A" reef thorium subfile

"I.Q" reef uranium subfile

"I.Q" reef thorium subfile

"B" reef uranium subfile

"B" reef thorium subfile

This delineation is done essentially according to the subdivision of the Denison Main Reef in the time dimension. The "B" reef is the oldest, the "I.Q" reef is younger and the "A" reef is the last deposition. Distinct and continuous unconformities both at the footwall and at the hangingwall of the "I.Q" reef make this subdivision of the Denison Main Reef according to age fully justifiable.

The lithologic classification of the sample segments were used to delineate two second order subfiles within both versions of the above defined first order subfiles. The restriction of the General File to sample segments whose lithology is classified as "conglomerate" and "quartzite" facilitated to make the second order subfiles homogeneous and reflective to their sedimentary environment. The stepwise increasing restrictiveness of the first and second order subfiles increases the homogeneity of the statistical samples which were sorted into each successive subdivision. At this level the General File is subdivisible according the following categories:

"A" reef uranium	conglomerate subfile
	quartzite subfile
"A" reef thorium	conglomerate subfile
	quartzite subfile
"I.Q." reef uranium	conglomerate subfile
	quartzite subfile
"I.Q." reef thorium	conglomerate subfile
	quartzite subfile
"B" reef uranium	conglomerate subfile
	quartzite subfile
"B" reef thorium	conglomerate subfile
	quartzite subfile

Having made the sample segments of the General File subdivisible both for uranium content and thorium content according to their stratigraphy and lithology, one more step was needed to achieve their complete homogeneization. The step is the establishment of

sortability according to size. Using the lengths (thickness) of the sample segments eight thickness classes were established for this purpose with the following limits:

<u>Thickness class</u>	<u>Thickness in feet</u>
1	0.0 → 1.0
2	1.0 → 1.5
3	1.5 → 2.0
4	2.0 → 3.0
5	3.0 → 4.0
6	4.0 → 5.0
7	5.0 → 10.0
8	10.0 → 26.0

4. Application of a random selection process to distribute the sample segments in statistical samples which satisfy the requirements of the subfiles

The previously detailed selective processes are capable of distributing the uranium and thorium content data of the General File in forty-two independent and homogenous statistical samples according to the subfile requirements. Such an arrangement would be fully satisfactory to prepare a data file for statistical analyses in scientific endeavours where statistics are traditionally used, for example in biology, psychology or sociology. The individual measurements or observations, accumulated into a statistical sample for analysis on these latter fields, are assumed to be independent from each other. Assumption of independence between individual observations,

grouped into a statistical sample, is a fundamental requirement in statistics. If this assumption is not justified the validity of conclusions, drawn from analyses of the statistical sample, will be jeopardized.

Geological considerations demand that assumption of independence between observations, collected spatially relatively close to each other, should be suspected. Explicitly speaking: the quantitatively expressed value of an observation on a physical or chemical variable in the earth's crust is influenced by its location. Appropriate examples would be: grain-size, fracture length, degree of alteration, etc. In all such cases the quantitative values of surrounding additional observations, if such are subsequently collected, will almost invariably indicate that the value of the original observation is affected by the values of the latter observations to a variable but estimable degree. Recognition of this phenomenon gave birth to a relatively new science: geostatistics. The ever present possibility of interdependence between geological observations from the same vicinity in a statistical sample makes the results of statistical analyses on it questionable. In order to prevent the inadvertent occurrence of a similar situation in the present exercise a sample segment selection procedure was devised, based on the following reasoning.

Uranium or thorium contents of sample segments in an ore body are the effects of the action of certain natural forces (Holland and Petersen, 1979). These natural forces are large enough to operate regionally. Locally their magnitude and direction is expected to be relatively uniform. Consequently within the limited volume of

space in a sampling locality, in the present case a single stratigraphic section, there is a distinct possibility that the uranium or thorium contents of neighboring sample segments are inter-related. To accumulate a set of observations on the uranium or thorium contents of sample segments into statistical samples, it is imperative to select them as far apart from each other as possible. The selection procedure based on this consideration will drastically diminish the possibility of interdependence between sample segments if the distance between them will be relatively large.

The General File of this study is based on the MEG Computer Data File. The stratigraphic sections, as noted earlier, in the MEG Computer Data File are at least 200 feet apart laterally. In the General File this distance is at least the same, commonly it is larger. The selection procedure, applied to the General File to accumulate the individual statistical samples, selected only one sample segment from every stratigraphic section into each statistical sample. This procedure made the occurrence of dependence between sample segments highly unlikely. So the selected sample segments within the individual statistical samples are considered as independent from each other. The random selection requirement of statistics is thus satisfied.

Seventy one statistical samples were assembled by the coordinated treatment of the General File with the above described selection procedures. The behaviour of the uranium content in the Denison Main Reef is reflected by 5556 sample segments in 37 statistical samples. The other 34 statistical samples deal with the thorium content distribution utilizing 3264 sample segments (Tables 2 and

3). Twenty two per cent of the General File, or 2477 sample segments, were eliminated by the selection procedures to make the assembled statistical samples acceptable for the requirements of statistics i.e., independence of observations within statistical samples and homogeneity in stratigraphic, lithologic and volumetric aspects.

NUMBER OF SAMPLE SEGMENTS UTILIZED IN THE STATISTICAL ANALYSIS

VARIABLE : U_3O_8

CLASS		"CASE"	1	2	5	6	3	4
		Reef	A		IQ		B	
		Rocktype	cong.	qtzite	cong.	qtzite	cong.	qtzite
1	Thickness (length) Limits in ft.	0-1	273	247	50	113	294	199
2		1-1.5	378	271	71	157	380	191
3		1.5-2	344	228	46	132	323	162
4		2-3	240	229	19	132	269	164
5		3-4	51	134	—	69	86	75
6		4-5	5	50	—	26	8	40
7		5-10	—	32	—	27	—	41
8		10-26	—	—	—	—	—	—
$\sum$: CASE			1291	1191	186	656	1360	872
$\sum$: Reef			2482		842		2232	
$\sum$: TOTAL			5556					

TABLE 2

NUMBER OF SAMPLE SEGMENTS UTILIZED IN THE STATISTICAL ANALYSIS

VARIABLE: ThO₂

CLASS	"CASE"		1	2	5	6	3	4
	Reef		A		IQ		B	
	Rocktype		cong.	qtzite	cong.	qtzite	cong.	qtzite
1	Thickness (length) Limits in ft.	0-1	243	106	35	42	221	73
2		1-1.5	327	129	60	63	297	53
3		1.5-2	283	99	38	60	258	38
4		2-3	212	104	10	44	209	33
5		3-4	45	38	—	22	74	7
6		4-5	5	15	—	5	8	—
7		5-10	—	—	—	8	—	—
8		10-26	—	—	—	—	—	—
$\sum$ CASE			1115	491	143	244	1067	204
$\sum$ Reef			1606		387		1271	
$\sum$ TOTAL			3264					

TABLE 3

STATISTICAL TREATMENT

The objective of the present study is to compare the uranium content and thorium content distributions in the Denison Main Reef by statistical methods in order to test the plausibility of the Modified Placer Hypothesis. To achieve this objective the Modified Placer Hypothesis was reformulated as a statistical null hypothesis whose acceptance or rejection can be calculated by statistical testing methods. As a next step the uranium and thorium content data of the General File, a collection of geological sampling data, was regrouped and organized into 71 statistical samples which are homogeneous and randomly selected representatives of stratigraphically, lithologically and volumetrically uniform natural components, or subdivisions, of the Denison Main Reef. While a collection of geological sampling data does not lend itself to statistical evaluation beyond simple averaging calculations, statistical samples are subjectible to systematic statistical analysis. In the present case the applied statistical treatment consisted of two sets of calculations. The first set belongs to the realm of Descriptive Statistics, the second is part of the methodology of Statistical Inference.

Descriptive Statistics Treatment

Statistical samples are representatives of "populations". Whole, complete "populations" are uncollectible and consequently unanalysable. In statistical parlance they are described as infinite. The description illustrates well why the synonym of "population" in statistics is "universe". Not being able to observe and

evaluate the characteristics of whole "populations", man developed the science of statistics by whose methods he can construct an evaluable representation of it. The representation is the statistical sample. Statistical samples can be handled with relative ease. The application of the computer made the treatment of even very large statistical samples attainable. Methods of Descriptive Statistics make it possible to extract well defined measurements from the statistical sample, called "statistics", which describe the character of the statistical sample as well as serve as estimators of the corresponding, for practical purposes unattainable, measurements from the parent population of the same (Krumbein, 1960). These estimated measurements, which describe the character of the parent population, are called "parameters" in statistical parlance.

There are many kinds of "statistics" calculable from a statistical sample. The purpose of the statistical analysis dictates which ones are needed. In the present case the comparison of the distribution patterns of uranium and thorium contents in the Denison Main Reef is investigated. Since the Denison Main Reef is both stratigraphically and lithologically heterogeneous, it was differentiated into six elements, or components, which are homogeneous from both stratigraphical and lithologic points of view. Furthermore, each of the six components, or elements, was subdivided into several subelements which are also volumetrically homogeneous. The result of the first differentiation was six "CASES". The next subdivision produced seventy one "CLASSES". Each "CLASS" is the statistical formulation of an uranium content or a thorium content "population", represented by a statistical sample. To reveal the character of the

distribution pattern of these seventy one "populations" each representative statistical sample was treated by a statistical program package of the Applications Program Library, Computer Science Centre, Energy, Mines and Resources Canada. The program package analyses virtually in every aspect of Descriptive Statistics an examined statistical sample. From the computer analysis those resulting "statistics", which were chosen as a basis for further calculations in the statistical Inference treatment, were tabulated, together with their classification, in Tables 4 to 15 inclusive. The Tables reveal the following information:

Number, stratigraphic and lithologic assignation of "CASE"

Treated variable, i.e., U_3O_8 or ThO_2

Number of volumetric "CLASS", within "CASE"

Number of observations in the statistical sample

Arithmetic Mean

Median

Variance

Range

Coefficient of variation

A clarifying statement is in order here relative to the tabulated values in the tables. When the Management of Denison Mines Limited graciously gave permission to utilize the uranium and thorium assay values for the purpose of the present study, they clearly specified that no actual uranium or thorium contents should be shown in the text. To comply with this restriction all "statistics" in Tables 4 to 15 inclusive were masked with the application of the following statistical theorem:

"If each of the observations is multiplied by a fixed quantity m , the new mean is m times the old mean, the new variance is m^2 times the old variance, and the new standard deviation is m times the old standard deviation." (Li, 1964).

It must be emphasized that the assays were masked only to make them tabulable in the above specified Tables. All further tabulations of calculation results are derived from the treatment of the real, unmasked data.

Other "statistics", calculated by the applied computer program package, as well as statistical tests, administered by the computer to each of the seventy-one statistical samples, were utilized to judge the correctness of the choice of the tabulated "statistics" for Statistical Inference treatment.

RESULTS OF THE DESCRIPTIVE STATISTICS TREATMENT

TABLES 4-9 INCLUSIVE

Descriptive "statistics" of 37 "CLASS" statistical samples,
grouped into 6 "CASES"

URANIUM CONTENT DATA

TABLES 10-15 INCLUSIVE

Descriptive "statistics" of 34 "CLASS" statistical samples,
grouped into 6 "CASES"

THORIUM CONTENT DATA

"CASE": #1, "A" REEF CONGLOMERATE
 VARIABLES: U₃₀₈

CLASS	NUMBER OF OBSERVATIONS	MEAN	MEDIAN	VARIANCE	RANGE	COEFF. OF VARIATION
1	273	6.9	4.6	119.5	135.7	1.6
2	378	7.1	4.6	73.5	80.9	1.2
3	344	7.0	4.8	44.7	41.3	1.0
4	240	6.7	5.4	31.5	41.6	0.8
5	51	6.9	4.6	27.5	24.1	0.8
6	5	8.2	6.9	11.1	8.5	0.4

TABLE 4

"CASE": #2, "A" REEF QUARTZITE

VARIABLES: U_3O_8

CLASS	NUMBER OF OBSERVATIONS	MEAN	MEDIAN	VARIANCE	RANGE	COEFF. OF VARIATION
1	247	1.0	0.8	0.7	4.3	0.9
2	271	1.3	0.8	4.5	30.1	1.7
3	228	1.0	0.8	0.9	7.8	1.0
4	229	0.9	0.8	1.1	11.8	1.1
5	134	0.7	0.4	0.4	4.0	1.0
6	50	0.6	0.5	0.1	1.7	0.7
7	32	0.6	0.4	0.2	1.9	0.8

TABLE 5

"CASE": #3, "B" REEF CONGLOMERATE
 VARIABLES: U_3O_8

CLASS	NUMBER OF OBSERVATIONS	MEAN	MEDIAN	VARIANCE	RANGE	COEFF. OF VARIATION
1	294	6.7	4.3	57.7	76.8	1.1
2	380	6.3	4.6	30.8	38.3	0.9
3	323	7.7	5.6	46.3	43.2	0.9
4	269	7.8	5.6	48.0	40.1	0.9
5	86	7.6	6.0	25.8	21.8	0.6
6	8	8.5	7.8	25.6	13.7	0.6

TABLE 6

"CASE": #4, "B" REEF QUARTZITE
 VARIABLES: U_{308}

CLASS	NUMBER OF OBSERVATIONS	MEAN	MEDIAN	VARIANCE	RANGE	COEFF. OF VARIATION
1	199	1.3	0.8	3.1	14.0	1.3
2	191	1.3	0.8	6.3	32.1	1.9
3	162	1.3	0.6	8.4	34.5	2.3
4	164	0.9	0.6	1.9	14.5	1.5
5	75	0.7	0.4	0.5	5.2	1.1
6	40	0.7	0.6	0.4	3.1	0.9
7	41	0.4	0.4	0.2	2.3	1.0

TABLE 7

"CASE": #5, "IQ" CONGLOMERATE
 VARIABLES: U_3O_8

CLASS	NUMBER OF OBSERVATIONS	MEAN	MEDIAN	VARIANCE	RANGE	COEFF. OF VARIATION
1	50	2.2	1.6	2.9	9.2	0.8
2	71	2.0	1.7	1.1	4.8	0.5
3	46	1.7	1.3	0.9	4.2	0.6
4	19	1.6	1.5	0.6	3.6	0.5

TABLE 8

"CASE": #6, "IQ" QUARTZITE
 VARIABLES: U₃O₈

CLASS	NUMBER OF OBSERVATIONS	MEAN	MEDIAN	VARIANCE	RANGE	COEFF. OF VARIATION
1	113	0.8	0.6	2.9	2.4	0.8
2	157	0.9	0.6	0.7	5.8	1.0
3	132	0.9	0.8	0.4	3.5	0.7
4	132	0.9	0.8	0.3	2.3	0.6
5	69	0.7	0.6	0.2	2.6	0.7
6	26	0.8	0.6	0.3	2.9	0.7
7	27	0.5	0.6	0.04	0.8	0.4

TABLE 9

"CASE": #1, "A" REEF CONGLOMERATE
 VARIABLES: ThO_2

CLASS	NUMBER OF OBSERVATIONS	MEAN	MEDIAN	VARIANCE	RANGE	COEFF. OF VARIATION
1	243	3.6	3.0	10.6	37.2	0.9
2	327	3.8	3.0	10.4	31.6	0.8
3	283	4.1	3.5	10.6	29.0	0.8
4	212	3.7	3.3	5.1	11.3	0.6
5	45	4.5	3.9	8.4	13.1	0.6
6	5	4.3	4.4	1.9	3.7	0.3

TABLE 10

"CASE": #2, "A" REEF QUARTZITE

VARIABLES: ThO_2

CLASS	NUMBER OF OBSERVATIONS	MEAN	MEDIAN	VARIANCE	RANGE	COEFF. OF VARIATION
1	106	1.3	1.2	0.6	4.4	0.6
2	129	1.6	1.2	2.6	15.4	1.0
3	99	1.5	1.2	1.7	8.5	0.9
4	104	1.3	1.2	0.6	4.9	0.6
5	38	1.4	1.1	0.6	2.7	0.6
6	15	1.4	1.2	0.6	3.0	0.6

TABLE 11

"CASE": #3, "B" REEF CONGLOMERATE
 VARIABLES: THO₂

CLASS	NUMBER OF OBSERVATIONS	MEAN	MEDIAN	VARIANCE	RANGE	COEFF. OF VARIATION
1	221	2.9	2.1	6.1	19.1	0.8
2	297	2.8	2.1	5.5	22.2	0.8
3	258	3.1	2.5	7.1	28.8	0.9
4	209	3.3	2.7	7.4	18.8	0.8
5	74	3.2	2.7	3.7	8.2	0.6
6	8	3.5	2.7	4.3	6.4	0.6

TABLE 12

"CASE": #4, "B" REEF QUARTZITE
 VARIABLES: ThO_2

CLASS	NUMBER OF OBSERVATIONS	MEAN	MEDIAN	VARIANCE	RANGE	COEFF. OF VARIATION
1	73	1.2	1.0	1.3	7.0	1.0
2	53	1.0	0.8	0.8	4.3	0.9
3	38	1.2	1.0	0.9	4.2	0.8
4	33	1.2	1.2	1.0	4.1	0.9
5	7	1.2	1.0	0.8	2.3	0.7

TABLE 13

22
OF / DE

"CASE": #5, "IQ" CONGLOMERATE
 VARIABLES: THO₂

CLASS	NUMBER OF OBSERVATIONS	MEAN	MEDIAN	VARIANCE	RANGE	COEFF. OF VARIATION
1	35	1.9	1.6	1.0	4.3	0.9
2	60	1.9	1.6	1.4	6.7	0.8
3	38	1.6	1.5	0.7	3.9	0.7
4	10	1.6	1.6	1.1	3.9	0.7

TABLE 14

"CASE": #6, "IQ" QUARTZITE

VARIABLES: ThO_2

CLASS	NUMBER OF OBSERVATIONS	MEAN	MEDIAN	VARIANCE	RANGE	COEFF. OF VARIATION
1	42	1.0	0.7	1.0	4.4	1.0
2	63	1.1	0.8	1.1	7.1	1.0
3	60	0.9	0.8	0.4	2.9	0.7
4	44	1.1	1.0	0.5	2.9	0.6
5	22	0.9	0.9	0.2	1.8	0.5
6	5	1.1	0.8	0.5	1.5	0.6
7	8	0.7	0.8	0.1	1.2	0.5

TABLE 15

Statistical Inference Treatment

A summary recapitulation of the essence of Statistical Inference is a necessary introduction to the description of the treatment rooted in it.

The scientific method of investigating natural phenomena can be either deductive or inductive. Scientific fields of inquiry where definite axioms are well established, as for example: euclidean geometry or newtonian physics, predict the consequences of natural processes by the use of deductive mathematics. Other scientific fields of inquiry have only hypotheses, or at best theories, at their disposal. Neither hypotheses nor theories being infallible as axioms, they are open to continuous scrutiny until repetitive investigations of experimental data establish their general validity. Successive investigations, arriving at positive results, will promote hypotheses to theories and the latter in turn will eventually become "laws" with the force of axioms, albeit only in rare cases. The tool of the scrutinization and investigation of experimental data is inductive statistics. One is tempted to say, though with some exaggeration, while deductive mathematics deals with an ideal or abstract world, inductive statistics concerns itself with the investigation of relationships and processes in the real world.

The present study investigates the plausibility of a hypothesis which is more popular than alternative hypotheses but not necessarily an infallible explanation of a natural phenomenon. According to the hypothesis the uranium content was deposited as detritus in the Denison Main Reef. The Reef also contains thorium. Thorium's detrital deposition is accepted as an unequivocal fact because nei-

ther theoretical geochemical reasoning nor observation of existing thorium deposits can suggest any other way of deposition in the Denison Main Reef (Adams and others, 1959; Rosholt and others; Gabelman, 1977). The depositional mode of both uranium and thorium should be reflected in their present distribution pattern. If their distribution patterns are the same now, their depositional mode was the same also at the time of the genesis of the ore deposit. Consequently to test the Modified Placer Hypothesis one must compare the two elements' distribution patterns. If the two distribution patterns are the same, then uranium was deposited detritally because it is accepted that thorium was deposited on that way. In such a case the Modified Placer Hypothesis should be accepted as valid. If, on the other hand the distribution patterns of the two elements are different then the depositional mode of uranium was not detrital and the investigated hypothesis should be rejected. The distribution patterns of the two elements cannot be observed and measured directly for two reasons. Firstly because the distribution patterns are reflections of the configuration of all existing uranium and thorium contents in the Denison Main Reef. They are essentially the distributions of, in the practical sense, "infinite" uranium content and thorium content "populations". Secondly because the Denison Main Reef is not a homogen geological entity. It consists of both stratigraphically and lithologically different components whose different age and different texture - the first defined by stratigraphy, the second by lithology - exercised influence on the uranium content and thorium content distribution patterns in them.

With the methods of Descriptive Statistics seventy one statistical samples were accumulated and evaluated as a first step of the statistical testing of the scrutinized hypothesis. These seventy one statistical samples are models or quantitative estimators of the distribution of uranium or thorium contents in volumetrically uniform subcomponents of the Denison Main Reef. Thirty seven statistical samples contain uranium content observations, thirty four statistical samples contain thorium content observations. All being models or estimators of the distribution patterns of uranium contents or thorium contents in their parent "populations" in the respective subcomponents of the Reef. Two central tendency estimators, the "statistics" mean and median, from each subcomponent or "CLASS" were grouped together in six components or "CASES" into which they belong stratigraphically and lithologically. This assembling of secondary statistical samples was done both with uranium contents and with thorium contents. The secondary statistical samples are models or estimators of the distribution of central tendency "parameters" in the six "CASES". In other words they are the observable and quantitatively treatable models of uranium or thorium content distributions in the six stratigraphically and lithologically distinct components of the Denison Main Reef.

Statistical Inference treatment in this study consisted of the comparison of uranium content distribution models between the six "CASES" on a one to one basis to discover which two, or more, of the models - secondary statistical samples - are representing the same parent distribution "populations". The same exercise was repeated with the secondary statistical samples formed from the means and medians of the thorium content primary statistical samples. The final

target of the exercise was to determine the relationship pattern of the uranium content distributions between the six "CASES" and the same with the thorium content distributions. The final decision between acceptance or rejection of the Modified Placer Hypothesis depended on the similarity or dissimilarity between the relationship pattern of the uranium content and thorium content distributions between the six "CASES".

In the previous two paragraphs it was outlined how and for what purpose the six secondary statistical samples, in short: "CASE" statistical samples were assembled. It was stated that they consist of central tendency estimators, means and medians, of uranium content and thorium content primary statistical samples, in short: "CLASS" statistical samples. The decision, to assemble "CASE" statistical samples from both means and medians of the "CLASS" statistical samples, demands an explanation which digresses slightly from the main theme of the present discourse.

Calculations selected from the methods of Descriptive Statistics produced "statistics" which define the central tendency and variability of thirty seven uranium content "CLASS" statistical samples and thirty four thorium content "CLASS" statistical samples. The same "statistics" are estimators of the respective "parameters" in the "CLASS" populations. Examination of the "statistics" and the results of statistical tests, applied to the statistical samples by computer programs, indicated that all seventy one "CLASS" statistical samples originate from parent populations whose unimodal normal distribution cannot be assumed safely. Furthermore, the deviation of the "CLASS" statistical samples from the normal distribution were

found to be different both in style and in degree. This heterogeneity of the "CLASS" statistical samples negated their possible uniformization through the changing of the individual observations in the General File, using transformation techniques to a higher function of theirs which would be normally distributed. Therefore, it was decided that all statistical analyses in the Statistical Inference treatment will be done according to the methods of classical statistics, based on the normal distribution, as well as by the methods of distribution-free or non-parametric statistics, a relatively younger field of the statistical science. Classical statistics requires that the distribution of the parent population of an analysed statistical sample should be assumed as normally distributed. Although the requirement of the normality assumption is not rigid and deviations from it are tolerable, the writer felt it is advisable to use also non-parametric statistics as a control. In addition, if the parallel usage of two independent statistical approaches produce non-contradictory results, the final conclusions of the exercise will be more substantiated because non-parametric statistics do not require any assumption about the distribution of an analysed statistical samples' parent population.

Descriptive Statistics treatment produced two estimators of the central tendencies of the populations, represented by the seventy one "CLASS" statistical samples. These are the sample means and the sample medians. The mean is the average of all observations in the statistical sample, the median is a 50 percent value, i.e. as many observations in the statistical sample are smaller than the median as many are larger. If the assumption of normal distribution is

valid, then the mean and the median are equal. As an estimator of the central tendency of the parent population the mean of the statistical sample is more efficient because it estimates the x-coordinate of the center of gravity of the area under the probability density curve of the parent population. The mean is much more sensitive to observations located relatively far from it, under the tails of the distribution curve, than the median. This is a definite advantage if two means are used to compare two statistical samples whose distribution curves are identical in shape, but if the two distribution curve shapes are drastically different, then the use of the means of the statistical samples could lead to a reduced level of dependability of the conclusions, deducted from the comparison. The median is less affected by a few "unusual" or "wild" observations in the statistical sample. Therefore it is less exposed, as an estimator of the population median, to the accidental vagaries to which every sampling process is more or less prone. Statistical Inference, based on the tenets of classical statistics, uses the mean of the statistical sample as one of its main tools. Non-parametric statistics-based Statistical Inference always utilizes the median. This dichotomy is more apparent than real. Deeper inquiry into the nature of statistical procedures had led to the recognition of the fact that the mean, as utilized in some calculations according to classical statistics, is nothing else but a "disguised median" (Li, 1964).

The Statistical Inference treatment of the data, derived by Descriptive Statistics methods from the General File, consisted of the one by one comparison of six "CASE" statistical samples to discover the relationship pattern of their parent populations in the

Denison Main Reef. The comparison was done between uranium content "CASE" statistical samples exclusively and between thorium content "CASE" statistical samples exclusively. The following independent comparison exercises were carried out:

A, One-way analysis of variance calculations (Classical statistics).

- a, One to one comparison between all six "CASE" statistical samples, assembled from "CLASS" statistical sample means of uranium contents.
 - b, One to one comparison between all six "CASE" statistical samples, assembled from "CLASS" statistical sample means of thorium contents.
-
- c, One to one comparison between all six "CASE" statistical samples, assembled from "CLASS" statistical sample medians of uraniums contents.
 - d, One to one comparison between all six "CASE" statistical samples, assembled from "CLASS" statistical sample medians of thorium contents.

B, Mann-Whitney tests (Non-parametric statistics).

- a, One to one comparison between all six "CASE" statistical samples, assembled from "CLASS" statistical sample means of uranium contents.
 - b, One to one comparison between all six "CASE" statistical samples, assembled from "CLASS" statistical sample means of thorium contents.
-
- c, One to one comparison between all six "CASE" statistical samples, assembled from "CLASS" statistical sample medians of uranium contents.
 - d, One to one comparison between all six "CASE" statistical samples, assembled from "CLASS" statistical sample medians of thorium contents.
-

The one-way analysis of variance calculations (Classical Statistics) and the Mann-Whitney tests (Non-parametric statistics) are analogous statistical hypothesis testing exercises. All exercises tested the same Null Hypothesis:

"THE PARENT POPULATIONS OF THE COMPARED SAMPLES ARE IDENTICAL"

In total sixty one-way analysis of variance calculations and sixty Mann-Whitney tests were done, both by computer programs applied to the data and manually, with the help of an electronic calculator.

ONE-WAY ANALYSIS OF VARIANCE CALCULATIONS

The analysis of variance, known by its acronym as ANOVA, is an important technique of statistical inference. It is used to decide whether two compared statistical samples have a common parent population or not (Moroney, 1951).

The technique compares two variation estimations derived from the same data. The first is the estimated population variance, calculated from the means of the two compared statistical samples; the second is also the estimated population variance, but it is based on the mean of the variances calculated within each of the two compared statistical samples. The first is the estimated variance AMONG or BETWEEN the parent populations of the two samples; the second is the average of the same variance calculated twice, individually and independently from WITHIN each of the two compared samples. A dimensionless ratio value, derived from division of the AMONG estimate by the WITHIN estimate should stay relatively close to unity as long as

the parent populations of the compared statistical samples are identical, i.e. one and the same. The ratio value, called an "F-function", is tabulated in terms of degrees of freedoms accorded to the number of compared samples (in the present case always two) and to the total number of observations participating in the analysis of variance tests. The tabulated "F-function" is the maximum value which the above detailed ratio can achieve if the compared samples were drawn from the same population. If the analysis of variance test produces a ratio value larger than the tabulated F value for the same combination of number of degrees of freedoms, then it indicates that the common parentage of the compared statistical samples is an unacceptable hypothesis. Then, in statistical parlance the Null Hypothesis must be rejected.

The technical details of the ANOVA calculations completed in the present work are outlined on Figure 7 (Pollard, 1977).

A partial extract of tabulated critical values of the "F-function" is shown on Table 16 (Li, 1964).

The numerical results of the sixty ANOVA tests are tabulated on Tables 17 to 20 inclusive. On these tables all instances where the resulting F values made the Null Hypothesis acceptable are marked with an asterisk.

In terms of acceptance or rejection the results of the hypothesis testing are shown as matrices on Figures 8 to 11 inclusive.

Algorithm and Key
for
Analysis of Variance
Calculations and Tables

x_1		x_2
Reef: }	}	Reef: }
Variable: }		Variable: }
Rocktype: }		Rocktype: }
n_1 :		n_2 :
described by serial No of "First case"		described by serial No of "Second case"

	x_1	x_1^2	x_2	x_2^2	
1					
2					
3					
4					
5					
6					
7					
	T_1 :	$\sum x_1^2$:	T_1 :	$\sum x_2^2$:	
$N = n_1 + n_2 =$	Column "M"		$SST = (\sum \sum x_{i,2}^2) - \frac{T_{..}^2}{N} =$	Column "SST"	
$K = 2$			$SSC = (\sum \frac{T_i^2}{n_i}) - \frac{T_{..}^2}{N} =$	Column "SSC"	
$K - 1 = 1$			$SSE = SST - SSC =$	Column "SSE"	
$N - K = \quad - 2 =$			$MSC = \frac{SSC}{K - 1} = \frac{\quad}{1} =$	Column "MSC"	
$T_{..} = T_1 + T_2 =$	Column "TSUM"		$MSE = \frac{SSE}{N - K} = \frac{\quad}{\quad} =$	Column "MSE"	
$T_{..}^2 =$	Column "SQTSUM"		$F = \frac{MSC}{MSE} = \frac{\quad}{\quad} =$	Column "F"	
$\frac{T_{..}^2}{N} =$					
$\sum \sum x_{i,2}^2 =$	Column "TSQ"				
$F_{\alpha = .05 (K-1, N-K)} =$					

$H_0: \mu_1 = \mu_2$ IS ACCEPTED
REJECTED

FIGURE 7

ANALYSIS OF VARIANCE
CRITICAL VALUES

$$F_{\alpha} = 0.05$$

N - K	K - 1 = 1
1	161.45
2	18.51
3	10.13
4	7.71
5	6.61
6	5.99
7	5.59
8	5.32
9	5.12
10	4.96
11	4.84
12	4.75
13	4.67
14	4.60

TABLE 16

A, ONE-WAY ANALYSIS OF VARIANCE CALCULATIONS
(CLASSICAL STATISTICS)

- a, One to one comparison between all six "CASE" statistical samples, assembled from "CLASS" statistical sample means of uranium contents.
- b, One to one comparison between all six "CASE" statistical samples, assembled from "CLASS" statistical sample means of thorium contents.

ANALYSIS OF VARIANCE RESULTS

THE COMPARED "CASE"(S) ARE FORMED FROM U_3O_8 MEANS

CASE VS CASE	N	TSUM	SQTSUM	TSQ	SST	SSC	SSE	MSC	MSE	"F"
1 2	13	25.330	641.609	84.169	34.814	34.431	.473	34.341	.043	797.897
1 3	12	45.426	2063.514	173.270	1.310	.080	1.230	.080	.123	.648
1 4	13	25.690	659.969	84.600	33.833	33.267	.566	33.267	.051	646.299
1 5	10	26.076	679.955	86.460	18.465	18.031	.434	18.031	.054	332.716
1 6	13	24.994	624.678	83.808	35.756	35.361	.395	35.361	.036	985.606
2 3	13	26.308	692.112	92.053	38.823	37.861	.962	37.861	.087	432.737
2 4	14	6.572	43.191	3.393	.307	.009	.298	.009	.025	.372
2 5	11	6.958	48.415	5.253	.852	.686	.166	.686	.018	37.306
2 6	14	5.876	34.523	2.601	.135	.008	.127	.008	.011	.766
3 4	13	26.668	711.177	92.493	37.787	36.732	1.055	36.732	.096	382.928
3 5	10	27.054	731.918	94.354	21.162	20.240	.923	20.240	.115	175.515
3 6	13	25.972	674.523	91.701	39.815	38.931	.884	38.931	.080	484.646
4 5	11	7.318	53.552	5.684	.816	.557	.258	.557	.029	19.411
4 6	14	6.236	38.882	3.031	.254	.035	.219	.035	.018	1.894
5 6	11	6.622	43.846	4.892	.906	.819	.087	.819	.010	84.945

TABLE 17

ANALYSIS OF VARIANCE RESULTS

THE COMPARED "CASE"(S) ARE FORMED FROM THO₂ MEANS

CASE VS CASE	M	TSUM	SQTSUM	TSQ	SST	SSC	SSE	MSC	MSE	"F"
1 2	12	16.829	283.204	29.227	5.627	5.420	.207	5.420	.021	262.057
1 3	12	22.237	494.475	42.087	.881	.588	.293	.588	.029	20.099
1 4	11	15.442	238.447	27.814	6.137	5.937	.200	5.937	.022	267.116
1 5	10	16.071	258.269	29.325	3.498	3.277	.221	3.277	.028	118.380
1 6	13	15.976	255.222	27.831	8.199	7.967	.232	7.967	.021	378.295
2 3	12	14.172	200.843	19.291	2.554	2.437	.117	2.437	.012	208.095
2 4	11	7.377	54.418	5.019	.072	.047	.025	.047	.003	17.256
2 5	10	8.006	64.094	6.529	.120	.074	.046	.074	.006	12.903
2 6	13	7.911	62.581	5.035	.221	.165	.056	.165	.005	32.383
3 4	11	12.785	163.456	17.878	3.019	2.908	.110	2.908	.012	237.231
3 5	10	13.414	179.935	19.389	1.396	1.264	.132	1.264	.016	76.752
3 6	13	13.319	177.294	17.895	4.249	4.107	.142	4.107	.013	318.287
4 5	9	6.619	43.811	5.116	.249	.209	.039	.209	.006	37.460
4 6	12	6.524	42.561	3.622	.076	.026	.049	.026	.005	5.318
5 6	11	7.153	51.164	5.133	.482	.411	.071	.411	.008	52.292

TABLE 18

ONE-WAY ANALYSIS OF VARIANCE

NULL HYPOTHESIS:

The parent populations of the compared samples are identical

ACCEPTED or **rejected**

SAMPLES: Formed from the arithmetic means of the "CASES"

VARIABLE: U_3O_8

Conglomerates:	Reef	A	IQ	B
	A	 	rejected	ACCEPTED
	IQ	rejected	 	rejected
	B	ACCEPTED	rejected	

Quartzites:	Reef	A	IQ	B
	A	 	ACCEPTED	ACCEPTED
	IQ	ACCEPTED	 	ACCEPTED
	B	ACCEPTED	ACCEPTED	

VARIABLE: ThO_2

Conglomerates:	Reef	A	IQ	B
	A	 	rejected	rejected
	IQ	rejected	 	rejected
	B	rejected	rejected	

Quartzites	Reef	A	IQ	B
	A	 	rejected	rejected
	IQ	rejected	 	rejected
	B	rejected	rejected	

FIGURE 8

ONE-WAY ANALYSIS OF VARIANCE

NULL HYPOTHESIS:

The parent populations of the compared samples are identical

ACCEPTED or **rejected**

SAMPLES: Formed from the arithmetic means of the "CASES"

VARIABLE: U_3O_8

Conglomerates:

Quartzites:	Reef	A	IQ	B
	A	rejected	rejected	rejected
	IQ	rejected	rejected	rejected
	B	rejected	rejected	rejected

VARIABLE: ThO_2

Conglomerates:

Quartzites:	Reef	A	IQ	B
	A	rejected	rejected	rejected
	IQ	rejected	rejected	rejected
	B	rejected	rejected	rejected

FIGURE 9

A, ONE-WAY ANALYSIS OF VARIANCE CALCULATIONS
(CLASSICAL STATISTICS)

- c, One to one comparison between all six "CASE" statistical samples, assembled from "CLASS" statistical sample medians of uranium contents.
- d, One to one comparison between all six "CASE" statistical samples, assembled from "CLASS" statistical sample medians of thorium contents.

ANALYSIS OF VARIANCE RESULTS

THE COMPARED "CASE"(S) ARE FORMED FROM U₃₀₈ MEDIAN

CASE VS CASE	M	TSUM	SQTSUM	TSQ	SST	SSC	SSE	MSC	MSE	"F"
1 2	13	18.350	336.722	45.113	19.211	18.023	1.188	18.023	.108	166.935
1 3	12	33.685	1134.679	97.918	3.361	.184	3.177	.184	.318	.578
1 4	13	18.200	331.240	45.000	19.520	18.352	1.168	18.352	.106	172.783
1 5	10	19.320	373.262	46.942	9.616	8.468	1.149	8.468	.144	58.975
1 6	13	18.400	338.560	45.100	19.057	17.914	1.143	17.914	.104	172.461
2 3	13	19.835	393.427	54.370	24.107	21.998	2.108	21.998	.192	114.775
2 4	14	4.350	18.923	1.453	.101	.002	.099	.002	.008	.194
2 5	11	5.470	29.921	3.395	9.675	.595	.080	.595	.009	67.312
2 6	14	4.550	20.703	1.553	.074	.000	.074	.000	.006	.029
3 4	13	19.685	387.499	54.258	24.450	22.361	2.089	22.361	.190	117.745
3 5	10	20.805	432.848	56.200	12.915	10.846	2.069	10.846	.259	41.931
3 6	13	19.885	395.413	54.358	23.941	21.878	2.063	21.878	.188	116.637
4 5	11	5.320	28.302	3.282	.709	.649	.060	.649	.007	96.889
4 6	14	4.400	19.360	1.440	.057	.003	.054	.003	.005	.632
5 6	11	5.520	30.470	3.382	.612	.578	.035	.578	.004	150.351

TABLE 19

ANALYSIS OF VARIANCE RESULTS

THE COMPARED "CASE"(S) ARE FORMED FROM ThO_2 MEDIANS.

CASE VS CASE	M	TSUM	SQTSUM	TSQ	SST	SSC	SSE	MSC	MSE	"F"
1 2	12	14.455	208.947	22.313	4.901	4.471	.430	4.471	.043	104.039
1 3	12	18.590	345.588	30.184	1.385	.848	.537	.848	.054	15.789
1 4	11	13.420	180.096	21.495	5.123	4.673	.449	4.673	.050	93.573
1 5	10	14.180	201.072	22.904	2.797	2.364	.433	2.364	.054	43.682
1 6	13	13.820	190.992	21.433	6.741	6.300	.441	6.300	.040	157.202
2 3	12	11.265	126.900	12.109	1.534	1.425	.109	1.425	.011	130.297
2 4	11	6.095	37.149	3.420	.043	.021	.022	.021	.002	8.776
2 5	10	6.855	46.991	4.829	.130	.125	.005	.125	.001	190.821
2 6	13	6.495	42.185	3.358	.113	.100	.013	.100	.001	83.606
3 4	11	10.230	104.653	11.291	1.777	1.648	.129	1.648	.014	114.926
3 5	10	10.990	120.780	12.700	.622	.510	.113	.510	.014	36.225
3 6	13	10.630	112.997	11.229	2.536	2.416	.120	2.416	.011	220.697
4 5	9	5.820	33.872	4.011	.248	.223	.025	.223	.004	62.467
4 6	12	5.460	29.812	2.539	.055	.022	.033	.022	.003	6.796
5 6	11	6.220	38.688	3.949	.432	.415	.016	.415	.002	229.163

TABLE 20

ONE - WAY ANALYSIS OF VARIANCE

NULL HYPOTHESIS:

The parent populations of the compared samples are identical

ACCEPTED or **rejected**

SAMPLES: Formed from the medians of the "CASES"

VARIABLE: U_3O_8

Conglomerates:

Reef	A	IQ	B
A		rejected	ACCEPTED
IQ	rejected		rejected
B	ACCEPTED	rejected	

Quartzites:

Reef	A	IQ	B
A		ACCEPTED	ACCEPTED
IQ	ACCEPTED		ACCEPTED
B	ACCEPTED	ACCEPTED	

VARIABLE: ThO_2

Conglomerates:

Reef	A	IQ	B
A		rejected	rejected
IQ	rejected		rejected
B	rejected	rejected	

Quartzites:

Reef	A	IQ	B
A		rejected	rejected
IQ	rejected		rejected
B	rejected	rejected	

FIGURE 10

ONE-WAY ANALYSIS OF VARIANCE

NULL HYPOTHESIS:

The parent populations of the compared samples are identical

ACCEPTED or rejected

SAMPLES: Formed from the medians of the "CASES"

VARIABLE: U_3O_8

Conglomerates:

Quartzites:	Reef	A	IQ	B
	A	rejected	rejected	rejected
	IQ	rejected	rejected	rejected
	B	rejected	rejected	rejected

VARIABLE: ThO_2

Conglomerates:

Quartzites:	Reef	A	IQ	B
	A	rejected	rejected	rejected
	IQ	rejected	rejected	rejected
	B	rejected	rejected	rejected

FIGURE 11

MANN-WHITNEY TESTS

The Mann-Whitney test is one non-parametric statistics equivalent of the analysis of variance technique of classical statistics. Its utilization is warranted over a larger field than that of ANOVA because it does not require any a priori assumption about the distribution of the parent populations of the statistical samples which the test compares (Meddis, 1975; Pollard, 1977).

Instead of the actual observations in the compared statistical samples the test uses the ranks of all participating observations. In preparation of the Mann-Whitney tests all observations in the test must be ranked according to either ascending, or descending order of magnitude. From these ranks the test calculates two values:

R and R', using simple arithmetics (Meddis, 1975).

R is the sum of ranks in the smaller sample.

R' is the result of the following equation:

$$R' = N_1(N_1 + N_2 + 1) - R$$

where: N_1 = the number of observations in the smaller sample

N_2 = the number of observations in the larger sample

Critical values, tabulated in statistical handbooks for the Mann-Whitney test in terms of the numbers of observations in the compared statistical samples, are compared with the R and R' values which the test produced. In such cases where the tabulated critical value is smaller than both R and R' the Null Hypothesis, i.e., "The parent

populations of the compared samples are identical", is acceptable.

In any other cases it must be rejected.

An abbreviated tabulation of Mann-Whitney test critical values is shown on Table 21 (Meddis, 1975).

The numerical results of the sixty Mann-Whitney tests are tabulated on Tables 22 to 25 inclusive. On these tables all instances where the test produced R and R' values which are both larger than the respective critical value, and judged the Null Hypothesis acceptable, are marked with an asterisk.

In terms of acceptance or rejection the results of the hypothesis testing are shown as matrices on Figures 12 to 15 inclusive.

B, MANN-WHITNEY TESTS
(NON-PARAMETRIC STATISTICS).

- a, One to one comparison between all six "CASE" statistical samples, assembled from "CLASS" statistical sample means of uranium contents.
- b, One to one comparison between all six "CASE" statistical samples, assembled from "CLASS" statistical sample means of thorium contents.

MANN-WHITNEY TEST

CRITICAL VALUES

"2-TAIL" 10%

N_1	N_2	CV
4	4	11
	5	12
	6	13
	7	14
5	5	19
	6	20
	7	21
6	6	28
	7	29
7	7	39

TABLE 21

MANN-WHITNEY TEST RESULTS
THE COMPARED "CASE"(S) FORMED FROM
 U_3O_8 MEANS

CASE vs CASE		N_1	N_2	R	R^1	CV	
1	2	6	7	63	21	29	
1	3	6	6	36	42	28	*
1	4	6	7	63	21	29	
1	5	4	6	10	34	13	
1	6	6	7	63	21	29	
2	3	6	7	63	21	29	
2	4	7	7	47	58	39	*
2	5	4	7	38	10	14	
2	6	7	7	59	46	39	*
3	4	6	7	63	21	29	
3	5	4	6	10	34	13	
3	5	4	6	10	34	13	
3	6	6	7	63	21	29	
4	5	4	7	38	10	14	
4	6	7	7	59	46	39	*
5	6	4	7	38	10	14	

TABLE 22

MANN-WHITNEY TEST RESULTS
THE COMPARED "CASE"(S) FORMED FROM

THO₂ MEANS

CASE vs CASE		N ₁	N ₂	R	R ¹	CV
1	2	6	6	57	21	28
1	3	6	6	57	21	28
1	4	5	6	15	45	20
1	5	4	6	10	34	13
1	6	6	7	63	21	29
2	3	6	6	21	57	28
2	4	5	6	15	45	20
2	5	4	6	34	10	13
2	6	6	7	63	21	29
3	4	5	6	15	45	20
3	5	4	6	10	34	13
3	6	6	7	63	21	29
4	5	4	5	30	10	12
4	6	4	7	38	10	14
5	6	4	7	38	10	14

TABLE 23

MANN - WHITNEY NON-PARAMETRIC TEST

NULL HYPOTHESIS:

The parent populations of the compared samples are identical

ACCEPTED or **rejected**

SAMPLES: Formed from the arithmetic means of the "CASES"

VARIABLE: U_3O_8

Conglomerates:	Reef	A	IQ	B
	A		rejected	ACCEPTED
	IQ	rejected		rejected
	B	ACCEPTED	rejected	

Quartzites:	Reef	A	IQ	B
	A		ACCEPTED	ACCEPTED
	IQ	ACCEPTED		ACCEPTED
	B	ACCEPTED	ACCEPTED	

VARIABLE: ThO_2

Conglomerates:	Reef	A	IQ	B
	A		rejected	rejected
	IQ	rejected		rejected
	B	rejected	rejected	

Quartzites:	Reef	A	IQ	B
	A		rejected	rejected
	IQ	rejected		rejected
	B	rejected	rejected	

FIGURE 12

MANN-WHITNEY NON-PARAMETRIC TEST

NULL HYPOTHESIS:

The parent populations of the compared samples are identical

ACCEPTED or rejected

SAMPLES: Formed from the arithmetic means of the "CASES"

VARIABLE: U_3O_8

Conglomerates:

Reef	A	IQ	B
A	rejected	rejected	rejected
IQ	rejected	rejected	rejected
B	rejected	rejected	rejected

Quartzites:

VARIABLE: ThO_2

Conglomerates:

Reef	A	IQ	B
A	rejected	rejected	rejected
IQ	rejected	rejected	rejected
B	rejected	rejected	rejected

Quartzites:

FIGURE 13

B, MANN-WHITNEY TESTS
(NON-PARAMETRIC STATISTICS)

- c, One to one comparison between all six "CASE" statistical samples, assembled from "CLASS" statistical sample medians of uranium contents.
- d, One to one comparison between all six "CASE" statistical samples, assembled from "CLASS" statistical sample medians of thorium contents.

MANN-WHITNEY TEST RESULTS
THE COMPARED "CASE"(S) FORMED FROM
 U_3O_8 MEDIAN

CASE vs CASE		N_1	N_2	R	R^1	CV
1	2	6	7	63	21	29
1	3	6	6	35.5	42.5	28 *
1	4	6	7	63	21	29
1	5	4	6	10	34	13
1	6	6	7	63	21	29
2	3	6	7	63	21	29
2	4	7	7	55	50	39 *
2	5	4	7	38	10	14
2	6	7	7	53	52	39 *
3	4	6	7	63	21	29
3	5	4	6	10	34	13
3	6	6	7	63	21	29
4	5	4	7	38	10	14
4	6	7	7	51	54	39 *
5	6	4	7	38	10	14

TABLE 24

MANN-WHITNEY TEST RESULTS
 THE COMPARED "CASE"(S) FORMED FROM
 ThO_2 MEDIANS

CASE vs CASE		N_1	N_2	R	R^1	CV
1	2	6	6	57	21	28
1	3	6	6	57	21	28
1	4	5	6	15	45	20
1	5	4	6	10	34	13
1	6	6	7	63	21	29
2	3	6	6	21	57	28
2	4	5	6	18.5	41.5	20
2	5	4	6	34	10	13
2	6	6	7	63	21	29
3	4	5	6	15	45	20
3	5	4	6	10	34	13
3	6	6	7	63	21	29
4	5	4	5	30	10	12
4	6	5	7	44.5	20.5	21
5	6	4	7	38	10	14

TABLE 25

MANN - WHITNEY NON-PARAMETRIC TEST

NULL HYPOTHESIS:

The parent populations of the compared samples are identical

ACCEPTED or **rejected**

SAMPLES: Formed from the medians of the "CASES"

VARIABLE: U_3O_8

Conglomerates:

Reef	A	IQ	B
A	 	rejected	ACCEPTED
IQ	rejected	 	rejected
B	ACCEPTED	rejected	

Quartzites:

Reef	A	IQ	B
A	 	ACCEPTED	ACCEPTED
IQ	ACCEPTED	 	ACCEPTED
B	ACCEPTED	ACCEPTED	

VARIABLE: ThO_2

Conglomerates:

Reef	A	IQ	B
A	 	rejected	rejected
IQ	rejected	 	rejected
B	rejected	rejected	

Quartzites:

Reef	A	IQ	B
A	 	rejected	rejected
IQ	rejected	 	rejected
B	rejected	rejected	

FIGURE 14

MANN - WHITNEY NON-PARAMETRIC TEST

NULL HYPOTHESIS:

The parent populations of the compared samples are identical

ACCEPTED or rejected

SAMPLES: Formed from the medians of the "CASES"

VARIABLE: U_3O_8

Conglomerates:

Quartzites:

Reef	A	IQ	B
A	rejected	rejected	rejected
IQ	rejected	rejected	rejected
B	rejected	rejected	rejected

VARIABLE: ThO_2

Conglomerates:

Quartzites:

Reef	A	IQ	B
A	rejected	rejected	rejected
IQ	rejected	rejected	rejected
B	rejected	rejected	rejected

FIGURE 15

INTERPRETATION OF RESULTS

The object of the thesis was to compare the uranium and thorium distribution patterns in the Denison Main Reef in the frame of a hypothesis testing exercise. It was done to test the tenability of uranium's detrital depositional mode, as proposed by the Modified Placer Hypothesis.

The Denison Main Reef was subdivided into three stratigraphic elements: the upper or "A", the middle or "I.Q" and the lower or "B" reefs. Each of the three elements were partitioned into two lithologic components: the coarse grained conglomerates and the fine grained quartzites. The twofold subdivision produced six components, each having its own distinct combination of stratigraphic position and lithologic composition. Four to seven classes were delineated for each of the six components according to the vertical lengths of the sample segments in the Data Base. The stepwise, repetitive differentiation produced 37 uranium content and 34 thorium content classes. The uranium content and the thorium content data were distributed into their respective classes. Finally the descriptive statistics of each class statistical sample were calculated and tabulated. The distribution of the Data Base into the class statistical samples is illustrated in Table 2 for uranium content and in Table 3 for thorium content. The descriptive statistics for the uranium content data are tabulated in Tables 4 to 9 inclusive. Tables 10 to 15 inclusive contain the descriptive statistics for the thorium content data.

Six new statistical samples were formed from the means of all class statistical samples belonging to each of the six compon-

ents. A similar set of six statistical samples were assembled from the medians of the respective class statistical samples. The six component representing statistical samples, formed from the means of uranium content, were compared pairwise with each other, using one-way analysis of variance tests to accept or reject the following null hypothesis:

"The parent populations of the compared samples are identical".

The six component-representing statistical samples, formed from the means of thorium content, were subjected to the same treatment. The numerical results of the analysis of variance calculations are tabulated in Tables 17 to 18. The acceptance or rejection of the null hypothesis is illustrated on matrices (Figures 8 and 9).

The medians of uranium and thorium content were also subjected to similar analysis of variance tests. The results are tabulated in Tables 19 and 20. The acceptance or rejection of the null hypothesis is illustrated on matrices (Figures 10 and 11).

Mann-Whitney tests were administered to the six component-representing statistical samples formed from the means of the uranium and thorium contents respectively. The numerical results of these calculations are tabulated in Tables 22 and 23. The acceptance or rejection of the null hypothesis is illustrated on matrices (Figures 12 and 13).

Finally Mann-Whitney tests were applied to the statistical samples formed from the uranium and thorium medians. The results are

in Tables 24 and 25. The acceptance or rejection of the null hypothesis is shown on matrices (Figures 14 and 15).

The four parallel, but from each other independent, sequences of tests (i.e. analysis of variance and Mann-Whitney tests on means and medians of both elements) produced identical results as illustrated in the four pairs of matrices (Figures 8 to 15 inclusive). These results are summarizable in the following four points:

1. Each of the six components in the Denison Main Reef has its own distinct thorium content population. The distribution pattern is therefore heterogeneous.
2. The uranium contents in the three fine grained, quartzitic components of the Denison Main Reef are encompassed by one population.
3. The uranium content in the coarse grained, conglomeratic components of the upper or "A" and lower or "B" reefs fall into one population.
4. The coarse grained, conglomeratic component of the middle or "I.Q" reef has its own, distinct uranium content population.

The results, summarized in these four points indicate that

- A. The heterogeneous nature of the thorium distribution in the reef reinforces the validity of the first assumption which was taken for the purpose of the thesis, i.e., thorium was deposited in the reef as solid detritus.
- B. The selectively uniformized nature of the uranium distribution in the reef reinforces the validity of the second assumption of the thesis, i.e. the distribution pattern of uranium in the reef was produced by the depositional mode of uranium.
- C. The distribution patterns of uranium and thorium in the Denison Main Reef are not analogous. Consequently the outcome of the statistical analysis do not allow the acceptance of the proposal, made by the Modified Placer Hypothesis, according to which the uranium in the reef was deposited as detritus.

In reference to A

The results of the comparative statistical analysis of the thorium content in the Denison Main Reef reinforce the first assumption on the beginning of the thesis that thorium was deposited detritally in the Reef. This proposition was accepted as axiomatic by the design of the experiment because thorium bearing minerals, due to their resistate nature will congregate in the heavy mineral fraction

of every independently deposited sedimentary load (Griffiths, 1967). The six components of the Reef were all deposited as detrital loads, different from each other in time of their deposition, in the hydraulic energy configuration of their depositing agents, or in both of these aspects. The presence of six different thorium content populations, repetitively demonstrated by the the sets of statistical analyses, also illustrate the diversity of the six components. In the case of thorium: a geological model, derived by deductive reasoning, based on the tenets of geochemistry and sedimentological observations and the numerical results, produced by the inductive reasoning process of statistical inference, based on a large, quantitative data file, mutually reinforce each other.

In reference to B

It has been postulated by one adherent of the Modified Placer Hypothesis that the initially detritally deposited uranium underwent subsequent dissolution, redistribution and precipitation (Ramdohr, 1957). This is questionable. If uranium minerals were dissolved in situ they would require either an oxidizing environment in the already deposited sediments, or an elevation of the temperature within the sediments to such a level which would produce thermal metamorphic effects. The (at least) temporary presence of an oxidizing environment in the already deposited sediments would not only dissolve the uranium but would have left some deteriorating effects (limonite formation) on the pyrite, which is a major rockforming mineral in the Denison Main Reef. A temporarily elevated temperature, high enough to cause uranium dissolution and some concomitant thermal

metamorphism, would have left behind regional alteration effects (clay mineral formation) on the hostrocks. Neither of these two possible permanent and attendant signs of in situ dissolution of uranium are evident in the Denison Main Reef.

A selective homogenisation process, which would uniformise the in situ dissolved uranium contents of two sedimentary layers regionally and bypass a similar layer, intercalated between the two, leaving the middle layer unaffected is difficult to imagine. The statistical analysis of the data suggested such a pattern because the upper and lower conglomeratic components have the same uranium content population, while the middle conglomeratic component hosts a different one.

In reference to C

All four statistical hypothesis test sequences were testing the acceptability of the following Null Hypothesis:

"The parent populations of the compared samples are identical"

The tests compared the distributions of the samples which infer the distributions of the parent populations. The tests, in the case of thorium unanimously rejected the Null Hypothesis in every case, demonstrating that each component has its own distinct thorium population, alien to all others.

In the case of uranium the tests accepted the Null Hypothesis in the comparison of the upper and lower conglomeratic components which have a common uranium population.

The tests also accepted, in the case of uranium the Null Hypothesis in the comparisons of the upper, middle and lower quartzitic components, which have another common uranium population. Finally the tests rejected, in the case of uranium, the Null Hypothesis in all comparisons of the middle conglomeratic component with the other five components, demonstrating that this component has its own distinct uranium population, alien to the two others.

Therefore:

While the thorium distribution pattern is divided to six different thorium populations, i.e. it is heterogeneous, the uranium distribution patterns is selectively and partly uniformised into two uranium populations which transcend stratigraphic divisions (but do not transcend lithologic ones) and has an additional uranium population which is restricted within the limits of a single component. The tests thus demonstrate that the uranium and thorium distribution patterns are not analogous to each other. With this demonstration the statistical experiment found the examined proposal of the Modified Placer Hypothesis unacceptable!

CONCLUSIONS

The present thesis has systematically compared in detail the uranium and thorium distribution patterns in the Denison Main Reef, within the framework of a statistical hypothesis testing exercise, in order to investigate the tenability of the postulated detrital origin of the uranium content in it. Four sets of analysis of variance tests and Mann-Whitney tests were applied to samples, formed from the means and medians of 37 uranium content and 34 thorium content samples, respectively. The Thesis Data Base consisted of 5556 uranium content and 3264 thorium content assays, extracted from the files of Denison Mines Ltd. with the company's permission.

In preparation to the tests the 8820 assays were distributed into six stratigraphically and lithologically delineated components of the Denison Main Reef. The selection criteria, according to which the assays were distributed, were designed in accordance with the requirements of statistical inference, which demands that statistical samples should be randomly selected, homogeneous and representative of their parent populations.

The four sets of tests produced identical results, summarized in the following four points:

1. Each of the six components in the Denison Main Reef has its own distinct thorium content population. The distribution pattern is therefore heterogeneous.

2. The uranium contents in the three fine grained, quartzitic components of the Denison Main Reef are encompassed by one population.
3. The uranium content in the coarse grained, conglomeratic components of the upper or "A" and lower or "B" reefs fall into one population.
4. The coarse grained, conglomeratic component of the middle or "I.Q" reef has its own, distinct uranium content population.

The results indicate that the distribution patterns of uranium and thorium are not analogous in the Denison Main Reef. Based on the assumptions, according to which

1. The thorium content was deposited as solid detritus in the Reef (Adams and others, 1959; Gabelman, 1977)
and
2. The distribution patterns of the elements reflect their depositional mode (Holland and Petersen, 1979),

the lack of analogy between the two distribution patterns made the postulated detrital origin of uranium in the Denison Main Reef unacceptable according to statistical hypothesis testing methods.

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