Quantification Model of Qualitative Geological Data Variables for Exploration Risk Assessment in Prospect Cu-Au Porphyry Deposit Randu Kuning, Wonogiri, Central Java

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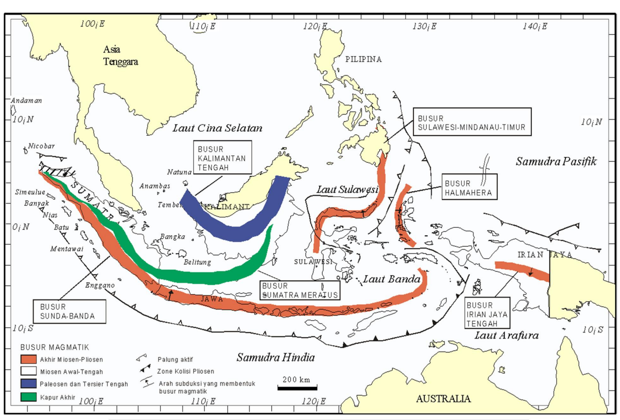
Abstract— Almost geological data variable contain some degree of uncertainty. Most decisions in mineral exploration was based on geological reports, measurements, calculations as well as ignorance of the geological uncertainty underlies all natural risks of the exploration effort. Risks affecting mineral exploration activities, among others caused by several things. Inherent natural variability in the process of geology and geological objects. Uncertainty on the conceptual and models, associated with incomplete knowledge and subjective interpretations of processes and geological objects. Errors can also occur when observing, measuring or evaluating samples or mathematical analysis of geological data. Data from exploration activities, can be grouped into two types of data, namely quantitative data (e g; grade) and qualitative data (geological data). Geological data variables still largely a qualitative data, resulting between some geologists are not infrequent errors of judgment (assessment of subjective data). This leads to misinterpretation of results of exploration that will ultimately impact on the exploration risk assessment. Currently, the quantification of qualitative data variable is one parameter which is becoming a necessity, because it will be easier in terms of interpretation, communication and measurable. Porphyry Cu - Au deposit in the Randu Kuning Prospect, Wonogiri has the characteristic geometry and grade distribution are quite complex. It is characterized by the appearance of some kind of vein and stockwork with different characteristics. Quantification of geological variables will result in a value that allows the quantification in quantifying exploration risk. For quantitative variables data (grade) using geostatistical methods, while for qualitative variables geological data using canonical correlation and multivariable regression.

Keywords— quantification, quantitative variables data, qualitative variable data, exploration risk assessment.

INTRODUCTION

a. Background

Western islands of Indonesia (mainly Java, Sumatera, until eastern of Flores Island) are controlled by two mayor magmatic plate, that is Indian-Australian oceanic plate and Eurasian continental plate, named the Sundaland or Sunda Banda arc. Sunda-Banda arc is one of the most important six major Tertiary arcs in Indonesia extending from Sumatra through Java to east of Damar Island, known has many ore deposits (Figure 1.)



Gambar 1. Penyebaran busur magmatik di Indonesia (sumber: Carlile dan Michell, 1994)

Figure 1. Indonesia tectonic map

The Randu Kuning area and its vicinity is a part of the East Java Southern Mountain Zone, mostly occupied by both plutonic and volcanic igneous rocks, volcanic clastic rocks, silisic clastic rocks as well as carbonate rocks. Magmatism and volcanism in this area is represented by the Mandalika Formation consisting mostly volcanic igneous rocks such as andesite-dacitic lavas, volcanic clastic rocks namely dacitic tuffs, and volcanic breccias. The rock unit was intruded by dioritic intrusive rocks. Volcanic clastic rocks of the Semilir Formation , as a product of the huge eruption, are exposed and scattered at the south of Selogiri area such as tuffs, lapilli tuffs, dacitic pumice breccias, tuffaceous sandstones and tuffaceous shales [1].

Mineralisation type of Randu Kuning prospect was interpreted as a porphyry Cu-Au ore deposit and a number gold-base metals epithermal deposits in its surrounding [1, 2, 3].

Many reseacher have recognized the mineralisation in the Selogiri area [1, 4, 5, 6], but detailed scientific study on the deposit is still limited, particularly to develope the genetic model of hydrothermal deposit in the Selogiri area.

The exiting Cu-Au mineralization in Randu Kuning is very interesting to do exploration activities. Exploration activities showed significant result to be made to the next stage up to mining. However, not all exploration results can be continued up to the mining stage. There must be a risk of failure.

Considering that exploration activities have a very high risk, it is necessary a way how to determine the level of confidence and at the same time determining the risk value at each stage of exploration, so that the risk of failure can be minimized to the next stage. Importance of research on quantifying the value of exploration risk will provide a clearer picture and measurable about the opportunities and risks that will happen.

In general, this research is expected to provide benefits in terms of solving one of the most crucial problems in exploration, namely the level of confidence and certainty. The main one in the quantitative assessment is that the uncertainty is stated explicitly, that allows to identify the sources of uncertainty, the possibility of reducing the sources of uncertainty and risk. Quantification of risks will also be able to give a clearer illustration of the opportunities as well as the failure of an exploration project, as well as increased expectations and confidence better to the success of exploration and investment projects.

b. Location and Accessibility

The Randu Kuning porphyry Cu-Au prospect area, situated in Selogiri, Wonogiri, Central Java, Indonesia. This location is reachable with four or two wheel vehicle, about 40 km to the south-east from Solo city, or approximately 70 km east of Yogyakarta city (Figure 2).

c. Exploration History

Explorations of copper and gold deposits in Wonogiri area have done since the Dutch era (1929-1935), and by reference of this exploration, then were followed by the

Japanese during the occupation of Indonesia (1942-1954).

After independence, in 1958, hiring the mine employs experts from Japan, the Indonesian government evaluated the existing hydrothermal ore deposits in Tirtomoyo, which stated that there were three abundant outcrops of quartz veins containing chalcopyrite.

On May 2009, PT. Alexis Perdana Mineral (recent is the owner of IUP in Selogiri) and PT. Oxindo Exploration subsidiary of the Minerals and Metals Group (MMG) signed a definitive Joint Venture Agreement to explore and developing the Selogiri prospect, and commenced the exploration activities [6]. In 2011, Augur Resources then has 90% register interest in PT. Alexis Perdana Mineral and the remaining 10% interest is held on behalf of PT. Oxindo [1].

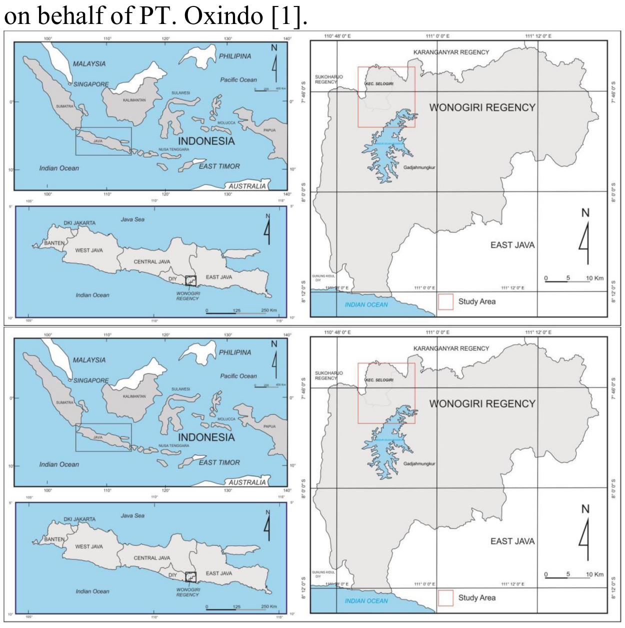


Figure 2. Location map of Selogiri area, Wonogiri

d. Methods

This paper is a preliminary study on risk assessment and quantification and part of the dissertation research progress. The data used in the paper are grade distribution from core drilling observation, drilling density, fracture density and from petrography analysis, than for risk assessment and risk quantification using binary coding, multiple regression and Monte Carlo.

BASIC THEORY

Until now, there has been widely applied how the determination of the success of exploration activities or risk of failure numerically (by weighting), because most are based on the results of geological interpretations, which in general, many in the form of qualitative data, so that the level of accuracy can not be expressed uniformly, depending on the author and how its interpretation. In this study is expected to be the dominant factor determining the major causes of failure of exploration risk and determine appropriate procedures to determine how to quantify the probability of mineral deposits existence based on geological models of deposit. Through the model of the weighting of each variable risk, it will be easier to

Formulation a relationship between the likelihood and consequences of risk. In the context of mineral exploration, risks may mean that the possibility of the project is providing financial results are not satisfactory. This risk can be expressed as a probability (P) failure, which is equal to one minus the probability of success (1-P) [7]. The main implication of this definition is that the risks can be measured, or at least estimated, and can be reduced if the probability of success can be improved.

Geoinformatics Exploration Inc. and Auzex Resources Ltd has been Conducting research and successfully tested [7]. Research using the framework of the probabilistic approach, by integrating the critical process variables formation of mineral deposits, scale and intensity of the precipitation of metals with the basic concepts of probability theory, financial analysis and decision. The results of this study resulted in the relationship between the geological potential and the probability of financial value.

The geological data parameters that can be quantified based on the level of geological confidence and presence of deposit is the age of rocks, deposit type, texture or structure of rocks, alteration and mineralogy, geochemistry, geophysics and mineral associations.

Uncertainty is always shadowing geological knowledge (geoscience) and its interpretations. In general, the uncertainty is still rarely expressed or calculated (quantified). Although it is difficult for parameter exploration risk very much, quantification of risk is not impossible to do. Furthermore, the results of this study successfully formulate the things that make the risk of mineral exploration. The first variable, consisting of natural variability inherent in geologic processes and objects of geology, which is in the nature and independent (eg uncertainty about location control ore deposits, the origin of the fluid mineralization, time and events deformation, as well as the nature of the order tectonic), For the second variable, uncertainty concepts and models, associated with incomplete knowledge and subjective interpretation of the object and geologic processes. Kind of uncertainty is almost impossible to measure and subject to an understanding of the risks and uncertainties in mineral exploration activities.

The risk in mineral exploration, strongly influenced by the geometry (shape, size, thickness, slope and depth) as well as the distribution grades of deposits, as well as the condition of the rock mass prospect area deposits of ore (vein, hanging wall and foot wall).

Conduct research using scoring models to determine the consequences scores, scores of opportunities, risk score and risk matrix. Simple mathematical equations ln $10^{(\log_{10} OS),}$ until the risk can be calculated the cost per unit time in the exploration activities.

The risk factor (or probability existence deposit) as one of the variables that need to be considered in the planning of exploration and determination of the level of geological confidence [8]. There is still a lack of research on risk assessment, especially the difficulty in determining the dominant factors causing the high risk of failure. Furthermore, the study also concluded that the quantification of genetic models of deposit is an important parameter in determining the success rate of exploration, but this genetic models in general are still much in the form of qualitative data.

Research in the Randu Kuning prospect, Selogiri find many types of rock, such as volcanic breccia, andesite lavas, tuffs and intrusive igneous rock diorite and andesite [9]. Also found three major alteration, namely profilit, advanced argillic and argillic-phyllic-potassic, covering 80% of the area carefully situations. Also found crustiform texture veining, disseminated and massive, and massive vein structure vein, stockwork and breccia diatreme. Various rock types, alteration, structure and texture veining found this is one indicator of the level of complexity of the deposit, as variables that affect the risk of exploration.

The best of this research is in the development of new alternatives in terms of determining the geological confidence as one of the reference preparation of the geological model and exploration models, especially with the determination of risk more accountable and easily communicated to all parties concerned.

Quantification Theory

Determining the quantity of a quantitative variables (eg; the geological model, a genetic model), can be done by statistical methods and/or geostatistics, whereas qualitative variable transformed into quantitative variables with methods Lingkert or regression analysis [8].

Quantification method of qualitative variables was done by mapping the modalities set of qualitative variables into numbers riel, in order to obtain a domain riel value in the area.

Suppose E is a set with card (E) = n, which is a sample of size n from a population. Ɯ element in E is called an individual or statistical units, then every ω in E, ω = 1,2, ..., n is the weight p (p ≠ 0).

A so-called quantitative statistical variables when the price of X (ω) is riel each ω in E. A qualitative said statistical variables for each individual ω when the price of Y (ω) is located in a collection of Q so that Q ε R. Q This is an area of values. The elements of Q are called modalities of Y, which is a value of qualitative variables. Variable Y is mapped to the formula $Y: E \rightarrow Q$,

$$Ɯ \rightarrow Y(ω) = m \quad (1)$$

Q is the set of modalities of Y, and m are the modalities owned Y. This situation applies to the assumption that there is at least one individual ω as modalities. Since Y is a qualitative variable , then needed another mapping :

$\partial Q \rightarrow R$, so

$\partial 0Y : E \rightarrow R$ is the quantitative variables (2)

For example, according Cammon (1992), the parameters of geological data that can be quantified based on the level of geological confidence and presence of deposits is the age of rocks, rock type, texture or structure, alteration, mineralogy, geochemistry, geophysics and mineral associations [8].

DATA PROCESSING

The data used in this study was obtained from direct measurement (primary data) and of the measurement results and the research that has been done previously (secondary data). Furthermore, the data was divided into two groups, namely quantitative data in the form of quantitative variables (declared with a default value/specific) and qualitative data/ qualitative variables (in the form of a statement or a range of values).

a. Quantitative Data Processing

Quantitative data processing explicitly using descriptive statistical approach or using conventional statistic and geostatistical calculations.

Statement of a normal distribution data was when the value $\overline{X}$, Mo and Me relatively coincide, the distance $\overline{X}$ against x_{min} and x_{max} ± equivalent and Sk value is close to zero. If this condition is not met, then the distribution of data was said to be non normally distributed. Determining the distribution of the data is normal or non normal is important in subsequent statistical analysis, especially geostatistical calculations.

Support program for the calculation of descriptive statistics use Minitab, GS + and Exel.

Transformation of data distribution was required when data was distributed in the form of non normal distribution. The method is often used and most practical is the Cooley - Tukey method. Cooley-Tukey transformation models described in outline form threads ladder shape (tail of the data distribution) and the value of skewness (Sk).

As a continuation of the phase of descriptive statistical analysis, geostatistical analysis can be done. To perform geostatistical analysis, required the preparation of the database in the form of coordinates of sample points and codification block contains a database (the metal grade, thickness, etc.). Making the variogram (variography) was a standard procedure in geostatistical analysis. With variogram analysis will be know of form the data structure, data distribution (direction and distance of the area of influence).

b. Qualitative Data Processing

The quantification stages of a qualitative data was conducted based on quantification using maximum coding (maximum codification) by input of all independent variables qualitative. Therefore it must be done quantification process for all possible combinations. This process can be done by using canonical correlation and multivariable regression analysis

With mathematical approach, qualitative variables that affect the risk could be arranged as followed :

$$Mq\ (V1, V2, V3, \ldots, Vn) \quad (3)$$

Where
Mq = function of qualitative variables
Vi = qualitative variables , i = 1,2,3,..., n

Associated with a genetic model of deposit, there are four (4) main variables that affect the formation of genetic models, namely the complexity of deposit, the control structure, mineralization and deposit geometry [8]. From the four variables, variable mineralization can be expanded into new two variables, i.e. the proportion of mineral ores and alteration intensity. The fifth variable is the main variable that has great opportunity in the possible risks and exploration risk quantification. For the other variables can be developed from these five variables

Based on the hypothesis that the exploration risk is directly correlated with the genetic model of deposit, which consists of five (5) main variables as mentioned previously, it can simply be arranged the following formula :

$$Cd\ (Vs, Va, Vm, Vg, Vd \quad (4)$$

Where : Cd = complexity of deposit
Vs = variable of structure control
Va = variable of alteration intensity
Vm = variable of number of metallic minerals
Vg = variable of metal grade
Vd = variable of drill spacing

c. Complexity Deposit Variable

The complexity of a deposit can be seen from two main factors, namely the shape or geometry deposit and grade distribution. Regularity geometry can be represented by a thick or thin deposit and continuity, while for the grade distribution indicated by the coefficient of variance (coefficient of variation; CV). A deposit shape was complex if shape and size was irregular. Is said to be simple if relatively uniform thickness, the shape is simple and easily modeled. CV with low value indicates the distribution of metal content or grade is relatively uniform.

Based on the classification proposed, the area of research, qualitative variables grouped in four deposit complexity criteria as follows (Table 1).

Table 1. Complexity deposit classification

Modality	Complexity deposit	CV criteria
1	Comp. geometry & comp. grade	high
2	Comp. geometry & simple grade	high
3	Simple geometry & comp. grade	high
4	Simple geometry & simple grade	low

d. Structure Control Variable

The structure is believed to be very important role in the processes pra-mineralization. Mineralization indicated stronger in the structures of major or minor, especially on the structure of faults and fractures. It seems more clear on the type of epithermal deposit, which is the final settling phase with low energy. Control structures in the field indicated from many or at least fractures and crack in the country rock.

In the implementation of measurement, control structure is one of them can be seen from the value of RQD (Rock Quality Designation) that can be seen and calculated from the results of drill hole coring.

e. Ore Mineral Variable

Ore mineralogy is one of the variables be indicate of mineralization processes are evolving. In the area Randukuning, Selogiri found indications of host mineralized ore Cu-Au is a mineral pyrite (FeS_2), chalcopyrite ($CuFeS_2$), sphalerite (ZnS), galena (PbS), chalcocite (Cu_2S), covelite (CuS), bornite (Cu_5FeS_4), magnetite (Fe_3O_4) and hematite (Fe_2O_3). Gold (Au) is found in the form of electrum and native (Idrus, et.al., 2015).

Epithermal deposit system formed a system of epithermal low sulfidation the overprinting porphyry Cu-Au with type quartz-sulphide Au deposit and carbonate-base metal Au where epithermal formed by the supply of heat sources, or may derived from different intrusion of indicated by the presence of epithermal veins which cut porphyry system.

Based on these results, it can be the assumption that a lot or a little mineral ore carrier Au-Cu can be used as a qualitative variables that affect the complexity of deposit. Analysis of the drill core samples taken from several locations provide data on the amount of mineral carrier of mineral Au and Cu.

f. Drilling Spacing or Drilling Density Variables

The distance between sample locations or sample points (in this study using the position of the core drill) is critical in determining the classification of the resource or reserve, and is also closely related to the level of risk. The closer the distance of the drill point, the rising value of the resources and reserves beliefs (value risk is reduced), so it will apply to the opposite case. The confidence level may change significantly when the position of the core drill to change, especially the deposit with complex grade distribution.

Based on the results of previous studies on primary Au deposit, to get in on the classification of inferred resources (inferred mineral resource) the distance between the drilling point> 200 m. Distance drilling point 100 m - 200 m applies to the inferred resource to the indicated resource determination (indicated mineral resource). To drilling point spacing of between 25 m - 50 m is used as a measured resource classification (measured resource). Based on the classification within the drilling point, the drilling point spacing used in complexity criteria are as follows: for a complex space <100 m, moderate 100 m-200 m and simple > 200 m.

g. Coding of Qualitative Variable

Quantification of qualitative variables is done with the maximum encoding using canonical correlation . The database used in the form of a binary number (1 or 0) of the options (modalities) of each qualitative variables. Each qualitative variables there is only one modality binary value of 1 (one), while other modalities should be 0 (zero). From the data of binary numbers are then calculated delta value (the value of quantification), maximum and multivariable regression quantification of qualitative variables and their coefficient of determination (probability index ore deposits).

The complete research steps can be seen in the flow sheet in Figure 4 (on the last page).

DISCUSSION

The first step, consider before making a risk assessment is to observe and select the variable data to be used in this assessment. Determination of five variables is important geology and adapted to the characteristics of the deposit to be studied.

For quantitative data (grade), calculation CV value is absolutely necessary, such as input data to determine the level of complexity of the deposit. High CV value indicates the complexity of the deposit is also high, and vice versa. This data will be used to classify models of deposit whether geometry or grade distribution are simple or complex.

In this study used regression analysis were used to study and measure the statistical relationship between two or more variables. Also studied the relationship between the variables studied (coefficient correlation R) or use the scatter plot diagram.

Calculation of varian estimates and block kriging performed for analysis variables quantitative data, aims to determine the difference (variance) of the errors which occurs in predicting the grade of a block of deposit, which is shown by the grade value of samples within a block or around the block. With the calculation of block kriging variance of the estimates and will facilitate weighting in the weighting of the risk of error, the appropriate grades and the estimated value of the block kriging estimation errors that have been modeled.

Quantification of the value of quantitative variables (the results of geostatistical analysis) and the quantification of qualitative variables (canonical analysis results) can be used to describe a genetic model of deposit that are useful in the exploration risk estimation. The combination of these two values quantification will generate new quantification value (combined) and combined probability.

When both types of variable data, qualitative data and quantitative data can already be made quantity value, then it may be a risk matrix and risk maps. Variables geological risk associated with the value of the quantification and quantification value distribution map, grouped into a matrix modalities consequences and opportunities, which in turn is weighted. risk matrix used using a standard New Zealand / Australian Standard 2008 (Figure 3).

		Concecuence level				
		1	2	3	4	5
Likelihood level	Descriptor	Insignificant	Minor	Moderate	Major	Catastrophic
1	Almost certain	1	10	100	1000	10 000
0.1	Likely	0.1	1	10	100	1000
0.01	Possible	0.01	0.1	1	10	100
0.001	Unlikely	0.001	0.01	0.1	1	10
0.0001	Rare	0.0001	0.001	0.01	0.1	1

Figure 3. Basic of matrix model semi-quantitative risk assessment

CONCLUSIONS

From the description in the previous chapters then can be taken several conclusions as follows :

1. The addition of qualitative variables with quantitative models of quantification into variable is expected to strengthen the conclusion of geostatistical estimation of the areas assessed.
2. With variable geological quantification can provide benefits in terms of solving one of the most crucial

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problems in exploration, namely the level of confidence and certainty. The main one in the quantitative assessment is that the uncertainty is stated explicitly,

3. Quantification of risks will also be able to provide a clearer picture of the opportunities as well as the failure of an exploration project, as well as increased expectations and confidence better to the success of exploration projects and investment.
4. Develop new alternatives in terms of determining the geological confidence as one of the reference preparation of the geological model and exploration models, especially with the determination of risk more accountable and easily communicated to all parties concerned

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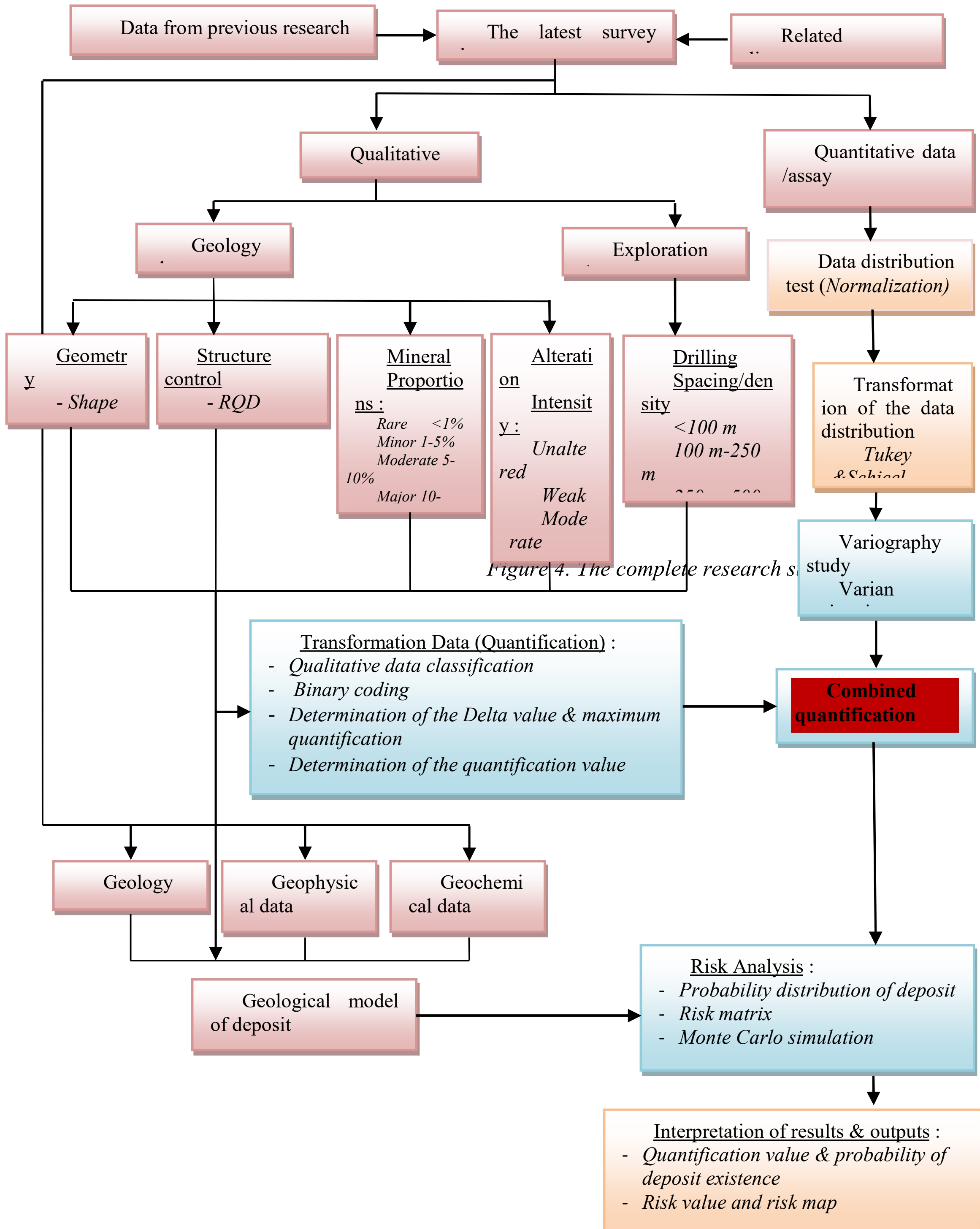

Figure 4. The complete research s