NICKEL RESOURCE ESTIMATION AND RECONCILIATION AT TÜRKMENÇARDAĞI LATERITE DEPOSITS

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ABSTRACT

NICKEL RESOURCE ESTIMATION AND RECONCILIATION AT TÜRKMENÇARDAĞI LATERITE DEPOSITS

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In recent years nickel is mostly produced from lateritic ore deposits such as nontronite, limonite, etc. Resource estimation is difficult for laterite deposits as they have a weak and heterogeneous form. 3D modeling software are rather suitable for deposits having tabular or vein type ores. In this study the most appropriate estimation technique for resource estimation of nickel laterite deposits was investigated.

One of the known nickel laterite deposits in Turkey is located at Türkmençardağı - Gördes region. Since the nickel (Ni) grade recovered from drilling studies seem to be very low, a reconciliation pit having dimensions of 40 m x 40 m x 15 m in x-y-z directions was planned by Meta Nikel Kobalt Mining Company (META), the license owner of the mine, to produce nickel ore.

13 core drilling and 13 reverse circulation drilling (RC) and 26 column samplings adjacent to each drillholes were located in this area. Those three sampling results
were compared to each other and as well as the actual production values obtained from reconciliation pit. On the other side 3D computer modeling was also used to model the nickel resource in Türkmençardağı - Gördes laterites. The results obtained from both inverse distance weighting and kriging methods were compared to the results of actual production to find out the applicability of 3D modeling to laterite deposits.

Modeling results showed that Ni grade of the reconciliation pit in Türkmençardağı - Gördes, considering 0.5% Ni cut-off value, by using drillholes data, inverse distance weighting method estimates 622 tonnes with 0.553% Ni and kriging method estimates 749 tonnes with 0.527% Ni. The actual production pit results provided 4,882 tonnes of nickel ore with 0.649% Ni grade. These results show that grade values seem to be acceptable but in terms of tonnage, there are significant differences between theoretical estimated values and production values.

Keywords: Türkmençardağı - Gördes Laterites, Resource Estimation, Reconciliation, Inverse Distance Weighting Method, Kriging Method

Türkiye’deki nikel laterit yataklarından bilinen bir tanesi Türkmençardağı – Gördes alanında bulunmaktadır. Sondaj çalışmalarından alınan nikel (Ni) tenörü çok düşük görüdüründen dolayı, nikel cevherini üretmek için x-y-z yönünde 40 m x 40 m x 15 m boyutlarında bir test ocağı açılması madenin lisans sahibi Meta Nikel Kobalt Madencilik A.Ş. (META) tarafından planlandı.

Alandan 13 karotlu sondaj ve 13 ters sirkülasyon sondaj ve her sondaj kuyusu için 26 kolon numunesi alınmıştır. Bu 3 sonuç birbirleriyle karşılaştırılmış ilaveten bu
test ocağının gerçek üretim değerleri elde edilmiştir. Diğer yandan Türkmençardağı - Gördes lateritlerindeki nickel kaynağı modellemek için üç boyutlu modelleme kullanılmıştır. Üç boyutlu modellemenin laterit yataklarına uygulanabilirliğini bulmak için uzaklığın tersi metodu ve krigleme metodu sonuçları gerçek üretim değerleriyle karşılaştırılmıştır.

Analiz sonuçları gösteriyor ki; % 0,5 sınır değeri alındığında sondaj datalarını kullanarak test ocağ alanının % Ni tenor değeri uzaklığın tersi metodu ile 622 ton % 0,553, krigleme metodu ile 749 ton % 0,527 olarak bulunmuştur. Gerçek üretim değerlerinde % 0,649 Ni tenörü ile birlikte 4,882 ton nickel cevheri bulunmuştur. Bu sonuçlar gösteriyor ki; tenör değerleri kabul edilebilir görünüyor fakat tonaja bakılırsa teorik değerler ile üretim değerleri arasında önemli farklar vardır.

Anahtar Kelimeler: Türkmençardağı - Gördes Lateritleri, Kaynak Kestirimi, Doğrulama Çalışmaları, Uzaklığın Tersi Metodu, Krigleme Metodu
To My Mother and Wife
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CHAPTER 1

INTRODUCTION

1.1 General Remarks

Nickel is a metal with major importance as it has various utilization fields in modern life. There are over 300,000 applications of nickel contributing to innovation and technology. Most commonly used areas of nickel are stainless steel and resistant alloy production as it is resistant to corrosion, oxidation, and heat. Nickel is declared as a critical raw material by the European Union (EU) in 2010 as its high economic importance and supply risk (European Commission Enterprise and Industry, 2010). Official price of nickel concentrate published daily by the London Metal Exchange (LME) is approximately 18,000 $/ton (LME, 2012). Low substitutability of nickel also makes it a critical raw material for EU as stainless steel industry has a major importance in the economy.

Majority source of world nickel production has been sulphide deposits. However, decreasing amount in this type of deposits gives way to lateritic type deposits, which also house a great amount of cobalt reserves. One of the known nickel laterite deposits in the country is located at Türkmençardağı - Gördes region and in this study Türkmençardağı laterite deposit is evaluated as a case study.

Non-uniform and dispersed ophiolitic melange structure of Türkmençardağı nickel laterites makes it difficult to estimate the grade, as well as the tonnage of the resource. On the other side, resource estimation methods need homogeneous zones. Moreover, 3D mine modeling software such as Micromine, Surpac, Vulcan, etc. is more suitable for tabular or vein type deposits. Therefore, in this study it is
investigated whether this type of ophiolitic melange can be modeled with these software and if it can be which estimation method is appropriate for this type of deposit.

1.2 Statement of the Problem

Laterite deposits are commonly found in a loose and soil like form so that a certain reserve type can not be assigned. There are no easily observed reserve limits with surrounding rock. Also, the heterogeneous form and uneven distribution of grade of such deposits makes close grade control during production essential; therefore, modeling stage is very challenging. This also makes chemical analysis essential as the grade distribution is easily varying even in a meter.

1.3 Objectives and Scope of the Study

The aim is to find out the difficulties in such heterogeneous deposits like complex structure of Türkmençardağı - Gördes nickel laterites during resource estimation analysis. In this study, 3D computer modeling results are compared with the actual results in order to find out the most appropriate estimation method.

This study focuses on nickel resource estimation in laterites in Manisa-Gördes region by kriging and inverse distance weighting methods. The elements of the main objective are:

i. Comparison of drill hole data with column sampling data,
ii. Calculation of actual production values,
iii. Resource estimation by 3D modeling using kriging method,
iv. Resource estimation by 3D modeling using inverse distance weighting method,
v. Comparison of estimation results with actual production figures of reconciliation pit.

The importance of this study is that there is not enough information related to nickel laterite modeling methods. Therefore, this study is thought to be a good source for future studies on nickel resource estimation.

1.4 Research Methodology

A reconciliation pit was exploited by META in Türkmençaradağı - Gördes mine field. The drillhole data was supplied to Hacettepe University to provide nickel resource estimation using kriging method in the study area (Tercan, 2012). Also the reconciliation pit was modeled by using Micromine software with inverse distance weighting method (META, 2010) in order to determine which method is most appropriate. The results of the modeling were compared with the actual production results and finally the suitability of these methods for this type of nickel deposits was discussed.

1.5 Outline of the Thesis

This thesis is composed of five chapters. In the first chapter, general information is given about the thesis and problem. In the second chapter, basic concepts about nickel and resource estimation are given. In the third chapter, general information is given about the Gördes region and Türkmençaradağı laterite deposits. In the fourth chapter, the results of the estimation methods and actual production results are discussed. In the last chapter, conclusions and recommendations are given.
CHAPTER 2

BASIC CONCEPTS ABOUT NICKEL AND RESOURCE ESTIMATION

2.1 General Information about Nickel

Similar hardness and strength to iron, nickel is a transition element composed of ferrous and nonferrous metal properties. This silvery-white metal is hard yet still bendable and easy to work with in comparison to iron. When alloyed with several other elements, nickel imparts toughness, strength, and resistance to corrosion. Also, it shows various other electrical, magnetic, and heat resistant properties (Blainey et al., 2003).

Some important physical properties of nickel are as follows (Bailey et al., 2002):

- Melting point : 1453 °C
- Boiling point : 2730 °C
- Specific gravity (25 °C) : 8.9
- Volume increase on melting : 4.5 %

2.1.1 Production and Consumption of Nickel

Although nickel is one of the most common elements in the composition of the earth, the fact that it is thinly spread in the earth’s crust raises many questions. Most of these resources occur in minerals such as nickeliferrous limonite – poorly crystalline to non-crystalline nickel-bearing ferric oxides in laterite deposits - and garnierite - a principle constituent of nickel bearing limonite (Blainey et al., 2003).
Today, more than 80% of the world’s nickel production is used in alloys as at least 3000 nickel alloys were brought to light so far. About 69% of the nickel output was reserved for the production of the stainless steel (Dalvi et al., 2004).

The approximate nickel consumption ratios in different fields are given in Figure 2.1.

![Figure 2.1 Nickel consumption ratios (Dalvi et al., 2004)](image)

As it can be seen from the Figure 2.1 the major utilization of nickel is stainless steel production, one of the very important construction materials, needs nickel in its composition to increase its corrosion resistance and strength.

World nickel production was at 1.416 million tonnes in 2007. However, between 2008 and 2009 nickel production decreased to 1.32 million tonnes due to economic crisis. But in 2010 it became sharply to 1.446 million tonnes and increased further to 1.589 million tonnes in 2011 (INSG, 2012).
2.1.2 Trend of Nickel Price in Recent Years

The nickel price in 2012 is changing between 15,000 and 22,000 USD/ton. Also the prices are increasing towards the end of the year. The trend of nickel price in 2012 can be seen from Figure 2.2.

![Figure 2.2 Trend of nickel price in 2012](image)

From Figure 2.2 it is concluded that maximum price of nickel reaches around $21,800 and minimum price is around $15,200 in 2012 so far. Additionally the mean price is around $17,700.

2.2 General Information about Laterite Deposits

Today the bulk of the nickel comes from two types of ore deposits: the first being the laterites with the principal minerals of nickeliferrous limonite and garnierite and
the second being the magnetic sulfide deposits with the principle minerals of pentlandite (Blainey et al., 2003).

The production of the nickel from laterite ores, however, is hardly a new option. It started about 100 years ago with the processing of the garnieritic ores from New Caledonia. Today, it presents itself as a new opportunity to expand the production capacity. That is, the lower capital and operating costs of the new laterite projects will affect the nickel supply considerably and, therefore, lower the prices immediately.

Nickel laterite deposits are formed from the weathering of nickel-bearing rocks. Typically, nickel laterites are composed of an upper limonite zone and a lower saprolite zone. These two zones must be treated differently to recover the nickel efficiently, due to the different proportions of iron, magnesium, and silica in each zone (Dalvi et al., 2004).

The world nickel resources and production ratios can be seen in the Figure 2.3.

![Figure 2.3 World nickel resources and production ratios (Dalvi et al., 2004)](image-url)
As given in the Figure 2.3, according to year 2004, nickel laterite deposits contained the majority of the world’s known nickel reserves – i.e. 60% of the world’s known nickel resources as the rest is sulphide ores. On the other hand, 40% of Ni production is done from laterite deposits and the rest is produced from sulphide deposits.

Nickel is produced from both nickel sulphide and nickel laterite deposits. However sulphide deposits have been the main source for the world’s nickel supply due to economic reasons (Dalvi et al., 2004). World’s nickel laterite resources distributions are given in Figure 2.4. Major nickel mining countries are Australia, New Caledonia, Madagascar, and Cuba (META, 2010).

![Figure 2.4 Distribution of world’s known nickel laterite resources (Dalvi et al., 2004)](image_url)
As given in Figure 2.4 New Caledonia has the largest laterite deposits with 21% share. The second major rate belongs to Australia.

Magnetic sulphide deposits are primary nickel deposits and they are formed by magnetic processes. These processes are mostly happens in Canada, the former Soviet Union, the Republic of South Africa, Australia, Zimbabwe, and Finland (Reimann et al., 1999).

The laterite deposits have a complicated geological history. They are formed by the ultramafic rocks outcropped over a huge area. These rocks are olivine-bearing, mainly dunite and olivine-pyroxene peridotite, and their serpentinized equivalents (Brand et al., 1998).

Peridotite, in fact, consists mainly of olivine, a magnesium iron silicate containing up to 0.3% nickel. In most of the rocks, the peridotite has been altered to serpentine, a hydrated magnesium silicate, before exposed to weathering. In time, groundwater containing carbon dioxide dissolves olivine and serpentine to form soluble magnesium, iron, nickel, and colloidal silica. When exposed to air, the iron rapidly oxidizes and precipitates by hydrolysis to form goethite and hematite. This layer stays near the surface of the deposit.

The decomposed nickel and magnesium, and the colloidal silica, on the other hand, penetrate downwards in the laterite deposit. This composition stays in solution so long as the solution is acidic. When the solution is neutralized by reaction with rock and soil, however, the nickel, silica, and some of the magnesium precipitate as hydrated silicates (Roorda and Queneau, 1973).

The following Figure 2.5 demonstrates a typical cross-section of a laterite deposit.
As given in Figure 2.5, a typical laterite deposit demonstrates a variety of chemical components with depth. Typically, they have two zones, an upper limonite zone and a lower saprolite zone. The former has a reddish color distinctly fading to brown on depth. The cobalt stays with the iron but tends to concentrate with depth. The lower level is the saprolite that has the highest nickel grades while being deficient in cobalt. Harder than the upper level, the saprolite is less weathered (Reimann et al., 1999).

Each of these zones has different proportions of magnesium, iron, and silica. Thus, it is necessary to treat each level separately, especially if an efficient recovery of nickel is needed (Dalvi et al., 2004).

<table>
<thead>
<tr>
<th>Depth of meter</th>
<th>Idealized Laterite</th>
<th>Approximation Analysis %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Overburden</td>
<td>Ni</td>
</tr>
<tr>
<td>1</td>
<td>limonite</td>
<td>≤ 0.8</td>
</tr>
<tr>
<td>2</td>
<td>limonite</td>
<td>0.8 to 1.5</td>
</tr>
<tr>
<td>3</td>
<td>transition zone</td>
<td>1.5 to 1.8</td>
</tr>
<tr>
<td>4</td>
<td>limonite</td>
<td>0.8 to 1.5</td>
</tr>
<tr>
<td>5</td>
<td>limonite</td>
<td>0.8 to 1.5</td>
</tr>
<tr>
<td>6</td>
<td>limonite</td>
<td>0.8 to 1.5</td>
</tr>
<tr>
<td>7</td>
<td>limonite</td>
<td>0.8 to 1.5</td>
</tr>
<tr>
<td>8</td>
<td>limonite</td>
<td>0.8 to 1.5</td>
</tr>
<tr>
<td>9</td>
<td>limonite</td>
<td>0.8 to 1.5</td>
</tr>
<tr>
<td>10</td>
<td>limonite</td>
<td>0.8 to 1.5</td>
</tr>
<tr>
<td>11</td>
<td>limonite</td>
<td>0.8 to 1.5</td>
</tr>
</tbody>
</table>

Figure 2.5 An idealized section through laterite deposit (Roorda and Queneau, 1973)
As such, the weathering of these nickel-bearing rocks forms nickels laterite deposits in time. Conversely, they contain economically usable reserves of nickel and usually cobalt.

Nickeliferrous limonite is a term used in referring to poorly crystalline to non-crystalline nickel-bearing ferric oxides in laterite deposits developed from ultrabasic rocks. Goethite is a principle constituent of nickel bearing limonite. The water content of limonite varies widely (Boldt, 1967).

Both type of nickel mineralization - laterite and sulphide - are found in Turkey. The main laterite resources in Turkey are in Manisa-Turgutlu-Çaldağ, Manisa-Gördes, Uşak-Banaz, Eskişehir-Mihalçık-Yunusemre and sulphide resources are in Bitlis-Pancarlı, Bursa-Orhaneli-Yapköyde and Sivas-Divriği-Gümüş (DPT, 2006).

2.3 Resource Estimation Methods

Resource estimation methods are practically divided into two groups, which are geometrical methods and geostatistical methods. The shape, dimension, and the complexity of the deposit affect the method selection as well as the type, dimension, and pattern of spacing of the sampling. According to Horton (2008) in resource estimation there are three basic parameters; grade, density and volume. Because nickel laterites are partially sensitive to estimates, resource volume estimates are important. The inverse distance weighting and kriging methods are the main interest of this study.

2.3.1 Polygonal Methods

Polygonal resource estimation method is a geometrical method. This method is based on the polygons areas, which is established around each drillhole. In this method, an area of influence is assigned to whole area. The polygon construction
procedure based on the theory that the influence of a hole extends halfway to the next adjacent hole is illustrated in Figure 2.6. Areas are then measured by planimeter or calculated analytically and subsequent calculations used for finding tonnage and grade (Hartman, 1987).

![Figure 2.6 Steps of a polygon construction (Hartman, 1987)](image)

Drillholes define the polygon and they should be selected, whereas, the orientation and configuration of the polygons are selected arbitrarily. The reason is to obtain the central drill hole with as uniform radius as possible (Güyagüler, 2007).

2.3.2 Triangular Methods

The triangular method can be said that it is a kind of polygonal methods with some modifications. The difference between triangular method and polygonal method is that three drillholes are used for constructing each triangle. The most important point of this method is that there is a gradual, linear, and continuous change between the sample points.
The advantage of the triangular method is that the data from three vertices are used to estimate the grade and thickness for the triangular prism (Hartman, 1987). Calculation procedure is the same with the polygonal method. Also the triangular method procedure can be seen in Figure 2.7.

Figure 2.7 Triangular method procedures (Hartman, 1987)
In a global estimation, if the triangles are equilateral, the average grade of ore for the triangle is the average of the grades in the three holes. If these triangles are not equilateral, weighted averages of the holes are considered (Güyagüler, 2007).

2.3.3 Cross-sectional Method

The suggested method requires one to prepare several different sections of the ore body. The holes for these sections should be more or less on coordinates. A set of sections crossing the major axis, for example, would be the most useful one. The boundary of the ore body, on the other hand, should be determined in view of the thickness and the grade of the ore.

The sum of the parallel or nonparallel sections dissecting the ore body forms the cross-sectional method. All of these sections with known grade and physical properties demonstrate the geologic data of the deposit. To build a model, they should be combined to one another by linear interpolation. To do that, either a gradual change could be assumed from one section to the next, or each section could be extended halfway to the next, suggesting a sudden change in the deposit (Badiozamani, 1992). Cross sectional methods calculation procedures can be seen from Figure 2.8.

---

Figure 2.8 Cross section calculation procedures (Hartman, 1987)
2.3.4 Inverse Distance Weighting Method

One of the most used practical methods in mine resource estimation methods is inverse distance weighting method. The inverse distance weighting method procedure is multidirectional, user-friendly, easy to understand, and is fairly accurate under a wide range of conditions (Lam, 1983). This method is some kind of deterministic method, which is used for multivariate interpolation. With this method values of unknown points are calculated and assigned by using the values of known points. To use this strategy, the weighted average of the data is used.

In this method it is expected that when two samples get closer, the values also get similar. The similarity in sample values will decrease when distance between them increases. Contrary, the difference between sample values will increase when distance increases. So there is a spatial relation in sample values. This relation depends on the distance.

2.3.5 Kriging Method

Geostatistics may be defined as the application of the theory of regionalized variables to the problems of earth sciences. The regionalized variable is a variable that at least has one coordinate and specific to a certain region such as a mineral deposit (Tercan, 2010).

Geostatistical methods were conducted either to get samples’ relationship in the deposit or find out the error in the calculations (Güyagüler, 2007).

As formulated by Isaaks and Srivastava (1989), the basic idea behind the geostatistics is verify quantitatively the possible relation in space of the data within an area, to approximate the ore reserve together with the calculation of the possible estimation error.
In kriging method the aim is to assign a best estimated value to unknown points at some location within an ore deposit. Best estimated value would be mostly the grade of the ore. In other words kriging is a set of linear regression routines, which minimize estimation variance from a predefined covariance model (Tercan, 2010).

There are some parameters that should be discussed when explaining kriging methods. These parameters are variogram (variogram function), range of influence, sill, and nugget effect. Any variogram model can be defined by three parameters: range ‘a’, nugget effect ‘C_0’, and sill ‘C’. Basically, variogram includes all of them. It shows a certain range of influence, sill and nugget effect.

In geostatistics, the spatial relation is determined by using variogram function. Variogram function is used in determining the basic features of the regionalized variable. In other words, the difference between the values of two random variables is a function of the distance between them. The parameters of a typical variogram function can be seen on Figure 2.9.

![Figure 2.9 The parameters of a typical variogram (Tercan, 2010)](image)

Range of influence means that if any other sampling points, which lie in a certain distance from the special point wanted to calculate, have influences to the
calculation. Sill is the variance of the sample used in estimation. In addition, nugget effect gives the measurement errors made by sampling, analyzing, and calculating, or a structure, which is smaller than the sampling grid.

There are three basic types of variogram model with sill, which are spherical, gaussian and exponential. Figure 2.10 shows these three types of variograms.

![Variogram Models](image)

Figure 2.10 Basic variogram models (Tercan, 2010)

Isaaks and Srivastava (1989) argue that the value at a given location can be estimated by all interpolation algorithms as a weighted sum of data values at surrounding locations. Yet this would be still a result of an interpolation algorithm, which could lead similar results for particular other cases. For instance (Bohling, 2005),

- For a case where the data were uniformly distributed throughout the study area, a very good estimation would be possible no matter what the interpolation algorithm.
- For a case where the data were fall in a few clusters with large gaps in between, the result could lead to unreliable estimates no matter what the interpolation algorithm.

According to Belous et al. (2000), the resource estimation by using software has some steps and benefits. The steps are database validation, exploratory data analysis, geological interpretation, geostatistical analysis, grade and specific gravity interpolation, estimation of waste, modeling results and resource reporting, and categorization. The followings, on the other hand, are the benefits: rapid project evaluation, reproducibility of estimates, ease of sensitivity analyses and cost savings.
CHAPTER 3

GENERAL CHARACTERISTICS OF GÖRDES LATERITES

3.1 General Information about Türkmençardağı Laterite Deposits

3.1.1 Location

The Türkmençardağı laterite deposits lies in the west part of Turkey, between Akhisar and Gördes, and close to the villages of Fundacık, Kalemoğlu and Çiçekli in Manisa province (Figure 3.1).

Figure 3.1 Location map of Türkmençardağı Mine Site (META, 2010)
Türkmençardağı pit is located at about 13 km away from Gördes county and 38 km away from Akhisar. The topography of the area nearby the pit is rather smooth and elevation changes between 950 m and 1050 m.

Continental climate is effective in Gördes where the summer is cool and dry; winters are cold and snowy. The average temperature of the area is 12°C where the coldest temperature recorded was -17.5°C and the hottest 44.2 °C.

The town of Gördes, with some 11,000 inhabitants, is connected by asphalt-paved road to Akhisar some 70 km to the west, then on to Manisa (115 km), and ultimately to the coast at Izmir (160 km). The project area is about 20 km from the center of Gördes and 45 km from Akhisar.

The connection from the main Gördes highway, which lies to the south of the site, to the project area is provided by a 2 km access road, 1.5 km of which is part of the old Gördes highway, and is, therefore, structurally sound. Numerous forest trails provide further access into the interior of the area. The nearest railway access is at Akhisar.

The study area is characterized by generally moderate relief with gentle hills dissected by numerous streams. Elevations generally rise from the north to the south across the area with the most important high points being Görenez Mountain (1,280 m), Seyhan Mountain (1,356 m), Kireçocağı Hill (1,091 m), Demir Hill (1,141 m), Demiroluk Hill (1,126 m), and Sümüllükür Hill (1,036 m). The Gördes and Simav rivers form the principal water courses in the region, whilst other minor streams also occur.

The Gördes area was identified as prospective for nickel laterites following a regional mapping programme undertaken by the Aegean Directory of the General Directorate of Mineral Research and Exploration (MTA) in 1987.
Lateritic occurrences were mapped over an area of 500 km$^2$. Trenches up to 4 m deep were excavated over areas of lateralized serpentine and samples showed anomalous nickel grades, mostly less than 1% Ni but with some values in excess of 2% Ni. It was found that the laterites tended to occur on the hilltops, having been eroded away in the valley areas (META, 2010).

In 2001, META acquired exploration licenses over the Gördes area. In 2003 further trenching and RC drilling was carried out. Eight trenches were excavated in the vicinity of Türkmençardağı Hill with positive results, with a number of samples containing up to 2% Ni.

### 3.1.2 Geology of the Site

Up to date geological study related to the site and environs has been carried out by Konak et al. (1980). A summary of this study is presented in this section and a generalized stratigraphic column of the region suggested by Konak et al. (1980) is given in Figure 3.2.

Different geological units starting with Paleozoic age are observed in the area. These units are summarized below according to principal geological times. Additionally, the regional geology is complex. The Gördes nickel laterite deposits originate from the weathering of peridotites, mainly dunite and harzburgite, belonging to the Eydemiçaray mesozoic formation, a complex ophiolitic unit.

Also intense tectonic activity in the region has resulted in ophiolites and limestones/sandstones/siltstones being strongly intermingled in a complex ophiolitic melange.
<table>
<thead>
<tr>
<th>Lithological Units</th>
<th>Lithology</th>
<th>Geologic Time Scale</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Soil</td>
<td></td>
<td>Holocene to Recent</td>
<td>Alluvial and fluviatile occurrences</td>
</tr>
<tr>
<td>Debris Flow</td>
<td></td>
<td>Upper Miocene-Pliocene</td>
<td>Lacustrine and travertine Occurrences</td>
</tr>
<tr>
<td>Yaykin Formation</td>
<td></td>
<td>Upper Miocene</td>
<td>Volcano-sedimentary Occurrences</td>
</tr>
<tr>
<td>Sidan Formation</td>
<td></td>
<td>Lower-Middle Miocene</td>
<td>Lacustrine and volano-sedimentary Occurrences</td>
</tr>
<tr>
<td>Gördes Formation</td>
<td></td>
<td>Eocene</td>
<td>Shallow Sea Sediments</td>
</tr>
<tr>
<td>Başlamış Formation</td>
<td></td>
<td>Upper Cretaceous</td>
<td>Ophiolitic Melange and Laterite Occurrences</td>
</tr>
<tr>
<td>Eydemirçay Formation</td>
<td></td>
<td>Upper Cretaceous</td>
<td>Deep Sea Sediments</td>
</tr>
<tr>
<td>Ulupinar Formation</td>
<td></td>
<td>Middle-Upper Cretaceous</td>
<td>Limestones (Platform Carbonates)</td>
</tr>
<tr>
<td>Görenez Limestone</td>
<td></td>
<td>Upper Triassic-Lower Jurassic</td>
<td>Detritic Sedimentary Occurrences</td>
</tr>
<tr>
<td>Hasköy Formation</td>
<td></td>
<td>Middle-Upper Triassic</td>
<td>Dolomitic Limestone</td>
</tr>
<tr>
<td>Gökbel Formation</td>
<td></td>
<td>Lower-Middle Triassic</td>
<td>Detritic and Carbonatic Formations</td>
</tr>
<tr>
<td>Çömlekçi Formation</td>
<td></td>
<td></td>
<td>Recrystallised limestones</td>
</tr>
<tr>
<td>Akpınar Formation</td>
<td></td>
<td></td>
<td>Metamorphic Sedimentary and Ophiolitic rocks</td>
</tr>
<tr>
<td>Keçidaği Formation</td>
<td></td>
<td></td>
<td>Metamorphic rocks (Gneiss and Schists)</td>
</tr>
<tr>
<td>Sarışın Formation</td>
<td></td>
<td></td>
<td>Meta-Granitic Rocks</td>
</tr>
<tr>
<td>Dibekdağ Formation</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.2 A generalized stratigraphic column observed in the region (Konak et al. 1980)
Locally, limestone both bound the lateritic formation at Türkmençardağı Hill north and south. The same limestone unit is observed under the laterite; it was intercepted at the end of the most of the drill holes completed on the deposit. General view of the study area can be seen on Figure 3.3.

![Figure 3.3 General view of the study area from the SE direction](image)

### 3.1.3 General Characteristics of Gördes Laterites

General characteristics of Gördes laterite formations are given below (META, 2010):
Fresh Serpentine Zone: Hostrock of serpentine is generally harzburgite. Fresh rock is generally dark green and black in colour but it can be seen as yellowish and brown levels in altered zones and its nickel (Ni) content is about 0.1-0.2%.

Altered Serpentine Zone: It is situated under the laterite formation. There are partially altered gossan textured serpentinite zones defined as “saprock” and completely altered zones called as “saprolite. There is also garnierite formation with a Ni grade upto 0.6% in the altered serpentinite zone. In some places of this zone very-high Ni content is determined locally.

Saprock Zone: It is on the fresh serpentinite zone and has an average thickness changing from 1-2 cm to a few ten meters. In general it has yellow – green colour but in silicified zone it can be seen as brown and reddish brown in colour. The clayey zone is widespread along the fractured zone, and garnierite plastering and nickel Ni – silicate formations can be seen very often on the fresh rock surface.

Saprolite Zone: It has an average thickness changing from centimeters to 10 – 15 m. It is yellow, greenish yellow, and bluish yellow in colour and generally comprised magnesite veins.

Garnierite is seen very often and sometimes blue and green clay (especially talc) can not be distinguished from the garnierite unit. It has an average Ni grade differing from 0.4% to 6% and it is characterized by low iron (Fe) content (5-10 %). There are zones with an average grade of 4% Ni and have an average thickness changing from 3 – 4 m and their Magnesium (Mg) content varies between 2 -10%.

Nontronite Zone: Thickness of this zone varies between 1 – 20 m. It is green and brown in colour and generally located at the upper part of the altered serpentinite zone. This zone is partly or completely clayey and comprised lens forms. Garnierite deposition is widespread in the interm zones and less at the lower zones.
This zone has an average Ni grade changing from 1.3% to 2.5% and it is very important for Ni deposition. Its Fe content varies between 15 - 20% generally. It was determined in the mineralogical studies that nickel - serpentine and nickel - simectite are the main minerals in this zone.

There are completely clayey interim zone and plastic clay above the nontronite zone. Their Ni content varies between 0.3 - 1% Ni and their Fe content varies between 8 - 15%.

**Limonite Zone:** It has an average thickness differing from 1 m to 30 m. It has clay and altered serpentine layers. This zone is dark red or brown in colour and it has Fe coloured altered serpentine in its interim zones.

The main mineralizations in this zone are goethite and hematite and they can have low or high amount of clay (smectite). Garnierite is seen very often but sometimes laminated green clay (especially talc and halloysite) can not be distinguished from the garnierite.

In general, Ni content varies between 0.3 - 2% in this zone but in some cases, garnierite zones cause rises in Ni values up to 20%. Fe content is much more than 20% and generally it varies between 25 - 50%.

Especially, in Türkmençardağı, where the most of the limonite mineralization is located, while being approached to fault zone as content varies between 0.3 – 2.5%. As because of the secondary hydrothermal effects and even in some places it can be much more than the Ni content. Mg average grade is around 2% in this zone. A typical formation of laterites can be seen from Figure 3.4.
3.1.4 General Characteristics of Türkmençardağı Laterites

Laterite formation at Türkmençardağı Hill is bounded with limestone unit both the north and the south direction. It is also observed under the laterite zone in the most of the drillholes except that are ended before cutting the base formation because of the technical reasons. The typical NW-SE direction profile observed at Türkmençardağı Hill is given in Figure 3.5.
A main fault with a strike of NE-SW direction exists and it divides the hill into two parts (Figure 3.6). Ore packages show lithological differences at eastern and western sides of this fault.

At the eastern part of Türkmençardağı Hill, profile starts with serpentine unit at the bottom and it is followed by saprolite, nontronitic laterite and the profile ends with silica containing limonitic laterite at the top.

Türkmençardağı laterite formation presents typical ophiolitic melange, sandstone, and siltstone lenses are observed in the patches. At the north-west part of Türkmençardağı Hill, neogene units cover laterite zones.
In the western sector of Türkmençardağı hill, limonite and/or siliceous limonite unit is overlaid by the base unit limestone. Section is followed by altered serpentine and again limonite and/or siliceous limonite unit is located at the top of this section. Limonite unit has a thickness of 5 – 20 m and has an average grade of 1% Ni and 20 - 40% Fe. This unit consists of silica and clay bands. Garnierite mineral can be seen at the contact zones of the limonite with the siliceous material. Ni content at these
contact zones increases up to 3 – 4%. Light green colour altered serpentine is located over the limonite and it has a mesh structure.

Kidney shaped magnesite occurrences can be seen in these mesh structures. Ni and Fe grades increase at the contact zones of the altered serpentine unit. Altered serpentine at these contacts can be seen as light brown in colour because of iron staining. Although altered serpentine is mostly clayish, silification and carbonation effects can be seen in the patches.

The more regular profile is observed at the eastern sector of Türkmençardağı Hill compared with the western sector. Limonite unit with silica and clay bands is located at the top. Below the limonite, nontronitic laterite unit is situated. Nickel content of this unit is higher than that of limonite unit. Average Ni grade of it is about 1.5% and its thickness varies from 5 m to 10 m. It is green in colour.

A saprolitic unit which has a lighter green colour is located below the nontronitic unit. The saprolitic unit is totally altered (clay content is over 20%). Saprolite has 0.3 - 0.5% Ni which is less when compared with the Ni content of the other units in the area.

Fresh serpentine is commonly located below the saprolitic units. Serpentine zone has 0.1-0.3% Ni and common rock type is harzburgite. Limonitic unit is again observed under the serpentine zone. Below the limonitic unit, rich ore lenses are observed especially at the contact zones of serpentine and limestone units.

In Türkmençardağı sector 202 test pits, 111 core and 84 RC drillholes were evaluated based on assay values for nickel, arsenic, iron and chromium and field observations and 8 limonite (Limonite-1, Limonite-2, Limonite-3, Limonite-4, Limonite-5, Limonite-6, Limonite-7 and Limonite-8) and 2 nontronite (Nontronite-1 and Nontronite-2) lenses were designed (Tercan et al., 2009).
According to cross-sections in north – south direction it was assessed that there was a basin like limonitic mineralization. The top view of Türkmençardağı deposit from Micromine software is represented in Figure 3.7.

A view of identified 8 limonite and 2 nontronite lenses modeled in Türkmençardağı sector are given below (Figure 3.8). Limonite bodies were shown as red and nontronite ones were shown green in colour below the surface topography.
3D solid model of nickel ore lenses in Türkmençardağı area can be seen in Figure 3.9 (Tercan et al., 2009).

Figure 3.8 Ore bodies below topography in Gördes - Türkmençardağı deposit (META, 2010)

Figure 3.9 3D solid model of nickel ore lenses in Türkmençardağı area (Tercan et al., 2009)
As given in Figure 3.9, the dominant type in the Türkmençardağı deposit is Limonite-1 lens. Since the area mostly consists of Limonite-1 (nearly 70% of estimated), in resource estimation analysis Limonite-1 type is used.

Plan and section view of nickel ore lenses in Türkmençardağı area is represented in Figure 3.10 (Tercan et al., 2009).

The Limonite-1 lenses lie below Nontronite lenses and Limonite-3 lenses as it can be seen from the section view of the Figure 3.10. Also it is clearly seen that the
dominant type of the study area is Limonite-1 lenses with brown colour in the figure above.

3.2 Previous Geological Studies Related to the Area

General Directorate of Mineral Research and Exploration (MTA) and foreign researchers had completed geological studies at various times. Most recent study for the general geology of MTA was done by Konak et al. (1980) between Gördes – Akhisar.

3.2.1. MTA Work

The first geological study in Gördes and the surrounding belongs to Tchihatcheff (1850). He explored Azimdağ ebonite in the western part of Gördes and metamorphic around Marmara Lake. In 1913, during his study around Marmara Lake, Philippson classified metamorphic formations in the region and named the age as Palaeozoic. According to Canet and Jaoul (1946), who have done the exploration at the same region, the age of this formation is Permo-Carbonifer.

Arpat and Norman (1961) have explored the Hasköy formation in the eastern part of Akhisar as metamorphic schists and classified two marble levels transitive with schists. They named marbles and schists as Palaeozoic aged and classified Jura-Creatase limestone above them as discordant. They also named serpentine gabbros and diabase inside sandstone, gray sandstone, marl and radiolarite group in the upper levels as intrusive.

Canik (1962) classified two type of limestone, one on the other with discordance, and named the lower one using fossils as Upper Jura-Lower Cretaceous and named the upper one as Upper Cretaceous. Upper Cretaceous Mixed Series which contains ophiolites is transgressive over limestone and layered on as discordance by Upper
Cretaceous-Paleocene flysch. The researcher named three discordance and accepted peridotite and serpentine were injected into the Upper Cretaceous mélange.

Ürgüp (1966), in his studies in southern part of Çaldağ and northern part of Turgutlu, thought that dunite, peridotite and serpentine cut both schist and Mesozoic aged limestone.

According to Oğuz (1967) fillat, sandstone, marble, dolomitic limestone and dolomite in Çaldağ are Paleozoic age. Below these rocks, radiolarite, diabase, serpentine and amphibolites belongs to Upper Cretaceous eugeosinclane and major tectonic phase should be end Upper Cretaceous – before Neogene.

According to Karamanderesi (1972), Mesozoic sediments were layered on Paleozoic aged metamorphic rocks and peridotit, dunit, and serpentine were settled as intrusive.

According to Dubertret and Kalafatçıoğlu (1973), in Gördes River, conglomerate and Permian-Mesozoic limestones layered on Precambrian Paleozoic aged metamorphic. Ultrabasic rocks are located on Maestristien limestones.

### 3.2.2. DAMA Engineering Work

In 2007 META assigned Dama Engineering to make the geological map of the area and both META and DAMA have used the geological map of Konak et al. (1980) for the geological studies. The Dama Engineering work is summarized below.

The study for general geology and mining geology for northern and western part of Gördes nickel basin was done by Dama Engineering. In this scope, DAMA prepared a geological map of 21,368 Ha in northern and western part of the basin (Figure 3.11).
The classification of geological units was done according to dominant lithologies but not formations. For example, limestone, sandstone, mudstone etc. laterite zones and silica were labelled in the map separately. Faults and structural components (layer direction etc.) determined during the study were labelled in the map.
3.2.3. META Work

The first geological studies for the southern part of Gördes nickel basin was done by META in 2004. In this study, geological units and lateritic zones of the southern part of Balikesir J20-d3 sheet were mapped. Geological units were named as lithological. For this reason, different aged limestones were named as the same unit. As there was no sufficient structural visual data in lateritic zones, limestones related with those lateritic zones were mapped in details with structural components.

Gördes lateritic nickel deposits are densely seen at the northern part of Fundacık village on Akhisar-Gördes highway in an area of 10 km x 20 km. The area identified as ophiolitic melange as given on the regional geological map presented in Figure 3.12.

Figure 3.12 Regional geological map (META, 2010)
Gördes laterite formations present different profiles at different parts in the area from north towards south. The figure includes the areas where nickel mineralization (limonite or nontronite) has been discovered after exploration studies were undertaken in the region. Comparisons of Gördes laterite formations with other formations in the world can be seen in the Figure 3.13.

Figure 3.13 Comparisons of Gördes laterite formations with other formations in the world (META, 2010)

As given in, Figure 3.13 Gördes nickel formation is a typical arid climate lateritization due to its chemical contents and profile characteristics.

3.3 Exploration Drilling at Türkmençardağı Laterite Deposit

As mentioned earlier in Türkmençardağı deposit both core drilling (TC) and reverse circulation drilling (RC) operations are done.
3.3.1 Core (TC) Drilling

Craelius D 260, Wirth and Levent 2002 brand hydraulic, rotary drilling machines had been used as drilling equipment till today. While taking cores, at hard floors T 76 type of 1.5 m core drills on the other hand at clayey grounds 1.5 m BW drill bits were used. Especially in silica zones rockbit drills (76 mm or 98 mm) were used because there was no penetration in drilling. Due to the presence of fractured and cracked units in the holes water circulation could not be provided and so there was a risk of collapse or subsidence. Since this type of problem was exist, in order to ensure progress in the drillhole, regulator cover NW was used (META, 2010).

In core drilling, because of problems arising from the floor average amount of daily drilling progress was around 10 meters. Not to disturb the core samples in clayey zones, water swivel was attached on BW regulator cover by an adaptor and hence samples were removed easily by water pressure (META, 2010).

3.3.2 Reverse Circulation (RC) Drilling

Up to date in RC drilling, Gemrot 500, Wirth 350 and RC 500 pneumatic drilling machines had been used. At RC drilling machines, bits in different diameters were used. Gemrot 500 pneumatic drilling machine used 5.5” RC bit, Wirth 350 pneumatic drilling machine used 4.5” and 4” RC bits and RC 500 pneumatic drilling machine used 5” RC bit. Drillholes located on hard rock units could be completed by using small diameter drilling bits.

Specified each drilling system maximum and minimum volumes of drillholes were calculated separately and volumetric percentage of drillholes have been evaluated. During RC drilling organic drilling fluids were used to help the progress. RC drilling had between 25-30 meters progress by day (META, 2010).
3.3.3 Locations of Drillholes

In 2003, META drilled 5 RC holes in the vicinity of Türkmençardağı Hill. In 2004, 42 RC holes were drilled in the vicinity of the open pit at Türkmençardağı Hill. In 2006, 8 wire-line core drilling have been carried out in the vicinity of the open pit on Türkmençardağı Hill. Main drilling program started in April 2007 and finished at the end of 2008 in Türkmençardağı area. Two views of this exploration drilling works are given in Figure 3.14.

![Figure 3.14 RC drilling in 2004 (left) and wire-line core drilling in 2006 (right)](image)

A total of 192 drill holes, 111 core drill (TC) and 81 reverse circulation drill (RC), were opened in the area since 2006. Annual distribution of these drill holes is such that 5 (all TC) in 2006, 105 (102 TC and 3 RC) in 2007, 80 (4 TC and 76 RC) in 2008 and 2 (all RC) in 2009. These drill holes in Türkmençardağı area are located on a map according to their coordinates given by META (Figure 3.15).
By the end of 2008, a total length of 11,432.1 m drillholes have been opened in the Türkmençardağı open pit. 5,163.1 m of it is made by core drill while the rest (6,169 m) is made by reverse circulation drilling method.

The minimum and the maximum spacings between the drillholes are 35 m and 190 m, respectively where the average distance is 60 m. According to the lenses defined by META, the individual surface (map) areas of the lenses and the number of drillholes within each lens are determined.

During drilling process some problems were observed. Due to these problems, the core recoveries from these holes were affected negatively and this caused problems in resource estimation. Ore recovery problems associated with core drilling are as follows;
i. **Heterogeneous structure of rock:** In some places, the limonitic ore contains silica layers or boulders in different sizes (Figure 3.16). Generally the nickel is in fine grain within the limonitic ore, when the drill bit hits high strength silica, it is possible that some of the fine grained Ni is washed away by the drilling fluid hence lowering the grade of the core sample.

![View of siliceous rocks in limonite zone](image)

*Figure 3.16 View of siliceous rocks in limonite zone*

ii. **Use of different bit types:** Often clayey and high graded Ni mineralization zones underlying the hard and siliceous levels. When thick, hard and strong siliceous layers met, these siliceous levels were drilled by rock bits instead of diamond bits. At these types of transition
zones there is loss of Ni because rock bits could not take samples. In addition to that if the rock bit passed into soft zones beneath the silica, the thicknesses of mineralization zones could not be taken accurately.

Recovery problems associated with RC drilling that may also lead to underestimation of Ni grades are as follows;

i. **Ore loss in the cyclone:** Especially in high grade limonitic rock, the Ni grade is in very fine particles in situ. During the drilling process some of the dust materials escape from the top of the cyclone and this could reduce the Ni grade estimation (Figure 3.17).

![Figure 3.17 Dust like particles in limonite parts in siliceous zones RC drilling](image-url)
ii. **Less recovery due to wall squeeze:** Another potential problem occurred in soft clayey zones where the RC drill crushed the ground instead of cutting. Crushed material was pushed and compressed to the wall of the drillhole and less material was taken from drilling.

iii. **Contamination due to drillhole wall collapse:** At siliceous limonitic mineralization regions, if moisture content of material is low, the circulation of air became more difficult and air blew into gaps increasing its velocity and samples could be contaminated from the upper parts of the bore walls.

### 3.3.4 Test Pit Column Sampling

In order to determine drilling losses, META excavated test pits at surface area covering 12 drillholes where surface mineralization was determined in 2008. Vertical channel samples are taken to replicate drill holes at the same place as the drill holes. To reveal the probable drilling losses and adequate comparison, sampling was done from the same meters with the drillholes. This study was carried out on 7 core drilling and 5 RC drilling.

First of all, sampling units and interval(s) were defined. Then face of test pits was cleaned by a hammer or a trowel until the fresh (uncovered) surface appeared. After that, channels with the same geometry were excavated (5 cm in depth and 15 cm in width) by a hammer or a trowel and sample was taken by the trowel below. Great attentions paid to have sufficient amount of representative samples of excavated surface. Hence each wall of the pit clearly (carefully) defined before taking sample.

Stratigraphical changes in the wall were assessed to determine where samples had to be taken within lithological types. Test channels (column) opened in lithological units with no defined orientation or bedding like laterites were oriented in the N – S
direction. In sampling hard-wearing plastic or fabric bags were used. Labels were used while sampling on field, also notes were recorded on every sample.

An example of this column sampling is shown in Figure 3.18 and detail is in Figure 3.19. Some representative column sampling visuals are given in Appendix – A.

Figure 3.18 Column sampling view at face

Figure 3.19 Close view of column sampling
CHAPTER 4

NICKEL RESOURCE ESTIMATION IN TÜRKMENÇARDAĞI LATERITE DEPOSITS BY KRIGING AND INVERSE DISTANCE WEIGHTING METHODS

4.1 Resource Estimation and Evaluation of Türkmençardağı Laterite Deposits

Nickel bearing rocks has a variable structure. It shows abrupt changes over short distances. In polygonal methods it is assumed that grade value does not change in the polygonal area. But this approach can not fit the nonhomogeneous deposits like nickel laterites. In order to apply this method the deposit should have tabular or vein type structure.

As explained before triangular method approach is a modification of polygonal method. As it is expected the logic behind this approach is similar with polygonal method. In triangular methods it is assumed that grade does not change in the triangular area. Because of the non-homogeneity this method is not suitable for nickel laterites either.

The same situation is also valid for the cross-sectional method. According to cross-sectional method approach grade value in the cross-sectional area does not change. But in reality nickel laterites have such a structure that grade value can be change even in 1 meter distance. Therefore this method is also not suitable for Türkmençardağı nickel laterites.
Based on the fact that explained above deposits having irregular and non-homogeneous structures can not be estimated by using polygonal, triangular, and cross-sectional methods.

Hence, in this study inverse distance weighting and kriging methods are investigated to find out which one is more suitable for nickel laterites.

**4.1.1 Reconciliation Work Plan**

To analyze which resource estimation method is more suitable for the study area, a reconciliation pit was excavated. Reconciliation pit area was determined according to location and previous drillholes analysis results. An area of 130 m in EW direction (between 35602450E - 35602580E) and 100 m in NS direction (between 4318550N - 4318650N) was defined as the most suitable location for reconciliation work.

The importance of this area is that Limonite-1 lenses are very near to topographic surface in its west of outside of the pit. As mentioned earlier 70% of Türkmençardağı deposit consists of Limonite-1 lenses.

As it is mentioned before core drilling of siliceous levels causes a systematic fall in nickel grade of limonite since soft limonite ore in siliceous zones were washed up by drilling liquid. On the other hand, in RC drilling, limonitic material between siliceous zones were removed just like dust particles.

In clayish zones, being relatively soft and damp, RC drilling causes the material to perfuse on the wall of drillholes. Generally in this type of ground, hard particles such as serpentine could be carried out by air and finally removed.

Therefore, in the reconciliation pit, twin drilling (RC drilling + core drilling) holes and sampling channels were applied at the same location. For this study total of 13
twin drilling work was done. The locations of reconciliation pit area can be seen from Figure 4.1.

![Figure 4.1 The top view of the reconciliation pit and drillholes location](image)

The dimension of 40 m x 40 m x 15 m in x-y-z directions was defined for test pit production. 13 RC drilling totally 230 m were completed in reconciliation pit area. After RC drilling work, 13 core drilling holes which were located 1 m north of RC drilling were done. Core drilling was totally 225 m.

The spacing between twin drillings was 10 m in the EW direction and 12 m in the NS direction. To see the benches, bench heights and bench numbers the AB (EW) section view of the reconciliation pit area is given on Figure 4.2. Additionally CD (NS) section can be seen on Figure 4.3.
Figure 4.2 Section view of reconciliation area in EW direction (AB section)

Figure 4.3 Section view of reconciliation area in NS direction (CD section)
Reconciliation work in the test pit was carried out as follows;

1. Drilling of RC holes and sampling at 1 m interval from these holes and analyze the cores for Ni contents,
2. Recording the lithology along with drillholes,
3. Examining the assay values and the lithology,
4. Suggesting a core drilling nearby each RC hole where appropriate,
5. Repeat the same procedure in part 1,
6. Estimating the mean Ni values of the blocks by inverse distance squared method and ordinary kriging method using Ni assay data,
7. Producing the ore and take the representative bulk samples and analyze them for Ni contents,
8. Comparing the production data with block model data.

The RC and core drilling locations in the reconciliation area presented in Figure 4.4.
The cross-section and model cut-off visuals are represented in Appendix-B.

**4.1.1.1 Comparison of Core Drilling with Reconciliation Pit Column Sampling Data**

A representative comparison graph of column sampling results and core drilling results are given in the Figure 4.5.

![Figure 4.5 Comparison of TC-134 core drilling data with related column sampling data in the reconciliation pit](image)

As it can be seen from the graph; in the drillhole coded TC-134 column sample analysis results approximately 22% higher in average nickel grade. The effect of
22% difference between these two data can be seen while comparing modeling results with the actual production data. In addition, generally column sampling grades are higher.

The rest of the study results of TC-133, TC-135, TC-136, TC-137, TC-138, TC-139, TC-140, TC-141, TC-142, TC-143, TC-144 and TC-145 drillholes are shown in the Appendix-C.

4.1.1.2 Comparison of Reverse Circulation Drilling with Reconciliation pit Column Sampling Data

A representative comparison graph of column sampling results and reverse circulation drilling results is given in the Figure 4.6.

![Figure 4.6 Comparison of RC-TC-197 RC drilling data with related column sampling data in the reconciliation pit](image-url)
As it can be seen from the Figure 4.6, in the drillhole coded RC-TC-197 column sample analysis results are approximately 30% higher in average nickel grade. The effect of 30% difference between these two data can be seen while comparing modeling results with the actual production data.


All 26 drilling logs belonging to reconciliation pit area are shown in Appendix-E.

### 4.1.2 Actual Production Results of Reconciliation Pit

Actual production was done by applying selective mining methods with trucks and shovels. The reconciliation pit area had 6 benches in east direction and 5 benches in west direction having approximately 2.75 meter depth. Each truck was numbered and material carried out stocked separately. From these stocks representative samples were taken by sampling method and analyzed to calculate the actual production figures. According to the analysis results stocks were combined based on their Ni grade values.

Based on these analysis 11,865 m$^3$ and 23,689 tonnes with 0.367 % Ni grade ore were produced in Türkmençardağı - Gördes reconciliation pit. When the cut-off grade was taken into account as 0.5 %, the produced amount was 4,882 tonnes with 0.649 % Ni grade.

The actual production values of each bench are also calculated, and the results are tabulated in Table 4.1.
Additionally the total actual production values are tabulated in Table 4.2.
The production results are shown on Table 4.2 at 0.5 Nickel cut-off grade tonnage and grade are 4,882 and 0.649 respectively. The cut-off Ni grade for determination of the economic limits of mining has been set at 0.5% by META and the modeling results evaluated according to this cut-off grade.

4.1.3 Resource Estimation of Türkmençardağı Laterite Deposits by Kriging Method

The experimental variograms in the downhole and main horizontal directions were calculated and interpretable results were obtained for the reconciliation pit area. The variogram model parameters determined by Tercan (2012) are listed in Table 4.3 where $C_0$ is nugget effect, $C_1$ is sill and $C_2$ is sill$^2$, $a_1$ is range$_1$ and $a_2$ is range$_2$.

Table 4.3 Variogram model parameters (Tercan, 2012)

<table>
<thead>
<tr>
<th>Reconciliation Pit</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_0$</td>
<td>0.006</td>
</tr>
<tr>
<td>$C_1$</td>
<td>0.025</td>
</tr>
<tr>
<td>$C_2$</td>
<td>0.030</td>
</tr>
<tr>
<td>$a_1$ (m)</td>
<td>1.4 (down hole)</td>
</tr>
<tr>
<td></td>
<td>1.6 (horizontal)</td>
</tr>
<tr>
<td>$a_2$ (m)</td>
<td>14 (down hole)</td>
</tr>
<tr>
<td></td>
<td>18 (horizontal)</td>
</tr>
</tbody>
</table>

Composite length was taken as 1 m. Moreover, both variograms are spherical. Weighted average procedure was applied for composite left overs. Figure 4.7 and Figure 4.8 shows the experimental horizontal and vertical variograms.
Figure 4.7 The omni-directional variogram of data in the reconciliation pit (Tercan, 2012)

Figure 4.8 The vertical variogram of data in the reconciliation pit (Tercan, 2012)
In order to test that the whether variogram models were not grossly incorrect or not, cross validation test was carried out. Table 4.4 shows cross validation results. The mean value was near to zero, the variance and mean kriging variance values were almost the same and additionally, the error value was close to 95%, so the results indicate that the variogram models were not inconsistent.

Table 4.4 Cross validation statistics (Tercan, 2012)

<table>
<thead>
<tr>
<th>Reconciliation pit</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.0001</td>
</tr>
<tr>
<td>Variance</td>
<td>0.0368</td>
</tr>
<tr>
<td>Number of data</td>
<td>454</td>
</tr>
<tr>
<td>Mean kriging variance</td>
<td>0.0363</td>
</tr>
<tr>
<td>Error % in ± 2σ</td>
<td>96</td>
</tr>
</tbody>
</table>

Block sizes were 5 m by 5 m horizontal by 3 m in vertical direction. Sub-blocking with sizes of 2.5 m by 2.5 m horizontal by 1.5 m in vertical elevation was also considered. Average block grades were estimated using ordinary kriging which is practical assumption in mining industry. The search strategy used to determine which nearby drill holes and which composites used for estimation is given in Table 4.5 (Tercan, 2012). These values were chosen based on the variogram parameters.

Table 4.5 The search strategy parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum number of samples</td>
<td>3</td>
</tr>
<tr>
<td>Maximum number of samples</td>
<td>20</td>
</tr>
<tr>
<td>Azimuth of major axis</td>
<td>0</td>
</tr>
<tr>
<td>Search distance of major axis (m)</td>
<td>20</td>
</tr>
<tr>
<td>Search distance of minor axis (m)</td>
<td>20</td>
</tr>
<tr>
<td>Search distance of vertical axis (m)</td>
<td>15</td>
</tr>
</tbody>
</table>

At first for modeling the reconciliation pit area drillholes data were used therefore the density was taken as 1.7 t/m³. The grade tonnage change with respect to benches based on both drilling and column data can be seen from Table 4.6.
Table 4.6 Grade tonnage change with respect to benches based on both drilling and column data (density: 1.7 t/m³)

<table>
<thead>
<tr>
<th>RC-DD DATA</th>
<th>AP</th>
<th>COLUMN DATA</th>
<th>Volume</th>
<th>Tonnage</th>
<th>% Ni</th>
<th>Volume</th>
<th>Tonnage</th>
<th>% Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut-Off (-)</td>
<td>1528</td>
<td>2598</td>
<td>0.251</td>
<td>3301</td>
<td>0.234</td>
<td>1528</td>
<td>2598</td>
<td>0.257</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.1%</td>
<td>1528</td>
<td>2598</td>
<td>0.251</td>
<td>3301</td>
<td>0.234</td>
<td>1528</td>
<td>2598</td>
<td>0.257</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.2%</td>
<td>1238</td>
<td>2104</td>
<td>0.269</td>
<td>3075</td>
<td>0.236</td>
<td>1528</td>
<td>2598</td>
<td>0.257</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.3%</td>
<td>225</td>
<td>383</td>
<td>0.342</td>
<td>62</td>
<td>0.333</td>
<td>225</td>
<td>383</td>
<td>0.339</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.4%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.6%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.1%</td>
<td>3750</td>
<td>6375</td>
<td>0.295</td>
<td>7052</td>
<td>0.312</td>
<td>3750</td>
<td>6375</td>
<td>0.301</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.2%</td>
<td>3525</td>
<td>5993</td>
<td>0.301</td>
<td>6792</td>
<td>0.313</td>
<td>3750</td>
<td>6375</td>
<td>0.301</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.3%</td>
<td>1584</td>
<td>2693</td>
<td>0.377</td>
<td>2966</td>
<td>0.418</td>
<td>1716</td>
<td>2917</td>
<td>0.369</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.4%</td>
<td>347</td>
<td>500</td>
<td>0.439</td>
<td>1304</td>
<td>0.514</td>
<td>328</td>
<td>558</td>
<td>0.419</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.5%</td>
<td>75</td>
<td>128</td>
<td>0.504</td>
<td>716</td>
<td>0.572</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.6%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.1%</td>
<td>2962</td>
<td>5036</td>
<td>0.326</td>
<td>5637</td>
<td>0.382</td>
<td>2962</td>
<td>5036</td>
<td>0.376</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.2%</td>
<td>2700</td>
<td>4990</td>
<td>0.338</td>
<td>5612</td>
<td>0.384</td>
<td>2962</td>
<td>5036</td>
<td>0.376</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.3%</td>
<td>1603</td>
<td>2725</td>
<td>0.396</td>
<td>3209</td>
<td>0.491</td>
<td>2156</td>
<td>3666</td>
<td>0.431</td>
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<tr>
<td>Cut-Off Ni ≥ 0.4%</td>
<td>881</td>
<td>1498</td>
<td>0.434</td>
<td>2181</td>
<td>0.557</td>
<td>1491</td>
<td>2534</td>
<td>0.476</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.5%</td>
<td>28</td>
<td>48</td>
<td>0.504</td>
<td>1387</td>
<td>0.618</td>
<td>366</td>
<td>622</td>
<td>0.521</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.6%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.1%</td>
<td>2100</td>
<td>3570</td>
<td>0.346</td>
<td>4212</td>
<td>0.423</td>
<td>2100</td>
<td>3570</td>
<td>0.424</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.2%</td>
<td>2100</td>
<td>3570</td>
<td>0.346</td>
<td>4212</td>
<td>0.423</td>
<td>2100</td>
<td>3570</td>
<td>0.424</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.3%</td>
<td>2025</td>
<td>3443</td>
<td>0.352</td>
<td>4212</td>
<td>0.423</td>
<td>2100</td>
<td>3570</td>
<td>0.424</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.4%</td>
<td>1481</td>
<td>2518</td>
<td>0.399</td>
<td>3054</td>
<td>0.491</td>
<td>1481</td>
<td>2518</td>
<td>0.500</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.5%</td>
<td>703</td>
<td>1195</td>
<td>0.452</td>
<td>2111</td>
<td>0.557</td>
<td>1256</td>
<td>2136</td>
<td>0.524</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.6%</td>
<td>16</td>
<td>27</td>
<td>0.524</td>
<td>1163</td>
<td>0.651</td>
<td>741</td>
<td>1259</td>
<td>0.568</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.2%</td>
<td>1341</td>
<td>2279</td>
<td>0.353</td>
<td>2913</td>
<td>0.517</td>
<td>1341</td>
<td>2279</td>
<td>0.475</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.3%</td>
<td>1341</td>
<td>2279</td>
<td>0.353</td>
<td>2913</td>
<td>0.517</td>
<td>1341</td>
<td>2279</td>
<td>0.475</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.4%</td>
<td>994</td>
<td>1689</td>
<td>0.392</td>
<td>2200</td>
<td>0.602</td>
<td>1097</td>
<td>1865</td>
<td>0.526</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.5%</td>
<td>300</td>
<td>510</td>
<td>0.487</td>
<td>1920</td>
<td>0.640</td>
<td>947</td>
<td>1610</td>
<td>0.551</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.6%</td>
<td>112</td>
<td>191</td>
<td>0.547</td>
<td>1430</td>
<td>0.704</td>
<td>600</td>
<td>1020</td>
<td>0.620</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.1%</td>
<td>19</td>
<td>32</td>
<td>0.605</td>
<td>1047</td>
<td>0.764</td>
<td>356</td>
<td>606</td>
<td>0.650</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.2%</td>
<td>450</td>
<td>765</td>
<td>0.395</td>
<td>574</td>
<td>0.485</td>
<td>450</td>
<td>765</td>
<td>0.514</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.3%</td>
<td>450</td>
<td>765</td>
<td>0.395</td>
<td>574</td>
<td>0.485</td>
<td>450</td>
<td>765</td>
<td>0.514</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.4%</td>
<td>338</td>
<td>574</td>
<td>0.439</td>
<td>526</td>
<td>0.518</td>
<td>412</td>
<td>701</td>
<td>0.536</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.5%</td>
<td>244</td>
<td>414</td>
<td>0.478</td>
<td>362</td>
<td>0.568</td>
<td>366</td>
<td>622</td>
<td>0.555</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.6%</td>
<td>103</td>
<td>175</td>
<td>0.534</td>
<td>187</td>
<td>0.736</td>
<td>262</td>
<td>446</td>
<td>0.604</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.6%</td>
<td>19</td>
<td>32</td>
<td>0.613</td>
<td>128</td>
<td>0.827</td>
<td>178</td>
<td>303</td>
<td>0.637</td>
</tr>
</tbody>
</table>

By using drillholes data at 0.5 nickel cut-off grade tonnage and grade are 749 and 0.527 respectively. By using column sampling data at 0.5 nickel cut-off grade tonnage and grade are 3,347 and 0.580 respectively. The total results of kriging method are tabulated in Table 4.7
Table 4.7 Kriging method results (density: 1.7 t/m$^3$)

<table>
<thead>
<tr>
<th>RC-DD DATA</th>
<th>AP</th>
<th>COLUMN DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>Tonnage</td>
<td>% Ni</td>
</tr>
<tr>
<td>Cut-Off (-)</td>
<td>12131</td>
<td>20623</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.1%</td>
<td>12131</td>
<td>20623</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.2%</td>
<td>11278</td>
<td>19173</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.3%</td>
<td>6225</td>
<td>10583</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.4%</td>
<td>2475</td>
<td>4208</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.5%</td>
<td>441</td>
<td>749</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.6%</td>
<td>38</td>
<td>64</td>
</tr>
</tbody>
</table>

In fact after production, i.e. after calculating the actual production volume and tonnage, it was seen that the density should be 1.99 t/m$^3$. For this reason the analysis should be revised by changing density.

The revised grade tonnage change (density: 1.99 t/m$^3$) based on both drilling and column data can be seen from Table 4.8.

Table 4.8 Kriging method results (density: 1.99 t/m$^3$)

<table>
<thead>
<tr>
<th>RC-DD DATA</th>
<th>AP</th>
<th>COLUMN DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>Tonnage</td>
<td>% Ni</td>
</tr>
<tr>
<td>Cut-Off (-)</td>
<td>12131</td>
<td>24226</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.1%</td>
<td>12131</td>
<td>24226</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.2%</td>
<td>11278</td>
<td>22523</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.3%</td>
<td>6225</td>
<td>12432</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.4%</td>
<td>2475</td>
<td>4943</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.5%</td>
<td>441</td>
<td>880</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.6%</td>
<td>38</td>
<td>75</td>
</tr>
</tbody>
</table>

The revised grade tonnage change with respect to benches based on both drilling and column data can be seen from Table 4.9.
Table 4.9 Grade tonnage change with respect to benches based on both drilling and column data (density: 1.99 t/m³)

<table>
<thead>
<tr>
<th>RC-DD DATA</th>
<th>AP</th>
<th>COLUMN DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>Tonnage</td>
<td>% Ni</td>
</tr>
<tr>
<td>Cut-Off (-)</td>
<td>1528</td>
<td>3052</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.1%</td>
<td>1528</td>
<td>3052</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.2%</td>
<td>1238</td>
<td>2472</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.3%</td>
<td>225</td>
<td>450</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.4%</td>
<td>59</td>
<td>119</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.5%</td>
<td>50</td>
<td>101</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.6%</td>
<td>19</td>
<td>38</td>
</tr>
</tbody>
</table>

BENCH 2

| Cut-Off (-) | 3750 | 7489 | 0.295 | 7052 | 0.312 | 3750 | 7489 | 0.301 |
| Cut-Off Ni ≥ 0.1% | 3750 | 7489 | 0.295 | 7052 | 0.312 | 3750 | 7489 | 0.301 |
| Cut-Off Ni ≥ 0.2% | 3525 | 7040 | 0.301 | 6972 | 0.313 | 3750 | 7489 | 0.301 |
| Cut-Off Ni ≥ 0.3% | 1584 | 3163 | 0.377 | 2966 | 0.418 | 1716 | 3427 | 0.419 |
| Cut-Off Ni ≥ 0.4% | 347 | 693 | 0.439 | 1304 | 0.514 | 328 | 655 | 0.419 |
| Cut-Off Ni ≥ 0.5% | 75 | 150 | 0.504 | 328 | 0.514 | 716 | 1506 | 0.504 |
| Cut-Off Ni ≥ 0.6% | 225 | 450 | 0.342 | 62 | 0.335 | 225 | 450 | 0.339 |

BENCH 3

| Cut-Off (-) | 2962 | 5916 | 0.326 | 5637 | 0.382 | 2962 | 5916 | 0.378 |
| Cut-Off Ni ≥ 0.1% | 2962 | 5916 | 0.326 | 5637 | 0.382 | 2962 | 5916 | 0.378 |
| Cut-Off Ni ≥ 0.2% | 2700 | 5392 | 0.338 | 5612 | 0.384 | 2962 | 5916 | 0.378 |
| Cut-Off Ni ≥ 0.3% | 1603 | 3201 | 0.396 | 3209 | 0.491 | 2156 | 4306 | 0.431 |
| Cut-Off Ni ≥ 0.4% | 75 | 150 | 0.504 | 328 | 0.514 | 716 | 1506 | 0.504 |
| Cut-Off Ni ≥ 0.5% | 225 | 450 | 0.342 | 62 | 0.335 | 225 | 450 | 0.339 |
| Cut-Off Ni ≥ 0.6% | 225 | 450 | 0.342 | 62 | 0.335 | 225 | 450 | 0.339 |

BENCH 4

| Cut-Off (-) | 2100 | 4194 | 0.346 | 4212 | 0.425 | 2100 | 4194 | 0.424 |
| Cut-Off Ni ≥ 0.1% | 2100 | 4194 | 0.346 | 4212 | 0.425 | 2100 | 4194 | 0.424 |
| Cut-Off Ni ≥ 0.2% | 2025 | 4045 | 0.352 | 4212 | 0.425 | 2100 | 4194 | 0.424 |
| Cut-Off Ni ≥ 0.3% | 1481 | 2958 | 0.399 | 3054 | 0.491 | 1481 | 2958 | 0.500 |
| Cut-Off Ni ≥ 0.4% | 703 | 1404 | 0.452 | 2111 | 0.557 | 1256 | 2509 | 0.524 |
| Cut-Off Ni ≥ 0.5% | 16 | 32 | 0.524 | 1163 | 0.651 | 74 | 1506 | 0.504 |
| Cut-Off Ni ≥ 0.6% | 225 | 450 | 0.342 | 62 | 0.335 | 225 | 450 | 0.339 |

BENCH 5

| Cut-Off (-) | 1341 | 2677 | 0.353 | 2913 | 0.517 | 1341 | 2677 | 0.475 |
| Cut-Off Ni ≥ 0.1% | 1341 | 2677 | 0.353 | 2913 | 0.517 | 1341 | 2677 | 0.475 |
| Cut-Off Ni ≥ 0.2% | 1341 | 2677 | 0.353 | 2913 | 0.517 | 1341 | 2677 | 0.475 |
| Cut-Off Ni ≥ 0.3% | 1341 | 2677 | 0.353 | 2913 | 0.517 | 1341 | 2677 | 0.475 |
| Cut-Off Ni ≥ 0.4% | 1341 | 2677 | 0.353 | 2913 | 0.517 | 1341 | 2677 | 0.475 |
| Cut-Off Ni ≥ 0.5% | 112 | 224 | 0.547 | 1430 | 0.704 | 600 | 1198 | 0.620 |
| Cut-Off Ni ≥ 0.6% | 19 | 38 | 0.613 | 128 | 0.827 | 178 | 356 | 0.637 |
4.1.4 Resource Estimation of Türkmençaradığı Laterite Deposits by Inverse Distance Weighting Method

META has tried to obtain the most reliable geological model to predict tonnage and grade data of the ore body. The consistency between assay, coordinate, and lithology data were checked with 13 core drilling and 13 RC drilling data. The statistical properties of Ni in assay data are summarized in Table 4.10.

Table 4.10 Descriptive statistics of Ni assay data

| Minimum | 0.09 |
| Maximum | 1.98 |
| No. of Points | 454 |
| Mean | 0.37 |
| Variance | 0.0611 |
| Standard Deviation | 0.2471 |

When the histogram related to assay data was reviewed, it could be concluded as grade distribution is normal distribution. The grade distribution is given in Figure 4.9.

Figure 4.9 The grade distribution of Ni
The consistency between data was controlled as mentioned above and these data input to Micromine in order to check the accuracy again. After prepared drillhole data, the units considered as ore were visualized.

At first by taking sections from drillholes 3D solid model was generated and blocks were fitted to solid model. After that main block model was restrained by pit solid model in order to obtain reconciliation pit block model. Additionally, the compatibility with reconciliation pit had been checked.

The figure of the block model can be seen in the following figure (Figure 4.10).

![Figure 4.10 Block model view](image)

The production volume was divided into main blocks and sub-blocks with equal shape and size. The size of main blocks are 5mx5mx3m and the number of them is 110 similarly the total number of sub-blocks having size 2.5mx2.5mx1.5m is 414. At first, again Ni grade values and 1.7 t/m³ density were assigned to the obtained reconciliation pit block model. To assign the composite assay data to the Ni grade values inverse distance weighting method was used. In this method inverse distance weighting power factor was assumed as 2 because of the practical reasons in mining.
industry. Also during this assigning procedure to the reconciliation pit block model a search ellipsoid was used. The properties of this search ellipsoid are tabulated in Table 4.11.

<table>
<thead>
<tr>
<th>Azimuth</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plunge</td>
<td>0</td>
</tr>
<tr>
<td>Azimuth factor</td>
<td>20</td>
</tr>
<tr>
<td>Dip</td>
<td>0</td>
</tr>
<tr>
<td>Dip Factor</td>
<td>20</td>
</tr>
<tr>
<td>Thick Factor</td>
<td>15</td>
</tr>
</tbody>
</table>

The data of search ellipsoid were chosen according to the data used in kriging method conducted by Tercan (2012). Additionally the view of the ellipsoid can be seen in Figure 4.11.

Figure 4.11 View of the search ellipsoid and solid model
After assigning the grades by inverse distance weighting method again the statistical properties were checked. The statistical properties of Ni in block model are summarized in Table 4.12.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Table 4.12 Descriptive statistics of Ni block data</strong></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>0.17</td>
</tr>
<tr>
<td>Maximum</td>
<td>1.72</td>
</tr>
<tr>
<td>No. of Points</td>
<td>614</td>
</tr>
<tr>
<td>Mean</td>
<td>0.32</td>
</tr>
<tr>
<td>Variance</td>
<td>0.0099</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.0993</td>
</tr>
</tbody>
</table>

When the histogram related to block data was plotted, it can be seen that the grade distribution shows normal distribution. The grade distribution is given in Figure 4.12.

Figure 4.12 The grade distribution of Ni in blocks
Created block model by using composite assay data was visualized with drillholes and controlled. The same colour codes were assigned for the same grade intervals to observe the consistency between block model and drillhole. The view of this situation is given in the Figure 4.13.

Figure 4.13 A view of block model with drillhole
The inverse distance weighting method grade and tonnage results based on both drilling and column data benches (density: 1.7 t/m³) are tabulated in Table 4.13.

Table 4.13 The inverse distance weighting method results based on benches (density: 1.7 t/m³)

<table>
<thead>
<tr>
<th></th>
<th>RC-DD DATA</th>
<th></th>
<th>COLUMN DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Volume</td>
<td>Tonnage</td>
<td>% Ni</td>
</tr>
<tr>
<td><strong>BENCH-1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cut-Off (-)</td>
<td>1528</td>
<td>2598</td>
<td>0.243</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.1%</td>
<td>1528</td>
<td>2598</td>
<td>0.243</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.2%</td>
<td>975</td>
<td>1658</td>
<td>0.269</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.3%</td>
<td>262</td>
<td>446</td>
<td>0.350</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.6%</td>
<td>9</td>
<td>16</td>
<td>0.612</td>
</tr>
</tbody>
</table>

| **BENCH-2**      |         |         |     |         |         |     |
| Cut-Off (-)      | 3750    | 6375    | 0.286 | 7052   | 0.312  | 3750  | 6375 | 0.305 |
| Cut-Off Ni ≥ 0.1%| 3750    | 6375    | 0.286 | 7052   | 0.312  | 3750  | 6375 | 0.305 |
| Cut-Off Ni ≥ 0.2%| 3525    | 5993    | 0.292 | 6972   | 0.313  | 3750  | 6375 | 0.305 |
| Cut-Off Ni ≥ 0.3%| 1603    | 2725    | 0.366 | 2966   | 0.418  | 1791  | 3044 | 0.375 |
| Cut-Off Ni ≥ 0.6%| 300     | 510     | 0.432 | 1304   | 0.514  | 609   | 1036 | 0.429 |
| Cut-Off Ni ≥ 0.8%|         |         |     | 716    | 0.572  |       |      |      |
| Cut-Off Ni ≥ 0.6%| 232     | 651     | 0.651 |         |         |       |      |      |

| **BENCH-3**      |         |         |     |         |         |     |
| Cut-Off (-)      | 2962    | 5036    | 0.327 | 5637   | 0.382  | 2962  | 5036 | 0.386 |
| Cut-Off Ni ≥ 0.1%| 2962    | 5036    | 0.327 | 5612   | 0.384  | 2962  | 5036 | 0.386 |
| Cut-Off Ni ≥ 0.2%| 2700    | 4590    | 0.339 | 5612   | 0.384  | 2962  | 5036 | 0.386 |
| Cut-Off Ni ≥ 0.3%| 1716    | 2917    | 0.393 | 3209   | 0.491  | 2157  | 3667 | 0.442 |
| Cut-Off Ni ≥ 0.4%| 816     | 1387    | 0.444 | 2181   | 0.557  | 1491  | 2534 | 0.494 |
| Cut-Off Ni ≥ 0.5%|         |         |     | 1387   | 0.618  | 703   | 1195 | 0.534 |
| Cut-Off Ni ≥ 0.6%|         |         |     | 641    | 0.701  |       |      |      |
| Cut-Off Ni ≥ 0.8%|         |         |     | 641    | 0.701  |       |      |      |

| **BENCH-4**      |         |         |     |         |         |     |
| Cut-Off (-)      | 2100    | 3570    | 0.344 | 4212   | 0.423  | 2100  | 3570 | 0.425 |
| Cut-Off Ni ≥ 0.1%| 2100    | 3570    | 0.344 | 4212   | 0.423  | 2100  | 3570 | 0.425 |
| Cut-Off Ni ≥ 0.2%| 2100    | 3570    | 0.344 | 4212   | 0.423  | 2100  | 3570 | 0.425 |
| Cut-Off Ni ≥ 0.3%| 1331    | 2263    | 0.404 | 3054   | 0.491  | 1556  | 2646 | 0.486 |
| Cut-Off Ni ≥ 0.4%| 497     | 845     | 0.475 | 2111   | 0.557  | 1331  | 2263 | 0.511 |
| Cut-Off Ni ≥ 0.5%| 159     | 271     | 0.546 | 1163   | 0.651  | 591   | 1004 | 0.586 |
| Cut-Off Ni ≥ 0.6%|         |         |     | 703    | 0.729  | 234   | 398  | 0.678 |

| **BENCH-5**      |         |         |     |         |         |     |
| Cut-Off (-)      | 1341    | 2279    | 0.349 | 2913   | 0.517  | 1341  | 2279 | 0.472 |
| Cut-Off Ni ≥ 0.1%| 1341    | 2279    | 0.349 | 2913   | 0.517  | 1341  | 2279 | 0.472 |
| Cut-Off Ni ≥ 0.2%| 1341    | 2279    | 0.349 | 2913   | 0.517  | 1341  | 2279 | 0.472 |
| Cut-Off Ni ≥ 0.3%| 919     | 1562    | 0.391 | 2200   | 0.602  | 1097  | 1865 | 0.521 |
| Cut-Off Ni ≥ 0.4%| 300     | 510     | 0.847 | 1920   | 0.640  | 947   | 1610 | 0.547 |
| Cut-Off Ni ≥ 0.5%| 103     | 175     | 0.552 | 1430   | 0.704  | 478   | 813  | 0.639 |
| Cut-Off Ni ≥ 0.6%| 19      | 32      | 0.693 | 1047   | 0.764  | 281   | 478  | 0.686 |

| **BENCH-6**      |         |         |     |         |         |     |
| Cut-Off (-)      | 450     | 765     | 0.397 | 574    | 0.485  | 450   | 765  | 0.504 |
| Cut-Off Ni ≥ 0.1%| 450     | 765     | 0.397 | 547    | 0.508  | 450   | 765  | 0.504 |
| Cut-Off Ni ≥ 0.2%| 450     | 765     | 0.397 | 547    | 0.508  | 450   | 765  | 0.504 |
| Cut-Off Ni ≥ 0.3%| 375     | 638     | 0.425 | 526    | 0.518  | 441   | 749  | 0.509 |
| Cut-Off Ni ≥ 0.4%| 244     | 414     | 0.487 | 362    | 0.588  | 366   | 622  | 0.539 |
| Cut-Off Ni ≥ 0.5%| 103     | 175     | 0.566 | 187    | 0.738  | 533   | 430  | 0.586 |
| Cut-Off Ni ≥ 0.6%|         |         |     | 128    | 0.827  | 141   | 239  | 0.622 |
By using drillholes data at 0.5 nickel cut-off grade tonnage and grade are 622 and 0.553 respectively. By using column sampling data at 0.5 nickel cut-off grade tonnage and grade are 3,443 and 0.580 respectively.

The total results of inverse distance weighting method are tabulated in Table 4.14.

Table 4.14 Total inverse distance weighting method results (density: 1.7 t/m$^3$)

<table>
<thead>
<tr>
<th>Cut-Off (-)</th>
<th>Volume</th>
<th>Tonnage</th>
<th>% Ni</th>
<th>Tonnage</th>
<th>% Ni</th>
<th>Volume</th>
<th>Tonnage</th>
<th>% Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC-DD DATA</td>
<td>12131</td>
<td>20623</td>
<td>0.312</td>
<td>23689</td>
<td>0.367</td>
<td>12131</td>
<td>20623</td>
<td>0.366</td>
</tr>
<tr>
<td>AP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COLUMN DATA</td>
<td>12131</td>
<td>20623</td>
<td>0.312</td>
<td>23689</td>
<td>0.367</td>
<td>12131</td>
<td>20623</td>
<td>0.366</td>
</tr>
</tbody>
</table>

Likewise, after production the analysis should be revised due to the change of the density. The revised total results (density: 1.99 t/m$^3$) can be seen on Table 4.15.

Table 4.15 Total inverse distance weighting method results (density: 1.99 t/m$^3$)

<table>
<thead>
<tr>
<th>Cut-Off (-)</th>
<th>Volume</th>
<th>Tonnage</th>
<th>% Ni</th>
<th>Tonnage</th>
<th>% Ni</th>
<th>Volume</th>
<th>Tonnage</th>
<th>% Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC-DD DATA</td>
<td>12131</td>
<td>24226</td>
<td>0.312</td>
<td>23689</td>
<td>0.367</td>
<td>12131</td>
<td>24226</td>
<td>0.366</td>
</tr>
<tr>
<td>AP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COLUMN DATA</td>
<td>12131</td>
<td>24226</td>
<td>0.312</td>
<td>23689</td>
<td>0.367</td>
<td>12131</td>
<td>24226</td>
<td>0.366</td>
</tr>
</tbody>
</table>

The results of inverse distance weighting method based on benches (density: 1.99 t/m$^3$) are tabulated in Table 4.16.
Table 4.16 The inverse distance weighting method results based on benches (density: 1.99 t/m³)

<table>
<thead>
<tr>
<th>RC-DD DATA</th>
<th>AP</th>
<th>COLUMN DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>Tonnage</td>
<td>% Ni</td>
</tr>
<tr>
<td>Cut-Off (-)</td>
<td>1528</td>
<td>3052</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.1%</td>
<td>1528</td>
<td>3052</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.2%</td>
<td>975</td>
<td>1948</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.3%</td>
<td>262</td>
<td>524</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.4%</td>
<td>9</td>
<td>19</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.5%</td>
<td>225</td>
<td>450</td>
</tr>
<tr>
<td>Cut-Off Ni ≥ 0.6%</td>
<td>9</td>
<td>19</td>
</tr>
</tbody>
</table>

4.2 Comparison of Applied Estimation Methods with Actual Production Results

Analyzing the above results it can be said that both resource estimation methods quite compatible each other in terms of grade, but it is not the same for tonnage.
When the cut-off grade increases, the tonnage difference between the actual production and estimation method results also increases.

There is a huge difference that can not be ignored. In order to specify the difference between these values a difference table is created and shown in Table 4.17.

Table 4.17 Difference between the reconciliation pit production results and estimation methods results according to drillholes data

<table>
<thead>
<tr>
<th>Cut-off Grade</th>
<th>Kriging results (KM)</th>
<th>Inverse distance weighting results (IDM)</th>
<th>Actual production results (AP)</th>
<th>Difference</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>AP / KM</td>
<td>AP / IDM</td>
</tr>
<tr>
<td>0.0</td>
<td>20,622</td>
<td>20,622</td>
<td>23,689</td>
<td>1.15</td>
<td>1.15</td>
</tr>
<tr>
<td>0.1</td>
<td>20,622</td>
<td>20,622</td>
<td>23,638</td>
<td>1.15</td>
<td>1.15</td>
</tr>
<tr>
<td>0.2</td>
<td>19,173</td>
<td>18,854</td>
<td>23,332</td>
<td>1.22</td>
<td>1.24</td>
</tr>
<tr>
<td>0.3</td>
<td>10,582</td>
<td>10,281</td>
<td>12,017</td>
<td>1.14</td>
<td>1.17</td>
</tr>
<tr>
<td>0.4</td>
<td>4,206</td>
<td>3,665</td>
<td>7,877</td>
<td>1.87</td>
<td>2.15</td>
</tr>
<tr>
<td>0.5</td>
<td>749</td>
<td>622</td>
<td>4,882</td>
<td>6.52</td>
<td>7.85</td>
</tr>
<tr>
<td>0.6</td>
<td>64</td>
<td>32</td>
<td>2,751</td>
<td>42.98</td>
<td>85.97</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cut-off Grade</th>
<th>Kriging results (KM)</th>
<th>Inverse distance weighting results (IDM)</th>
<th>Actual production results (AP)</th>
<th>Difference</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>AP / KM</td>
<td>AP / IDM</td>
</tr>
<tr>
<td>0.0</td>
<td>0.316</td>
<td>0.312</td>
<td>0.367</td>
<td>1.16</td>
<td>1.18</td>
</tr>
<tr>
<td>0.1</td>
<td>0.316</td>
<td>0.312</td>
<td>0.368</td>
<td>1.16</td>
<td>1.18</td>
</tr>
<tr>
<td>0.2</td>
<td>0.325</td>
<td>0.322</td>
<td>0.37</td>
<td>1.14</td>
<td>1.15</td>
</tr>
<tr>
<td>0.3</td>
<td>0.391</td>
<td>0.389</td>
<td>0.494</td>
<td>1.26</td>
<td>1.27</td>
</tr>
<tr>
<td>0.4</td>
<td>0.451</td>
<td>0.460</td>
<td>0.572</td>
<td>1.27</td>
<td>1.24</td>
</tr>
<tr>
<td>0.5</td>
<td>0.527</td>
<td>0.553</td>
<td>0.649</td>
<td>1.23</td>
<td>1.17</td>
</tr>
<tr>
<td>0.6</td>
<td>0.609</td>
<td>0.693</td>
<td>0.734</td>
<td>1.21</td>
<td>1.06</td>
</tr>
</tbody>
</table>

Without considering cut-off grades both for inverse distance weighting method and kriging method results were compared to actual production results.
14.9% difference in tonnage values. This difference comes from siliceous rocks in the production stage. If the geologic solid model includes heterogeneous minerals such as ore and siliceous bed rock, then no estimation method can give reasonable results. So whether estimation method produces good results depends on goodness or representativeness of the solid model. If solid model includes heterogeneous zone, one never expect that estimation techniques produce current results.

The comparison of kriging and inverse distance weighting methods based on both drilling and column data with actual production figures based on tonnage values is given in Figure 4.14.

Figure 4.14 The comparison of applied estimation methods based on tonnage values (5x5x3 block sizes)
When 0.5% cut-off grade, which is the grade considered in the project, was applied the tonnage difference between kriging method results and actual production results becomes approximately 6.52 times. On the other hand the same case for the inverse distance weighting method results is 7.85 times.

The block sizes were created as 5x5x3 sizes. The above results are based on these analyses. But a revised analysis was done by changing the block sizes as 1x1x1 dimensions. The smaller block sizes analysis comparison graph also can be seen in Figure 4.15. It is seen that there is not a noticeable difference by decreasing block sizes.

Figure 4.15 The comparison of applied estimation methods based on tonnage values (1x1x1 block sizes)
When the evaluation was also made according to each bench, depending on the drillholes data both resource estimation methods can not reach the actual production values when a cut-off grade was applied. Like the total production and estimation method results when the cut-off grade increases, the tonnage difference between the actual production and estimation method results also increases.

Using estimation methods and a set block size there appears to be a tendency to reduce the predicted grade in the block. Many field and drilling samples show higher grade levels than block models in same locations. The smaller grade in the blocks could be a result of:

- Core samples can be underestimated,
- Blocks within the ore body are generally rigid in size and they do not correspond to changes in grades or lithology. Therefore lower grade ore, such as silica layers, and other low nickel layers reduce the overall grade predicted in blocks,
- Unless there are similar or higher grades between 2 boreholes the method rapidly reduces the grade away from the holes.
CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The main conclusions derived from this study are:

1. Since the geometrical methods do not represent the nonhomogeneous deposit like nickel laterites, they did not applied in this study.

2. The presence of siliceous layers in laterites, at about 20% according to drillhole logs in area decreased nickel grades both for RC and core drilling studies. Although the theoretical density was calculated as 1.7 t/m³ according to drillholes data, in the production the actual density was calculated as 1.99 t/m³.

3. The nickel grades determined from column sampling results in reconciliation pit were greater than both RC drilling and core drilling, as expected.

4. In reconciliation pit area, assuming 0.5% Ni cut-off value, by using core drilling and RC drilling data inverse distance weighting method gave 0.553% Ni grade, while kriging method results was 0.527% Ni grade. In addition by using column sampling data both inverse distance weighting and kriging method results gave 0.580% Ni grade. However actual production result was 0.649% Ni grade.

5. In reconciliation pit area, assuming 0.5% Ni cut-off value, by using core drilling and RC drilling data inverse distance weighting method gave 622 tonnes Ni, while kriging method results was 749 tonnes Ni. In addition by using column sampling data inverse distance weighting method gave 3,443 tonnes Ni, while kriging method results was 3,347 tonnes Ni. However actual production result was 4,882 tonnes Ni.
6. When using the column samplings data, inverse distance weighting methods gave 42% and kriging method gave 46% difference on tonnage values and both methods gave 12% difference on grade values.

7. Whatever the method for assessing grades changes between cores, the presence of silica boulders within the limonite in particular meant that mining within the blocks will generally achieve higher grades as these silica blocks, that are likely to lower block grade, can be easily separated during mining to increase mined grade.

8. When the blocks sizes reduced to 1x1x1 dimensions, the results show not a noticeable difference.

9. Although the general pattern of spacing between drillholes in Türkmençardağı nickel laterites 60 m x 60 m, in reconciliation pit area 12 m x 10 m drillhole spacing was used. Therefore decreasing the spacing between drillholes gave similar results to larger spacing.

10. As a result, this reconciliation study has showed the trends of the average Ni grade and tonnage during mining is higher than what would have been predicted from 3D modeling.

The main recommendations related to this study are:

1. The inconsistency between 3D model results and actual production results started with the applied cut-off grades. Without considering cut-off grade, inverse distance weighting and kriging methods can be used for total tonnage and average grade calculations. Geostatistical conditional simulations can probably better represent even considering 0.5% cut-off grade.
2. Considering the ophilotic melange structure of Türkmençardağı Gördes nickel laterites, indicator kriging can be tried.

3. Increasing the depth of reconciliation pit area and also choosing an arbitrarily area may give more representative results.

4. This study need be done for all limonite and nontronite lenses in the area in order to associate the results.
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APPENDIX A

COLUMN SAMPLING VISUALS

Figure A.1 A view of column sampling
Figure A.2 Column sampling view
APPENDIX B

RECONCILIATION PIT VISUALS

Figure B.1 E-W section of reconciliation pit and twin drills
Figure B.2 3D isometric view of solid model

< 0.5 %Ni

≥ 0.5 %Ni
APPENDIX C

COMPARISON OF CORE DRILLING WITH RECONCILIATION PIT COLUMN SAMPLING DATA

Figure C.1 Comparison of TC-133 core drilling data with related column sampling data in the reconciliation pit
Figure C.2 Comparison of TC-135 core drilling data with related column sampling data in the reconciliation pit

Figure C.3 Comparison of TC-136 core drilling data with related column sampling data in the reconciliation pit
Figure C.4 Comparison of TC-137 core drilling data with related column sampling data in the reconciliation pit

Figure C.5 Comparison of TC-138 core drilling data with related column sampling data in the reconciliation pit
Figure C.6 Comparison of TC-139 core drilling data with related column sampling data in the reconciliation pit.

Figure C.7 Comparison of TC-140 core drilling data with related column sampling data in the reconciliation pit.
Figure C.8 Comparison of TC-141 core drilling data with related column sampling data in the reconciliation pit

Figure C.9 Comparison of TC-142 core drilling data with related column sampling data in the reconciliation pit
Figure C.10 Comparison of TC-143 core drilling data with related column sampling data in the reconciliation pit.

Figure C.11 Comparison of TC-144 core drilling data with related column sampling data in the reconciliation pit.
Figure C.12 Comparison of TC-145 core drilling data with related column sampling data in the reconciliation pit.
APPENDIX D

COMPARISON OF RC DRILLING WITH RECONCILIATION PIT COLUMN SAMPLING DATA

Figure D.1 Comparison of RC-TC-196 RC drilling data with related column sampling data in the reconciliation pit
Figure D.2 Comparison of RC-TC-198 RC drilling data with related column sampling data in the reconciliation pit

Figure D.3 Comparison of RC-TC-199 RC drilling data with related column sampling data in the reconciliation pit
Figure D.4 Comparison of RC-TC-200 RC drilling data with related column sampling data in the reconciliation pit.

Figure D.5 Comparison of RC-TC-201 RC drilling data with related column sampling data in the reconciliation pit.
Figure D.6 Comparison of RC-TC-202 RC drilling data with related column sampling data in the reconciliation pit.

Figure D.7 Comparison of RC-TC-203 RC drilling data with related column sampling data in the reconciliation pit.
Figure D.8 Comparison of RC-TC-204 RC drilling data with related column sampling data in the reconciliation pit

Figure D.9 Comparison of RC-TC-205 RC drilling data with related column sampling data in the reconciliation pit
Figure D.10 Comparison of RC-TC-198 RC drilling data with related column sampling data in the reconciliation pit

Figure D.11 Comparison of RC-TC-207 RC drilling data with related column sampling data in the reconciliation pit
Figure D.12 Comparison of RC-TC-208 RC drilling data with related column sampling data in the reconciliation pit
APPENDIX E

DRILLHOLE LOGS

Figure E.1 Drillhole log of RC-TC-196
**Figure E.2 Drillhole log of RC-TC-197**

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Lithology</th>
<th>Description</th>
<th>Recovery</th>
<th>St. Size</th>
<th>Lab. No.</th>
<th>Ni (%)</th>
<th>Fe (%)</th>
<th>As (%)</th>
<th>Cr (%)</th>
<th>Sub. Dens.</th>
<th>Add. Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>Clay</td>
<td>Containing silt, clay, calcite</td>
<td></td>
<td>0.0.0</td>
<td>0.0.0.0</td>
<td>0.0.0</td>
<td>0.0.0</td>
<td>0.0.0</td>
<td>0.0.0</td>
<td>0.0.0</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>Clay</td>
<td>Containing silt, clay, calcite</td>
<td></td>
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<td>0.0.0.0</td>
<td>0.0.0</td>
<td>0.0.0</td>
<td>0.0.0</td>
<td>0.0.0</td>
<td>0.0.0</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>Clay</td>
<td>Containing silt, clay, calcite</td>
<td></td>
<td>0.0.0</td>
<td>0.0.0.0</td>
<td>0.0.0</td>
<td>0.0.0</td>
<td>0.0.0</td>
<td>0.0.0</td>
<td>0.0.0</td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>Clay</td>
<td>Containing silt, clay, calcite</td>
<td></td>
<td>0.0.0</td>
<td>0.0.0.0</td>
<td>0.0.0</td>
<td>0.0.0</td>
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<td></td>
</tr>
<tr>
<td>2.0</td>
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<td>Containing silt, clay, calcite</td>
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<td>0.0.0</td>
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<td>0.0.0</td>
<td>0.0.0</td>
<td>0.0.0</td>
<td></td>
</tr>
</tbody>
</table>

End Of Hole
Figure E.3 Drillhole log of RC-TC-198
Figure E.4 Drillhole log of RC-TC-199
Figure E.5 Drillhole log of RC-TC-200
Figure E.6 Drillhole log of RC-TC-201
Figure E.7 Drillhole log of RC-TC-202
Figure E.8 Drillhole log of RC-TC-203
Figure E.9 Drillhole log of RC-TC-204
Figure E.10 Drillhole log of RC-TC-205
Figure E.11 Drillhole log of RC-TC-206
Figure E.12 Drillhole log of RC-TC-207
Figure E.13 Drillhole log of RC-TC-208
Figure E.14 Drillhole log of TC-133
Figure E.15 Drillhole log of TC-134
Figure E.16 Drillhole log of TC-135
Figure E.17 Drillhole log of TC-136
Figure E.18 Drillhole log of TC-137
Figure E.19 Drillhole log of TC-138
Figure E.20 Drillhole log of TC-139
Figure E.21 Drillhole log of TC-140
Figure E.22 Drillhole log of TC-141
Figure E.23 Drillhole log of TC-142
Figure E.24 Drillhole log of TC-143
Figure E.25 Drillhole log of TC-144
Figure E.26 Drillhole log of TC-145