ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

GEOSTATISTICAL EVALUATION OF LEAD AND ZINC ORE BODY IN BALYA-HASTANETEPE MINE IN TURKEY

M.Sc. THESIS

Ezgi TOKA

Department of Mining Engineering

Mining Engineering Programme

Thesis Advisor: Assoc. Prof. Dr. Cüneyt Atilla ÖZTÜRK

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

BALYA-HASTANETEPE KURŞUN - ÇİNKO MADENİNİN JEOİSTATİSTİKSEL YÖNTEMLERLE DEĞERLENDİRİLMESİ

YÜKSEK LİSANS TEZİ

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Maden Mühendisliği Anabilim Dalı

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Tez Danışmanı: Assoc. Prof. Dr. Cüneyt Atilla ÖZTÜRK

DECEMBER/2015

Ezgi Toka, a **M.Sc.** student of ITU **Institute of / Graduate School of Mining Engineering Department** student ID 505121004, successfully defended the **thesis** entitled "**GEOSTATISTICAL EVALUATION OF LEAD AND ZINC ORE BODY IN BALYA HASTANETEPE MINE IN TURKEY**", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor : **Assoc. Prof. Dr. Cüneyt Atilla ÖZTÜRK**
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Date of Submission : 27 November 2015
Date of Defense : 23 December 2015

To my family,

FOREWORD

The aim of the thesis is to estimate the lead and zinc mine reserve where located in the northeast of the town Balya, Balikesir province in the north west Turkey, with particular reference to Hastane Tepe by using the geostatistical methods with respect to the distribution of variables with the lowest standard error.

I would like to special thanks to my supervisor Assoc. Prof. Dr. Atilla Ozturk and also thanks to Dr. Murat Ozkan from Istanbul Technical University. Additionally thanks to Prof Dr. Gerd Rantitsch from Montanuniversitaet Leoben and Prof. Dr. Thomas Oberndorfer from MineIt Company for their help during my thesis study in Montanuniversitaet Leoben.

I would like to thank to Dedeman Mining Company for essential information they provide regarding the thesis. Also special thanks to Mr. Adil Alku, Director of Research and Development for 15 years, Mr. Ali Rıza Güç Chief engineer of the field and Mr. Zafer Erel.

I'm indepted to Assoc. Prof. Dr. Yusuf Süha Nizamoğlu for his support and believe in me. Also thanks to Büşra Ertuğrul, Cemalettin Erdoğan, Enver Ferah and Mohammad Lashgari for their support during master study in Istanbul Technical University.

This thesis strives to align to international best practice for Mineral Resource reporting and it completed by considering JORC code implement.

November 2015

Ezgi TOKA
(Geologist)

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ABBREVIATIONS

Pb	**:** Lead
Zn	**:** Zinc
Ag	**:** Silver
QA/QC	**:** Quality Assurance and Quality Control of Geochemical Data
JORC	**:** The Joint Ore Reserves Comittee
ASX	**:** Australian Securities Exchange
NZX	**:** New Zealand Stock Exchange
CP	**:** Competent Person
SGeMS	**:** Standford Geostatistical Modelling Software
MTA	**:** Maden Tetkik Arama
CRM	**:** Standardized Samples
RQD	**:** Rock Quality Designation
SCR	**:** Solid Core Recovery
S	**:** Covariance
OK	**:** Ordinary Kriging

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GEOSTATISTICAL EVALUATION OF LEAD AND ZINC ORE BODY IN THE BALYA-HASTANETEPE MINE IN TURKEY

SUMMARY

The Balya district is located near in the town of Balya in province of Balıkesir, North-West of Turkey. Dedeman Mining company hold the license of Balya-Hastanetepe where a lot of research studies have made since 2007 and adjacent license hold by Eczacıbasi-Esan company, and also they have been producing lead and zinc ore since 2009. Dedeman is one of the major mining companies operating in Turkey; their main target is chromite and lead-zinc ores, exporting specific concentrates worldwide. Dedeman initially started their mining operations in 1947 producing chromite ore in Kayseri-Pınarbaşı.

Although exploration studies have been proceeded at the site for advance drilling works, this study is prepared by considering 184 diamond drill holes that area ready for the evaluation for present. So far, over 33,000 m of core drilling has been carried out outlining the mineralization over a target area of Hastanetepe Hill. On the other hand, this study with its largest database is one of the important exploration evaluation study for the ore deposit area.

Database validation, drill holes log photos, core boxes, sample results and all of the data related to drill holes examined as a preliminary studies. In addition, field visit was made with authorized personnel in Dedeman Mining Company. After data validation studies, 3-dimensional ore body modelling, geostatistical evaluation, block modelling and grade estimation studies were made respectively.

This study mainly covers geostatistics evaluation and resource estimation for the mine. Two different programs were used, one of them is SGeMS (The Stanford Geostatistical Modelling Software) produced and developed by Stanford university for geostatistical evaluation and the other one is one of the most popular geology and mine planning software named Surpac were used for ore modelling, block modelling and grade estimation. The variograms determined from the SGeMS software are used for evaluating the results determined from the Surpac software geostatistical interface. Only variograms determined from Surpac geostatistical module is presented in this thesis in order to avoid the mass use of variogram determined from the other geostatistical software.

Total volume of the solid model created in this study is 1,503,167 m^3. Geostatistical investigations were then initiated to determine the reserve and grade estimations. Statistical analyses were firstly carried out to understand the distribution behaviour of the variables that are lead (Pb), zinc (Zn) and silver (Ag). According to the statistical evaluations, geostatistical investigations were then initiated. Firstly raw data were used to determine the best available estimations from kriging. However due to the low correlations between actual and estimated values for each regionalized variables (ReVs), 1 m composite data applied to the transformed data for each ReVs

were used in geostatistical applications. In order to make 3 dimensional estimations, which is the most important innovative section of this study, search ellipsoid were used to make geostatistical estimations. Optimizations were also applied to obtain highly correlated actual and estimated values from cross validations, hence optimized search ellipsiods dimensions were determined. After that ordinary kriging method is applied to estimate the ReVs magnitude for unsampled points in the study area. Hence, distribution maps for each ReVs are then determined for the study area that shows the magnitude for each desired locations 3 dimensionally. Finally, reserve and grade relations are obtained to demonstrate reserve quality of the ore deposit that is vital for ore body validation as well as mine planning. This study will be a good application especially for metalliferious ore bodies to evaluate the reserve quality and quantity based on 3 dimensional geostatistical approaches.

BALYA-HASTANETEPE KURŞUN - ÇİNKO MADENİNİN JEOİSTATİSTİKSEL YÖNTEMLERLE DEĞERLENDİRİLMESİ

ÖZET

Çalışma alanı Türkiye'nin kuzey batısında bulunan Balıkesir ili Balya ilçesi yakınlarındadır. Çok eski tarihlerden beri çeşitli uygarlıklar tarafından çalışıldığı yöredeki kalıntılardan anlaşılan Balya madeni, 1881'li yıllarda bir Fransız şirketi tarafından işletilmiş ve faaliyetine 1938 yılına kadar devam etmiştir. 1974-1981 yılları arasında bölgede Maden Tetkik Arama (MTA) tarafından jeolojik, jeofizik ve sondaj çalışmaları yapılmıştır ve bölge 'Arı-Orta Mağara', 'Sarısu Sahası' ve 'Hastane Tepe' bölümlerine ayrılmıştır. Tez kapsamında Hastanetepe bölgesinde yapılan çalışmalara ve bu bölgede bulunan cevherleşmeye odaklanılacaktır. Lisansı Dedeman Madencilik şirketine ait olan Balya-Hastanetepe bölgesinde 2007 yılından beri sondajlı arama çalışmaları yapılmıştır. Aynı zamanda Türkiye'de bir başka önemli şirketlerden olan Eczacıbaşı-Esan şirketi de Dedeman Madenciliğe ait ruhsat alanının bitişiğindeki ruhsatta 2009 yılından beri kurşun-çinko üreterek faaliyet göstermektedir. Dedeman Madencilik şirketi Türkiye'de faaliyet gösteren önemli maden şirketlerinden olup dünya çapında konsantre ihracatı yapmaktadır. Şirketin ana faaliyet alanları krom ve kurşun-çinko'dur. Dedeman şirketi madenciliğe 1947 yılında Kayseri-Pınarbaşı ilçesinde krom üretimi ile başlamıştır.

Bölgede Permiyen yaşlı kireçtaşları olistolit ve olistromları bulunan Triyas yaşlı sedimanter kayaçlar ile Tersiyer volkanik kayaçları yüzeylenmektedir. Triyas filişi olarak bilinen sendimenter birim MTA Genel Müdürlüğü tarafından bölgesel yapılan jeoloji çalışmalarında Balya Formasyonu, metemorfizma geçirmiş kayaçlar ise Karakaya formasyonu olarak tanımlanarak haritalanmıştır.

Üç ayrı cevherleşme bulunmaktadır bunlar skarn tipi, damar tipi ve saçınımlı tip cevherleşmelerdir. Genellikle skarn tipi cevherleşme kireçtaşı ve dasit kontak zonlarında, damar tipi cevherleşme dasit ve kireçtaşı içerisinde, saçınımlı tip cevherleşme ise dasit içerisinde gözlenmektedir. Cevherleşmenin genel istikameti 45^0 Kuzeydoğu-Güneybatı ve eğimi 45^0 kuzey batıya doğrudur. Cevherleşmeler topografyanın 30 metre altından 300 metre derinliğe kadar devam etmektedir. Karakteristik mineraller galen, pirit, sfalerit ve kalkopirittir.

Sahada sondajlı arama çalışmaları devam etmesine rağmen tez çalışması başlangıç tarihi dolayısıyla 184 adet sondajı ve bu sondajlara bağlı verileri kapsamaktadır. Bu zamana kadar Hastanetepe bölgesinde hedef olarak belirlenen alanda mineralizasyon göz önünde bulundurularak 33.000m den fazla sondaj çalışması Dedeman Madencilik şirketi tarafından tamamlanmıştır.

Tez çalışması kapsamında kurşun-çinko maden yatağının jeoistatistiksel yöntemler kullanılarak değerlendirilmesi ve rezerv-tenör ilişkisinin en düşük hata varyansı ile belirlenmesi temel olarak hedeflenmiştir.

Başlangıç çalışmaları olarak yapılacak tüm incelemelerin ve tahminlerin temelini oluşturması dolayısıyla veri değerlendirmesi ve veri control çalışmaları tamamlanmıştır. Bu kontroller veritabanı kontrolleri, sondaj log ve karot fotoğraflarının kontrolleri, analiz sonuçları ve şirketin elinde bulunan bütün verilerin kontrol edilmesi işlemleridir. Ek olarak Dedeman Madencilik şirketinden yetkili kişiler ile birkaç kez saha ziyaretleri gerçekleştirilmiş; sondaj verileri, sondaj yerleri ve jeolojik oluşumlar yerinde gözlenmiştir. Veri doğrulama işlemleri tamamlandıktan sonra şirket tarafından farklı tenörlerde ve kayaçlardan alınan numunelerin yoğunluk değerleri incelenmiştir. Yapılan incelemeler sonucunda yoğunluk değerlerini kurşun cevheri ile ilişkilendirmenin ve rezerv tahmini yaparken bu ilişkiyi kullanmanın güvenilir olduğuna karar verilmiştir.

Şirket tarafından AutoCAD olarak tarafıma iletilen topografik haritanın Surpac programı kullanılarak üç boyutlu ortamda üçgenlenmesi sağlanmıştır. Surpac yazılımı dünya çapında madencilik alanında kullanılan bir programdır ve tez çalışması kapsamında bu program; cevher modelleme, jeoistatistiksel kestirimler, blok modelleme ve tenör ataması aşamalarında kullanılmıştır.

Sondaj çalışmalarına bağlı olarak elde edilen verilerden oluşturulan veritabanı ile ilgili incelemeler tamamlandıktan sonra bu veritabanının üç boyutlu ortama aktarılması ve sondajların incelenmesi işlemleri tamamlanmıştır. Yapılan inceleme sonrasında, sahadadan ve şirketten elde edinilen bilgiler değerlendirilerek çalışma alanındaki cevherleşmeyi en iyi yansıtacağı düşünülen yerlerden alınması planlanan kesitler belirlenmiştir.

Kesit yöntemi ile sahanın üç boyutlu cevher modellemesi tamamlanmıştır. Cevher modeli tamamlanırken sahanın jeolojik durumu temel alınmıştır. 169 adet ayrı cevherleşme oluşturulmuştur. Oluşturulan cevherleşmeler jeolojik oluşumlar ve sondajlardan alınan numunelerin analiz sonuçlarına göre birbirinden ayrılmıştır.

Sahadaki numunelerin analiz sonuçlarının temel istatistik, histogram ve variogram incelemeleri yapılmıştır. Bu incelemer Stanford universitesi tarafından jeoistatistiksel değerlendirmeler amacıyla oluşturulan ve geliştirilen SGeMS (The Stanford Geostatistical Modelling Software) programında bölge hakkında fikir edinilmesi amacıyla yapılmış sonrasında Surpac programında doğrulanarak kullanılmış ve tez çalışması kapsamında bu programdan alınan verilerden yararlanılmıştır.

Cevherleşme fay, kırık ve çatlak sistemlerine bağlı hidrotermal sokulumlar ile bağlantılı olduğundan analiz değerleri küçük mesafeler içerisinde değişimler gösterebilmektedir. Bu nedenle her bir cevherleşmenin sondaj üzerinde tanımlayıcı olduğu numuneler birleştirilmiş ve istatistiksel hesaplamaların bu veriler üzerinden yapılmasının gerçeğe daha yakın rezerv tenör tahminlerinin yapılabilmesi açısından önemli olduğuna çapraz doğrulama testleri sonucunda karar verilmiştir. Rezerv-tenör tahmini yapılırken veriler 1m lik kompozitlere dönüştürülmüştür. Bu veriler üzerinde jeoistatistiksel incelemeler yapıldıktan sonra rezerv-tenör tahmini için gerçeğe en yakın değerlerin en düşük hata kestirimiyle eldesi için gerekli olan parametreler variogram incelemesi ve çapraz doğrulama testleri sonrası belirlenmiştir.

Dağılım yapısı belirlenen verilerin variogram analizinde yönlü variogram modelleri oluşturulup, deneysel ve teorik variogram grafikleri çizilerek yatağın anizotropi durumuna bakılmıştır. Variogramların ve anizotropi haritalarının incelenmesi sonucunda cevherleşmelerin çoğunluğunun izotropik yapı gösterdiğine karar verilmiştir.

Üç boyutlu cevher modellemesi sonucu kaynağın hacmi 1.503.167 m^3 olarak elde edilmiştir. Oluşturulan cevher modeli 5x5x5 metrelik bloklara ayrılmıştır. Bu bloklarda cevherleşmenin genel olarak damar tipi gözlendiği göz önünde bulundurularak cevherleşmenin daraldığı yerlerde devamlılığı sağlayabilmek amacıyla 1,25x1,25x1,25 metrelik yardımcı bloklara ayrılmıştır.

Tenör ataması yapılırken bilinen değer ile tahmin edilmiş değer arasındaki farkı en aza indiren doğrusal tahmin tekniği olan Ordinary Kriging yöntemi kullanılmıştır.

Belirlenen parametreler kullanılarak bloklara kurşun, çinko ve gümüş tenör atamaları yapılmıştır. Tenör ataması yapıldıktan sonra bloklardaki kurşun değerlerine göre yoğunluk ataması yapılmıştır. Yoğunluk tüm bloklara 2,87 olarak tanımlanmış daha sonra kurşun değeri %2'den küçük olan bloklara 2,71 ve %8'den büyük olan bloklara 3.76 olarak atanmıştır.

Tenör ataması yapıldıktan sonra toplam tonaj 4.314.312 olarak hesaplanmış ve bu tonajdaki cevherleşmenin ortalama tenörü Pb % 3,92, Zn % 1,91 ve Ag 62,18 gr/ton'dur.

Tez çalışması kapsamında JORC uluslarası standart kabullerinden yararlanılmış ve JORC 2012 raporu saha değerlendirmesi aşamalarında klavuz olarak kullanılmıştır. JORC, Avustralya'da 1969 yılında bir spekülasyonun borsada verdiği zararlar sonucu kurulmasına karar verilen ve 1971 yılında kurulan Avustralya Mineral Konseyi (MCA)'nin kurulduktan 18 yıl sonra yayınladığı raporla belirlediği standartlara verilen isimdir. 1989 yılında yayınlanan ilk rapordan sonra 5 kere güncellenen JORC standartları dünyada bir çok kuruluş tarafından bağlayıcı olarak kabul edilmiştir.

1. INTRODUCTION

The Balya district is located near the town of Balya in the province of Balıkesir, North-West of Turkey. Dedeman Mining Company has carried over 33,000 m of core drilling out outlining the mineralization over a target area of Hastanetepe Hill.
Geostatistics has been around for some 60 to 70 years and has been widely practiced for the last 40 or so years in the mining community. Even with this significant history, it continues to be an area of confusion at times. It is still considered as a unintelligible method of calculating resource estimates by geologists, mining engineers, and other mining professionals.

Resource estimation is the most important process of creating a three-dimensional model of in situ mineralization based on drillhole samples and current geological knowledge. This process is principal for mining engineers plan, design and extract mineralization economy. Geostatistical analysts based on the ore modelling to define volumes and so the geological understanding is crucial. It took as a based and always made co-operation with knowlegable geologist in the Company while thesis and studies prepared.

Also, reporting standards and reporting guidelines in the western world taking into consideration fussily. JORC Code, NI43-101 and the SAMREC code are the common reporting standards about resource estimation. The Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (The ‘JORC Code’) sets out minimum standards, recommendations and guidelines for Public Reporting in Australasia of Exploration Results, Mineral Resources and Ore Reserves. The Joint Ore Reserves Committee (‘JORC’) published their first report in 1971 and published the first edition of report in 1989. After that version, they revised and updated edition of the Code in 1992, 1996, 1999, 2004 and 2012. The code endorsed by Mineral Council of Australia and the Financial Services Institute of Australasia as a contribution to good practice. The Code have adopted by and included in the listing rules of the Australian Securities Exchange (ASX) and the New Zealand Stock Exchange (NZX).

The principles governing the operation and application of the JORC Code are Transparency, Materiality and Competence. Transparency requires that the reader of a Public Report is provided with sufficient information, the presentation of which is clear and unambihuous, to understand the report and not be misled by this information or by omission of material information that is known to the Competent Person. Materiality requires that a Public Report contain all the relevant information that investors and their professional advisers would reasonably require, and reasonably expect to find in the report, for the purpose of making a reasoned and balanced judgement regarding the Exploration Results, Mineral Resources or Ore Reserves being reported. Where relevant information is not supplied an explanation must be provided to justify its exclusion. Competence requires that the Public Report be based on work that is the responsibility of suitably qualified and experienced persons who are subject to an enforceable professional code of ethics (the Competent Person) (JORC Code, 2012).

As can be seen in the aforementioned definitions, evaluation of an ore deposit in terms of resource, reserve, and quality has two main steps that are determining and evaluating data. In the first stage, to determine the data about the resource and quality for an ore body must be gathered from boreholes. Drilling, obtaining required samples and required laboratory and in-situ tests are generally well standardized by some communities such as JORC. The number of the data as well as the number of the required quality tests should be also decided based on the type of the orebody as per the international standard. Whenever the studies regarding determining data section is satisfiying, next step, evaluation data, should be ready for studying.

During the evaluation of the data section, engineers and geologist should investigate the distribution of variables not only for its magnitude but also for its locations. Hence, the statistics applied in this section mostly described as geostatistics due to the spatial dependence of the variables. The most important aim of this research is to investigate the advance geostatistical methodologies to evaluate lead&zinc orebody located in Balya district. Application of 3 dimensional research approaches is used as an innovative investigations based on geostatistics to decrease the variance of estimated values obtained from kriging methods.

1.1 Purpose of Thesis

The aim of the thesis is to estimate grade and modelling of reserve distribution of complex base metals mining as Balya lead and zinc mine by using geostatistical methods respect to the distribution of variables with the lowest standard error.
According to the aim of this study, the steps can be found in Figure 1.1 summarize as substances in below:

- **Field Studies**: Contains surface geology evaluation, studies connected to mine occurance, drillhole data evaluation, observing drilling process and historical data investigation studies. It is a crucial to see the studies in situ, data fundamental for all of the studies and it is main determinative factor.
- **Database Development**: Considering the integrated mining software and its needs organized. All data from drillholes prepared in excel files format and then converted to Microsoft Access file format. When this study completed, the JORC complementation took into consideration meticulously.
- **Data Validation**: This section has to complete in fussiliy. Organization of the comparision of datas containing drillhole depth, ore occurance, dip, azimuth, geology, log photos, core boxes, sample assay results and laboratuar testing standards, drillhole excel logs and database with each others and create a validation file in excel format.
- **Ore Body Modelling**: Ore body is modelled by taking sections all over the study area in same direction mostly vertical to ore occurance.
- **Block Modelling:** The block model consists of interpolated values instead of true measurements. It provides a method for estimating volume, tonnage, and average grade of a 3D body. Modelled ore separate to blocks for proper grade estimation and mine planning.
- **Histograms:** Histograms made both in excel files and SGeMS geostatistical analysis program and compared the real and estimated data.
- **Variogram Analysis:** The analysis of spatial continuity in a sample data set is about comparing samples according to the distance and orientation between the samples base for to making estimation. The variogram models evaluation and estimation of ore distribution.
- **Estimation**: Ordinary kriging method used for grade and tonnage estimation, while taking the parameters from variogram analyses.

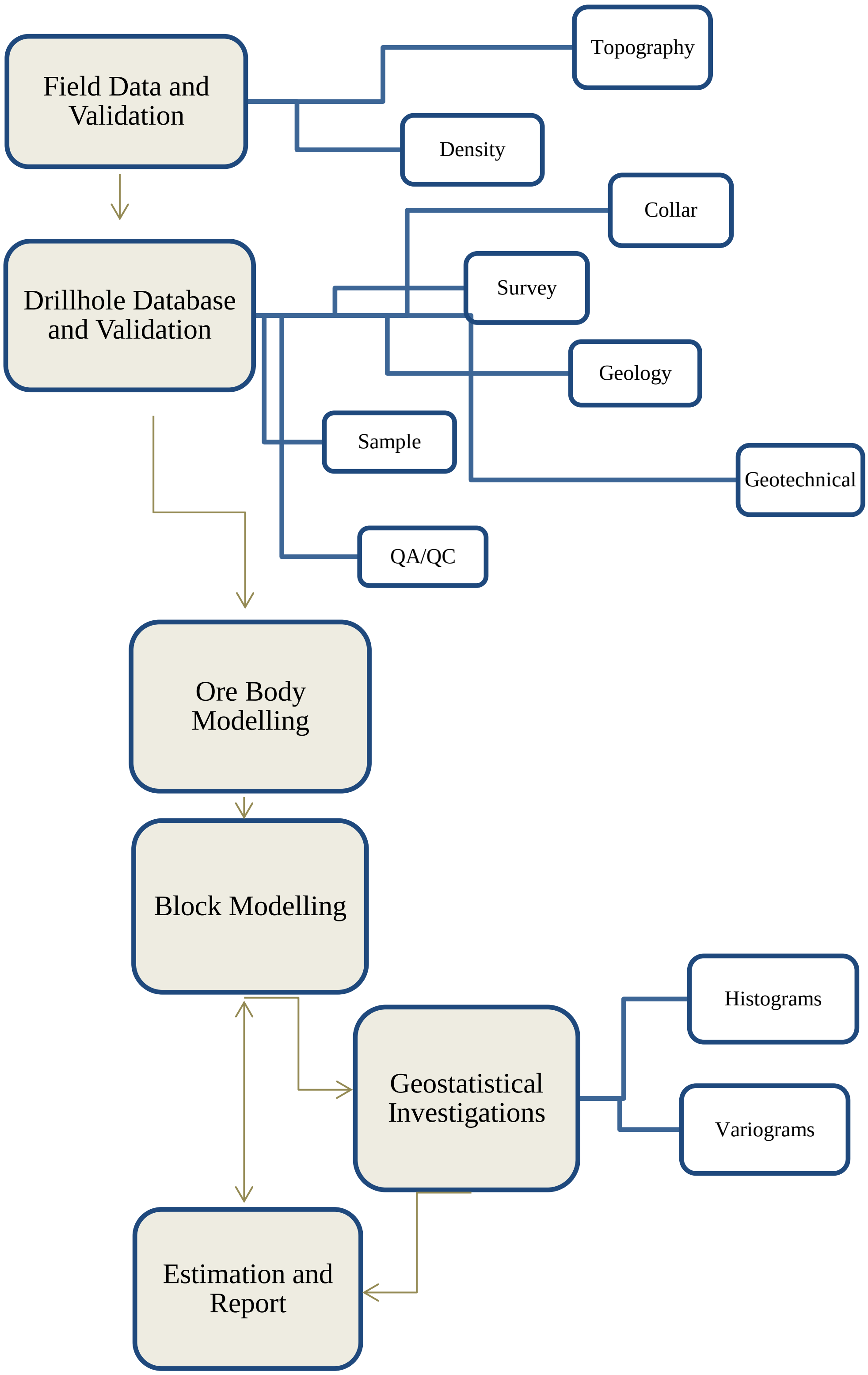

Figure 1.1 : Study flow chart.

1.2 Literature Review

Literature review is divided into two main sections; gology of study area and geostatistical review.

1.2.1 Geological Review

There are many geological studies in the study area. These studies are related with mine site geology, minerology and origin of mine deposit. The literature review will be focus in Balya, summarized below.

P. de TchPhatcheff (1886) carried out geological investigation and found out the volcanic rocks while Neumayr (1886) analyzed the fossils and finally it iwas the first time mentioned about Triassic age in this area.

Bukowski (1892) considered the shales and sanstones met with in the Ari mine to be of the same age as the limestone. In addition, Bukowski (1892) proposed a geological map showing the contact (at Kızoluk Bunar) of the (Permian) limestone and the conglomeratic sandy limestone that proves latter has been deposited on the former by a transgression of Triassic sea.

Enderle (1900) examined limestones in Balya district in detail and gave the permo-Carbonifer age.

Weiss and Berg thought that the occurance of ore body is connected with andesite and the limestone that is carbonifer age with metamorphic contact in 1901. And Phllipson tried to connection between rock in Paleozoic age around the Balya and volcanic rocks in 1915 (Erel, 2011).

Kovenko (1940) studied about the mine geology and formations consisting ore in Balya district and it was identified four different ore occuration as porfiric ore, ore in limestone, ore between layers in sedimanter rocks and lastly as contact veins. Besides defining the ore formations fault sets and andesite dikes were also defined in this study.

Aygen (1956) asserted that limestone could be only found in the formations comprising of Permian age. To the north and northwest, however, he reports Permian arkoses overlying the limestone. Aygen (1956) separated schist and sandstone as a Triassic age. Moreover, he added that contact ore is not important in Balya. He only records gentle or moderate dips in his tectonic diagrams, but in Kiziltepe hills and Asarlik Tepe the conglomerate series in most outcrops shows nearly vertical dips. In addition, he mapped the geology of Balya district and discussed the stratigraphical and tectonical relationship.

Kaaden (1957) mentioned that Balya mine located in the contact zone between Neogen volcanic rocks and adjacent suitable area, added to that it cuts formations comprising of the ages between Permien and Triassic.

Gjelsvik (1958) adverted that since the deposits of Balya seem to be typical samples of subvolcanic mineralization, it would be interesting to find out the depth of the mineralization. As well, he emphasized that the most intense mineralization has to be occurred at an altitude of 0 to 300 m. Furthermore, the other important thing he mentioned that the ore in Balya could be belongs to transmission type between epithermal and mesothermal ore occurrence.

The complicated structural pattern of the area is possibly due to recumbent folding during both the Hercynian and Alpine orogenies (Gjelsvik, 1958)

Mohr (1959) said that the lavas, tuff and agglomerates combined with andesitic and dacitic rocks are Triassic age and ore occurred between dacite and older sediments or contact zone around that.

Gjelsvik (1962) brought up that the Permian limestone above the Triassic formations discordantly and the ore occurrences are located in dacite and intense folded limestone.

Ovalioglu (1973) identified the ore source as a good example for subvolcanic-hidrothermal and contact metamorphic composition.

Akyol (1975) reported that the Balya mine wastes that are over one million are significant economically, the average grade for flotation wastes are 4,20% Pb, 3,50% Zn and the average grade for smelter waste are 3,50% Pb and 10,40% Zn.

Akyol (1977) explained geology round the mine as claimed that there are Paleozoic, Mesozoic and Tarsier age formations and many magmatic activities represented with volcanics. Balya mine located in contact zone with limestone blocks, and it monitored in limestone fractures.

Akyol (1979) divided ore in three types as a contact type, vein type and disseminated ore. In addition, he mentioned that when the research studies developed along north, south and east side of the study area, reserve would increase in high possibility and there is asidic intrusive rock in depth or near the mine.

Uçurum (1987) worked out evaluation of Balya lead and zinc wastes in separately.

Aydinli (2004) examined rock petrography for south part of Balya district where is also operated by a mining company.

SRK Consulting Company (2010) completed feasibility studies for Balya mine including reserve, grade and geotechnical studies. The company carried the report using over 16,000 m core drilling and the consultant company also used nearest neighborhood method for the estimation. Cut off grade for the productability of the ore from underground was designed by the consultant company as per Pb content as well as Zn and Ag content in terms of Pb Equivalency. The evaluation of the ore deposit based on cut off grade can be found in Table 1.1 which is indicated as 1.0 for each parameter.

Table 1.1 : Reserve results from SRK.

	CutOff	Indicated				Inferred				Total			
		Tonnes	**Pb**	**Zn**	**Ag**	**Tonnes**	**Pb**	**Zn**	**Ag**	**Tonnes**	**Pb**	**Zn**	**Ag**
		ton	%	%	ppm	ton	%	%	ppm	ton	%	%	ppm
By Pb Cut-Off	5	9.51	7.94	4.24	97.30	22.00	5.14	0.48	45.40	9.54	7.93	4.23	97.20
	4.5	19.85	6.20	2.51	74.40	4.98	4.54	0.54	49.60	24.82	5.87	2.11	69.40
	4	38.11	5.23	1.66	59.70	16.58	4.30	0.62	42.90	54.69	4.95	1.34	54.60
	3.5	53.64	4.81	1.34	55.60	19.71	4.22	0.55	42.60	73.35	4.65	1.13	52.10
	3	127.35	3.88	0.91	44.80	50.92	3.59	0.45	37.40	178.27	3.79	0.78	42.70
	2.5	279.04	3.25	0.92	38.40	97.37	3.16	0.54	34.50	376.42	3.23	0.82	37.40
	2	587.07	2.71	0.85	32.90	256.15	2.58	0.59	30.40	843.22	2.67	0.77	32.10
	1.5	936.96	2.35	0.90	29.90	425.75	2.25	0.73	27.80	1.362.717	2.32	0.85	29.30
	1	1.424.470	1.98	0.97	25.60	672.92	1.89	0.85	23.60	2.097.388	1.95	0.93	25.00
	0.5	1.627.859	1.84	0.95	23.80	783.09	1.74	0.83	21.90	2.410.950	1.81	0.91	23.20
	0	1.636.948	1.83	0.95	23.80	799.12	1.72	0.85	21.80	2.436.072	1.80	0.92	23.10
By Pb Equivalent Cut-Off	5	54.84	6.77	2.63	52.00	14.75	5.18	1.52	38.90	69.59	6.44	4.00	49.10
	4.5	110.91	5.74	2.37	44.60	32.77	4.93	1.90	37.40	143.68	5.56	4.14	42.70
	4	174.92	5.20	2.10	40.40	54.70	4.66	1.78	35.20	229.63	5.07	3.79	38.90
	3.5	324.13	4.51	1.79	35.00	119.71	4.13	1.60	31.60	443.83	4.41	3.34	34.00
	3	550.93	3.99	1.50	31.90	212.24	3.75	1.35	29.30	763.17	3.93	2.82	31.10
	2.5	849.71	3.56	1.29	29.80	351.47	3.35	1.21	27.60	1.201.185	3.50	2.46	29.10
	2	1.250.404	3.14	1.07	26.90	589.65	2.91	0.96	24.90	1.840.053	3.07	2.01	26.20
	1.5	1.542.183	2.89	0.99	24.50	733.31	2.69	0.89	22.80	2.275.489	2.82	1.86	23.90
	1	1.632.275	2.80	0.96	23.80	796.13	2.58	0.85	21.90	2.428.408	2.73	1.79	23.20
	0.5	1.636.948	2.79	0.95	23.80	799.12	2.57	0.85	21.80	2.436.072	2.72	1.78	23.10
	0	1.636.948	2.79	0.95	23.80	799.12	2.57	0.85	21.80	2.436.072	2.72	1.78	23.10

Erel (2011) made a study about reserve estimation and modelling Balya lead-zinc deposit using geostatistical methods and the study covers 80 drillholes, 14.562 m. Ordinary kriging method was used for the estimation and the result can be found in Table 1.2.

Table 1.2 : Reserve results from Erel.

Ore	Reserve (tonnes)	Mean
Lead	12.999.219	2.81%
Zinc	5.823.826	2.12%
Silver	3.913.479	77.86 (gr/t)

A detailed study about the geology of the site can be found in the section 2 of this study entitled as Geology and Mineralization.

1.2.2 Geostatistical Review

Geostatistical methods were found when classical statistics unsuitable for estimating disseminated ore reserves. Mineral Resources and their subsequent conversion to Ore Reserves are of key importance to mining companies. Over time only changes has been in difference between methods we are using for estimation. In the beginning of mining activities, miners made basic interpretations like sampling, chemical analyses and estimation of ore thicknesses for day-to-day operations of a mine. Beside the advantage on day-to-day operations, mining companies' reliable estimation is critical also in a feasibility studies. There is thus a requirement for high-quality interpretation and estimation to be supported by high-quality data. Any company expecting to make sound investment or operational decisions must base this on both relevant and reliable information.

The reliable estimation of mineral resources and ore reserves is critical to all mining operations irrespective of size or commodity (Annels, 1991).

From 1954 to 1963, while working with the French Geological Survey in Algeria and in France, Matheron discovered the pioneering work of the South African school on the gold deposits of the Witwatersrand, and formalized the major concepts of the theory that he named Geostatistics. The "classical" geostatistics (linear geostatistics based on stationary covariance and variogram) was fully developed in his thesis. The regionalized variable under study, as Matheron called it, is then conveniently modelled as a Random Function (Matheron, 1963). After he speak of geostatistics at the NATO conference called ‘Advanced Geostatistics in the Mining Industry’ in Rome during 1975, geostatictics recognized in academically.

Matheron developed Ordinary kriging method to address the estimation of average block grades by weighting surronding samples according to the semivariogram in 1960’s. Indicator kriging is an estimation method developed by Switzer (1977) and Journel (1983) to address the problem of how to weight outliers in skewed distributions such as found in precious metal deposits.

Because of the versatility, classical geostatistics methods emerged as the methods of choise for many spatial estimation applications (Matheron, 1963; Journel, 1989).

Journel (1989) determined the experimental semi variogram function.

Rosenbaum et al. (1997) used geostatistics as a tool to estimate lithology.

Tercan and Köse (1997) show how well known the geostatistical structure is for a particular chromium deposit and to connect this structure with geological findings.

An application to estimate 8 months convergence for Bolu Tunnels, Turkey from cokriging technique was proposed by Tercan (1998) that is a rare example for the use geostatistics in tunnel projects such as Ozturk and Simdi (2012).

Similarly, Ozturk and Nasuf (2002) proposed the use of geostatistical applications for tunneling to estimate rock quality designation (RQD), compressive strength (CS), Schmidt hammer hardness (SHH), and net cutting rate (NCR) for 800 m of the Eyup sewerage tunnel using kriging.

Geostatistics were successfully used for rock mass rating (RMR) evaluation from borehole and MT resistivity data (Oh et al., 2004).

Jeon et al. (2009) applied ordinary and indicator kriging and sequential indicator simulation to estimate RMR around the tunnel. The results in this study also support the use of geostatistics to estimate geotechnical properties as ReVs.

Oh (2012) proposed the integration of seismic velocity and resistivity data for the evaluation of rock quality based on geostatistical methods.

A detailed review about the geostatistical methodologies can be found in the 5th section in this study titled as Geostatistical Modelling Methodology.

1.3 Hypothesis

The hypothesis of this thesis is classified in below to capture the purpose of the study that is to define the reserve and grade relation for Balya Pb-Zn metalliferous mine deposit.

1) Quality and quantity of the reserve should be defined based on the reserve amount and the grade of the each metals, so the amount of reserve can be classified for the ores that can be also classified from poor to rich.

2) The other important investigation especially required for mine planning studies is to show the poor and rich ore zones in the study area based on regionalization, so not only the amount of reserve can be classified but also the distribution can be also determined based on location, which is essential for mining.

3) The abovementioned purposes required applications of modelling methodologies that can be conventional or geostatistical. Conventional modelling techniques mostly and only considering the magnitude of a variable while geostatistical methodologies are used magnitude and location of variable for the investigations. Due to this difference, geostatistical methods have less error variance for the estimation of variable.

4) A regional dependency function must be determined in the geostatistical applications that is determined from regionalized variable depending on location and magnitude for variable.

5) Geostatistical methods are applied in different engineering and scientific disciplines from hydrology to mining. Classical approaches for geostatistical applications is to assign a one value for each sampled point in the study area and 2 dimensional distribution map can be obtained from geostatistical applications. However in mining, it is required to obtain 3 dimensional view of the distribution of the regionalized variable in the study area that required different procedure based on classical geostatistical methodologies.

6) 3 dimensional distribution maps for the ore deposit located in Balikesir Balya would be determined as the main outputs of this research to obtain the values of lead, zinc and silver content distribution based on 3 dimensional geostatistical investigations.

7) In order to obtain these distribution maps, statistical evaluation of regionalized variables that are Pb, Zn, and Ag were completed, then semi-variogram functions were determined for isotropic and anisotropic situations as well as downhole variograms to show the dependence based on depth.

8) Search ellipsoid dimension optimization was carried out after determining the variogram functions. Cross validation between actual and estimated values is used to understand the most suitable search ellipsoid dimension.

9) Ordinary kriging was applied to estimate the magnitude of each variable for unsampled locations in the study area. Hence, it is possible to obtain 3 dimensional distribution maps of each variable in the Balya Lead and Zinc Mine.

10) Reserve and grade estimation was finally applied again for each variable to obtain the quality and quantity of each variable in the study that shows the productability of the Balya Lead and Zinc Mine.

2. GEOLOGY AND MINERALIZATION

2.1 Study Area

Balya study area located 50 km North-West of Balikesir province and it is in North-West of Turkey (Figure 2.1). Balya population has decreased to 13.912 from 2014 census.

Balya has hot and dry weather in summer and depth of winter with rain. District is 230 meters above sea level. However, summer is not hot as Mediterranean climate; it has partly fresh air due to both the attitude and location. The hottest months are July and August; the coldest months are January and February.

Balya mines have been worked since the time of Pericles, but regular operations with the application of scientific and modern mining methods were started about 1880. The country surrounding the mines, as well as the whole of this portion of Anatolia, consists of a series of little hills of different altitudes of 250 - 400 m, seldom attaining the height of 500 - 600 m. above sea level. The general dip of the surface as well as the strike of the valley are the North East and North. All the rivers and streams carry small Quantities of water and some of them disappear altogether during the months of August or September (Kovenko, 1940).

A French mining company (Societe Miniere Metallurgique de Penarroya) produced 3.5 to 4Mt of lead and zinc between 1880 and 1939, additionally produced 1.000T of silver and 3.000kg of gold.

Etibank and an American company conducted a research program and drilled 5 locations. However the data for these 5 holes have not been found. MTA drilled 5 more holes between 1966 and 1974. The systematic exploration of MTA was conducted between 1974 and 1980. This work covers IP/EM and 40 more drill holes. MTA subdivided Balya prospect as 3 locations namely Sarisu, Hastanetepe and Ari-Orta. Reserve estimation for these locations are as follows;

Table 2.1 : Reserve results from MTA.

	Tonnage (Mt)	Pb %	Zn %	Cu %
Sarisu	1.1	4.18	1.65	
Hastanetepe	1.2	4.18	0.68	
Ari-Orta	4.4		7	

Silver and gold grades are not clear from the reports. After 1978 the Balya area has been divided in two licenses, which belong to ESAN Company (Old Balya) and Dedeman Mining (Hastanetepe).

Currently Eczacıbaşı Esan operates the Balya mine adjacent to study area since 2008.

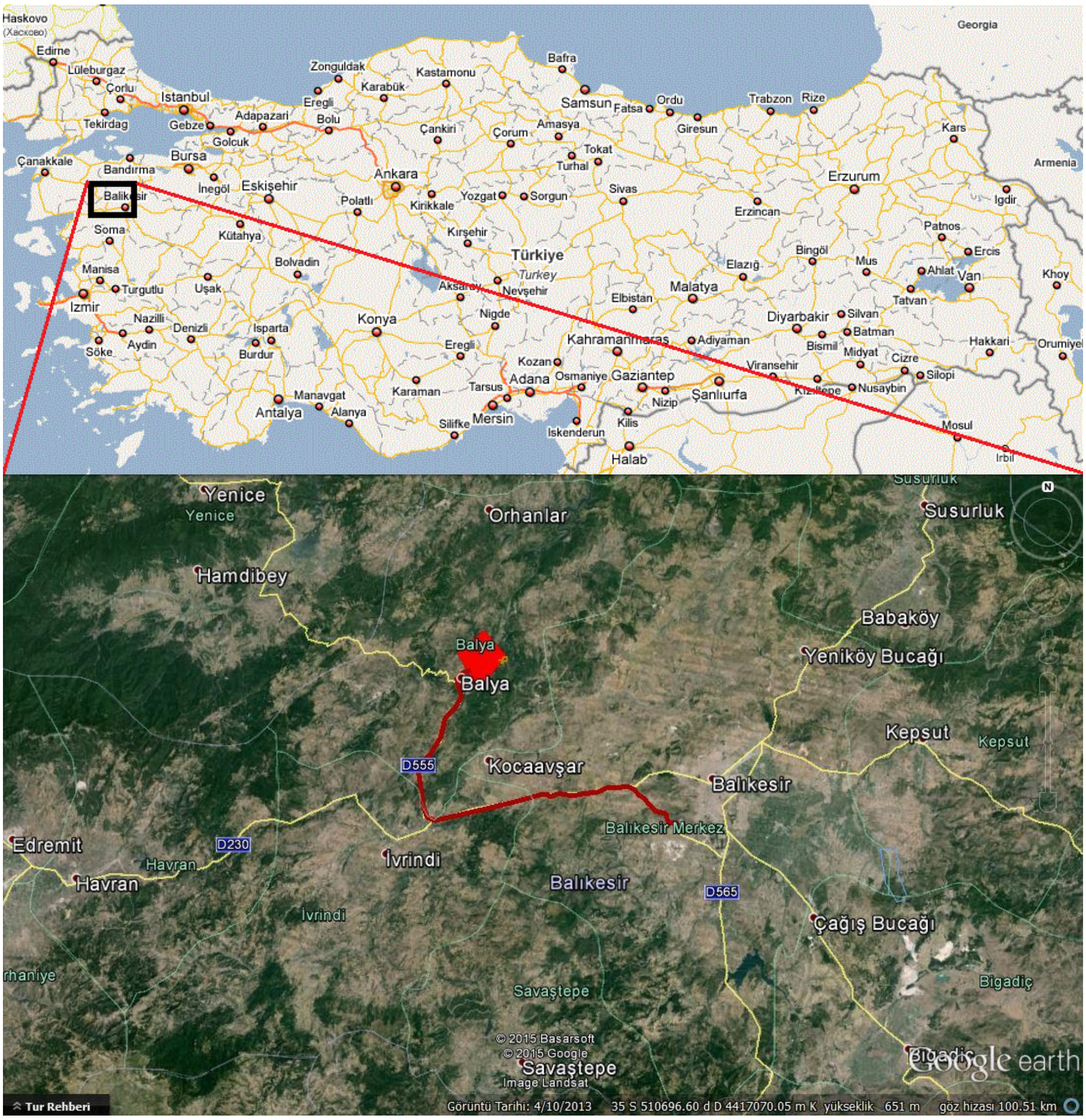

Figure 2.1 : Study area location map.

2.2 Regional Geology

Balya region is located along the Sakarya Zone of the Pontides (Figure 2.2). Permo-Triassic aged highly deformed and partly metamorphosed clastic and volcanic series of the Sakarya Zone is called as Karakaya Formation. Okay & Göncüoğlu (2004) gives a comprehensive review on the Karakaya Complex. They have described the unit as: “It is generally subdivided into two parts: The structurally lower part, called the Lower Karakaya Complex, consists of a mafic lava-mafic pyroclastite-shale-limestone succession metamorphosed in the greenschist and blueschist facies during the Late Palaeozoic or Triassic. The structurally upper part containing highly deformed Permian and Triassic clastic, volcaniclastic and volcanic rocks with exotic limestone blocks. There are currently two different models for the depositional setting and tectonic evolution of the Karakaya Complex. The rift model, which assumes the Karakaya Complex, formed in a Late Permian rift, which developed into a marginal oceanic basin and closed by the latest Triassic. The subduction-accretion model regards the Karakaya Complex as subduction-accretion units of the Palaeo-Tethys.” The non-metamorphosed equivalence of the Karakaya Formation is called Balya Formation by MTA (Turkish Geological Survey) geologists. In Balya region, both Karakaya & Balya formations are cut by Tertiary volcanics (i.e. Şapcı volcanic).

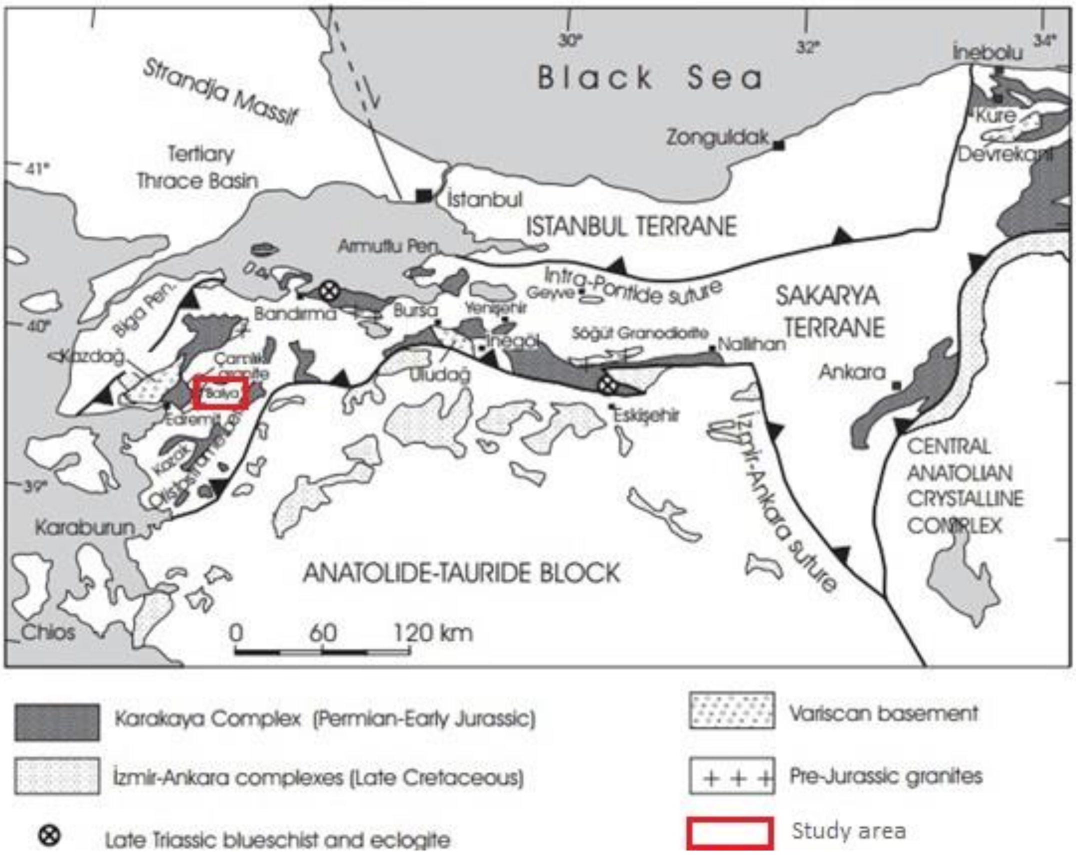

Figure 2.2 : Tectonic map of western anatolia showing the distribution of the Karakaya complex and related units (from Okay & Göncüoğlu, 2004).

2.3 Site Geology

The Hastanetepe prospect within the Balya License covers an area of about 1,000 × 500 meters. Study area is dominated by Tertiary volcanics, Permian limestone and Upper Triassic sedimentary formation. At a prospect scale, distinction can be made between a Neogene dacite and andesite magmatic units.

Magmatic rocks are mainly dacite, rhyolite and andesite, rarely basalt.

Permian Limestone is observed as massive bodies that have poor bedding planes. Its color ranges from dark grey to earthy white. Locally it has sandy and clayey horizons. The unit is observed as olistostromes in the Upper Triassic sediments and allochtonous blocks thrusted over the Upper Triassic sediments.

Upper Triassic Sediments are made up of sandy limestone, siltstone and sandstone alternation with conglomerate to the upper part of sequence. Its color range from dark green to grey and rarely black.

In the latest MTA report (Balcik et al., 1981), dacite is defined as porphyritic subvolcanic intrusive and forms dykes, sills and small stocks. Dacite mainly emplaced along the NE-SW structures. At the contacts with Permian Limestone, skarn minerals have been developed (wollastonite, tremolite, diopsite, sillimanite, epidote, scapolite and garnet).

Major fault system is closely associated with the mineralization. The general structural orientation within the prospect area is NE-SSW to N-S, with crosscutting E-W structures. The surface expression of the structures can generally be observed sub-vertical and has been interpreted to dip steeply to the north and west.

A major E-W fault usually marks the southern limits of the prospect, and may represent an offset from the mineralization which was exploited in the old Balya mine to the south. Figure 2.3 provides the geological setting of the site.

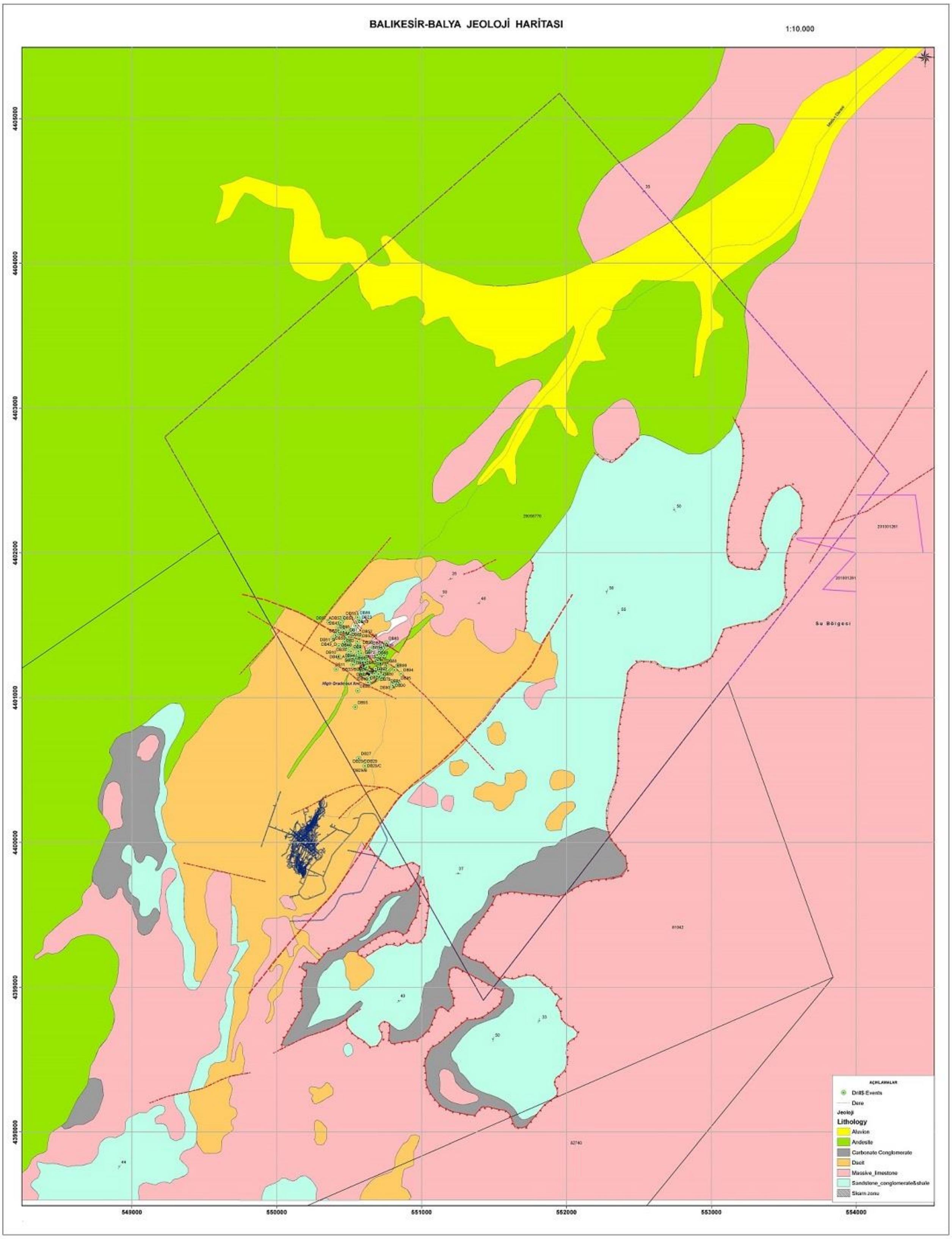

Figure 2.3 : Regional geology map

2.4 Mineralization and Deposit Type

Hastanetepe ore body located north of mines known as 'Arı-Orta Mağara' and 'Sarısu Sahası'. Both ore occurrences have same characteristic as geological and mineralization type.

The mineralization occur three types as skarn type in the contact area between limestone and dacite, as vein type both observed in dacite and limestone and as a disseminated in dacite. General mineralization strike is NE-SW 45^0 and dip direction is 45^0 to the north-west. Ore bodies are 30-300 m below the present surface. The characteristic sulfide minerals congregation consists of galena, sphalerite, pyrite and chalcopyrite. Minor components are pyrrhotite, marcasite, bismuth, arsenopyrite and bornite. The gangue minerals assemblage is typical of skarn-type mineralization strongly influenced by limestone country rocks and consists of garnet, epidote, quartz, calcite, fluorite and minerals of the actinolite group.

Ore comparise of galena often contain significant amounts of silver as included silver sulfide mineral phases or as limited solid solution within the galena structure. Related galena occurance, silver entity mostly involved with lead content in this area. In the superior part of the primary zone the galena predominates, but going deeper the blende quantities increase (Kovenko, 1940).

The mineralization in Balya is characteristically occur as irregular and discontinuous pods and lenses, although there is commonly an overall structural and lithological control.

3. DATA DETERMINATION AND VALIDATION

The quality of the resource estimate is directly depend on the quality of data procedures.

Drill hole sample data will be used to predict tonnages and grades. Statistical analyses will be used with geological and other technical information to make inference decisions. The sample database has to provide for sound and robust decision making (Rossi and Deutsch, 2014).

All of the data examined and the studies that completed by company authorized person reviewed. Company gave the following informations about data sharing procedure and it deducted that data have transparency and can be reach by anyone works related with Balya (Figure 3.1).

Field geologist recorded drilling advance to daily report, when drilling complete for each drill hole its geology and geotechnical results are then recorded. Before 2012 it was sent to head office weekly, after that date company started to use Enterprise Resource Planning (ERP) system for sharing and field geologist constitude drilling reports on that system which can be reach by the engineers or executives (Figure 3.2). 43 drillholes data archived in that system. Moreover, all of the informations about drilling that include base informations like coordinates, elevation, dip and azimuth informations and also sample details, geological details, survey measurements, QA/QC and geotechnical details can be found in excel format for each drillholes at head office (Figure 3.2).

Data management engineers create databases for geological modelling and the other mine development projects. This thesis also contains the development of database and validation studies for all of the data with comparison. Database and validation file can be seen in Figure 3.3 and 3.4.

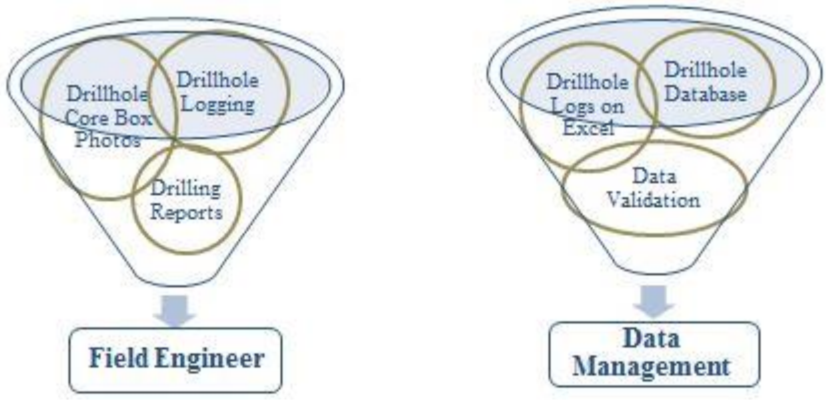

Figure 3.1 : Data determination and process scheme

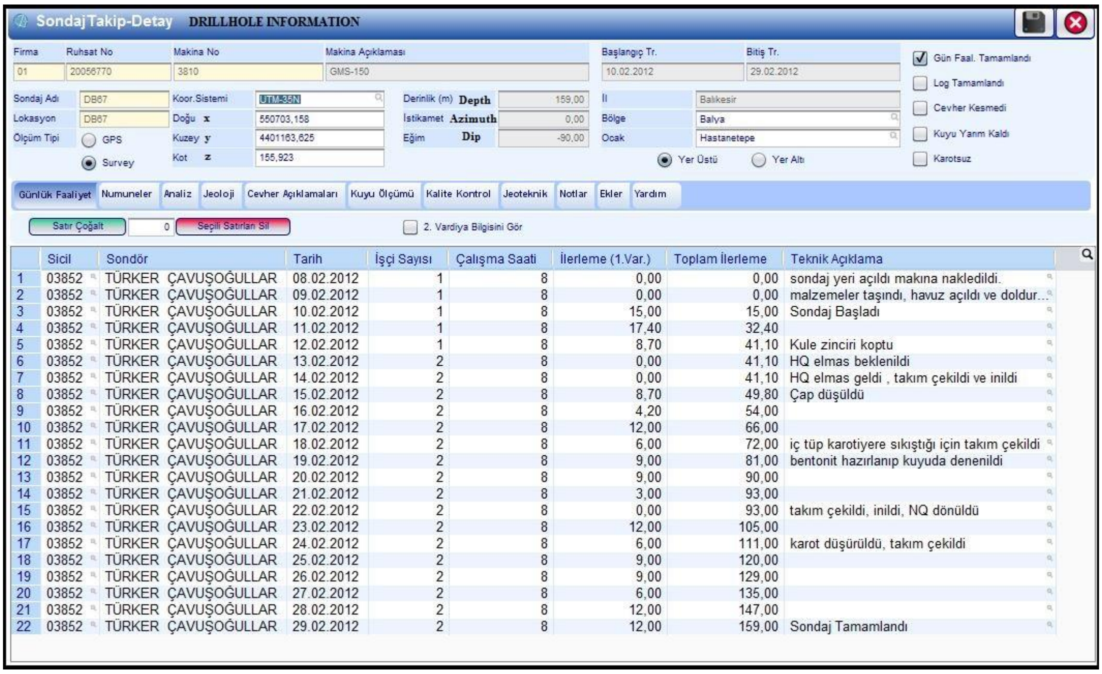

Figure 3.2 : Drillhole logging on ERP system

PROJE ADI:	A.R 20056770 BALYA		
Lokasyon:			
Sondaj No:	DB67	Kuyu Derinliği:	159
Doğu:	550703.158	Başlangıç Tarihi:	10.02.2012
Kuzey:	4401163.625	Bitiş Tarihi:	29.02.2012
Kot:	155.923	Hazırlayan	Ezgi Toka-Ali Rıza Güç
Ölçüm Tipi:	SURVEY	Sondörler:	Türker Çavuşoğulları
Koordinat Sistemi:	UTM-35N	Proje Sahibi:	Dedeman Madencilik
İstikamet:			
Eğim:	90	Kuyu Ölçüm Değerleri	Derinlik
Kuyu Çapı:	HQ-NQ		İstikamet
Makina Tipi	Gms 150		Eğim

SONDAJ LOGU

En iyi gözlem:

Kuyu	Numune								Analiz				Cevher
Kuyu Adı	Giriş	Çıkış	Metre	Numune No.	Kayaç Tipi	Karot (%)	Spesifik Gravite	QAQC	Pb (%)	Zn (%)	Ag (g/ton)	Sınıflama	Tipi
DB67	0.00	25.60	0.00										WASTE
DB67	25.60	27.00	0.00	6958	DAC				8.84	1.63	177		ORE
DB67	27.00	29.50	0.00	6959	DAC				0.62	0.15	10		ORE
DB67	29.50	31.00	0.00	6960	AND				0.43	0.1	3		ORE
DB67	31.00	32.40	0.00	6961	AND				0.26	0.56	2		ORE
DB67	32.40	35.30	0.00	6962	AND				0.45	0.16	7		ORE
DB67	35.30	37.00	0.00	6963	AND				0.54	0.13	12		ORE
DB67	37.00	38.20	0.00	6964	AND				39.34	25.56	1160		ORE
DB67	38.20	39.60	0.00	6965	AND				64.46	12.77	1442		ORE
DB67	39.60	40.70	0.00	6966	AND				17.98	43.61	291		ORE
DB67	40.70	41.10	0.00	6967	AND				7.82	13.8	218		ORE
DB67	0.00	0.00	0.00	6968	AND			Standart Numune	1.24	0.34	43		WASTE

Log | Jeoloji | Analiz | QAQC | GD Calculations | RQD | Log Foto | Lejant

Figure 3.3 : Drillhole logging in Ms. Excel format.

hole_id	EASTING	NORTHIN	RL	SURVEYI	DEPTH	Start Date	End date	Ore	ZONE	HOLE PATH	DRILL_TYP	PROJECT NAI	PROSPECT
DB1	550486.990	4401435.780	175.08	SURVEY	201.00	16.01.2007	27.01.2007			Vertical	DD	BALYA	BALIKESIR
DB1_A	550486.990	4401435.780	175.08	SURVEY	220.00	14.12.2009	26.12.2009			Curved	DD	BALYA	BALIKESIR
DB1_B	550486.990	4401435.780	175.08	SURVEY	195.00	26.12.2009	31.12.2009		üretim boşluğu	Curved	DD	BALYA	BALIKESIR
DB1_C	550486.990	4401435.780	175.08	SURVEY	38.00	01.01.2010	01.01.2010			Curved	DD	BALYA	BALIKESIR
DB1_D	550486.990	4401435.780	175.08	SURVEY	62.00	01.01.2010	05.01.2010		üretim boşluğu	Curved	DD	BALYA	BALIKESIR
DB3	550462.420	4401363.900	176.68	SURVEY	150.00	28.01.2007	05.02.2007		üretim boşluğu	Vertical	DD	BALYA	BALIKESIR
DB3_A	550469.390	4401385.000	176.31	SURVEY	136.00	06.02.2007	13.02.2007		üretim boşluğu	Curved	DD	BALYA	BALIKESIR
DB8	550513.250	4401319.580	185.61	SURVEY	203.00	15.02.2007	27.02.2007			Vertical	DD	BALYA	BALIKESIR
DB10	550424.620	4401281.870	171.24	SURVEY	204.00	01.03.2007	13.03.2007		üretim boşluğu	Vertical	DD	BALYA	BALIKESIR
DB10_A	550426.180	4401283.150	171.32	SURVEY	180.00	14.03.2007	26.03.2007		üretim boşluğu	Curved	DD	BALYA	BALIKESIR
DB11	550410.240	4401196.680	176.02	SURVEY	205.00	27.03.2007	06.04.2007			Vertical	DD	BALYA	BALIKESIR
DB12	550493.960	4401282.010	180.03	SURVEY	180.00	25.04.2007	03.05.2007			Vertical	DD	BALYA	BALIKESIR
DB12_A	550494.090	4401282.250	180.06	SURVEY	153.00	04.05.2007	10.05.2007			Curved	DD	BALYA	BALIKESIR
DB13	550501.970	4401363.180	183.51	SURVEY	203.00	11.05.2007	21.05.2007			Vertical	DD	BALYA	BALIKESIR
DB14	550503.970	4401395.310	185.10	SURVEY	219.00	22.05.2007	08.06.2007			Vertical	DD	BALYA	BALIKESIR
DB14_A	550503.970	4401395.310	185.10	SURVEY	210.00	01.02.2010	13.02.2010			Curved	DD	BALYA	BALIKESIR
DB14_B	550503.970	4401395.310	185.10	SURVEY	96.00	13.02.2010	16.02.2010			Curved	DD	BALYA	BALIKESIR
DB15	550540.470	4401286.200	180.11	SURVEY	92.00	22.06.2007	27.06.2007			Vertical	DD	BALYA	BALIKESIR
DB16	550549.460	4401296.370	182.84	SURVEY	201.00	27.06.2007	09.07.2007			Vertical	DD	BALYA	BALIKESIR
DB17	550528.110	4401429.360	186.02	SURVEY	75.00	10.07.2007	14.07.2007		üretim boşluğu	Vertical	DD	BALYA	BALIKESIR
DB18	550519.320	4401464.810	176.44	SURVEY	257.00	17.07.2007	04.08.2007			Vertical	DD	BALYA	BALIKESIR
DB19	550545.010	4401498.330	176.54	SURVEY	180.00	05.08.2007	15.08.2007			Vertical	DD	BALYA	BALIKESIR
DB20	550571.610	4401276.280	178.87	SURVEY	252.00	17.08.2007	31.08.2007			Vertical	DD	BALYA	BALIKESIR
DB21	550547.601	4401258.735	175.65	SURVEY	162.00	01.09.2007	09.09.2007			Vertical	DD	BALYA	BALIKESIR
DB22	550561.795	4401320.565	190.36	SURVEY	231.00	10.09.2007	25.09.2007			Vertical	DD	BALYA	BALIKESIR
DB23	550569.616	4401534.921	176.30	SURVEY	231.00	17.09.2007	22.11.2007			Vertical	DD	BALYA	BALIKESIR
DB23_A	550569.616	4401534.921	176.30	SURVEY	180.00	01.01.2008	24.01.2008	Not Intersected		Curved	DD	BALYA	BALIKESIR
DB23_B	550569.616	4401534.921	176.30	SURVEY	184.00	01.02.2008	03.03.2008	Not Intersected		Curved	DD	BALYA	BALIKESIR
DB24	550582.561	4401307.324	189.05	SURVEY	190.00	26.09.2007	07.10.2007			Vertical	DD	BALYA	BALIKESIR
DB25	550606.386	4401278.932	179.78	SURVEY	262.00	17.10.2007	03.11.2007			Vertical	DD	BALYA	BALIKESIR
DB26	550588.684	4401262.219	176.79	SURVEY	257.50	04.11.2007	26.11.2007			Vertical	DD	BALYA	BALIKESIR

Collar | Survey | Geology | QAQC | Assay | Geotechnical | Analiz | Legend

Figure 3.4 : Drillhole database.

BOREHOLE	VALIDATION										HOLE LENGTH
	Excel Sheet	Analytical	Ore	Downhole	RQD	HOLE DIAMETER	RECOVERY	QAQC	Core Box	Laboratory Assay	
DB1	CHECKED	ALS	CHECKED	NA	42	CHECKED	93	CHECKED	CHECKED	CHECKED	201.00
DB1_A	CHECKED	ALS	CHECKED	CHECKED	61.68	CHECKED	86.86	CHECKED	CHECKED	CHECKED	220.00
DB1_B	CHECKED	ALS	CHECKED	CHECKED	72	CHECKED	92	CHECKED	CHECKED	CHECKED	195.00
DB1_C	CHECKED	ALS	CHECKED	NA	12	CHECKED	58	CHECKED	CHECKED	CHECKED	38.00
DB1_D	CHECKED	ALS	CHECKED	CHECKED	14	CHECKED	58	CHECKED	CHECKED	CHECKED	62.00
DB3	CHECKED	ALS	CHECKED	NA	18	CHECKED	76	CHECKED	CHECKED	CHECKED	150.00
DB3_A	CHECKED	ALS	CHECKED	NA	48	CHECKED	66	CHECKED	CHECKED	CHECKED	136.00
DB8	CHECKED	ALS	CHECKED	NA	54	CHECKED	91	CHECKED	CHECKED	CHECKED	203.00
DB10	CHECKED	ALS	CHECKED	NA	44	CHECKED	92	CHECKED	CHECKED	CHECKED	204.00
DB10_A	CHECKED	ALS	CHECKED	NA	38	CHECKED	82	CHECKED	CHECKED	CHECKED	180.00
DB11	CHECKED	ALS	CHECKED	NA	41	CHECKED	90	CHECKED	CHECKED	CHECKED	205.00
DB12	CHECKED	ALS	CHECKED	NA	46	CHECKED	84	CHECKED	CHECKED	CHECKED	180.00
DB12_A	CHECKED	ALS	CHECKED	NA	75	CHECKED	93	CHECKED	CHECKED	CHECKED	153.00
DB13	CHECKED	ALS	CHECKED	NA	74	CHECKED	85	CHECKED	CHECKED	CHECKED	203.00
DB14	CHECKED	ALS	CHECKED	NA	66	CHECKED	87	CHECKED	CHECKED	CHECKED	219.00
DB14_A	CHECKED	ALS	CHECKED	CHECKED	68.7	CHECKED	91	CHECKED	CHECKED	CHECKED	210.00
DB14_B	CHECKED	ALS	CHECKED	CHECKED	43	CHECKED	81	CHECKED	CHECKED	CHECKED	96.00
DB15	CHECKED	ALS	CHECKED	NA	33	CHECKED	69	CHECKED	CHECKED	CHECKED	92.00
DB16	CHECKED	ALS	CHECKED	NA	46	CHECKED	83	CHECKED	CHECKED	CHECKED	201.00
DB17	CHECKED	ALS	CHECKED	NA	49	CHECKED	80	CHECKED	CHECKED	CHECKED	75.00
DB18	CHECKED	ALS	CHECKED	NA	63	CHECKED	95	CHECKED	CHECHED	CHECKED	257.00
DB19	CHECKED	ALS	CHECKED	NA	62	CHECKED	96	CHECKED	CHECHED	CHECKED	180.00

Figure 3.5 : Drillhole validation.

3.1 Field Data and Validation

3.1.1 Density

A geological model is used to predict the mineralized volume, and this volume in turn is multiplied by its in-situ density to obtain an estimated tonnage for deposit. Any error made in density determination and estimation is directly incorporated into tonnage estimates (Rossi and Deutsch, 2014).

86 core samples had submitted to a laboratory by the company to determine the specific gravity value. After investigation into the density values considering rock type and grade values, it is concluded that the amount of density changes related with ore body. So, densities of lead and zinc compared and it observed that the density values should determine consistent with lead values (Figure 3.6). It can seen from table that the density values shown variation from 2.33 to 6.82 according to grade of lead values and it is crucial to use different density values to estimated blocks that have various lead occurances to make best tonnage estimates (Table 3.1). Reserve tonnage calculations has been made considering mean density values for different Pb% grade for Pb<2% ore, 2<Pb<8% ore and Pb>8% ore respectively.

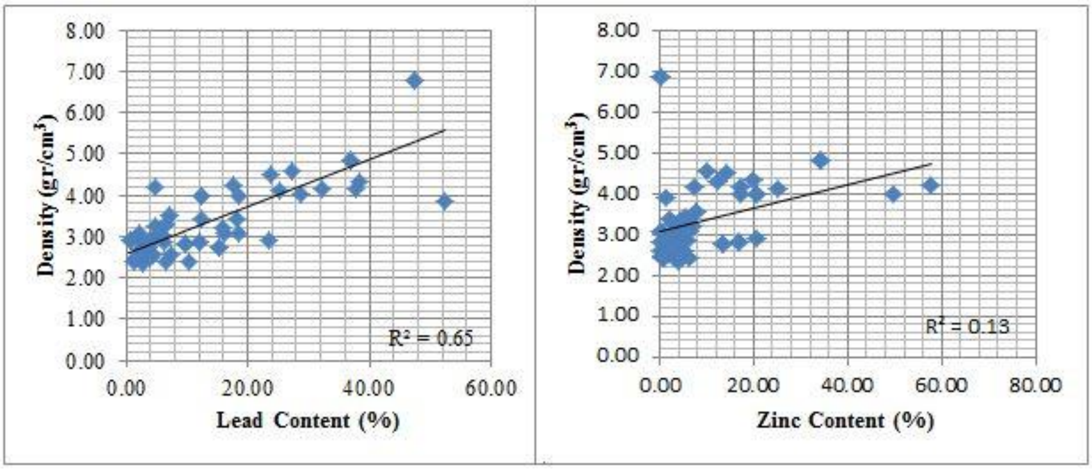

Figure 3.6 : Density-lead and density-zinc grade comparison.

Table 3.1 : Density based on Pb grade.

Pb (%) - Specific Gravity			
	2 <	**2 < %Pb < 8**	**8 >**
Mean	2.71	2.87	3.76
Minimum	2.40	2.33	2.38
Maximum	3.03	4.21	6.82

Table 3.2 : Density based on Pb% grade.

Lead	Drillhole	Sample no	Interval From	Interval To	Pb (%)	Zn (%)	Density (g/cm^3)
% <2	DB1	114	75	78	0.13	0.02	2.83
		137	125	127	0.66	0.07	2.77
		138	127	130	0.11	0.03	2.74
		139	130	132	0.05	0.03	2.58
		143	145	147	1.06	1.53	2.73
		144	147	149	0.93	1.15	2.71
	DB8	148	30	32	0.68	0.32	2.96
		151	36	37.5	1.21	0.9	2.75
		2304	63	65	0.03	0.04	2.52
		2306	67	68.5	0.04	0.04	2.65
		2311	95	97	0.36	0.546	2.78
	DB18	556	18	20	0.01	0.02	2.7
		565	40	41	1.18	0.935	2.73
		590	85	87	0.46	0.79	2.66
		569	47	49	0.43	0.62	2.69
		625	198	201	0.05	0.02	2.54
	DB20	672	33	36	0.24	0.45	2.53
		703	132	134	1.51	1.48	3.03
		704	134	135.5	0.02	0.02	2.71
		707	143	144	0.87	0.32	2.95
		721	171	174	0.02	0.01	2.51
	DB37	2594	37	39	0.14	0.15	2.95
		2604	55	57	1.18	0.86	2.74
		2606	57	59	0.61	0.52	2.66
		2626	109	111	0.01	0.02	2.97
		2628	113	115	0.53	0.49	2.4
	DB38_A	2792	135	137	0.5	3.31	2.93
	DB60_A	6538	116.8	118	1.63	0.86	2.48
	DB61_C	6656	91.5	93.1	1.28	0.6	2.4
2 < % < 8	DB8	187	124	125	4.32	0.936	2.82
	DB18	592	88	89	2.96	5.3	3.03
		595	93	96	2.86	6.23	2.98
	DB20	682	63	66	2.29	4.07	2.78
	DB37	2640	186	187.4	3.39	3.28	2.79
	DB38_A	2777	109.5	110.5	6.57	4.68	3.3
	DB48_B	4355	148	149.5	3.97	4.3	2.59
		4356	149.5	151	4.47	5.11	2.58
	DB48_C	4397	135	136.2	7.42	0.35	2.59
		4399	137.8	139.2	6.88	8.23	3.55

Table 3.2 continue : Density based on Pb% grade.

Lead	Drillhole	Sample no	Interval From	Interval To	Pb (%)	Zn (%)	Density (g/cm^3)
2 < % < 8	DB53_A	4920	141.2	143	6.59	1.21	2.41
		4937	168	170	4.08	3.93	2.89
		4944	181	184	4.51	2.99	2.98
		4945	184	185.5	6.13	6	2.86
	DB60_A	6495	61	62.5	3.56	3.86	2.76
		6469	62.5	63.7	2.19	1.81	2.53
		6498	65	66.4	2.57	2.36	2.66
	DB60_B	6681	63.7	64.6	2.21	5.3	3.06
	DB60_C	6749	57	60	3.54	0.13	2.8
	DB61_A	6284	108.4	110	2.72	4.39	2.33
	DB61_B	6602	115.2	116.5	3.93	3.36	2.44
		6605	120.35	122	3.01	1.57	2.86
	DB61_C	6657	93.1	93.5	4.83	58	4.21
	DB63	6925	177	180	5.88	0.95	3.01
		6926	180	181.5	4.78	2.99	3.23
		6927	181.5	183.3	2.22	4.19	2.52
% > 8	DB1	125	99	100	21.3	5.59	4.57
		129	106	108	7.67	3.28	2.89
	DB8	165	58	59.6	16.6	16.85	4.32
		170	76.5	77.5	11.2	15	2.89
	DB18	572	53	54	17.4	24.7	4.02
	DB20	708	144	146	9.08	13.9	3.77
		740	204	207	11.4	9.42	3.35
	DB38_A	2778	110.5	112	12.4	21	3.71
	DB40	2818	77	78.5	16.1	0.59	3.54
	DB53_A	4919	139.2	141.2	36.7	34.2	4.8
		4921	143	144.5	47.4	0.25	6.82
		4938	170	172	18.15	2.03	3.4
		4946	185	187	15.6	13.5	2.75
		4947	187	187.4	23.3	20.9	2.94
	DB60_A	6537	115.7	116.8	11.85	1.81	2.84
	DB61_A	6285	110	110.5	18.4	50.3	3.97
		6328	172.8	174	23.9	14.45	4.48
		6329	174	175.1	38.5	20.2	4.34
		6330	175.1	176.2	32.4	17.35	4.16
		6333	179.2	181	37.9	7.41	4.17
		6334	181	183	17.8	12.65	4.29
		6335	183	185	27.4	10.3	4.57
		6336	185	187.1	12.55	5.78	3.41

Table 3.2 continue : Density based on Pb% grade.

Lead	Drillhole	Sample no	Interval From	Interval To	Pb (%)	Zn (%)	Density (g/cm^3)
% > 8	DB61_B	6601	113.9	115.2	15.85	7.22	3.19
		6603	116.5	117.4	10.35	6.8	2.38
		6604	117.4	120.35	16.05	6.63	3.06
	DB_62	6206	116.5	117.8	9.55	17.15	2.82
		6207	117.8	119.2	28.9	17.7	4.01
		6208	119.2	120.3	25.4	25.4	4.11
		6209	120.3	121.2	52.4	1.69	3.86
		6210	121.2	121.8	18.55	0.34	3.1

3.1.2 Topography

The topographic wireframe surface was generated in Surpac from CAD with surface creation tool (Figure 3.7). And the CAD version given by the company. Topography was made by company's land surveyors using by 34 polygons in a scale with 1/1000 and it mapped in AutoCAD on May 2009 (Figure3.8).

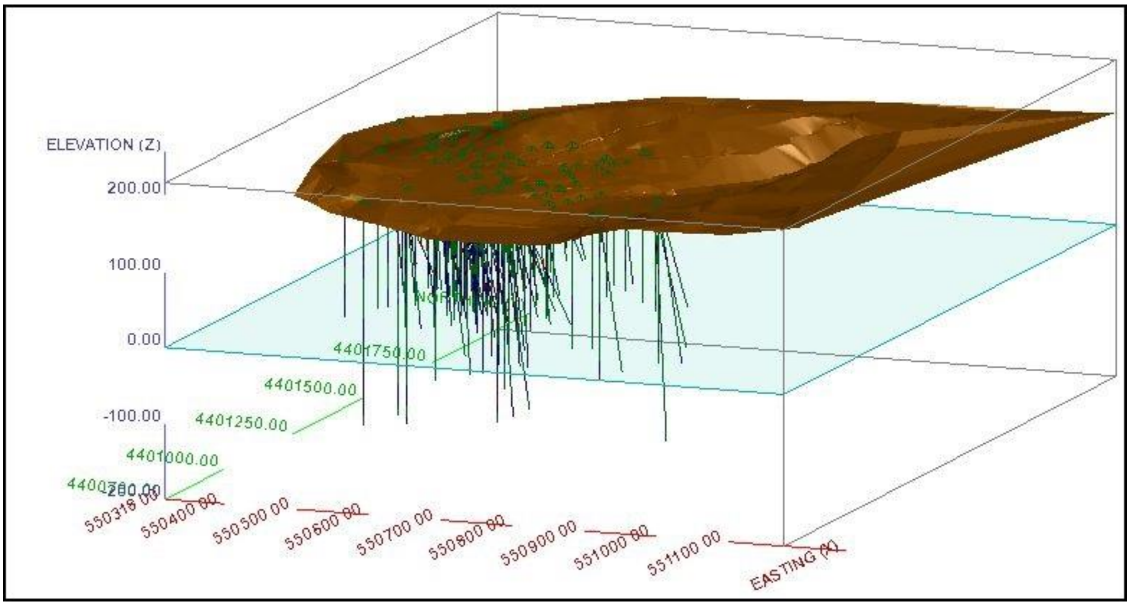

Figure 3.7 : Topography with drillholes on Surpac

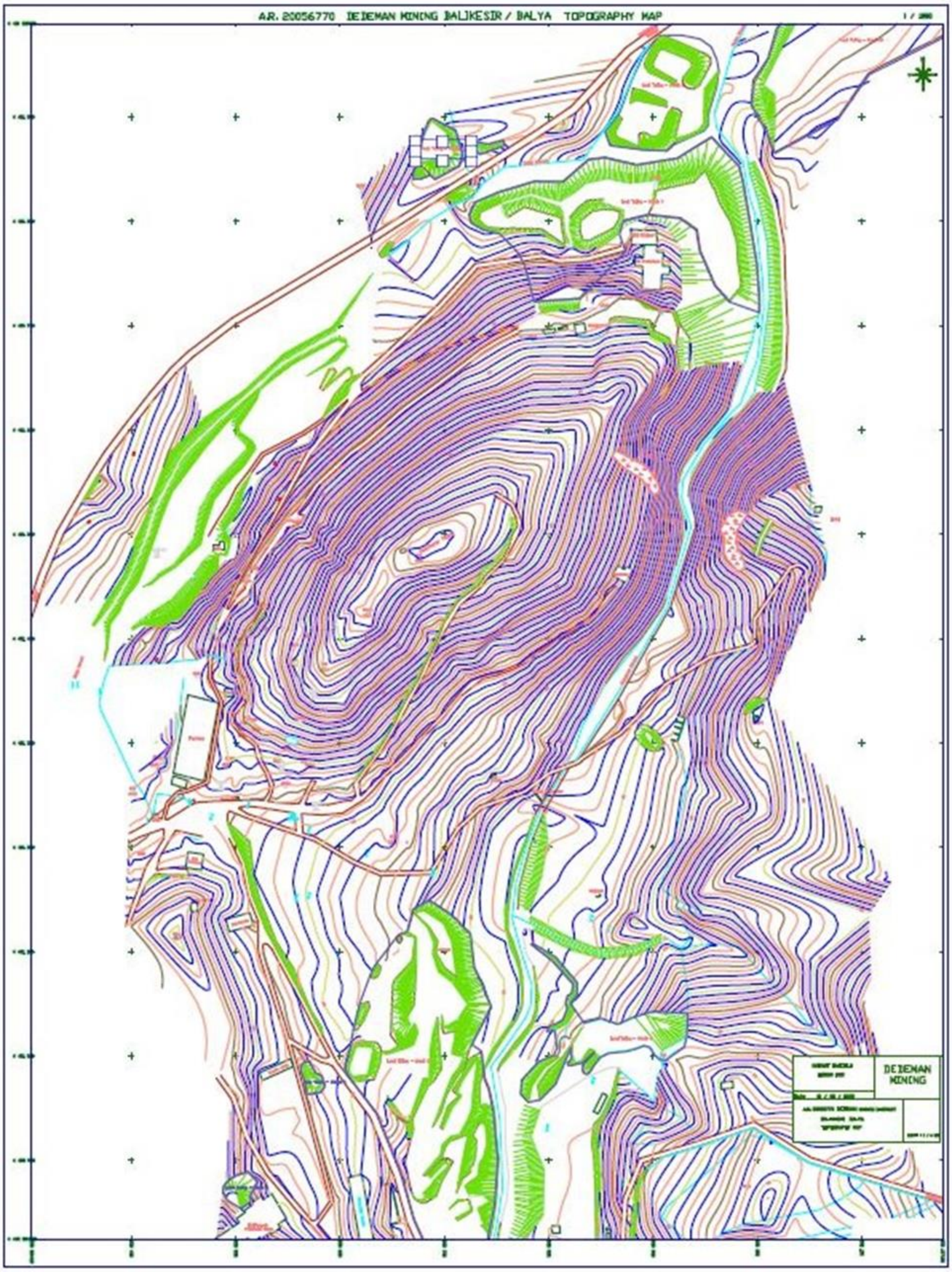

Figure 3.8 : Autocad version of Balya topography map

3.2 Drillholes Database and Validation

About 184 diamond drill holes, 33.153 m, were made and research works still going. 6 drillholes which are DB29, DB29_A, DB29_B, DB29_C, DB29_D and DB27 haven't include the study for the reason of distance to other drillholes and study area. Company completed these drillholes in the locations close to Sarısu and Ari-Orta mines that are far away from the study area where is Hastanetepe to see the continuity of mineralization.

The drillhole mapping procedures, core sections, sampling procedures and the study area geology as well as structural geology was carried out with respect to standards of JORC.

To store the drill holes, plastic core boxes are used with the plastic separators to control the meters of drillholes. Drillholes are stored in a special building in field area. The drillhole core samples were halfing for sampling and chemical analyses in storage area.

Each core box is photographed. Natural light is used for pictures of drillhole core when possible, or use adequate artificial lighting (Figure 3.9).

Geological and core recovery informations are transformed to a grid lined paper sheet (Figure 3.10) for each drillholes, using a 1:200 scale.

Drilling have undertaken by the Company's Atlas Copco Diamec and Longyear LF70 machines.

Figure 3.9 : Drillhole Core Boxes

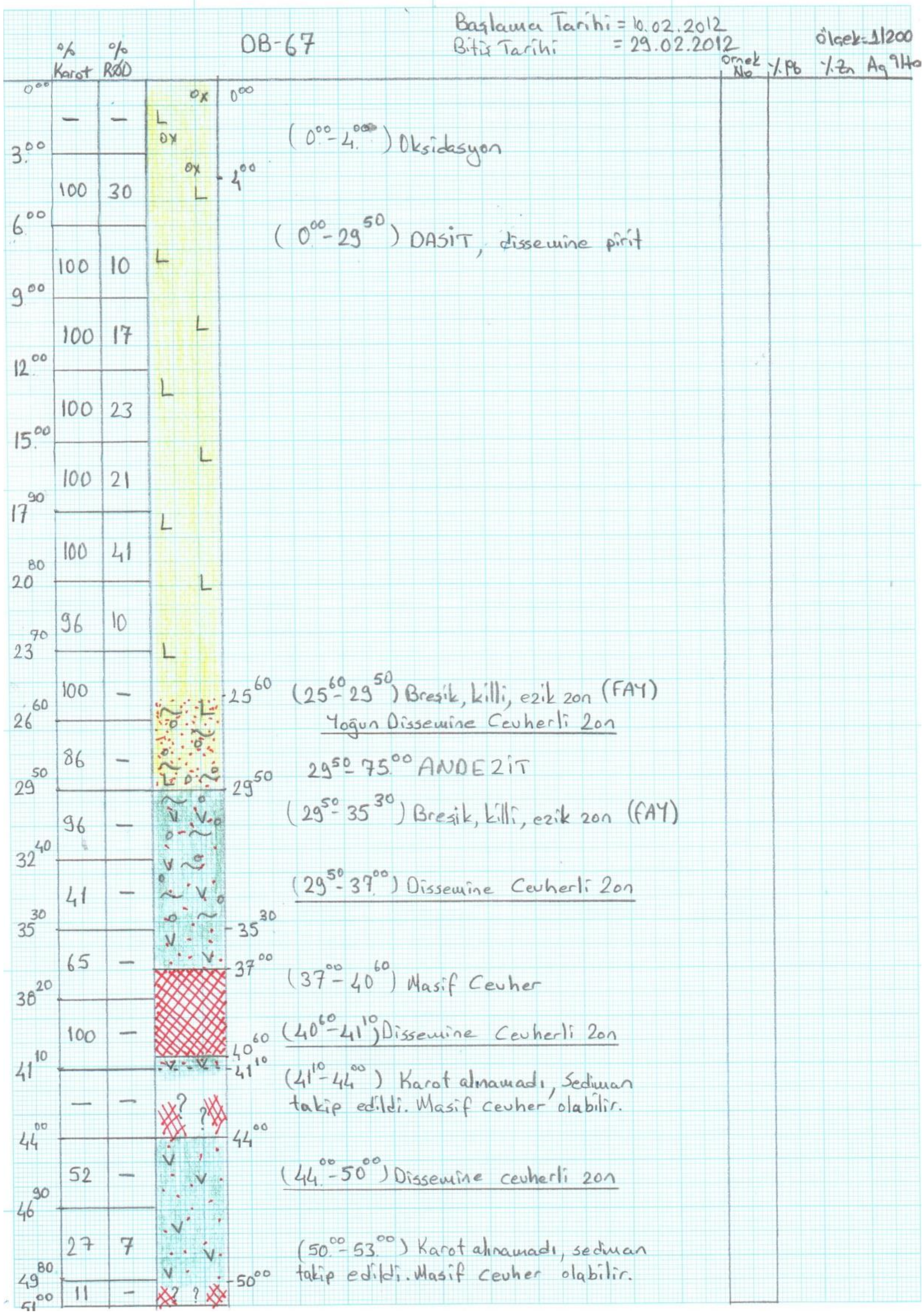

Figure 3.10 : Diamond Drillhole Logging Example

3.2.1 Collar

Current database consists with 184 drill holes and its following informations. Collar table contains hole-id, easting and northing coordinate, elevation and length of the hole. Other optional fields are project information, starting and ending date, hole-path, etc. Hole path is also important for some integrated mining computer programs, so it should be well defined.

3.2.2 Survey

The drillhole survey data allows software programs to graphically depict deviation of both dip and azimuth to show a realistic drillhole trace location in 2D and 3D. Down hole survey table fields also include, azimuth and dip.

52 drillholes azimuth and dip information has measured to see inclination in hole using Flexit Single Shot Downhole surveying tool and its standardized measurement average is 30 meter. It decided that there is significant reliance on survey data so holes have not inclination eventfully.

3.2.3 Geology

Company has detailed geology discrimination on database for each hole. Geology table include hole-id, depth-from, depth-to, structure, rock-type, alteration, mineralization, mineral description, etc.

3.2.4 Sample

Sample data requirements can vary significantly depending on the project. It should include the metals of interest and other elements that impact the project especially for metalliferious mines. In this study, sample table include depth-from, depth-to, pb%, zn%, ag (gr/t), batch-no, sample no, etc.

Total 13,214 meter drillholes are sampled. Average sample length of drillholes are 1.85 meter and length varies between 4 m and 0.30 m. Apart from that, only one sample was taken just to obtain and investigate grade values for waste rock having 20.5 m length.

3.2.5 Quality Assurance and Quality Control of Geochemical Data

A selection of Geostats (Pty) Ltd. base metal reference material is utilised for Balya Pb-Zn mine as base standard samples defined as CRM. The CRM's performed well by plotting within the 2 standard deviation limits either side of the mean for the respective CRM. There are 16 CRM failures out of 900 samples although there was 26 CRM failures according to the QA/QC investigations. After detailed investigations of these 26 samples, 10 of them were identified that were totally belong to standard samples named as GBM 902-3 and GBM 305-6. Because of the fact that the total values of failured samples were accounted as 16 out of 900 samples tested for QA/QC investigations. The pulp duplicates correlated well with the original values. The regressions through the origin produced slopes close to 1:1. Very few duplicates exceeded the 20% differential, which is utilised an industry benchmark. The blank values returned only trace values of Pb and Zn, except for two samples that sample number of one of them is 4022 and the other one is 3891. These samples should be checked to see if it was in fact a CRM not a blank.

QA/QC protocol has been implemented since 2007. Blanks, standard and pulp duplicates are tested and their results have been graphed by the Company staff. A process is underway to increase the QA\QC quota to industry best practise levels.

3.2.6 Geotechnical

It contains core recovery and rock quality designation (RQD) calculations. Solid core recovery (SCR) is the borehole core recovery percentage of rock core.

RQD is the other parameter that can measure rock quality and it’s a modified core recovery percentage in which unrecovered core, fragments and small pieces of rock, and altered rock are not counted so as to downgrade the quality designation of rock containing these features. It is a rough measure of the degree of fracture in a rock mass, measured as a percentage of the drill core in lengths of 10 cm or more.

181 of 184 drillholes core recovery and RQD values were calculated by field geologist. Average length weighted core recovery is 87.04% while average RQD is calculated as 41.55%.

4. ORE BODY MODELLING METHODOLOGY

Ore body must be quantified to be used in mining design and production process. The process in sometimes called as deterministic geologic modelling due to the absence of a measure for uncertainity, hence conventional approaches to obtain block solid model of ore deposit should be applied from the interpretations on cross-sections and plan maps (Rossi and Deutsch, 2014). Ore body model is a representation or an interpretation of a mineral deposit. The deposit could be any commodity, including gold, iron, or coal. A methodology is prepared to obtain solid modelling of an orebody in Figure 4.1.

Balya orebody model started with a critical review of existing drill hole and surface sample data as well as topographic map and plans with current geological interpretation.

The modeling of the ore body was performed using Surpac 3D software and sectional method were used. An area of mineralisation in each section is outlined considering by grade value of samples, geological formations and both previous and next sections. Mineralization extends in the middle of two adjacent cross-sections when the continuity ends in the subsequent cross-sections. Ore body string and solid model view can be seen in Figure 4.2.

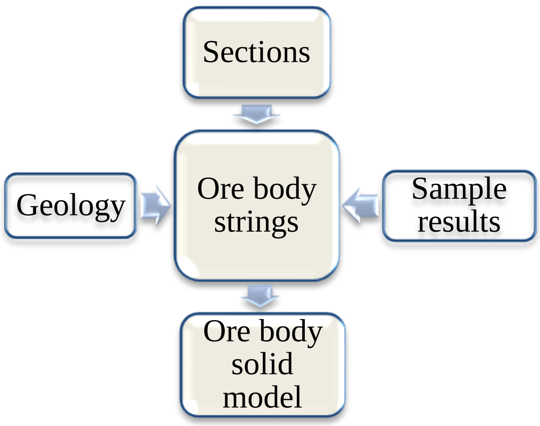

Figure 4.1 : Solid model methodology

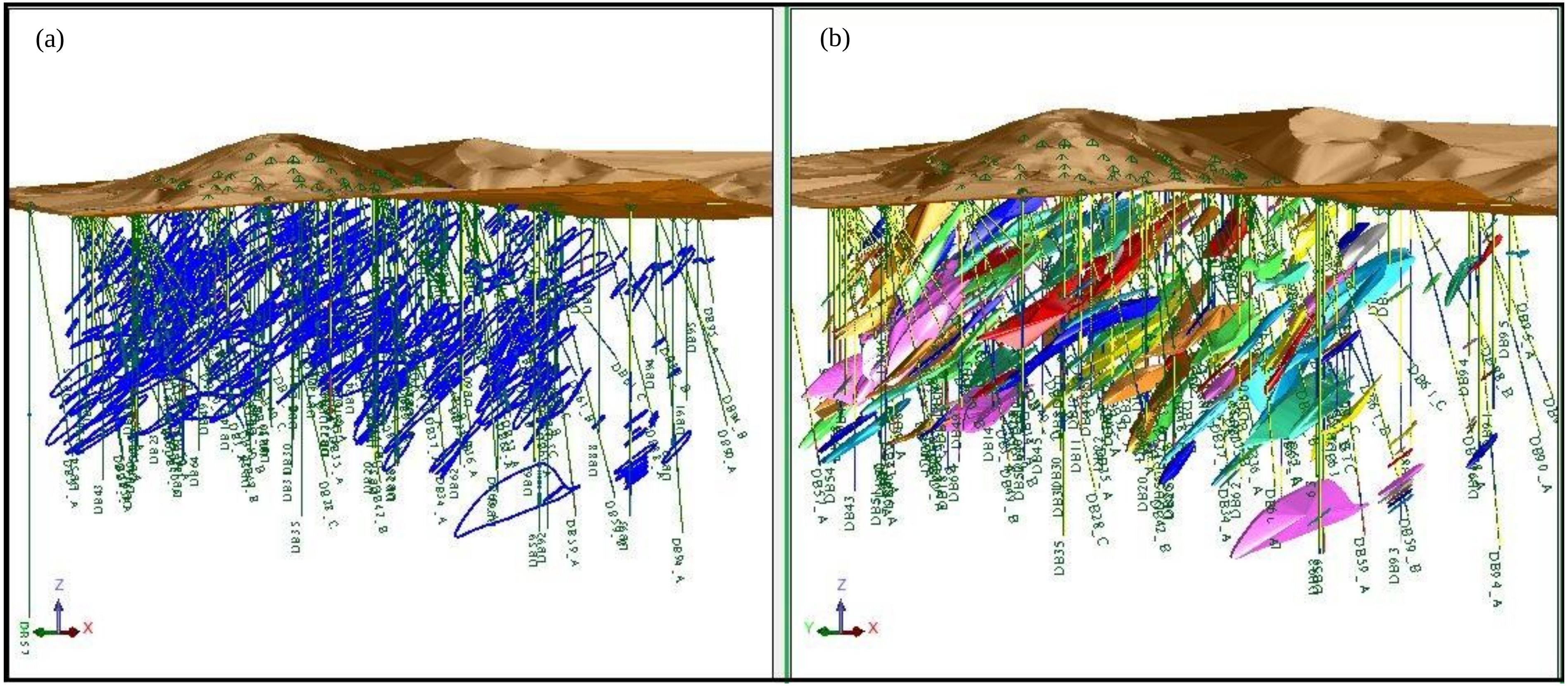

Figure 4.2 : Balya ore body (a) strings and (b) solid models

4.1 Sections

Development of a solid geological model is assisted by geological correlation between boreholes according to the drilling log database.

17 cross sections have taken based on Hastanetepe ore deposit. Moreover, section 17-17’ has not been considered including drillholes far from the Hastanetepe study area (Figure 4.3). These sections arranged to reflect almost same meters from front and back, approximetly 20 meters between each section. Drillholes reflected the section closest to themselves. An example is prepared to show the cross-sections of 8-8’ and 9-9’ in Figure 4.4.

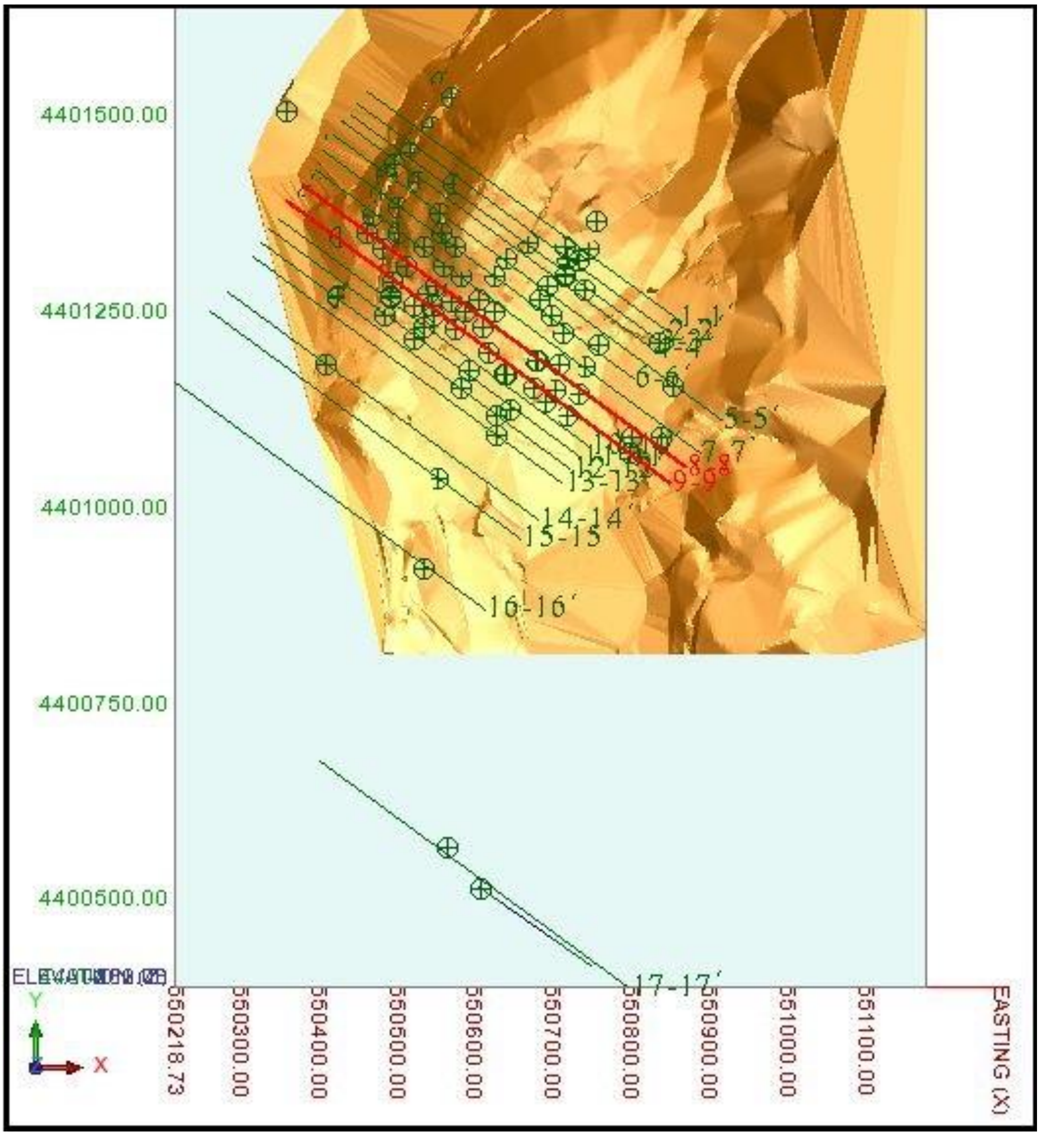

Figure 4.3 : Sections in plan view

4.2 Solid Model

Because of the mineralization is generally considered to be related to fault and fracture system, there are a lot of ore occurance as a both vein and dissemine. Therefore, it had modelled 169 different ore solid including little occurrences (Fig. 4.5, 4.6, 4.7) considering mainly geology and sample assay results.

Besides the main ores, also ores that occurances proved only one or two drillholes had modelled for resource study. Little ore occurences can be develop by drilling studies along the southwestern area of Hastanetepe.

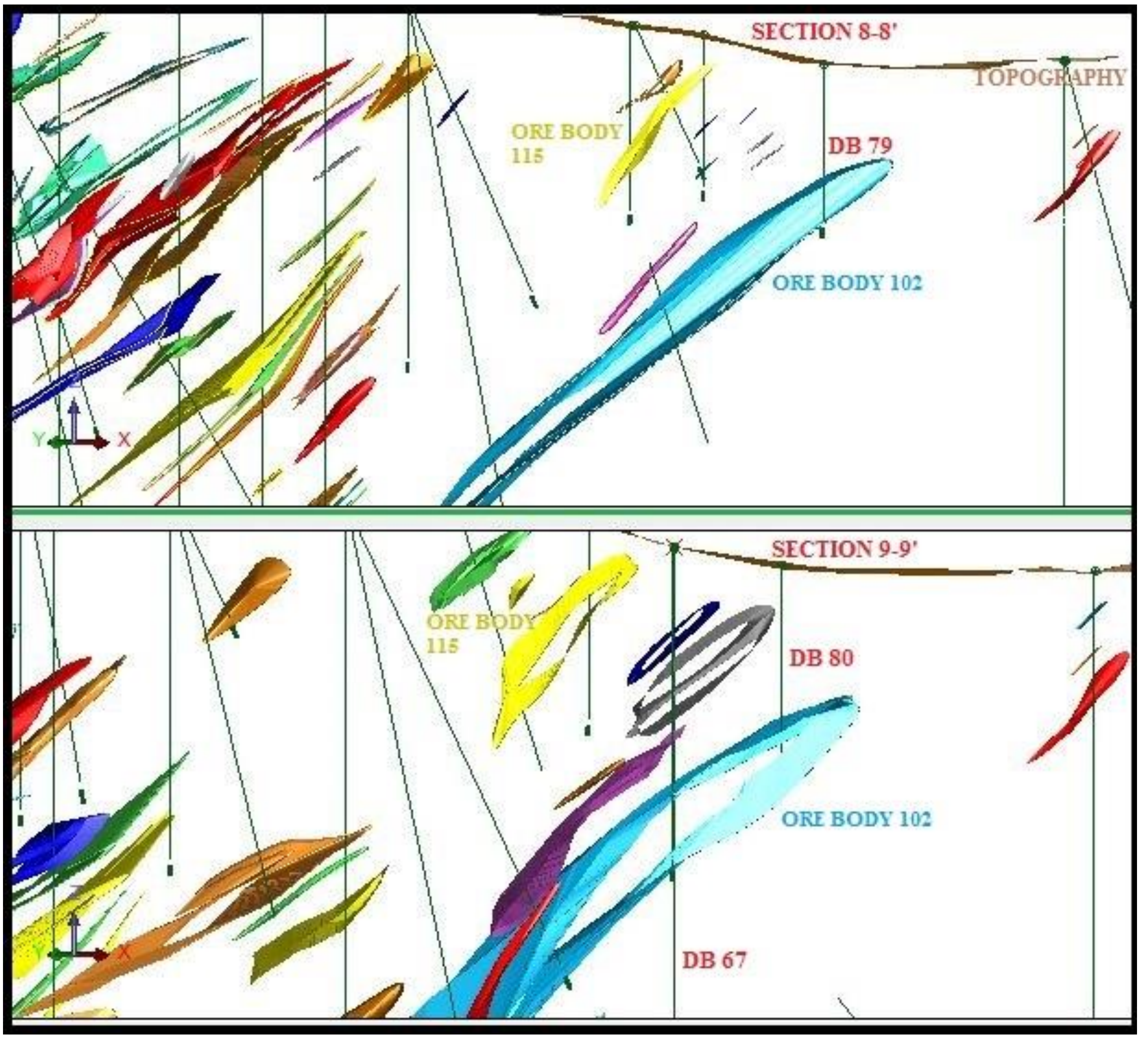

Figure 4.4 : Section 8-8’ and 9-9’ view

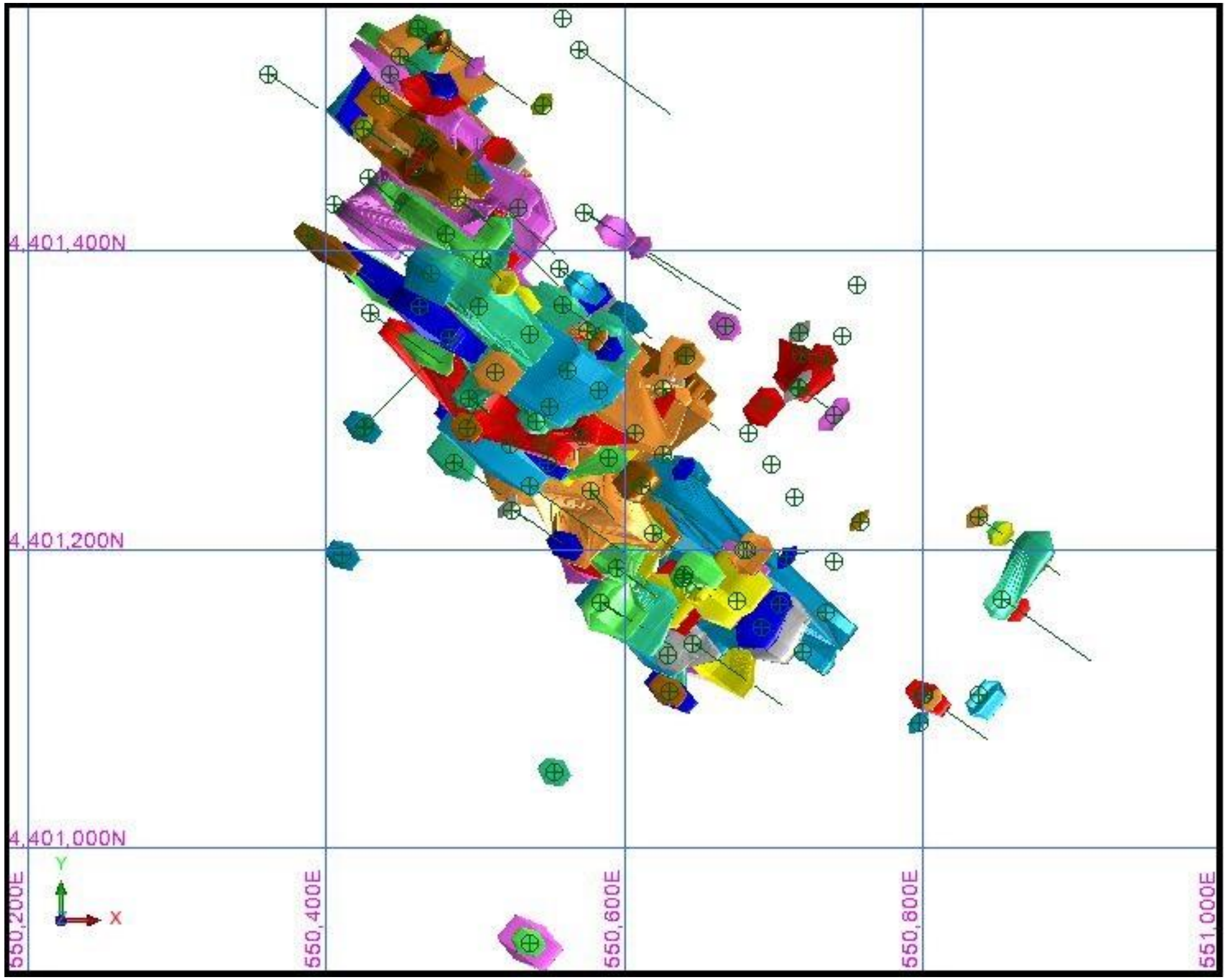

Figure 4.5 : Ore body solid model on Northing and Easting view

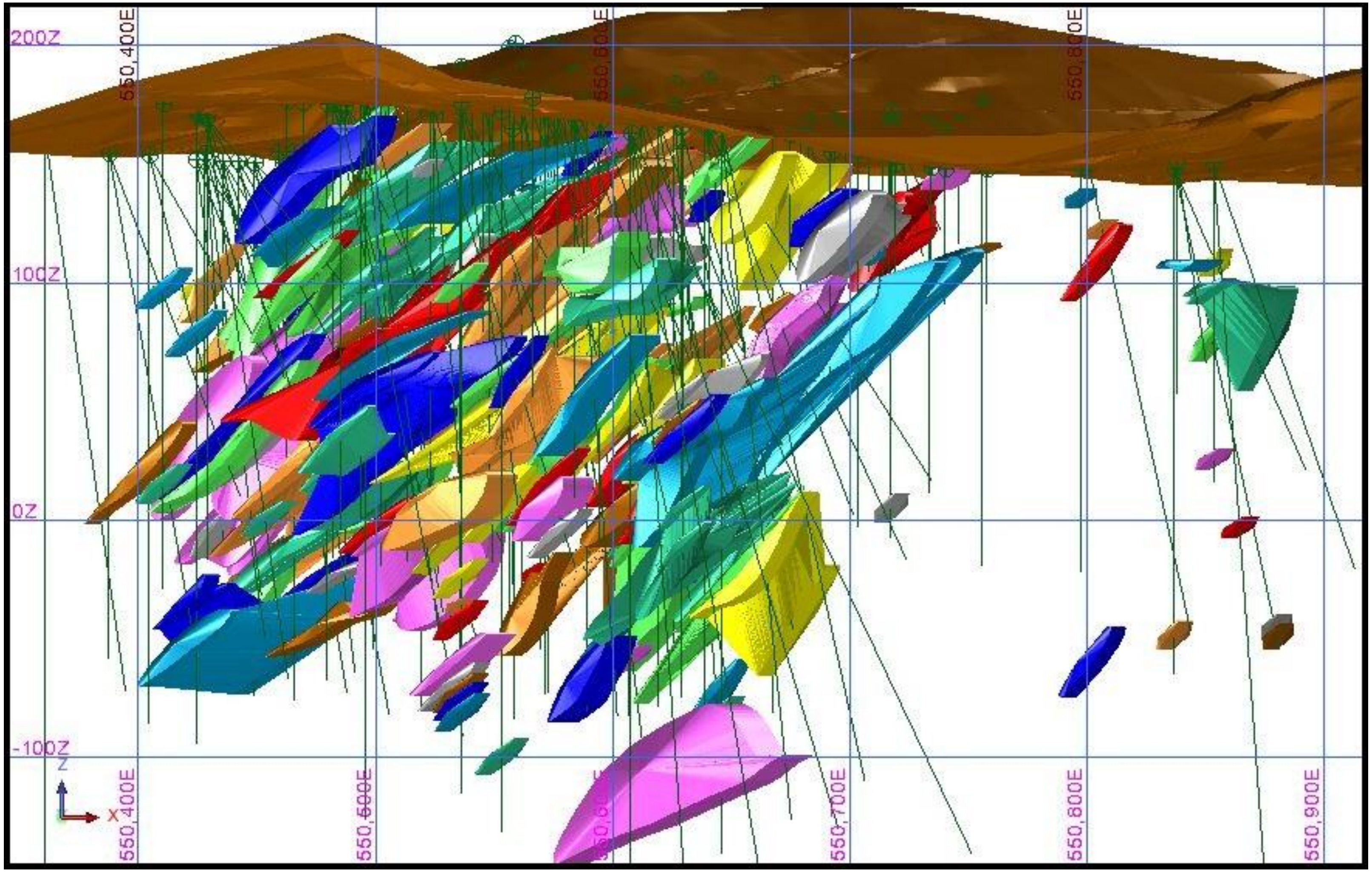

Figure 4.6 : Ore body solid model on Elevation and Easting view

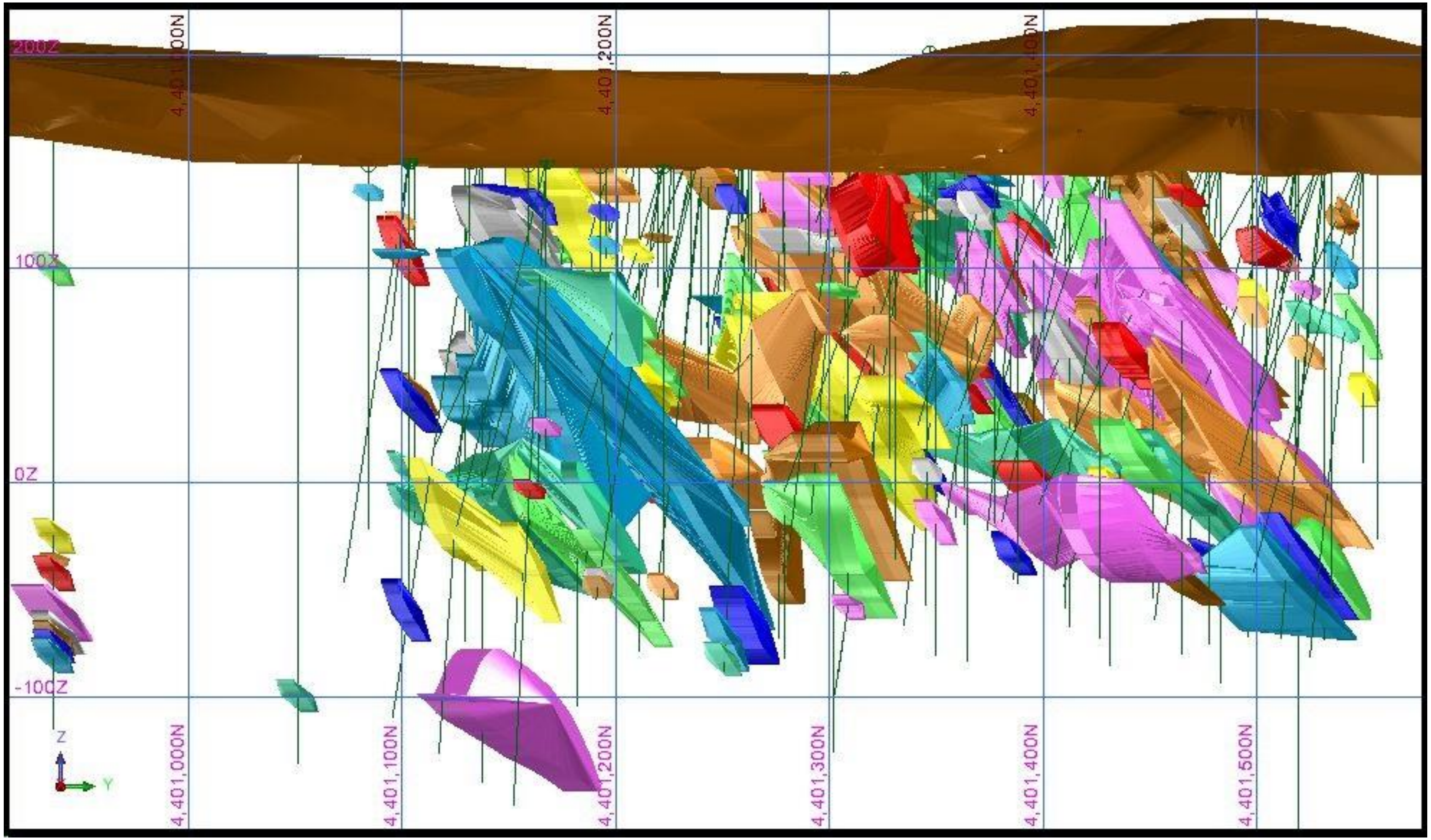

Figure 4.7 : Ore body solid model on Elevation and Northing view

4.3 Block Model

The block size should be decided based on the drillhole data spacing and other engineering considerations. Larger blocks are easier to estimate than smaller blocks in the sense that the predicted grades are more likely to be close to the actual grade of block. On the other hand, too large a block size is not useful for pit optimization and mine planning. Typical mine planning packages work on smaller blocks that discretize to time interval on which the mine plan is based (Rossi and Deutsch, 2014). Considering that knowledge block model have maden in using 5x5x5 m block size with 1.25x1.25x1.25 m sub-blocking. Because of there are a lot of ore occurences in study area and ore describe as vein type, it decided to use sub-blocking for to reflect it better. Block coordinates and parameters as shown in Table 4.1. Total block is 353,768 and its storage efficiency is 99.36% (Fig. 4.8).

Table 4.1 : Block model parameters.

	Y	**X**	**Z**
Minimum Coordinates	4400917	550377.3	-144.62
Maximum Coordinates	4401562	550892.3	180.38
User Block Size	5	5	5
Minimum Block Size	1.25	1.25	1.25
Total Blocks		353,768	
Storage Efficiency		99.4%	

Attribute Name	**Type**	**Decimals**	**Background Description**
Ag	Real	2	-1
Pb	Real	2	-1
Sg	Real	2	2.87
Zn	Real	2	-1

Block models constrained using both ore body solid model and topography (Fig. 4.9). Lead, zinc and silver estimation had made to that constrained blocks.

After estimation using lead grades, density assign to the each block. Two different constrained blocks were used. Constrain have made to lead values less than 2% and density value assign that blocks as 2.71, and then another contrain which lead values more than 8% have made and density value assign that blocks as 3.76.

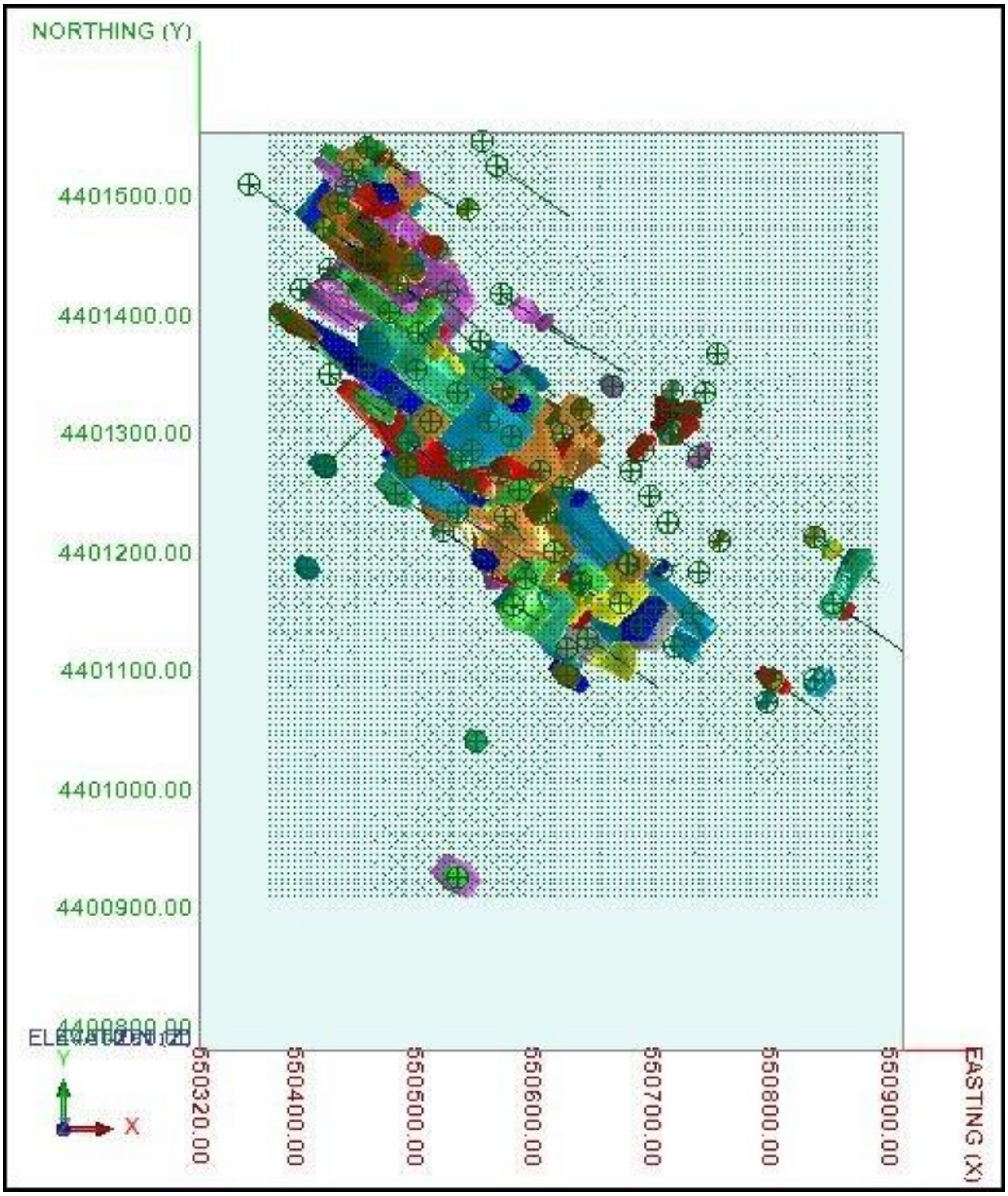

Figure 4.8 : All blocks with ore model on Northing-Easting view.

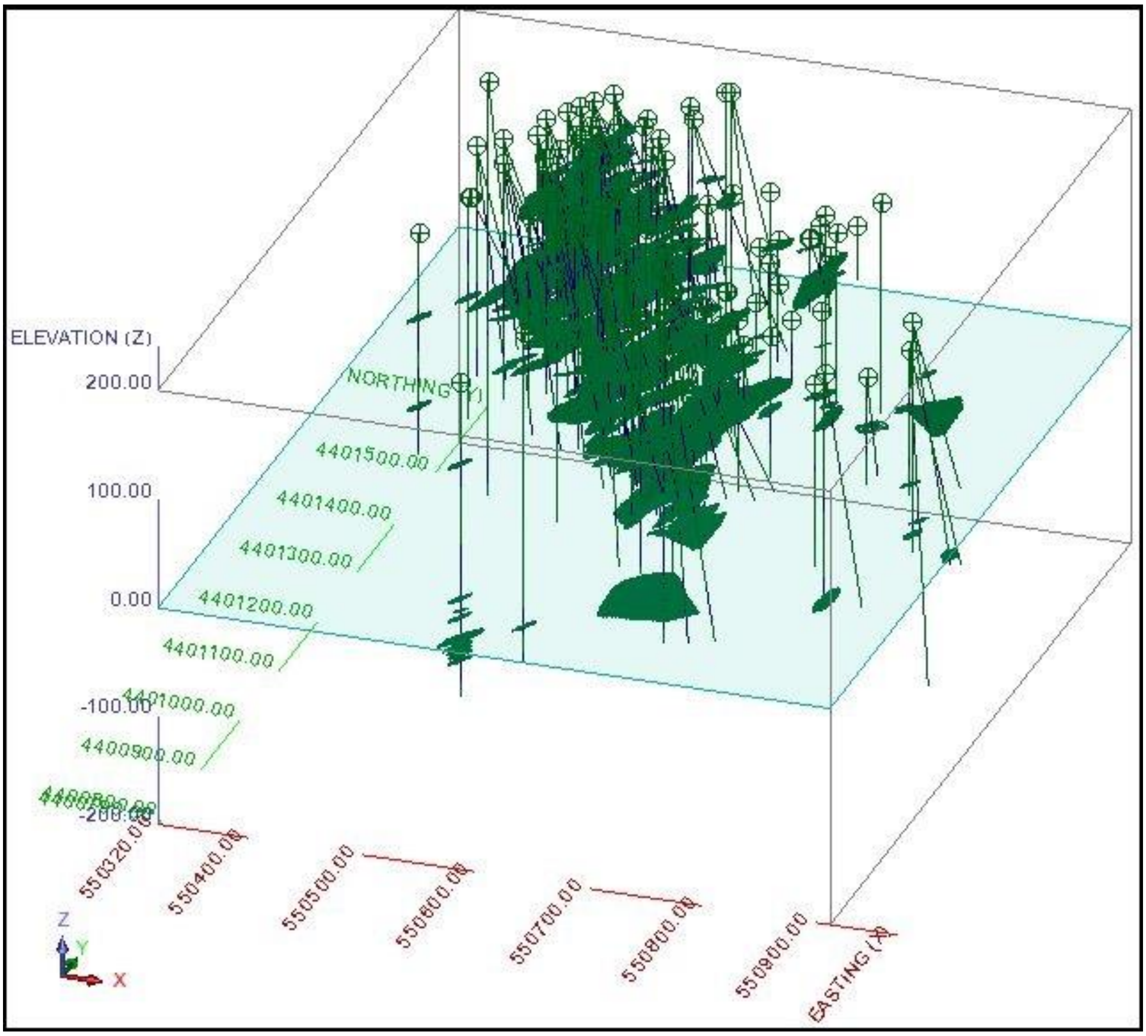

Figure 4.9 : Constrained block model view.

5. GEOSTATISTICAL MODELLING METHODOLOGY

Problems in mining, such as unbiased estimation of recoverable reserves, initially drove the development of geostatistics (Khan and Deutsch, 2008).

Statistical basic investigations have been made both for raw and estimated data carried out in Ms. Excel and descriptive statistic with sample inside ore body. A methodology to decide determining variogram for estimation procedure is proposed as detailed in Figure 5.1. As can be seen in this method structure, 1-m composite data applied for a transformed data is used to obtain a proper regional dependency function having a highly correlated cross validation results.

Sample data transformed by each ore occurences have one sample result on related drillholes. Average mean of it had been made on excel to find better connection between known and estimated grade values. This transformation only made for values inside ore body different length for each ore body and each drillhole in it, so it calculated with average mean and accepted like one sample. Then these values added to Surpac database and 1 m composite database has been made. These transformed data used for estimation of grade and tonnage value in study area.

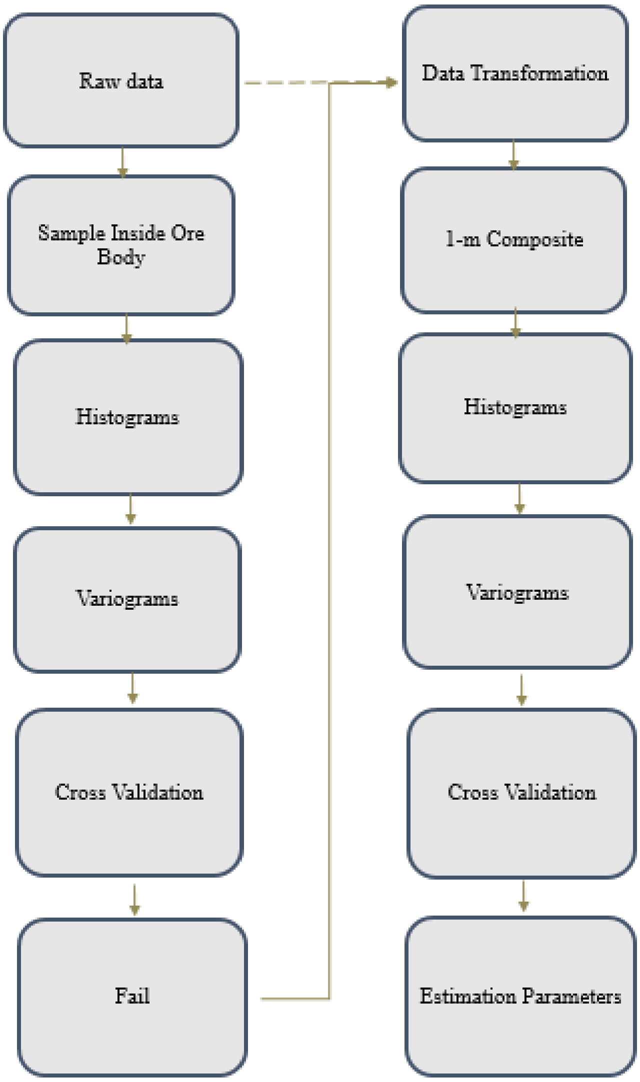

Figure 5.1 : Geostatistical investigation process

5.1 Statistical Investigations

5.1.1 Descriptive statistics

Using the relationship between lead, zinc and silver from the equations as shown in table 5.1 where S means covariance estimation made for lead, zinc and silver relatively (Figure 5.2). Investigations carried out using all of the samples in this area. As it can be seen in graphs, it can be estimated lead or silver values using the others with average R^2: 0.78 and that's kind a evidence about relationship between lead and silver occurances in Hastanetepe mine.

Table 5.1 : Formula using for estimation.

$b0 + b1\ (ag) + b2\ (zn) = pb$	$b0 + b1\ (ag) + b2\ (pb) = zn$	$b0 + b1\ (pb) + b2\ (zn) = ag$
$b1\ s^2_{ag} + b2\ S_{ag,\ zn} = s_{ag,pb}$	$b1\ s^2_{ag} + b2\ S_{ag,\ pb} = s_{ag,zn}$	$b1\ s^2_{pb} + b2\ S_{pb,\ zn} = s_{pb,ag}$
$b1\ S_{ag,\ zn} + b2\ S^2_{zn} = s_{zn,pb}$	$b1\ S_{ag,\ pb} + b2\ S^2_{pb} = s_{pb,zn}$	$b1\ S_{pb,\ zn} + b2\ S^2_{zn} = s_{zn,ag}$

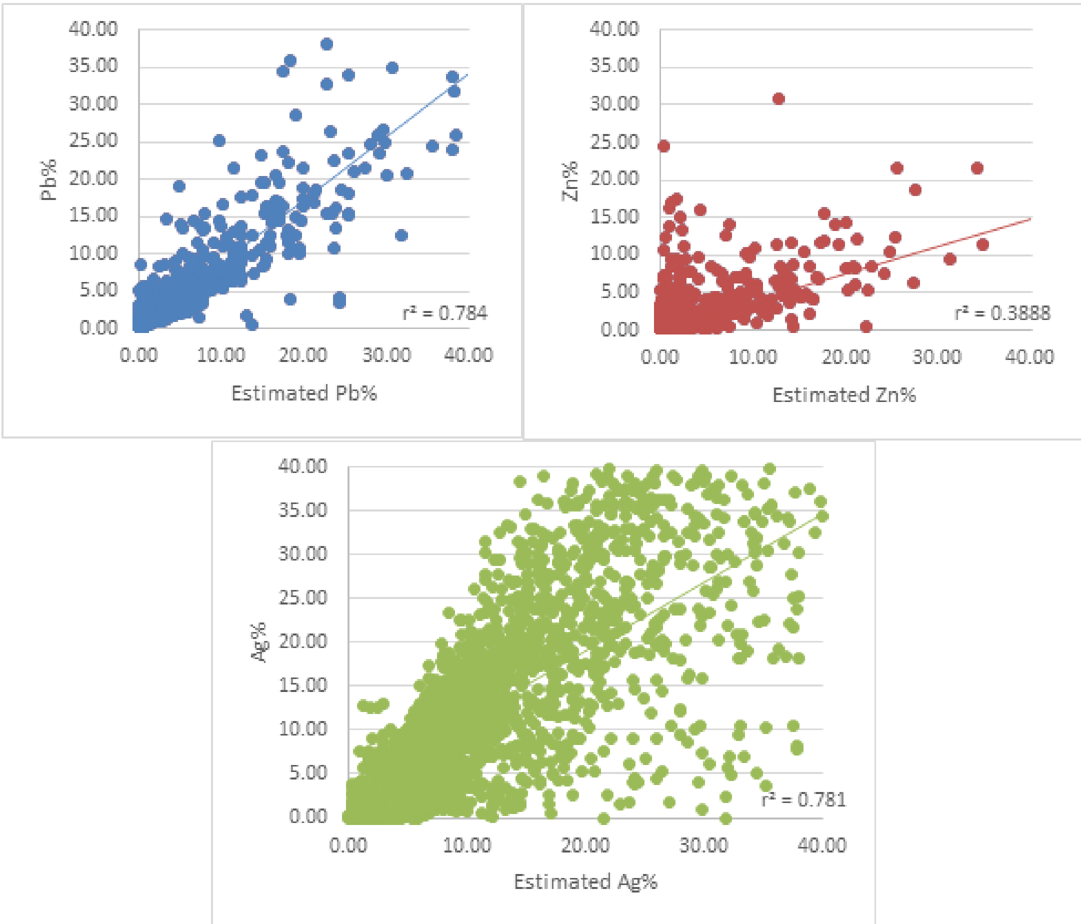

Figure 5.2 : Estimations from multiple linear regression models.

Descriptive statistic was completed using sample data inside orebody which population is 1684 (Table 5.2). According to that basic statistic evaluation, lead values change from 0.01 to 64.46 and its mean percentage is 3.65 % with a standard deviation of 5.85. Zinc values are between 0 and 58% and its mean percentage is 2.04 % with a standard deviation of 4.39, and finally silver values between 0.25 and 1442 (gr/ton) and its mean percentage is 55.88 % with a standard deviation of 109.02.

Table 5.2 : Descriptive statistic results for sample inside orebody.

Pb		Zn		Ag	
Mean	3.65	Mean	2.04	Mean	55.88
Standard Error	0.14	Standard Error	0.11	Standard Error	2.66
Median	1.79	Median	0.68	Median	23.50
Mode	1.21	Mode	0.04	Mode	11.50
Std. Deviation	5.85	Std. Deviation	4.39	Std. Deviation	109.02
Sample Variance	34.21	Sample Variance	19.28	Sample Variance	11886.05
Kurtosis	24.30	Kurtosis	44.57	Kurtosis	50.32
Skewness	4.27	Skewness	5.61	Skewness	5.96
Range	64.45	Range	58.00	Range	1441.75
Minimum	0.01	Minimum	0.00	Minimum	0.25
Maximum	64.46	Maximum	58.00	Maximum	1442.00
Sum	6146.47	Sum	3431.11	Sum	94099.20
Count	1684	Count	1684	Count	1684

Descriptive statistic completed using sample transformed data for each ore occurences on each drillholes which population is 588 (Table 5.3). According to that basic statistic evaluation, lead values change from 0.01 to 40.60 and its mean percentage is 3.07 % with a standard deviation of 4.38; zinc values are between 0.01-27.60 and its mean percentage is 1.82 % with a standard deviation of 3.05; silver values between 0.25-931.24 and its mean percentage is 50.07% with a standard deviation of 85.67.

Table 5.3 : Descriptive statistic results for sample on each ore occurences.

Pb		Zn		Ag	
Mean	3.07	Mean	1.82	Mean	50.07
Standard Error	0.18	Standard Error	0.13	Standard Error	3.53
Median	1.82	Median	0.83	Median	26.85
Mode	1.71	Mode	0.08	Mode	0.25
Standard Deviation	4.38	Standard Deviation	3.05	Standard Deviation	85.67
Sample Variance	19.17	Sample Variance	9.31	Sample Variance	7339.64
Kurtosis	27.47	Kurtosis	21.11	Kurtosis	48.09
Skewness	4.64	Skewness	3.97	Skewness	6.02
Range	40.59	Range	27.59	Range	930.99
Minimum	0.01	Minimum	0.01	Minimum	0.25
Maximum	40.60	Maximum	27.60	Maximum	931.24
Sum	1806.27	Sum	1073.03	Sum	29444.07
Count	588	Count	588	Count	588

5.1.2 Histograms

As briefly and remarkable explained by Isaaks and Srivastava (1989), data speak most clearly when they are organized. Histograms are one of the most useful presentations of data sets as a graph.

The samples display a log normal distribution (Figure 5.3, 5.4, 5.5) as right skewed on lead and zinc.

Figure 5.3 : Histograms for non-transformed and log transformed values for Pb variable.

Figure 5.4 : Histograms for non-transformed and log transformed values for Zn variable.

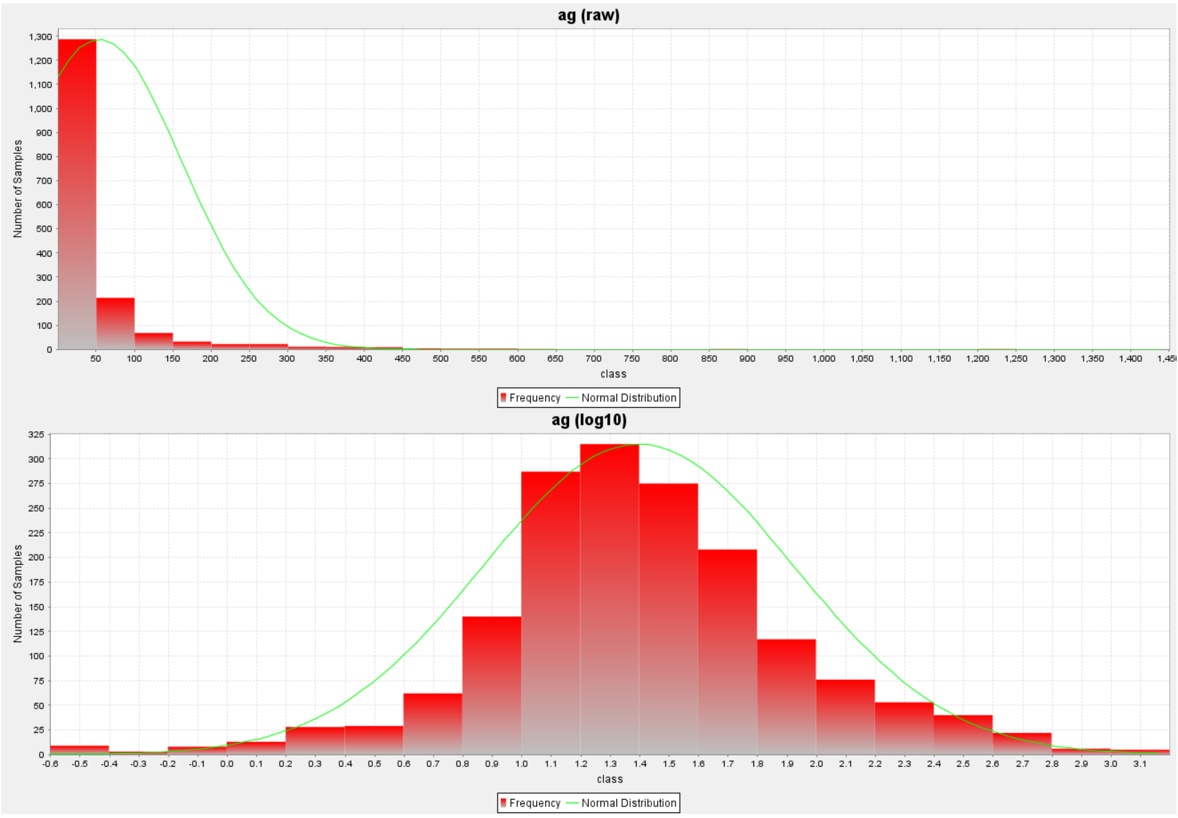

Figure 5.5 : Histograms for non-transformed and log transformed values for Ag variable.

Histogram and its statistical results have made respectively for transformed data as per 1 m composited that has a 3297 sample. According to that data evaluation lead data changes between 0.01% and 40.60%, zinc data changes between 0.001% and 27.60%, silver data changes between 0.25 gr/ton and 931.24 gr/ton. Also the other informations of it in Table 5.4. Also histograms for this transformed data as shown in Figure 5.6, 5.7 and 5.8.

Table 5.4 : Histogram statistical results for 1m composited data

	Pb %	Zn %	Ag gr/t
Number of Samples		3297.00	
Minimum Value	0.01	0.001	0.25
Maximum Value	40.60	27.60	931.24
Mean	3.14	1.70	48.29
Median	2.07	0.88	29.15
Geometric Mean	1.85	0.68	26.80
Variance	15.47	6.72	5713.61
Standard Deviation	3.93	2.59	75.58
Coefficient of variation	1.25	1.52	1.56
Skewness	4.67	3.99	6.62
Kurtosis	32.63	26.68	64.31
Natural Log Mean	0.62	-0.39	3.28
Log Variance	1.43	2.33	1.36

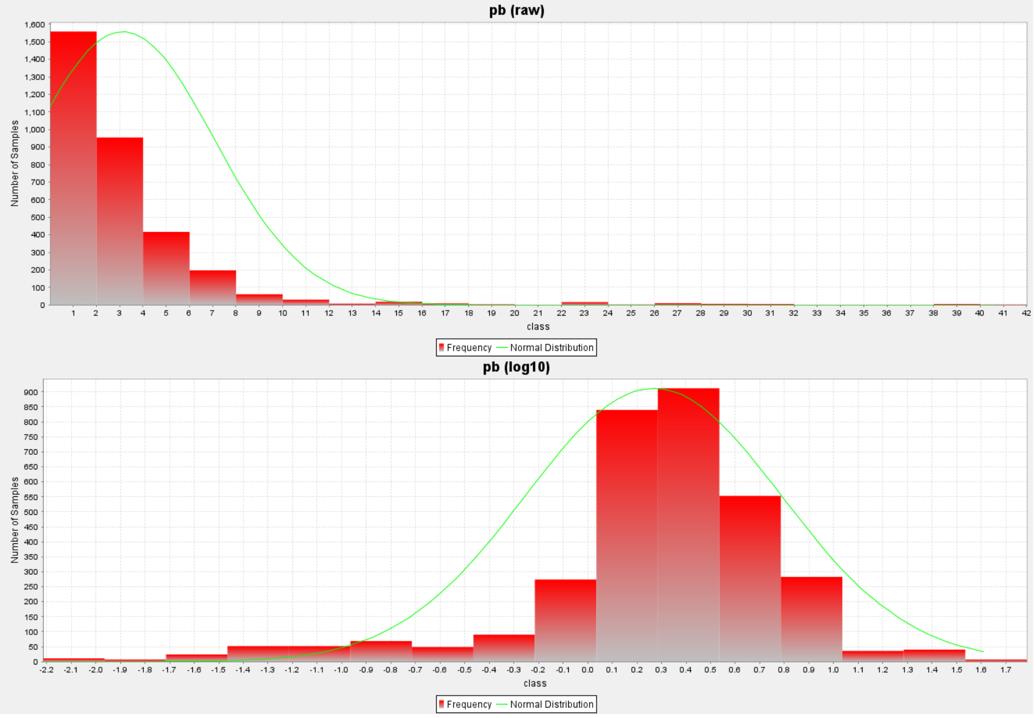

Figure 5.6 : Histograms for non-transformed and log transformed values for 1-m composite Pb variable.

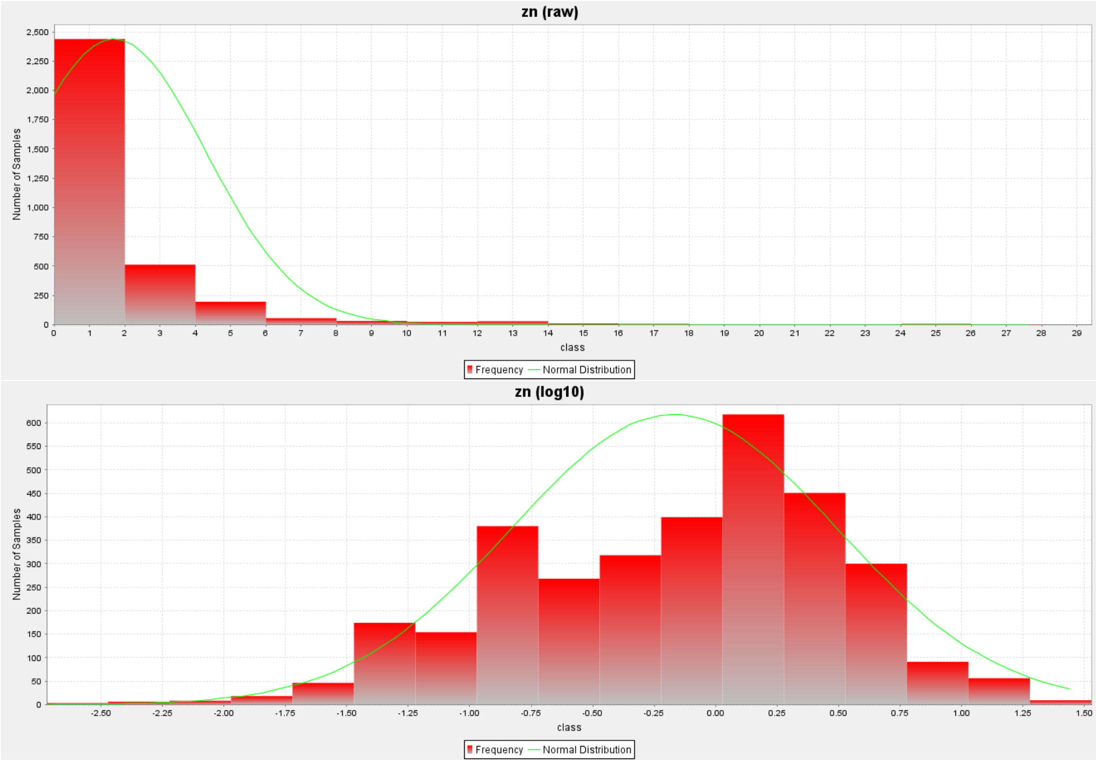

Figure 5.7 : Histograms for non-transformed and log transformed values for 1-m composite Zn variable.

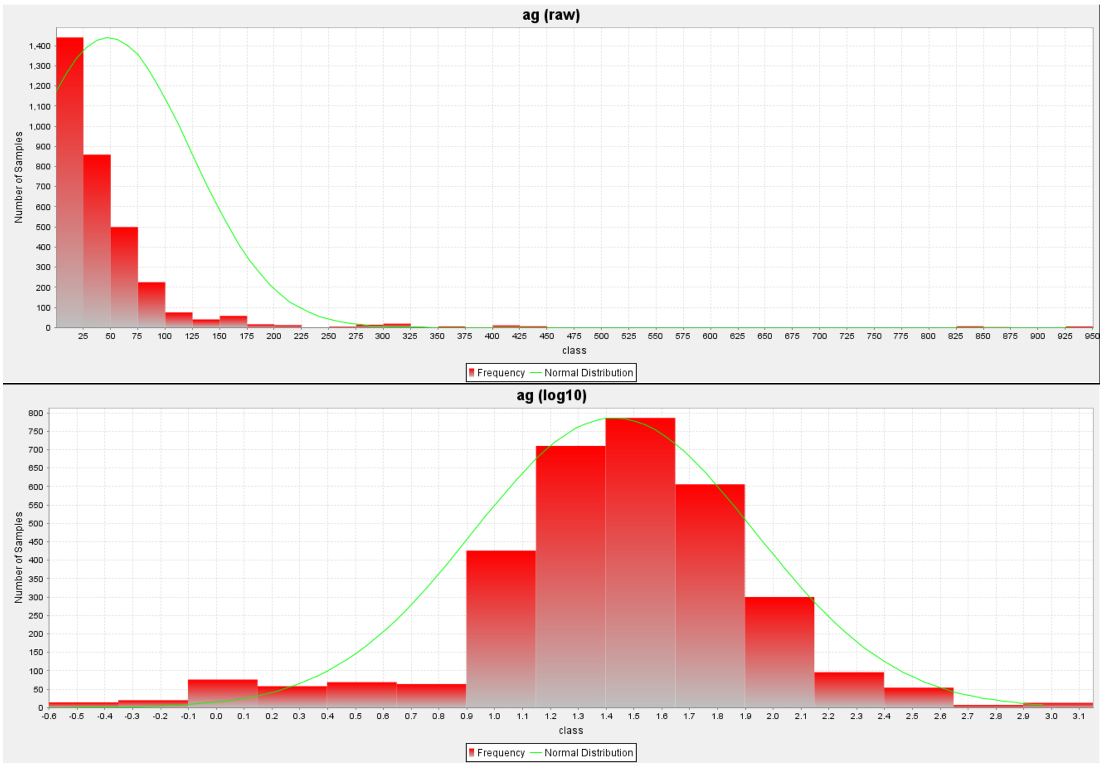

Figure 5.8 : Histograms for non-transformed and log transformed values for 1-m composite Ag variable.

After examining 1m composited data's probability plot graphs, it can deducted that lead values have seven population, zinc values have six population and silver values have ten different data population in study area as it seen their inflection points (Figure 5.9).

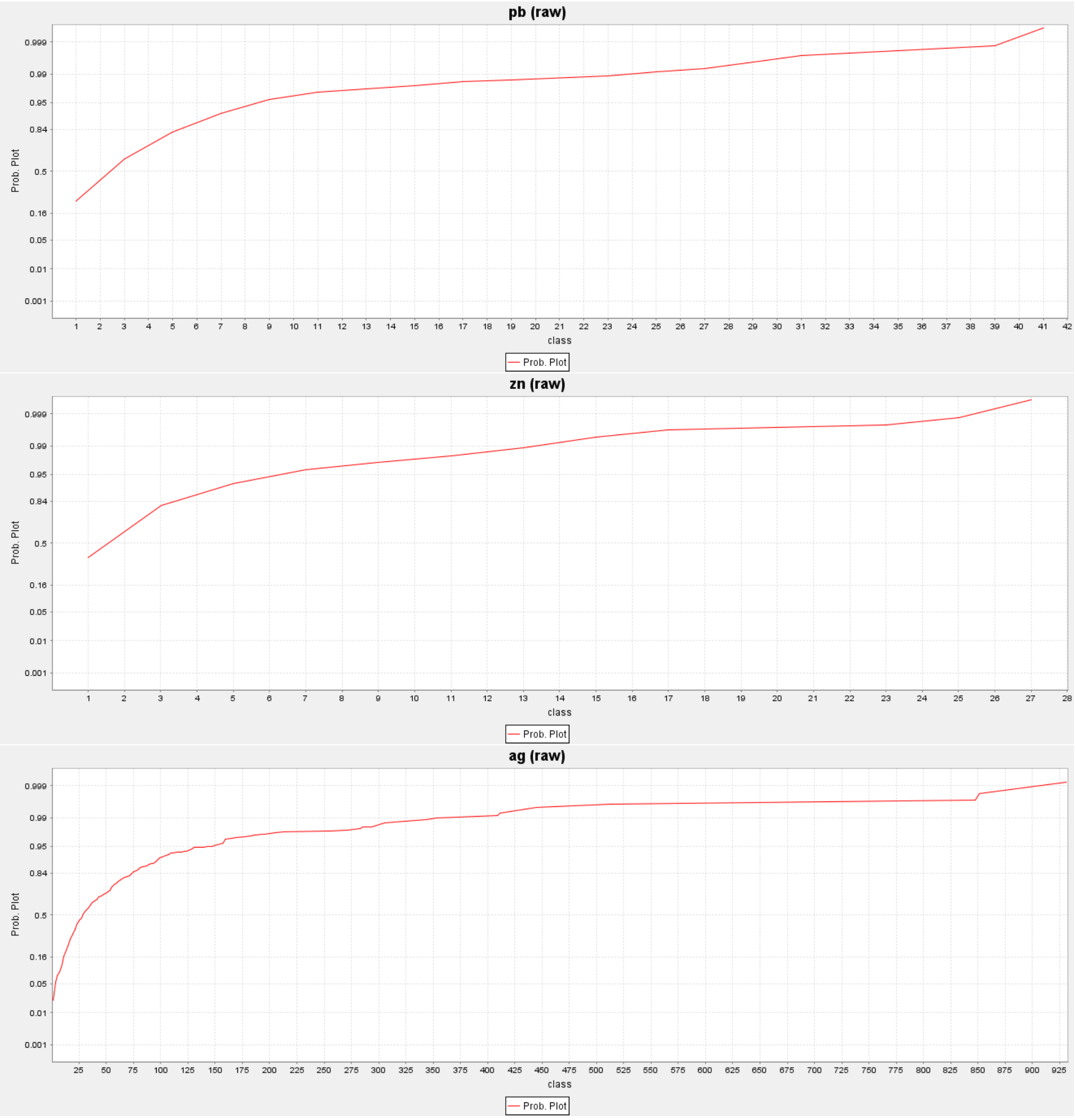

Figure 5.9 : Probability plot for 1-m composited Pb, Zn and Ag variables.

5.2 Spatial Descriptive Statistics

Spatial data analysis aims at extracting implicit knowledge such as spatial relations and patterns that is not explicitly stored in spatial databases. It distinguishes itself from classical data analysis in that it associates each object the attributes under consideration including both non-spatial and spatial attributes.

The most important different for earth science data sets from the others is that the data belong to some location in space. Data set spatial features has the mostimportance for example extreme values location, the overall trend, or the degree of continuity (Isaaks and Srivastava, 1989).

5.2.1 Regionalization

Regionalization is the first step of geostatistical methodology. Sample data must be appointed in a certain location in order to obtain regionalized variable. Coordinates of each sample based on drill hole data should be appointed on variables to transform random variable to regionalized variable. Sample variables are mostly indicated with z in geostatistical terms, and tables are prepared after regionalization by considering x and y as locations and z as variable magnitude. This is used to apply 2 dimensional geostatistical approaches, added to that, depth of the sample as parameter called h is used to prepare a 3 dimensional data set for spatial statistical research in 3 dimensional environment. Table 5.5 and Figure 5.10 is prepared to show the regionalization of daha used in this study.

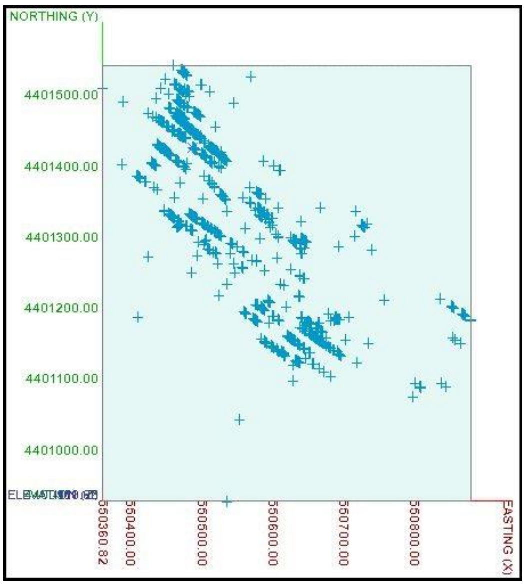

Figure 5.10 : Drillholes location map using for regionalization.

Table 5.5 : Regionalized samples example for one drillhole.

Hole_id	Northing	Easting	Elevation	Pb %	Zn %	Ag (gr/t)	Sample No
DB66	4401458	550459	83.755	2.61	0.823	20.9	7424
DB67	4401164	550703.2	129.623	8.84	1.63	177	6958
DB67	4401164	550703.2	118.323	39.34	25.56	1160	6964
DB67	4401164	550703.2	117.023	64.46	12.77	1442	6965
DB67	4401164	550703.2	115.773	17.98	43.61	291	6966
DB67	4401164	550703.2	115.023	7.82	13.8	218	6967
DB67	4401164	550703.2	111.173	13.78	0.79	4.5	6970
DB67	4401164	550703.2	109.723	3.46	8.26	263	6971
DB67	4401164	550703.2	85.423	1.71	1.33	20	6978
DB67	4401164	550703.2	82.423	0.15	0.19	1	6979
DB67	4401164	550703.2	79.423	0.94	2.57	26	6982
DB67	4401164	550703.2	76.423	0.79	1.11	25	6983
DB67	4401164	550703.2	73.423	23.93	12.96	224	6984
DB67	4401164	550703.2	71.223	31.78	9.45	216	6985
DB67	4401164	550703.2	69.773	0.71	1.25	11	6986
DB67	4401164	550703.2	68.473	29.59	7.18	502	6987
DB67	4401164	550703.2	66.973	3.1	2.94	62	6988
DB67	4401164	550703.2	65.273	15.9	12.86	173	6989
DB67	4401164	550703.2	63.723	8.2	5.97	128	6990
DB68	4401328	550733.6	142.225	12.31	9.86	237	6995
DB68	4401328	550733.6	141.025	16.76	13.91	280	6996
DB68	4401328	550733.6	140.025	0.88	1.15	10	6997
DB68	4401328	550733.6	139.225	12.48	14.58	193	6998

5.2.2 Semivariogram functions

Definition for regional independence function called as variogram as can be seen in Figure 5.11 can be found in below ariogram terms describe in below (Coombes, 2008).

The nugget effect (C_0): Difference between samples where to take them almost adjacent to each other. Base metals are expected to have a lower nugget effect than precious metals.

The sill (C): Sill is the separation between samples increases until reached a distance beyond which the difference between sample grades is not dependent on their separation.

The range: It is the distance till samples are no longer spatially correlated. The range is the distance at which the total sill is reached.

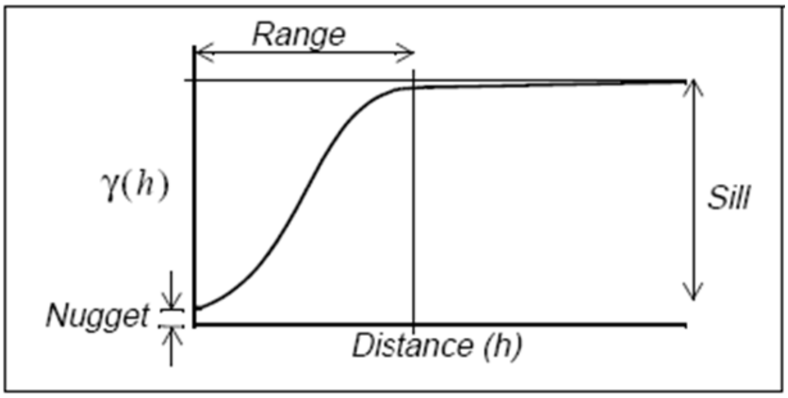

Figure 5.11 : Variogram terms

There are four type of variogram models which are spherical model, exponential model, gaussian model and hole effect model. Most common model is spherical model, besides the exponential and Gaussian models are similar in concept to it. They are designed to handle varying conditions of decay with distance of sample dependency; they both become asymptotic to the C_0+C value for large distances (Houlding, 2000). In this study spherical model used and 1m composited data examined for the best grade and tonnage estimation.

In this study, omnidirectional, anisotropic and downhole variograms were determined and the results are given in the below sub sections.

5.2.2.1 Anizotropic SVs

An anisotropic condition exists when the rate of change data values is different for different directions. Experimental variograms shown that data can be accept like isotropic so there is not much difference between varied directions in the study area as expected based on anisotropy maps (Figure 5.12, 5.13 and 5.14) . Also Anizotropic SVs parameters as shown in Table 5.6.

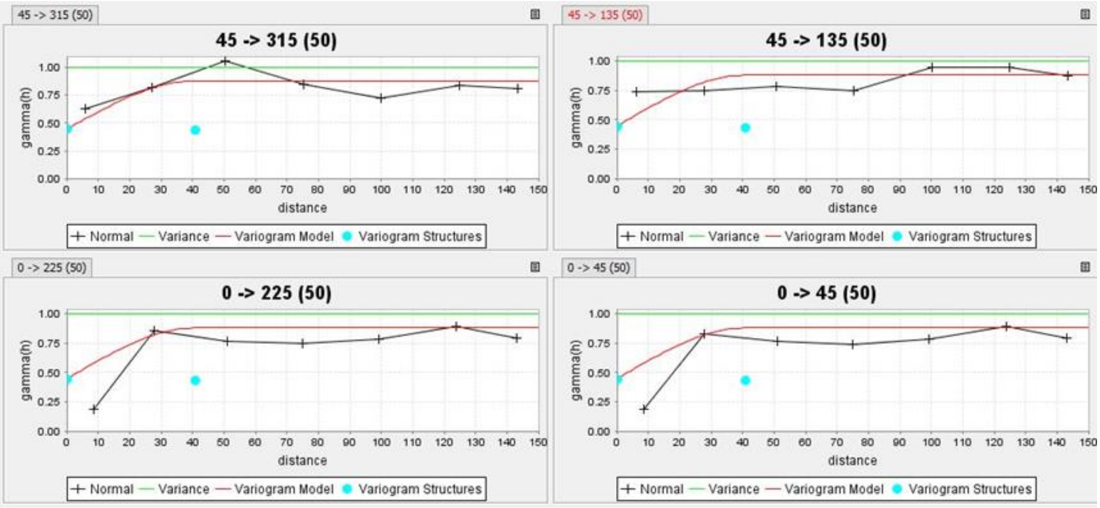

Figure 5.12 : Anisotropic experimental and theoretical variograms for Pb

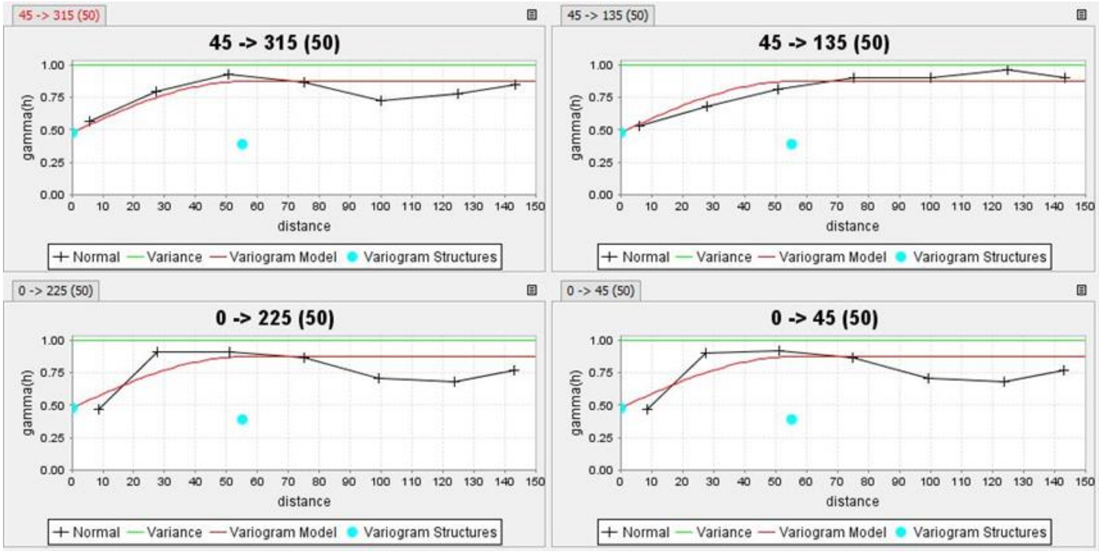

Figure 5.13 : Anisotropic experimental and theoretical variograms for Zn

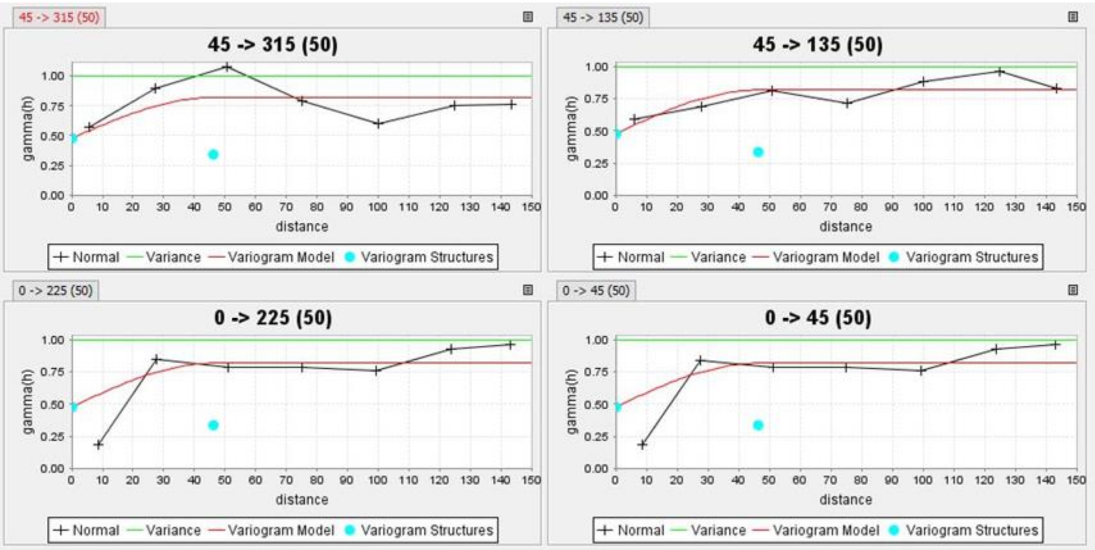

Figure 5.14 : Anisotropic experimental and theoretical variograms for Ag

Table 5.6 : Anizotropic SV parameters.

	Nugget Effect	Model	Sill	Range
Pb 1m composited	0.02	Spherical	0.69	42.54
Zn 1m composited	0.42	Spherical	0.31	86.83
Ag 1m composited	0.03	Spherical	0.68	42.88

5.2.2.2 Downhole SV

Downhole variables can be determined by considering data for -90^0 dip direction. Downhole variograms should be used as a part of 3 dimensional geostatistical investigations. The downhole SVs for each parameter can be found in Figure 5.15, and the SV parameters are given in Table 5.7. Results of sill, range and nugget effect are close enough to interprete the similarity of each parameter for the investigation in -90^0 dip direction.

Table 5.7 : Downhole SV parameters.

	Nugget Effect	Model	Sill	Range
Pb 1m composited	0.08	Spherical	0.64	67.77
Zn 1m composited	0.13	Spherical	0.52	73.08
Ag 1m composited	0.08	Spherical	0.65	53.44

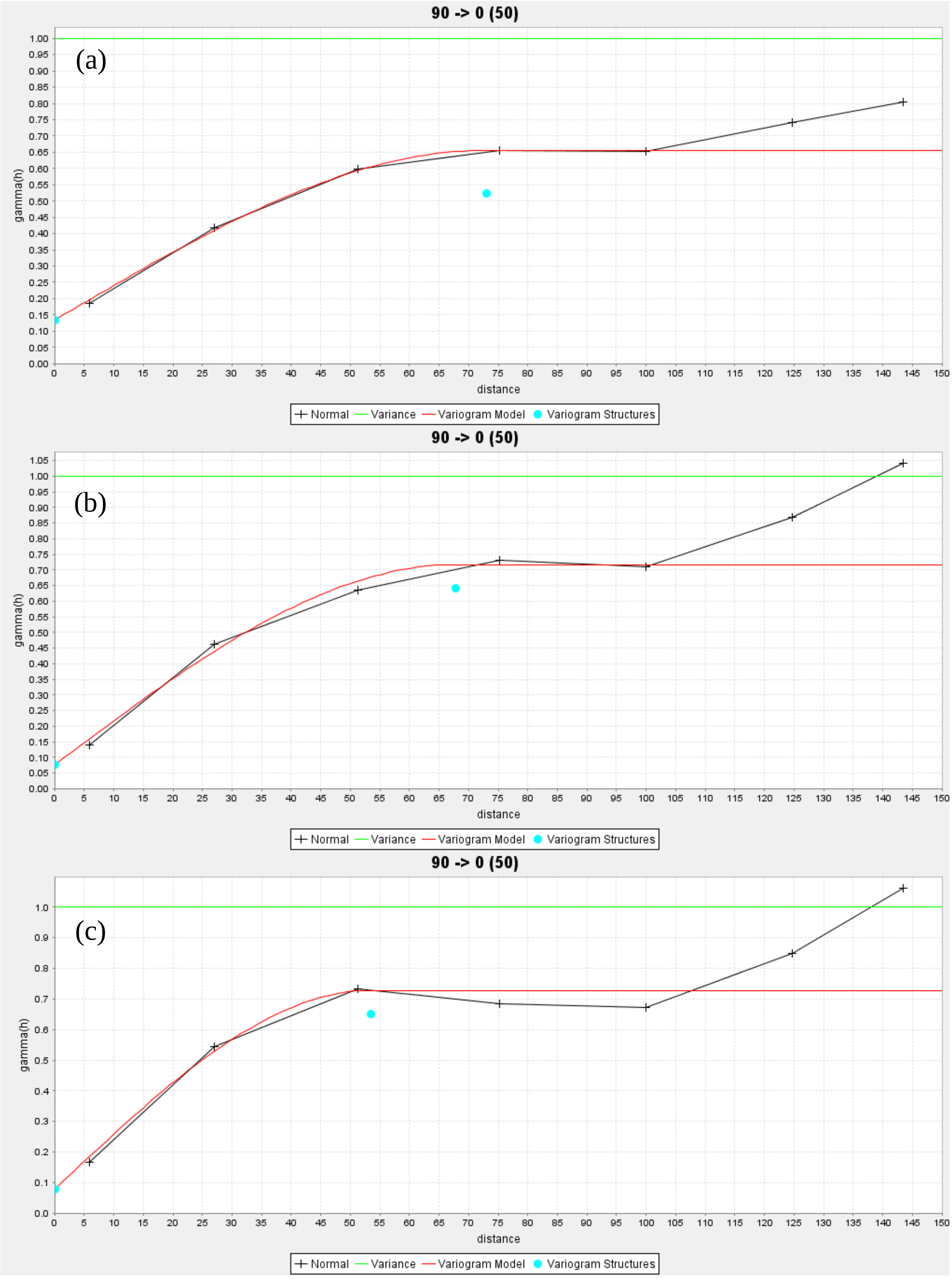

Figure 5.15 : Downhole SV for (a) Pb, (b) Zn, (c) Ag.

5.2.2.3 Omnidirectional SV

Omni-directional variogram calculated for each of the variables. Subsequently considering anizotropy maps given in Figure 5.16, it concluded that the best variogram and data trend seen in omnidirectional. Omnidirectional variogram models can be seen in Figure 5.17 and also parameters that belongs to it is in Table 5.8.

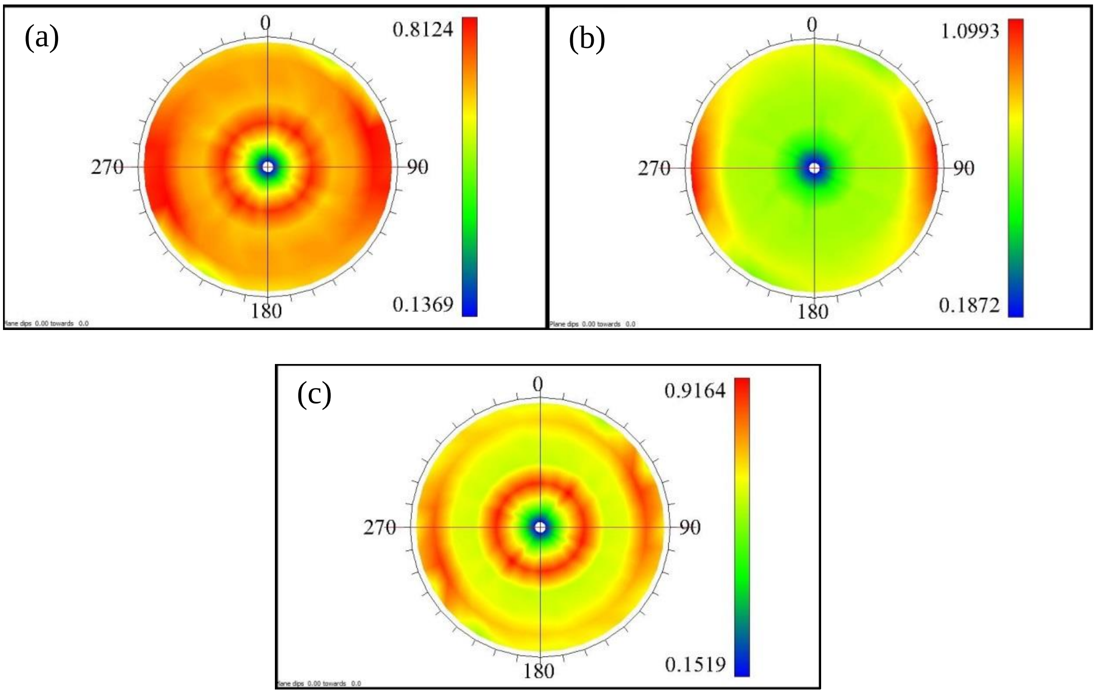

Figure 5.16 : Anizotropy maps for (a) Pb, (b) Zn and (c) Ag.

Table 5.8 : Omnidirectional SVs parameters.

	Nugget Effect	Model	Sill	Range
Pb 1m composited	0.01	Spherical	0.75	53.12
Zn 1m composited	0.10	Spherical	0.59	54.89
Ag 1m composited	0.21	Spherical	0.86	58.63

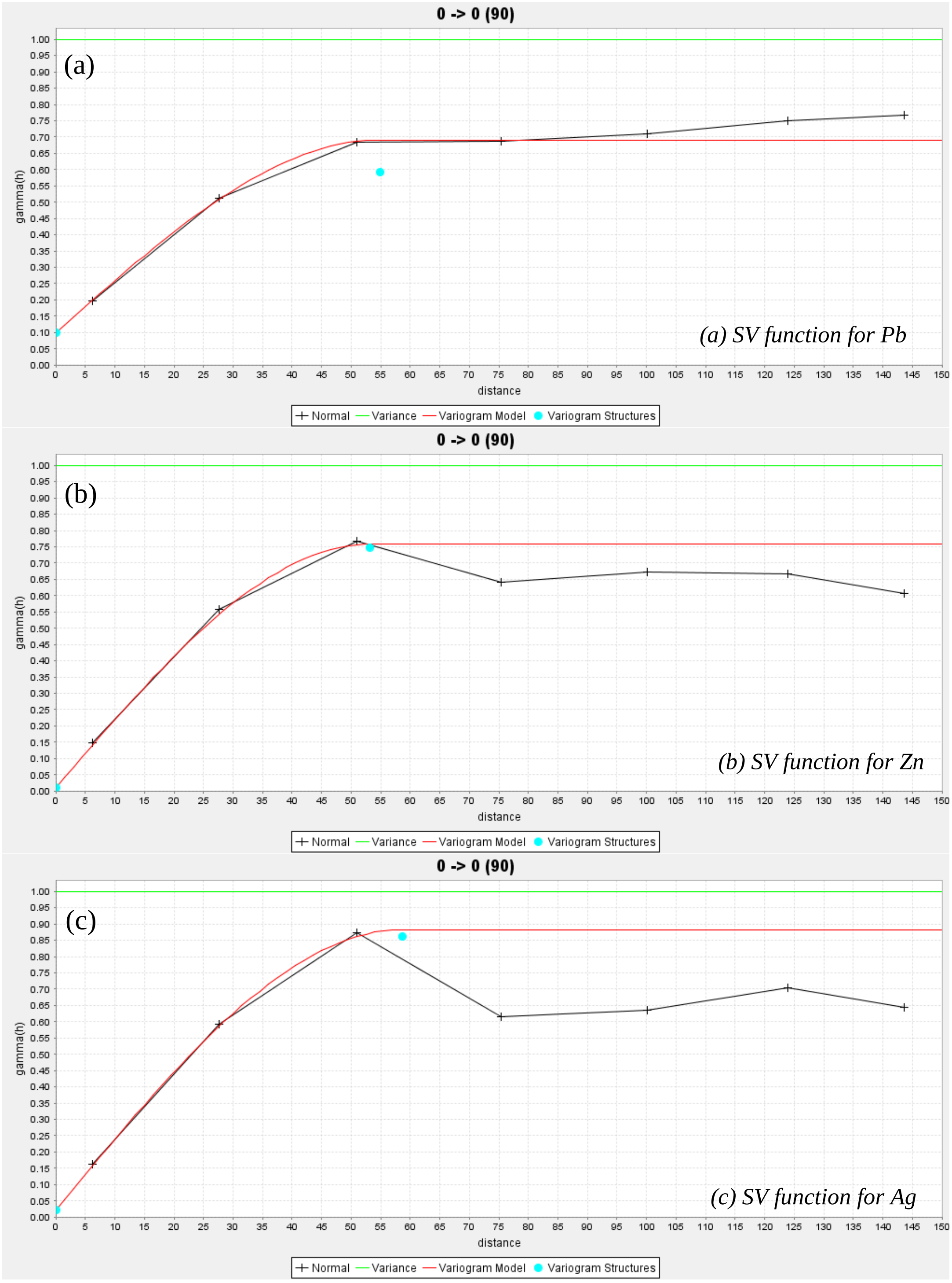

Figure 5.17 : SV functions for (a) Pb, (b) Zn and (c) Ag.

5.3 Search Ellipsoid and Cross Validation

Search ellipsoid is used to solve the estimation problems in 3 dimensional geostatistical approaches. Ellipsoid has 3 dimension with length, width and radius. On the other hand, ellipsoid direction should be also defined by using bearing and dip direction. In this study, dip and bearing dimension of search ellipsoid is taken as constant value as 45^0 as per the similarity of the ore deposit. Different values for ellipsoid geometrical dimensions are also considered from 15 m to 150 m to understand the effect of search ellipsoid dimension for the estimation methodology. Search ellipsoid that decided to use for estimation after detailed cross validation analyses as given below can be seen in Figure 5.18.

A semi-variogram model is only an approximation of the spatial variability of the measured conditions. In turn, the measured conditions, are represented by the available sample population, are not always representative of the real conditions. There is no way we can verify this since we do not know real conditions. The only way we can obtain an indication of the degree to which a set of samples represents the real conditions is to perform a round of infill sampling.

The estimated value should be close to the omitted sample value; ideally, the equal to one. The difference is unlikely to be zero since the sample value itself is not included in the estimation process. This ratio is called as error statistics (Houlding, 2000).

In order to optimize the estimation procedure results obtained from ordinary kriging, different search ellipsoids were used for estimation. Cross validation results were also used to select the best optimize search ellipsoid. In this step of the geostatistical application, 90 different search ellipsoid were applied to gain cross validation results for three differen variables that are Pb, Zn and Ag. Correlation coefficient and average kriging error parameters were used to decide the success of the estimation procedure. Input parameters of the search ellipsoid is selected as number of samples to krig a point and distance that means radius, length, and width of the ellipsoid is equal each other.

In the following Table 5.9 the results obtained from cross validation analyses determined from different search ellipsoid models are given for each ReVs.

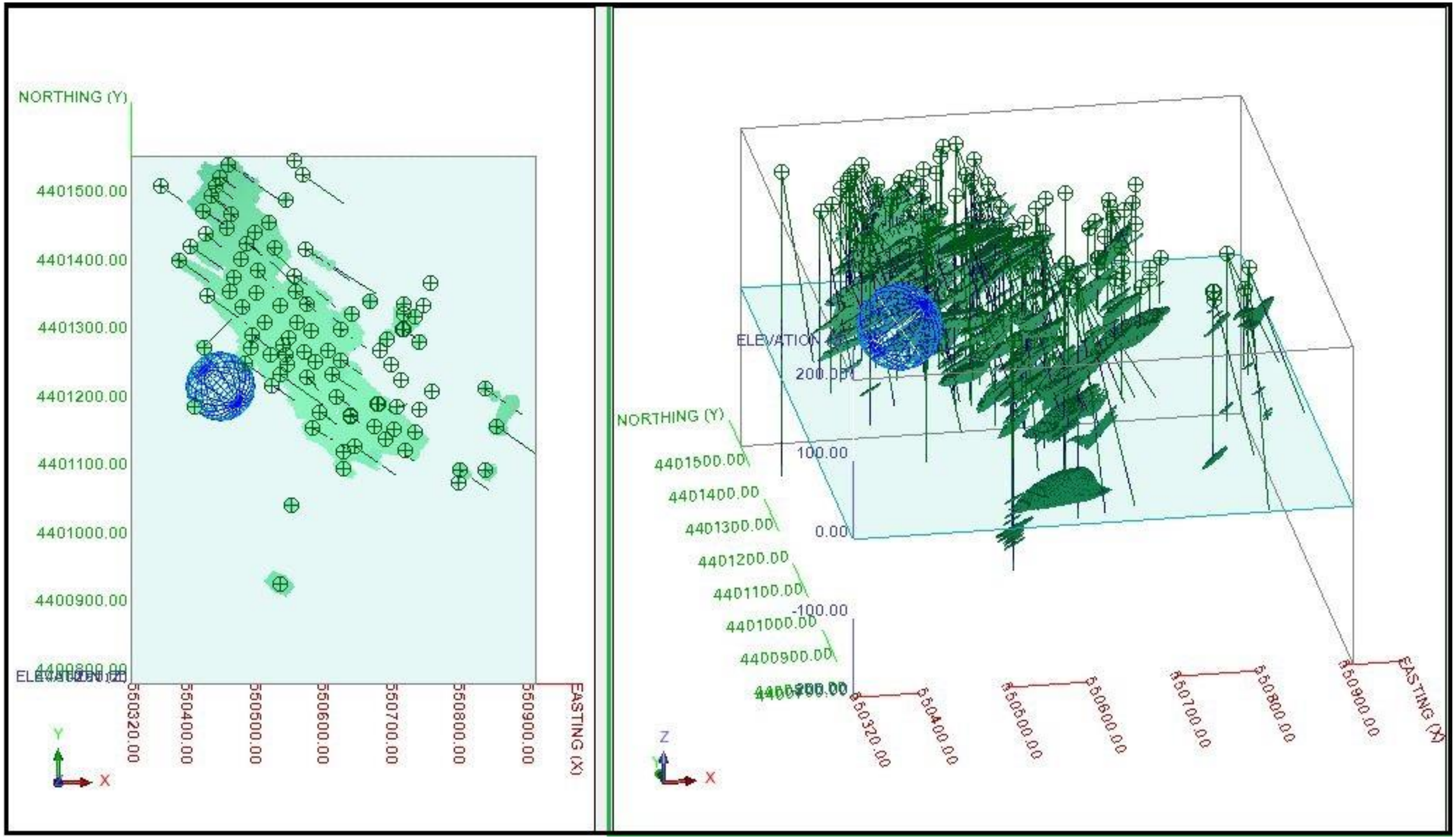

Figure 5.18 : Search ellipsoid view with ore blocks.

Table 5.9 : Cross validation results

Variables	Number of Samples to Krig a Point	Search Ellipsoid Distance	Correlation Coefficient	Average Kriging Error
Pb	10	15	0.983	0.043
		25	0.980	0.044
		50	0.977	0.044
		80	0.975	0.045
		100	0.975	0.045
		150	0.975	0.045
Zn	10	15	0.965	0.153
		25	0.964	0.152
		50	0.965	0.153
		80	0.963	0.153
		100	0.962	0.153
		150	0.962	0.153
Ag	10	15	0.974	0.060
		25	0.971	0.060
		50	0.972	0.061
		80	0.970	0.062
		100	0.970	0.062
		150	0.970	0.062
Pb	20	15	0.983	0.043
		25	0.980	0.044
		50	0.979	0.044
		80	0.977	0.045
		100	0.976	0.045
		150	0.976	0.045
Zn	20	15	0.964	0.152
		25	0.963	0.152
		50	0.965	0.152
		80	0.962	0.152
		100	0.961	0.152
		150	0.961	0.152
Ag	20	15	0.974	0.060
		25	0.971	0.060
		50	0.973	0.061
		80	0.971	0.061
		100	0.970	0.061
		150	0.970	0.062

Table 5.9 continue : Cross validation results

Variables	Number of Samples to Krig a Point	Search Ellipsoid Distance	Correlation Coefficient	Average Kriging Error
Pb	30	15	0.983	0.043
		25	0.980	0.044
		50	0.979	0.044
		80	0.977	0.044
		100	0.976	0.044
		150	0.977	0.045
Zn	30	15	0.964	0.152
		25	0.963	0.152
		50	0.965	0.151
		80	0.962	0.152
		100	0.961	0.152
		150	0.962	0.152
Ag	30	15	0.974	0.060
		25	0.971	0.060
		50	0.973	0.061
		80	0.971	0.061
		100	0.970	0.061
		150	0.971	0.061
Pb	40	15	0.983	0.043
		25	0.980	0.044
		50	0.979	0.044
		80	0.977	0.044
		100	0.976	0.044
		150	0.977	0.045
Zn	40	15	0.964	0.152
		25	0.963	0.152
		50	0.964	0.151
		80	0.962	0.152
		100	0.961	0.152
		150	0.961	0.152
Ag	40	15	0.974	0.060
		25	0.971	0.060
		50	0.973	0.061
		80	0.971	0.061
		100	0.970	0.061
		150	0.971	0.061

Table 5.9 continue : Cross validation results

Variables	Number of Samples to Krig a Point	Search Ellipsoid Distance	Correlation Coefficient	Average Kriging Error
Pb	50	15	0.983	0.043
		25	0.980	0.044
		50	0.979	0.044
		80	0.976	0.044
		100	0.976	0.044
		150	0.977	0.045
Zn	50	15	0.964	0.152
		25	0.963	0.152
		50	0.963	0.151
		80	0.962	0.152
		100	0.961	0.152
		150	0.961	0.152
Ag	50	15	0.974	0.060
		25	0.971	0.060
		50	0.973	0.061
		80	0.970	0.061
		100	0.970	0.061
		150	0.971	0.061

After all of the analyses carried out as above mentioned, number of sample to krig a point is selected as 40 while ellipsoid width and length is selected as 50 m due to the high correlation coefficient as well as low kriging error variance. In order to use the most available data for the estimation, sample number for the estimation is selected as 40 although with the less number of sample there is also quite well results in terms of higher correlation.

Cross validation results for the selected search ellipsoid parameter are given in Figure 5.18 for Pb, Zn, and Ag. Highly correlated relations between estimated and actual values of ReVs encourage to apply geostatistical methods for the study area to obtain distribution maps for each ReVs individually.

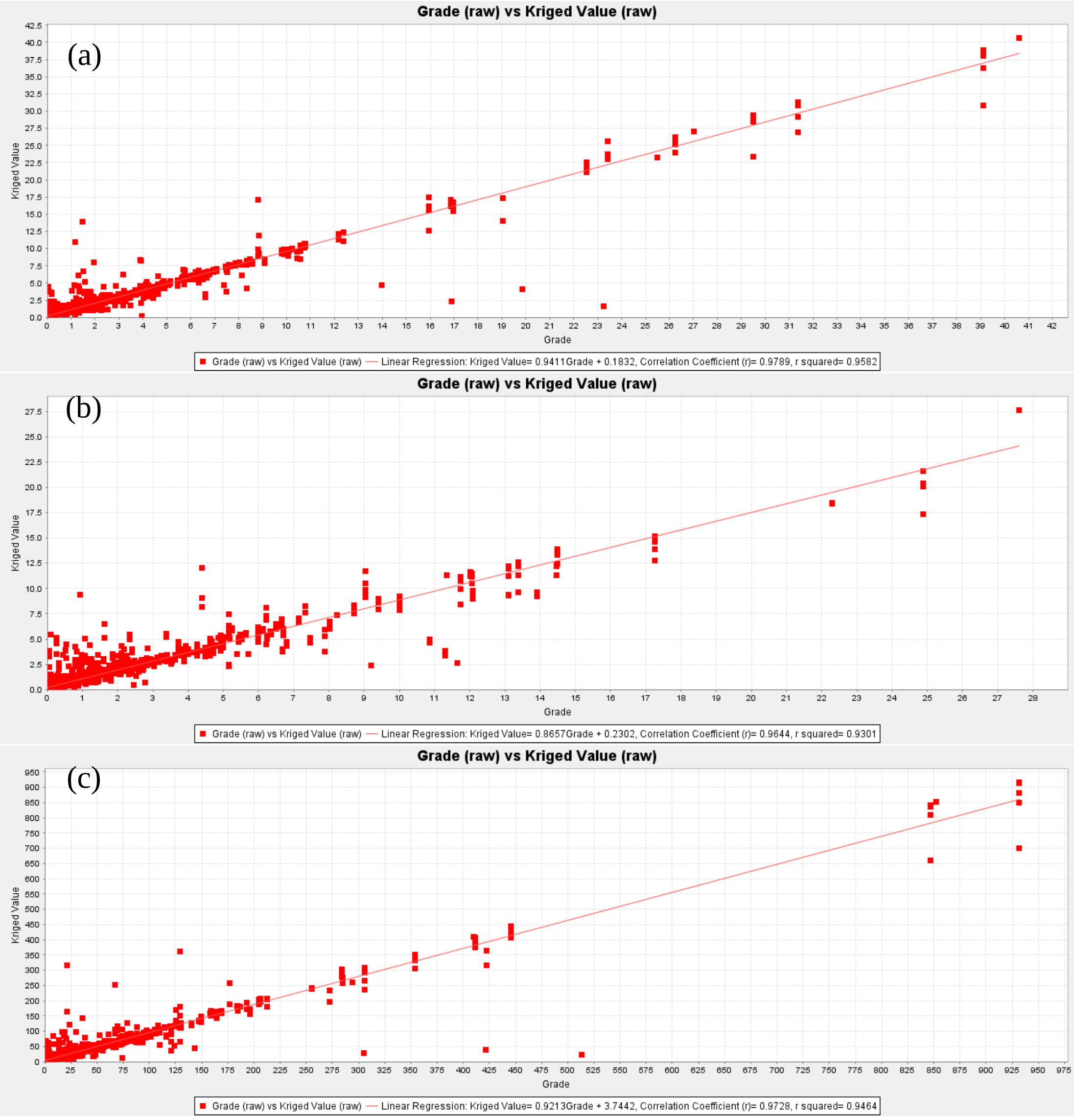

Figure 5.19 : Comparison of the grade and kriged data for (a) Pb, (b) Zn, (c) Ag.

5.4 Estimation Methodology

Ordinary Kriging (OK) method described as below from Rossi and Deutsch (2014). Ordinary Kriging method is regarding the same minimum error variance linear estimate at where the true value is unknown. As a opposite to Simple Kriging, OK does not make any prior assumptions using mean value. By requiring global unbiasedness, OK constrains the sum of the weights to be 1.0, and as a result the mean does not need to be known. It assumed the unknown mean for the volume being estimated constant:

$$\mathrm{z(u)^* - m} = \sum_{i=1}^{n} \lambda\mathrm{i} \,.\, [z(ui) - m]$$

$$\mathrm{z(u)^*} = \sum_{i=1}^{n} \lambda\mathrm{i\ z(ui)} + [1 - \sum_{i=1}^{n} \lambda\mathrm{i}].\,\mathrm{m}$$

The condition $\sum_{i=1}^{n} \lambda\mathrm{i} = 1$ described as unbiasedness condition when the mean m is not known. Ordinary kriging principle based on the recognition that the sum of the weights is 1.0. Since OK is most often applied within moving search neighborhoods, i.e., using different data sets for different locations u, the implicit re-estimated mean denoted m*(u) depends on the location u. Thus the OK estimator is a type of Simple Kriging, where the constant mean value m is replaced by a location-dependent estimate m*(u).

Ordinary kriging is a non-stationary algorithm. It corresponds to non-stationary Random Function model with varying mean but stationary covariance. This ability to rescale locally the RF model Z(u) to a different mean value m*(u) explains the robutstness of the OK algorithm.

The OK system is also a system of normal equations, but with an additional constraint: the sum of weights equal to 1. The Lagrange formalism is again used to obtain the oprimal weights and derive the OK system of equations. Using the more general notation to take into account the different support of the samples and the blocks being estimated, the derivation of the OK system is

$$Q(\lambda i = 1, \ldots.., n, \mu) \quad = \sigma^2 E + 2\mu[\textstyle\sum_{i=1}^{n} \lambda i - 1\,] \rightarrow \text{minimum}$$

Taking the partial derivative with respect to the weights and the Lagrance multiplier.

$$\frac{\partial Q}{\partial \lambda a} = -2\,\mathrm{C}(V, va) + 2 \sum_{\beta=1}^{n} \lambda\beta \mathrm{C}(va, v\beta)$$

$$+ 2 \cdot \mu = 0, \qquad \forall a = 1, \ldots., n$$

$$\frac{\partial Q}{\partial \mu} = \sum_{j=1}^{n} \lambda j - 1 = 0$$

With m being the Lagrance parameter introduced due to the constraint that the weights sum up to 1. The resulting OK system and the corresponding OK variance are

$$\sum_{j=1}^{n} \lambda j \mathrm{C}(vi, vj) + \mu = \mathrm{C}(V, vi), \forall i = 1, \dots., n$$

$$\sum_{j=1}^{n} \lambda j = 1$$

$$\sigma^2 K = \mathrm{C}(V, V) - \mu - \sum_{a=1}^{n} \lambda a \mathrm{C}(V, va)$$

Ordinary Kriging method were used for estimation with the search ellipsoid parameters shown in Figure 5.20. and omnidirectional variogram parameters used for each base metal estimation.

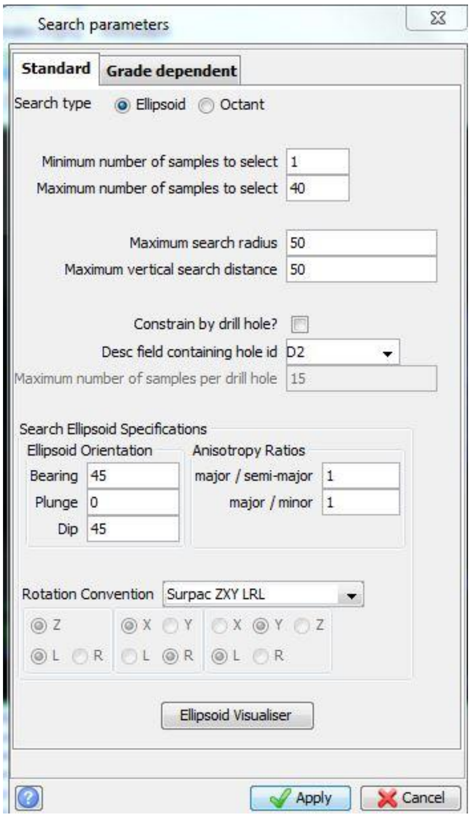

Figure 5.20 : Ellipsoid parameter for OK system.

After all of the investigations and running the kriging technique for the estimations, the following distribution maps as well as cross-sections are determined as a main part of the geostatistical investigations. Hence, the most important purpose of the study is completed when the section is successfully determined (Figure 5.21-5.32).

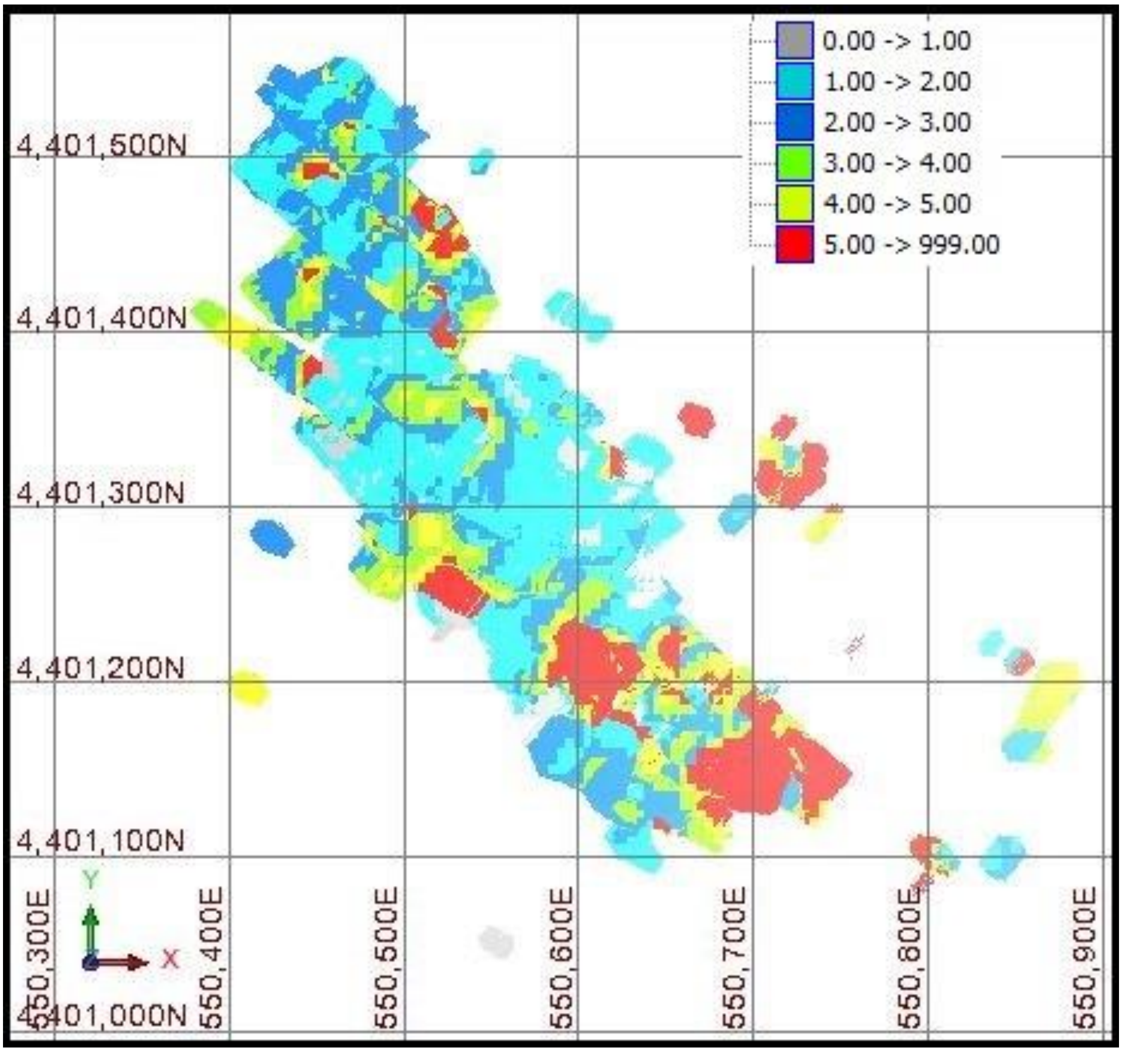

Figure 5.21 : Estimated blocks plan view by Pb% grade.

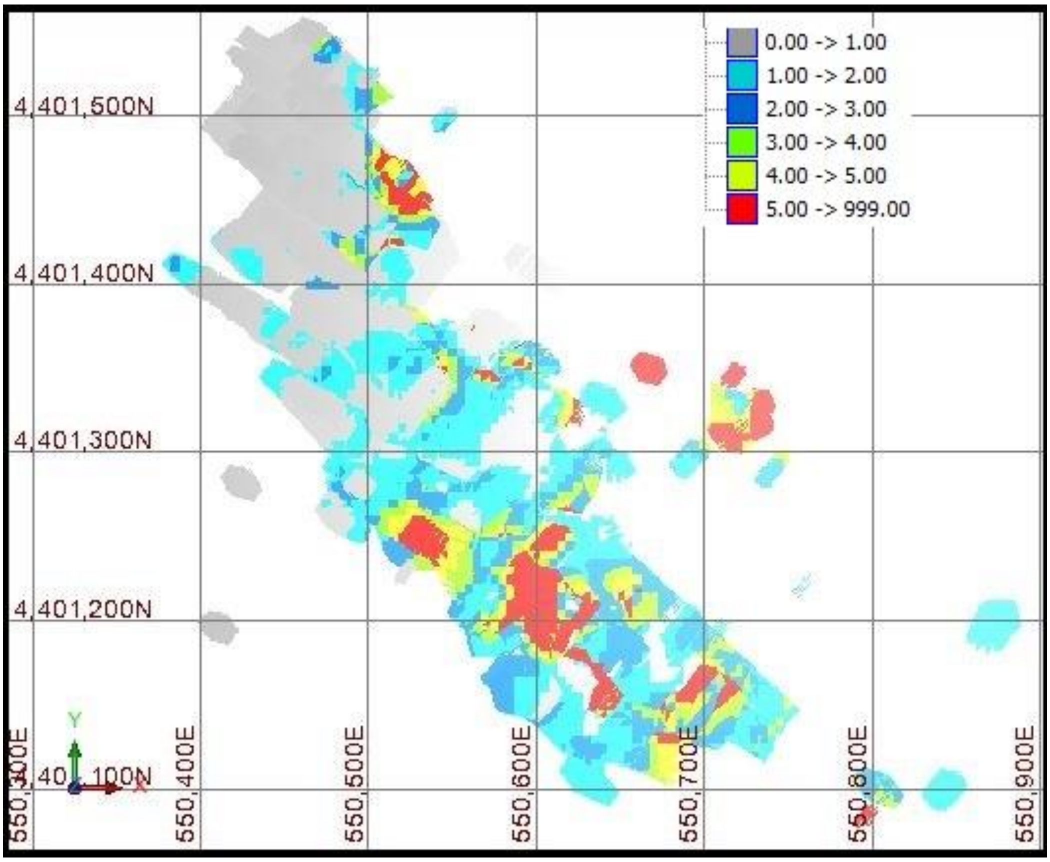

Figure 5.22 : Estimated blocks plan view by Zn% grade.

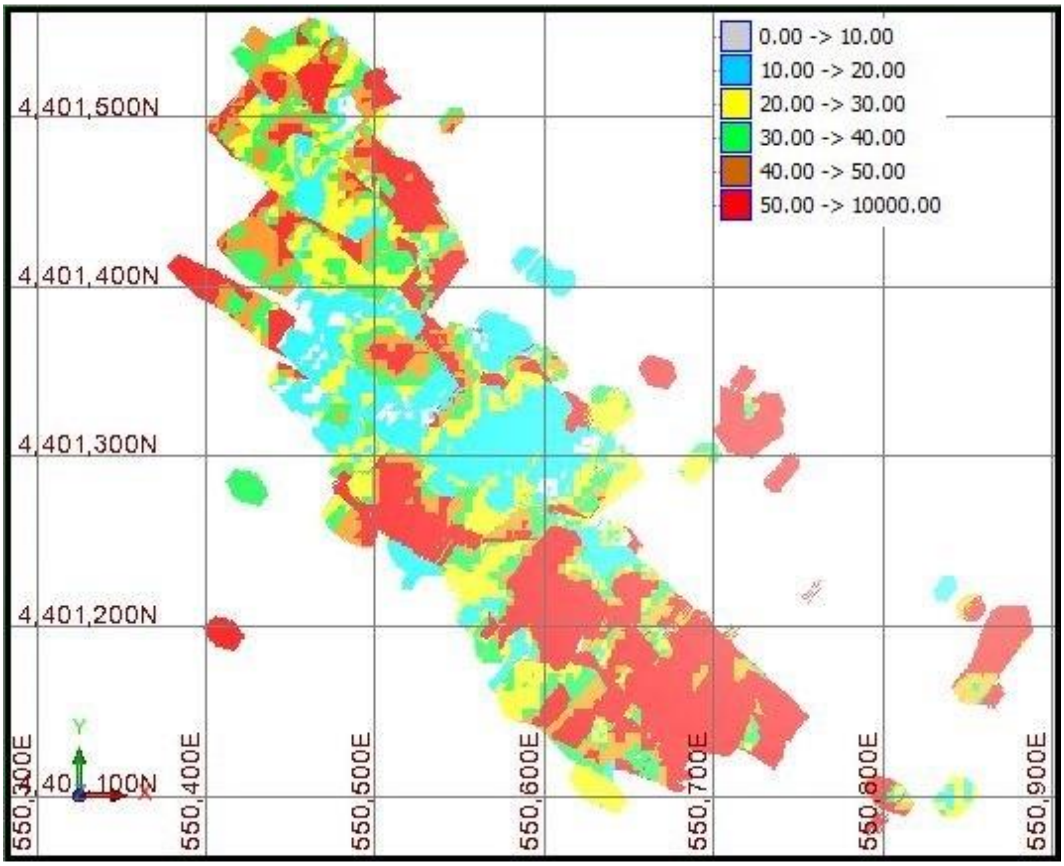

Figure 5.23 : Estimated blocks plan view by Ag (gr/ton) grade.

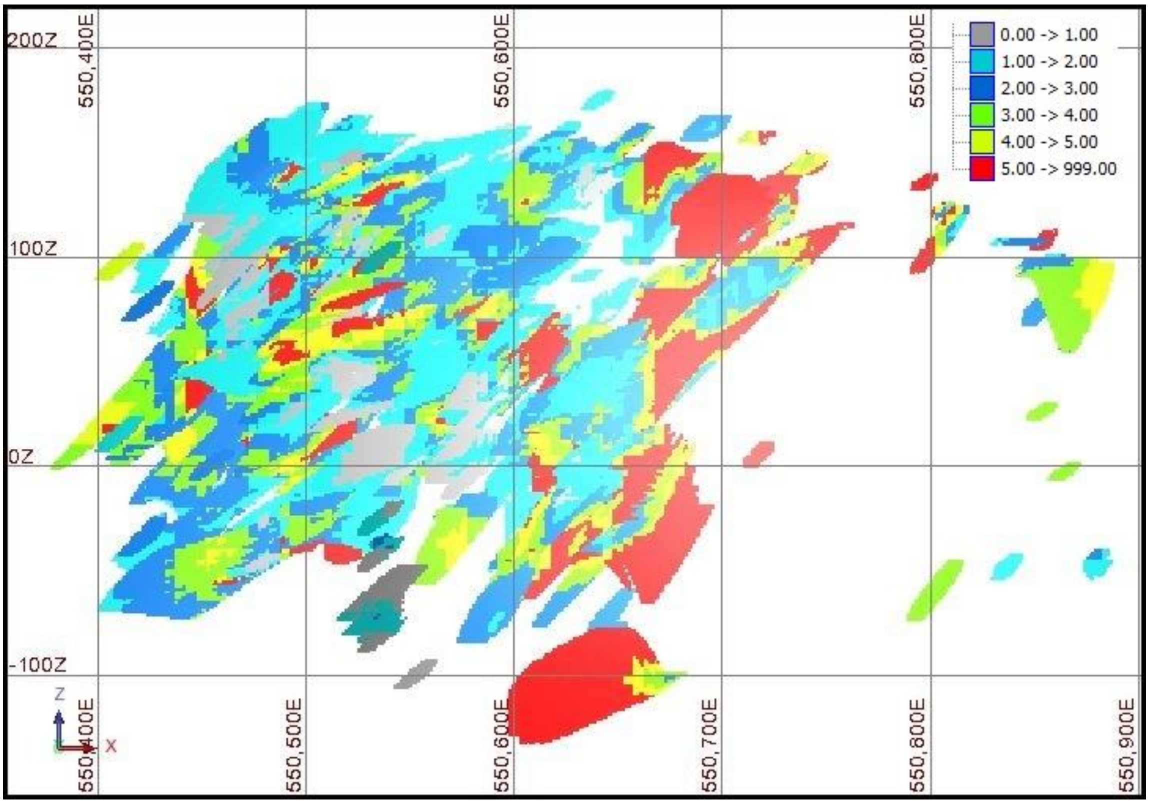

Figure 5.24 : Estimated blocks Easting-Elevation view by Pb (%) grade.

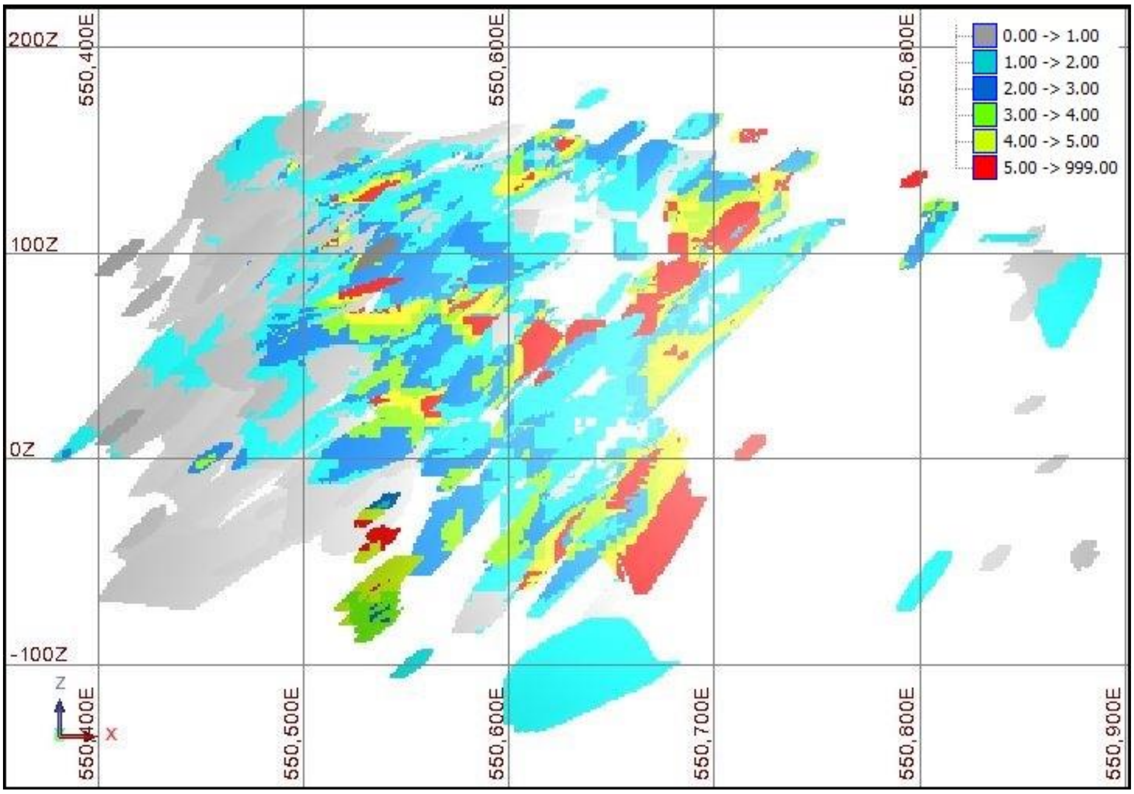

Figure 5.25 : Estimated blocks Easting-Elevation view by Zn (%) grade.

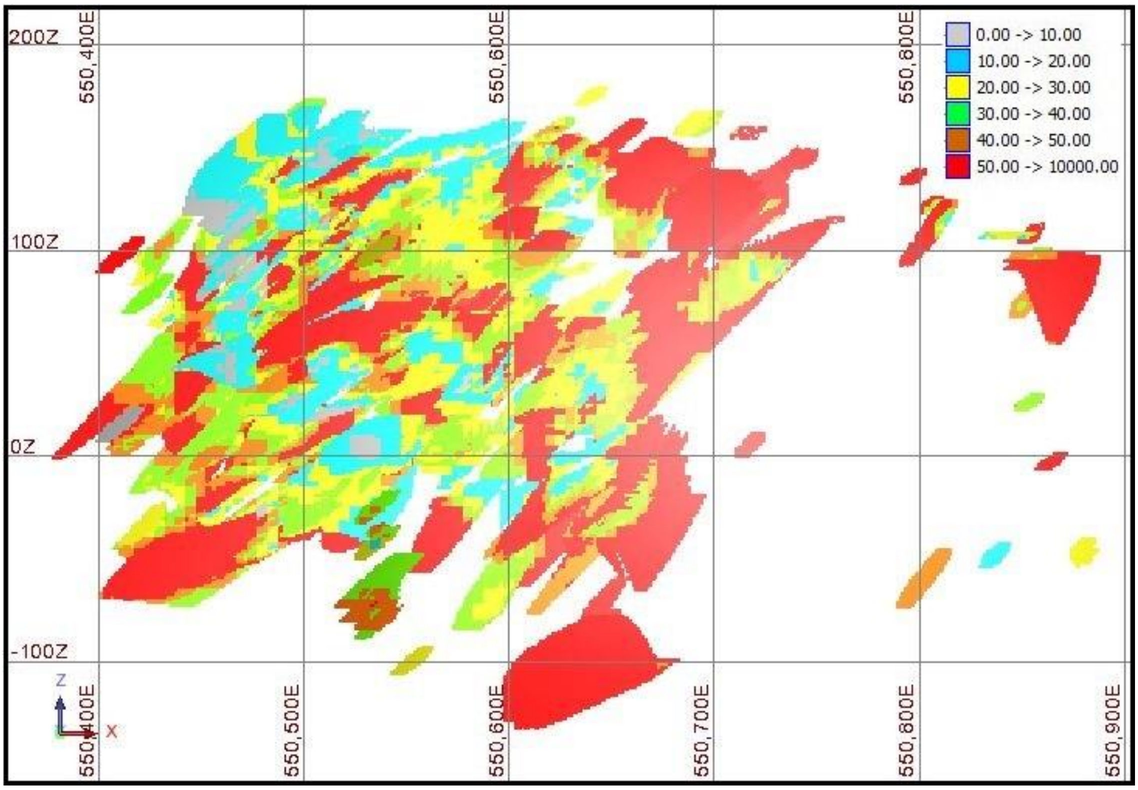

Figure 5.26 : Estimated blocks Easting-Elevation view by Ag (gr/ton) grade.

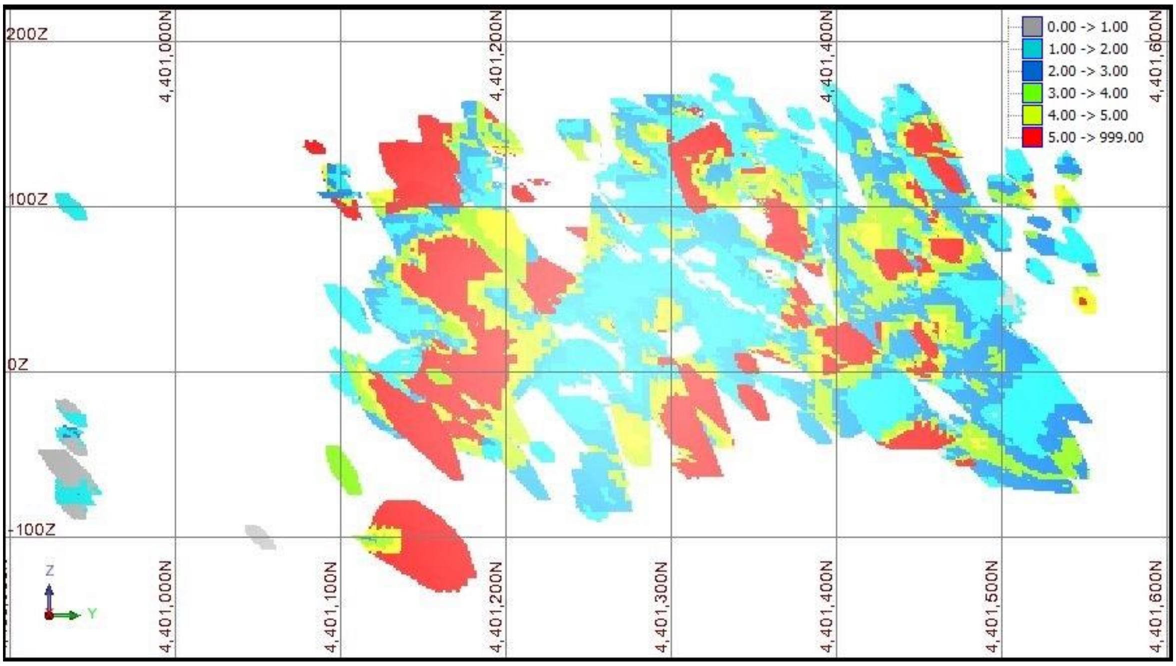

Figure 5.27 : Estimated blocks Northing-Elevation view by Pb (%) grade.

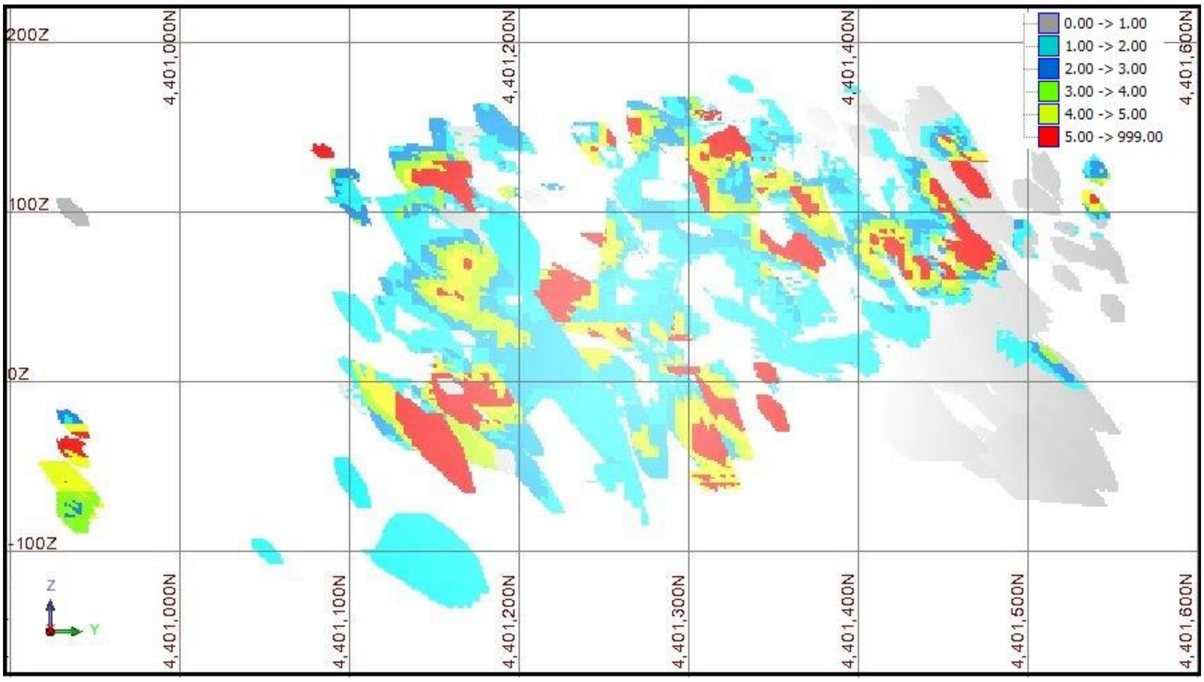

Figure 5.28 : Estimated blocks Northing-Elevation view by Zn (%) grade.

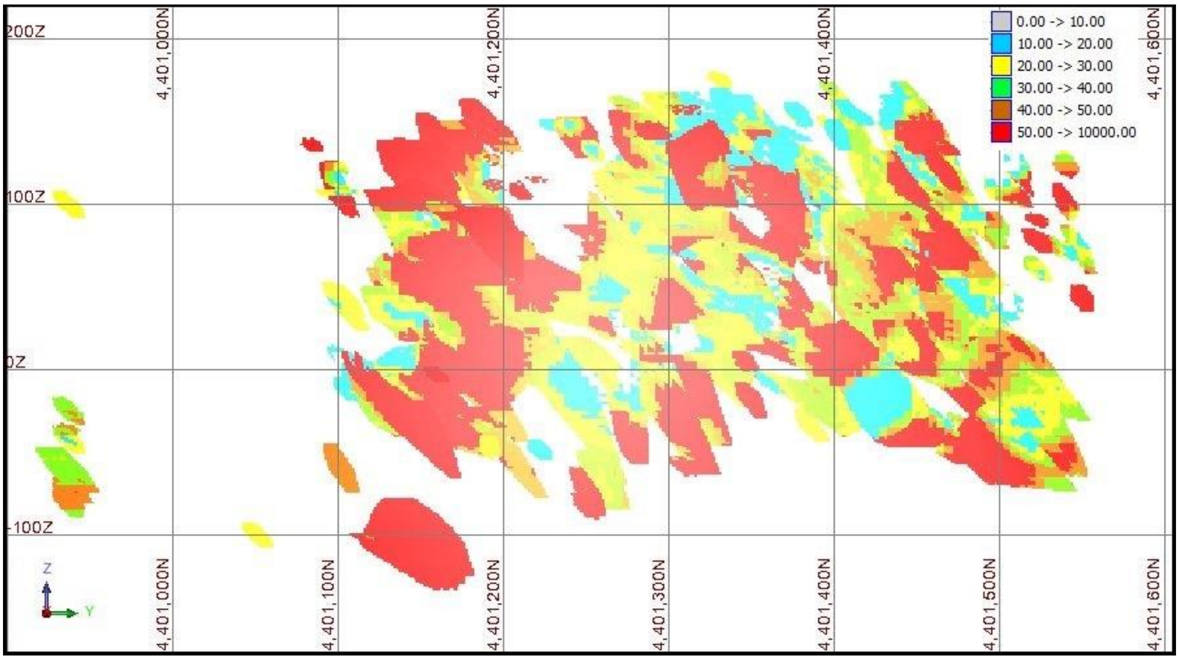

Figure 5.29 : Estimated blocks Northing-Elevation view by Ag (gr/ton) grade.

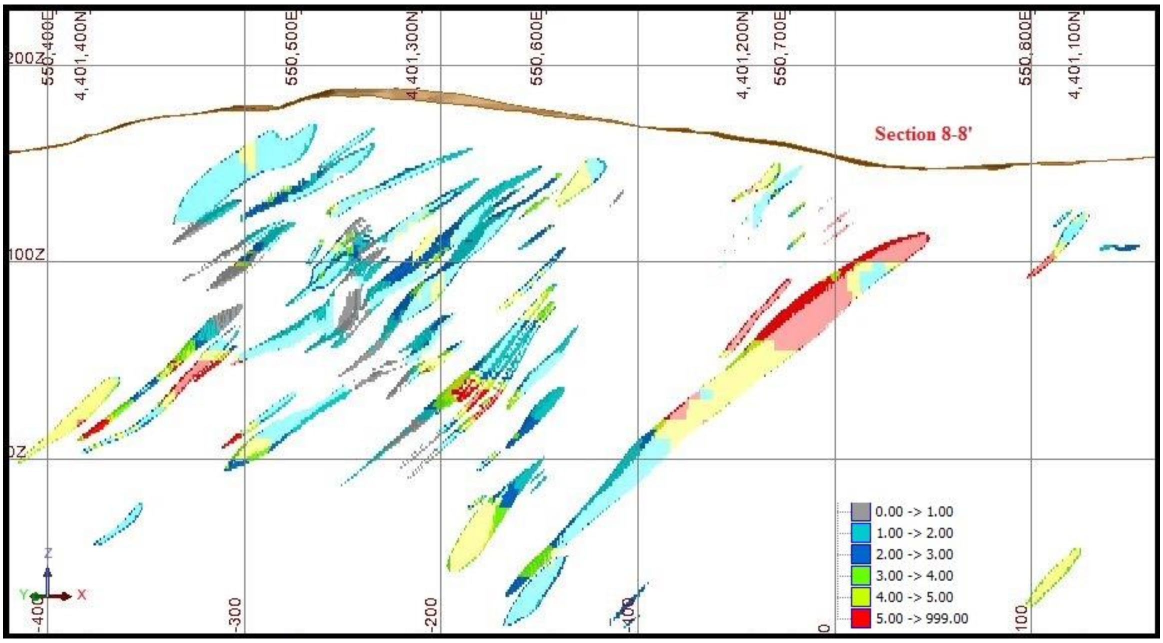

Figure 5.30 : Estimated blocks with Pb (%) grade on Section 8-8'.

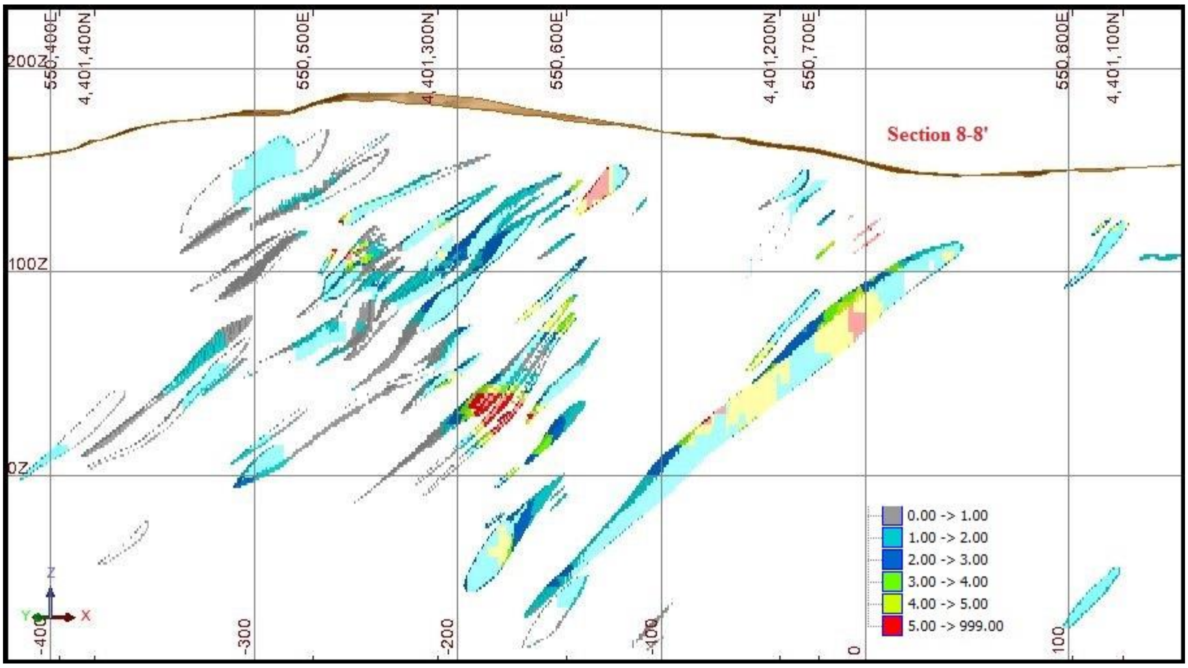

Figure 5.31 : Estimated blocks with Zn (%) grade on Section 8-8'.

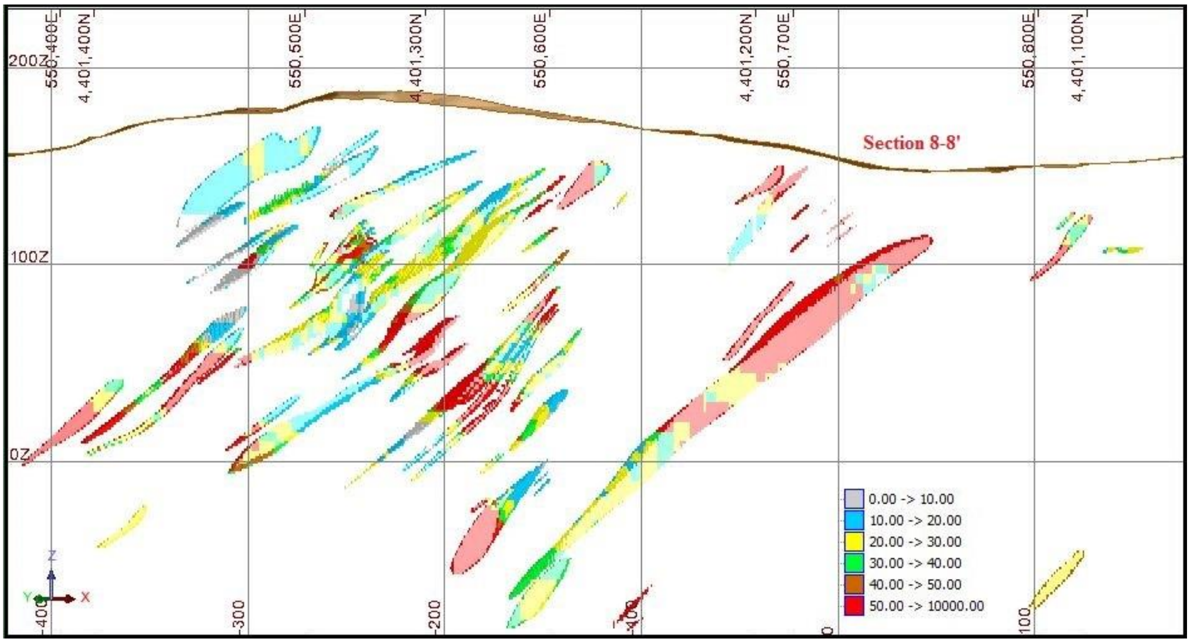

Figure 5.32 : Estimated blocks with Ag (gr/ton) grade on Section 8-8'.

6. RESERVE QUALITY INVESTIGATIONS

Quality is also an important part of reserve estimations for the validation of the mine site as well as mine planning activities. The amount of ore related with its metal content or grade should be the most important consequences of geostatistical applications. In this part, the results derived from the geostatistical application to obtain quality distribution of the ReVs in the study area are used to otain reserve & grade relationships.

Firstly, lead content of the orebody are distributed based on geostatistically investigations and the following table is prepared to show the quantity versus quality.

Table 6.1. Reserve and grade relation for Pb%.

Reserve Based on Pb% Intervals					Reserve Based on Cut-Off Grade		
Pb (%)	**Volume (m^3)**	**Density (gr/cm^3)**	**Reserve (Ton)**	**Average Grade (Pb%)**	**Cut-Off Grade (Pb%)**	**Reserve (Ton)**	**Average Grade (Pb%)**
0.0 -> 1.0	67,072	2.71	181,766	0.74	0.00	4,314,312	3.92
1.0 -> 2.0	349,873	2.71	948,696	1.51	1.00	4,132,546	4.06
2.0 -> 3.0	369,223	2.87	1,059,822	2.51	2.00	3,183,850	4.83
3.0 -> 4.0	267,818	2.87	769,605	3.44	3.00	2,124,028	5.98
4.0 -> 5.0	128,010	2.88	368,570	4.42	4.00	1,354,423	7.42
5.0 -> 10.0	248,770	3.2	796,860	6.94	5.00	985,853	8.55
10.0 -> 20.0	44,553	3.63	161,556	13.88	10.00	188,993	15.33
20.0 -> 100.0	7320	3.75	27,437	23.86	20.00	27,437	23.86

According to the results determined from the geostatistical applications, more than 4 million tons of ore having more than 1% Pb that is selected as cut off grade for the production that has average grade as per 4.06% Pb content (Table 6.1).

A graph to show the reserve – grade relation for Pb% intervals as well as cut off grade for Pb% can be seen in Figure 6.1.

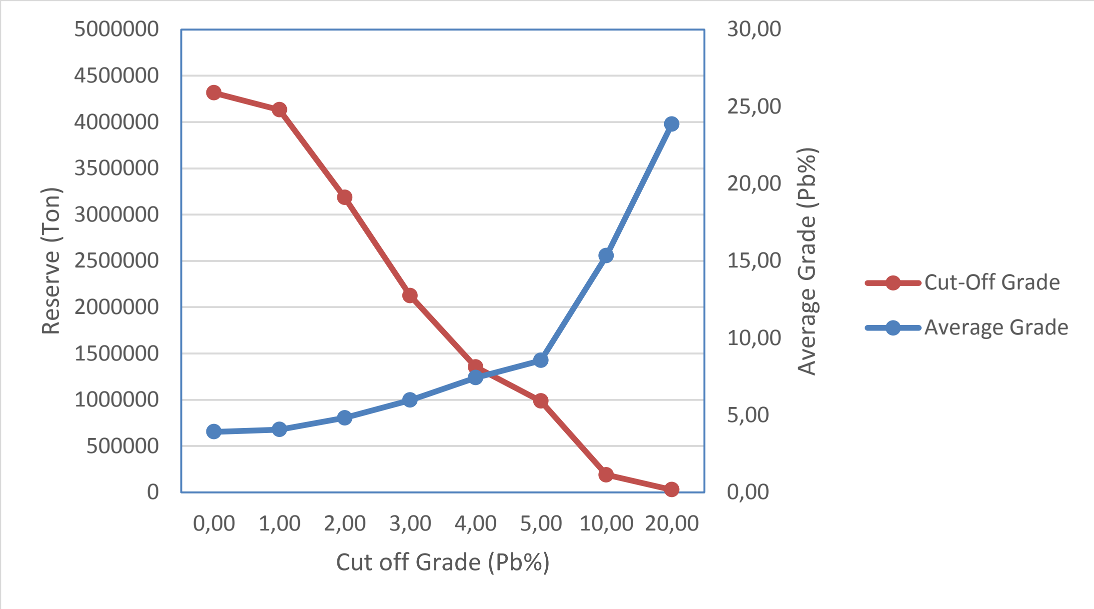

Figure 6.1 : Reserve and grade relation for Pb%.

Considering the results determined from the geostatistical applications, more than 2.5 million tons of ore having more than 1% Zn that is selected as cut off grade for the production that has average grade as per 2.87% Zn content (Table 6.2).

Table 6.2. Reserve and grade relation for Zn%.

Reserve Based on Zn% Intervals					Reserve Based on Cut-Off Grade		
Zn (%)	**Volume (m^3)**	**Density (gr/cm^3)**	**Reserve (Ton)**	**Average Grade (Zn%)**	**Cut-Off Grade (Zn%)**	**Reserve (Ton)**	**Average Grade (Zn%)**
0.0 -> 1.0	597,727	2.81	1,679,699	0.40	0.00	4,314,314	1.91
1.0 -> 2.0	402,602	2.95	1,186,967	1.53	1.00	2,634,615	2.87
2.0 -> 3.0	210,600	2.87	604,652	2.46	2.00	1,447,648	3.97
3.0 -> 4.0	116,373	2.95	343,747	3.44	3.00	842,996	5.05
4.0 -> 5.0	62,824	3.10	194,866	4.48	4.00	499,249	6.16
5.0 -> 10.0	82,604	3.26	269,358	6.58	5.00	304,383	7.24
10.0 -> 20.0	9,527	3.54	33,685	11.81	10.00	35025	12.31
20.0 -> 100.0	371	3.61	1340	24.81	20.00	1340	24.81

A graph to show the reserve – grade relation for Zn% intervals as well as cut off grade for Zn% can be seen in Figure 6.2.

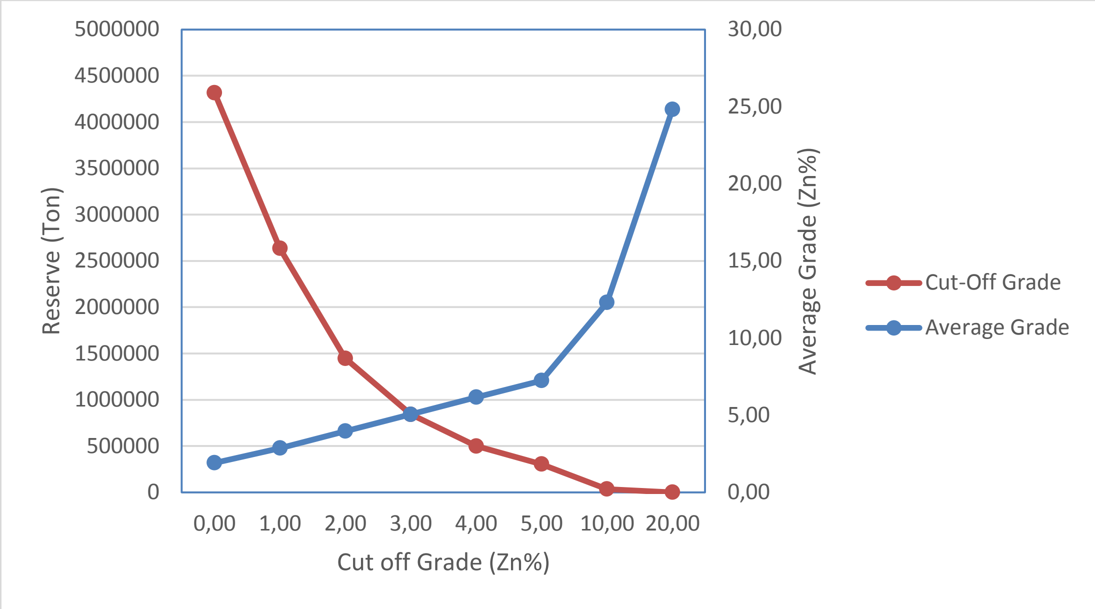

Figure 6.2 : Reserve and grade relation for Zn%.

According to the results determined from the geostatistical applications, more than 4 million tons of ore having more than 10% Ag that is selected as cut off grade for the production that has average grade as per 63.19% Ag content (Table 6.3).

Table 6.3. Reserve and grade relation for Ag (gr/ton).

Reserve Based on Ag (gr/ton) Intervals					Reserve Based on Cut-Off Grade		
Ag (gr/ton)	**Volume (m^3)**	**Density (gr/cm^3)**	**Reserve (Ton)**	**Average Grade Ag (gr/ton)**	**Cut-Off Grade Ag (gr/ton)**	**Reserve (Ton)**	**Average Grade Ag (gr/ton)**
0.0 -> 10.0	29,053	2.71	78,743	7.59	0.00	4,314,312	62.18
10.0 -> 20.0	203,219	2.72	552,084	15.45	10.00	4,235,569	63.19
20.0 -> 30.0	237,184	2.78	660,216	25.12	20.00	3,683,485	70.35
30.0 -> 40.0	231,613	2.84	657,866	34.97	30.00	3,023,269	80.23
40.0 -> 50.0	200,758	2.86	574,453	44.84	40.00	2,365,403	92.81
50.0 -> 100.0	372,965	2.91	1,083,751	67.45	50.00	1,790,950	108.2
100.0 -> 1000.0	207,848	3.40	707,199	170.65	100.00	707,199	170.65

A graph to show the reserve – grade relation for Ag gr/ton intervals as well as cut off grade for Ag gr/ton can be seen in Figure 6.3.

Figure 6.3 : Reserve and grade relation for Ag gr/ton.

7. CONCLUSIONS AND RECOMMENDATIONS

This thesis study covers evaluation of Balya-Hastanetepe lead and zinc ore body using geostatistical methods. Dedeman Mining company hold the licence of study area and the company have 33,000 m of core drilling that totally 184 diamond drillholes up to date of study started.

Data validation and determination and was main step of the study . Considering the fact that quality of the resource estimate is directly depend on the quality of data procedures, this chapter took into deeply.

Solid model of the ore body created using sectional method as a base of 3 dimesion geostatistical investigations. So, total volume of the solid model created in this study is 1,503,167 m^3.

This study mainly covers geostatistics evaluation and resource estimation for the mine. After statistical investigation studies spatial descriptive statistics completed. Related with spatial descriptive statistic studies semivariograms examined therefore the data distribution observed as isotropic.

Statistical analyses were firstly carried out to understand the distribution behaviour of the variables that are lead (Pb), zinc (Zn) and silver (Ag). According to the statistical evaluations, geostatistical investigations were then initiated. Firstly raw data were used to determine the best available estimations from kriging. However due to the low correlations between actual and estimated values for each regionalized variables (ReVs), 1 m composite data applied to the transformed data for each ReVs were used in geostatistical applications.

In order to make 3 dimensional estimations, which is the most important innovative section of this study, search ellipsoid were used to make geostatistical estimations. Optimizations were also applied to obtain highly correlated actual and estimated values from cross validations, hence optimized search ellipsiods dimensions were determined and it decided to use following parameters as number of samples to krig a point is 40 and distance for search ellipsoid is 50.

Ordinary kriging method is applied to estimate the ReVs magnitude for unsampled points in the study area. Hence, distribution maps for each ReVs are then determined for the study area that shows the magnitude for each desired locations 3 dimensionally. Finally, reserve and grade relations are obtained to demonstrate reserve quality of the ore deposit that is vital for ore body validation as well as mine planning (Table 7.1).

Table 7.1 : Reserve and grade results for all variables.

Reserve	**Pb (%)**	**Zn (%)**	**Ag (gr/ton)**
4,314,312	3.92	1.91	62.18

This study will be a good application especially for metalliferious ore bodies to evaluate the reserve quality and quantity based on 3 dimensional geostatistical approaches with reliable data.

It is recommended that a large scale drilling grid to be established towards testing the extent of the mineralization between Hastanetepe and the adjacent mines which are called as Sarisu and Ari-Orta.

REFERENCES

Annels A.E., (1991). *Mineral Deposit Evaluation*: A practical Approach. Chapman and Hall, London, p 436.

Akyol, Z., (1975). *Balikesir ili Balya civarının jeolojisi*. İstanbul Üniversitesi, Fen Fakültesi, Jeoloji Kürsüsü, Diploma Çalışması, (not published)

Akyol, Z., (1977). *Balya Madeni Civarının Jeolojisi*. Jeoloji Mühendisliği Dergisi, S.10-27

Akyol, Z., (1979). *Balya Kurşun-Çinko Maden Yatağı*. Jeoloji Mühendisliği Dergisi, S.48-58

Aygen, T., (1956). *Balya Bölgesinin Jeolojisinin İncelenmesi.* M.T.A Volume S DNU-11, Ankara.

Aydinli, H.S, (2004). *Balya (Balıkesir) Güney Bölgesi Kayaçlarının Petrografik İncelenmesi.* Yüksek Lisans Tezi, Hacettepe Üniversitesi, Ankara (not published).

Balçık, A., Kurul, A., Tufan, A., Tüzün, R., Tüzün, D., (1981), *Balya Madeni-Hastanetepe ve Sarısu Sahası Jeoloji Raporu*, MTA Rap. No 7327

Bukowski, G., (1892). *Die geologischen Verhaeltnisse der Umgebung von Balya-Maden*.- Sitz. Kais Akad., Wien, Math.-Nat. Kl. I.

Coombes, J., (2008). *The Art and Science of Resource Estimation*. Subiaco, W.A. Coombes Capability, 2008.

Dedeman Mining Company, (2009). *Balya Drilling Study,* Balya, Balıkesir (not published).

Enderle, J., (1900) *Über eine anthrakolithische Fauna von Balia Maden in Kleinasien*. Beitr. Pal. Öst.-Ung., 13, 49-109., Wien.

Erel, Z., (2011). Balya (*Balıkesir) Polimetalik Medan Yatağı Rezervinin Jeoistatistik Yöntemle Analizi,* Yüksek Lisans Tezi, Çukurova Üniversitesi, Adana. (not published)

Gemcom (2007). *Geostatistical,* Geology and Mine Planning Software, Germany.

Gemcom (2007). *Block Model,* Geology and Mine Planning Software, Germany.

Gemcom (2007). *Ore Body Modelling,* Geology and Mine Planning Software, Germany.

Gjelsvik, T., (1958). *Notes on the geology of Balya Mine.* M.T.A Journal, No:51.

Gjelsvik, T., (1962). *Kuzeybatı Anadolu Pb-Zn zuhurlarında yapılan araştırmalar.* M.T.A Journal, S 59.

Houlding, W.S., (2000). *Practical Geostatistics: Modelling and Spatial Analysis*. Springer Verlag, Berlin.

Isaaks, E.H., Srivastava, R.M., (1989). An Introduction to Applied Geostatistics. Oxford University Press. New York.

Jeon, S., Hong, C., You, K., (2009). *Design of tunnel supporting system using geostatistical methods*. In: Huang, Liu (Eds.), Geotechnical Aspects of Underground Construction in Soft Ground-Ng, pp. 781–784.

JORC Code (2012).*Joint Ore Reserves Committee*, Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves, Australia, (not published)

Journel, A.G., (1983). *The indicator approach to estimation of spatial distributions*, in T.B. Johnson and R. J. Barnes, eds., Proceedings of the 17th International Symposium of the Applications of Computers and Operations Research in the Mineral Industry: New York, Society of Mining Engineers, p. 793-806.

Journel, A.G., (1989). *Fundamentals of Geostatistics in Five Lesson*, American Geophysical Union, 2000 Florida Avenue, NW, Washington, DC 20009, USA.

Kaaden, G., (1957). *Canakkale, Biga, Edremit yarımadası bölgesindeki jeolojik saha çalışmaları ve maden yatakları rapor* (not published).

Kovenko, V., (1940). *Balya Lead Mines*. MTA Journal. No 4/21 Ankara.

Leuangthong O., Khan, D.K., Deutsch, C.V., (2008). Solved Problems in Geostatistics. Wiley-Interscience, New Jersey.

Matheron, G., (1963). Principles of geostatistics. Economic Geology, v.58, no. 8, 99. 1246-1266

Mohr, M., (1959). Balya mıntıkasındaki kurşun zuhurlarının prospeksiyonu, No 2703, MTA, Ankara

Neumayr, M., (1886) *Über Trias und Kahlenfcalk-verstelner ungen aus dem vestlichen kleinasien* Anz. d. Kais. Akad d. Wiss. Wien

Oh, S., Lee, D.K., Chung, H., (2004). *Geostatistical integration of MT and borehole data for RMR evaluation*. Environ. Geol. 46, 1070–1078.

Oh, S., (2012). *Geostatistical integration of seismic velocity and resistivity data for probabilistic evaluation of rock quality*. Environ. Earth Sci.. http://dx.doi.org/ 10.1007/s12665-012-1978-3.

Okay, A.İ., Güncüoğlu M.C., (2004). *Turkish Journal of Earth Sciences*, Vol. 13, pp. 77-95.

Ovalıoglu, R., (1973). *Biga Yarımadasının Jeolojisi* – Maden Yatakları ve Bakır-Kurşun-Çinko Mineralizasyonu İçin Ümitli Olan Bölgeleri, Madencilik Dergi, Cilt XII, 6, p. 1-22.

Ozturk, C.A., (2001). Maden yataklarının jeoistatistiksel değerlendirilmesinde kriging ve PCSY tekniklerinin karşılaştırılması. Yüksek Lisans Tezi, İstanbul Teknik Universitesi, Fen Bilimleri Enstitüsü, İstanbul. (not published).

Ozturk, C.A., Nasuf, E., (2002). *Geostatistical assessment of rock zones for tunnelling. Tunn*. Underground Space Technol. 17.

Ozturk, C.A., Simdi, E., (2012). *Subway Project in Istanbul, Turkey*. In Proc. 46th US Rock Mechanics/Geomechanics Symposium (ARMA 2012), Chicago, USA.

Pincock Perspectives (2001). *Geostatistics*-Colorado, USA, (not published)

Rosenbaum, M.S., Rosen, L., Gustafson, G., (1997). *Probabilistic models for estimating lithology*. Eng. Geol. 47, 43–55.

Rossi, M. E., Deutsch C. V., (2014). *Mineral Resource Estimation*– Springer Science Business Media Dordrecht, p. 44, 139.

Saraç, C., Tercan, A.E., (1996). Grade and reserve estimation of the tulovasi borate deposit by block kriging. International Geology Review, vol. 38, p. 832-837.

Srk Consulting Company, (2010). *Balya Pb-Zn-Ag Project Scoping Study,* Ankara (not published).

Switzer, P., (1977). Estimation of spatial distributions from point sources with application to air pollution measurement. Bulletin of the International Statistical Institute, 47.

TchPhatcheff, P., (1886), *Asie mineure, description physique de cette contrée 8 vol*, Paris.

Tercan A.E., Köse A., (1997). *Bir Krom Yatağında Jeoistatistiksel Yapının Variogramlarla Belirlenmesi*, Türkiye 15. Madencilik Kongresi, Ankara, 3-9

Uçurum, M., (1987). *Balıkesir-Balya Kurşun Çinko sahasındaki Jig ve birinci flotasyon atıklarının teknolojik değerlendirilmesi*. Mining Journal. V 26. P 3

APPENDICES

APPENDIX A: Company permission letter
APPENDIX B: Cross sections

APPENDIX A

20.11.2015

ISTANBUL TECHNICAL UNIVERSITY

MINE FACULTY

MINING ENGINEERING DEPARTMENT

To whom it may concern,

Dedeman Mining Company allowed to usage of company's data relevant with Balikesir-Balya province to Ezgi Toka in her thesis study.

Please be informed,

Director of Research and Development Department

Adil Alku

APPENDIX B

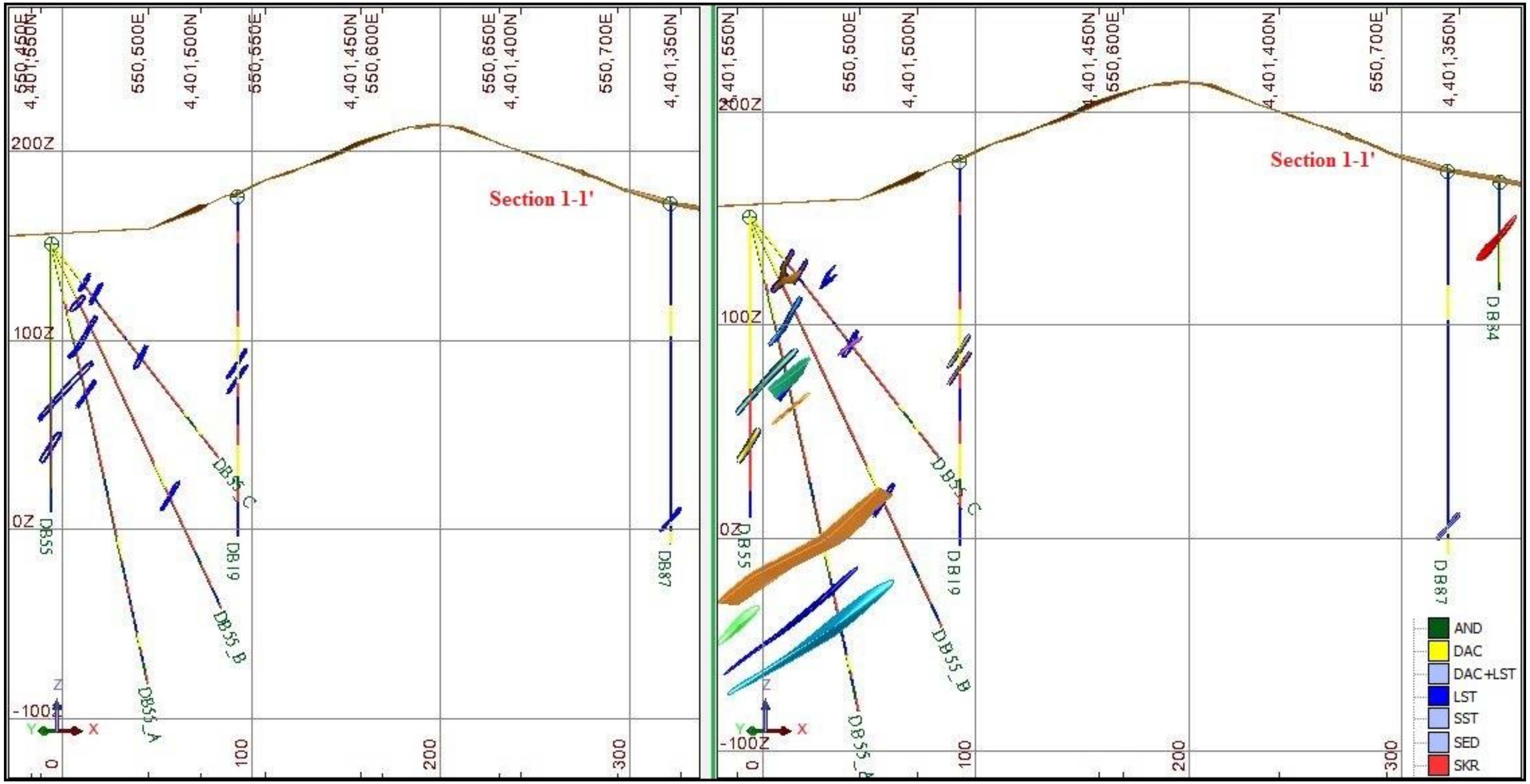

Figure B.1 : Section 1-1’ view of ore strings and solid models.

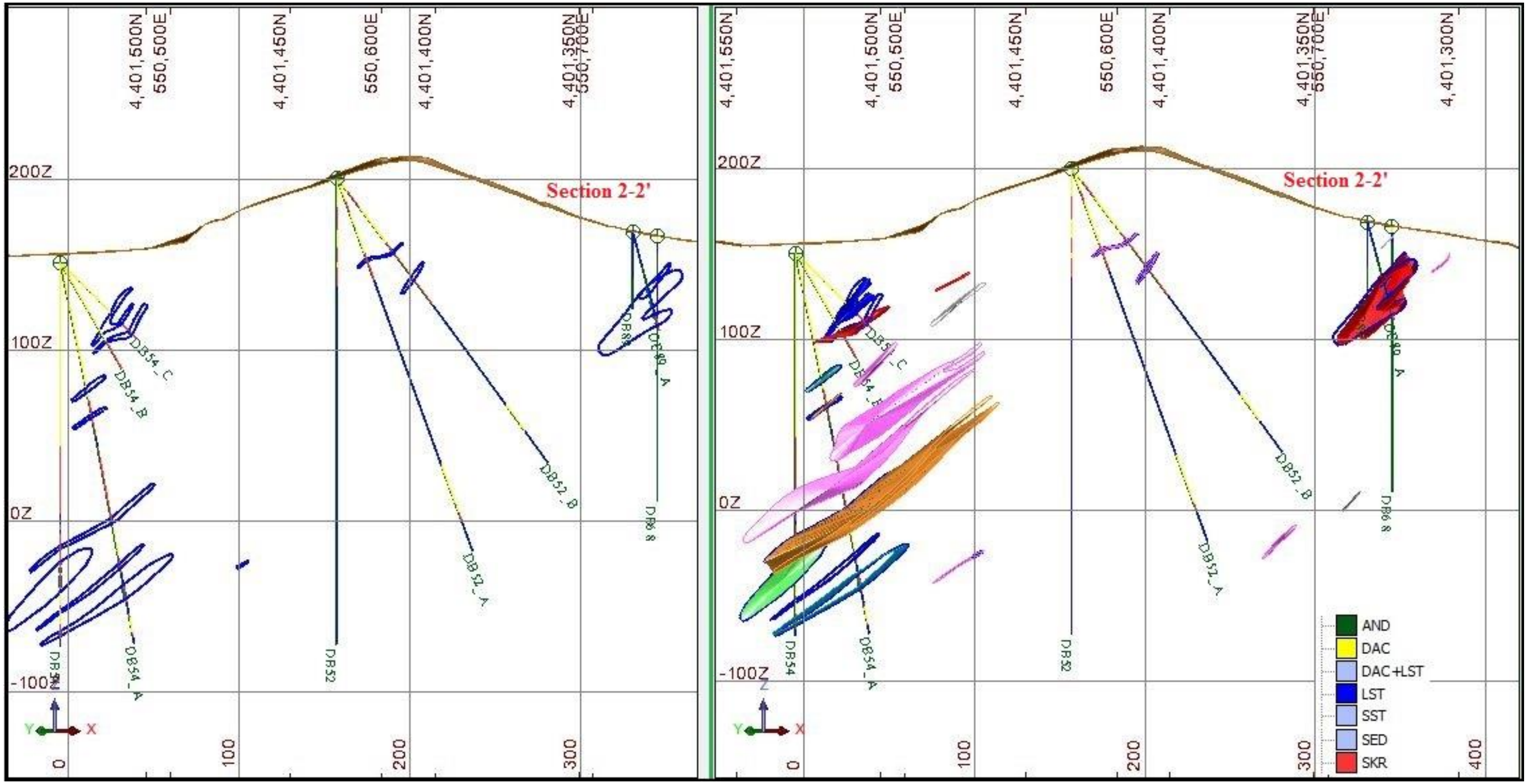

Figure B.2 : Section 2-2’ view of ore strings and solid models.

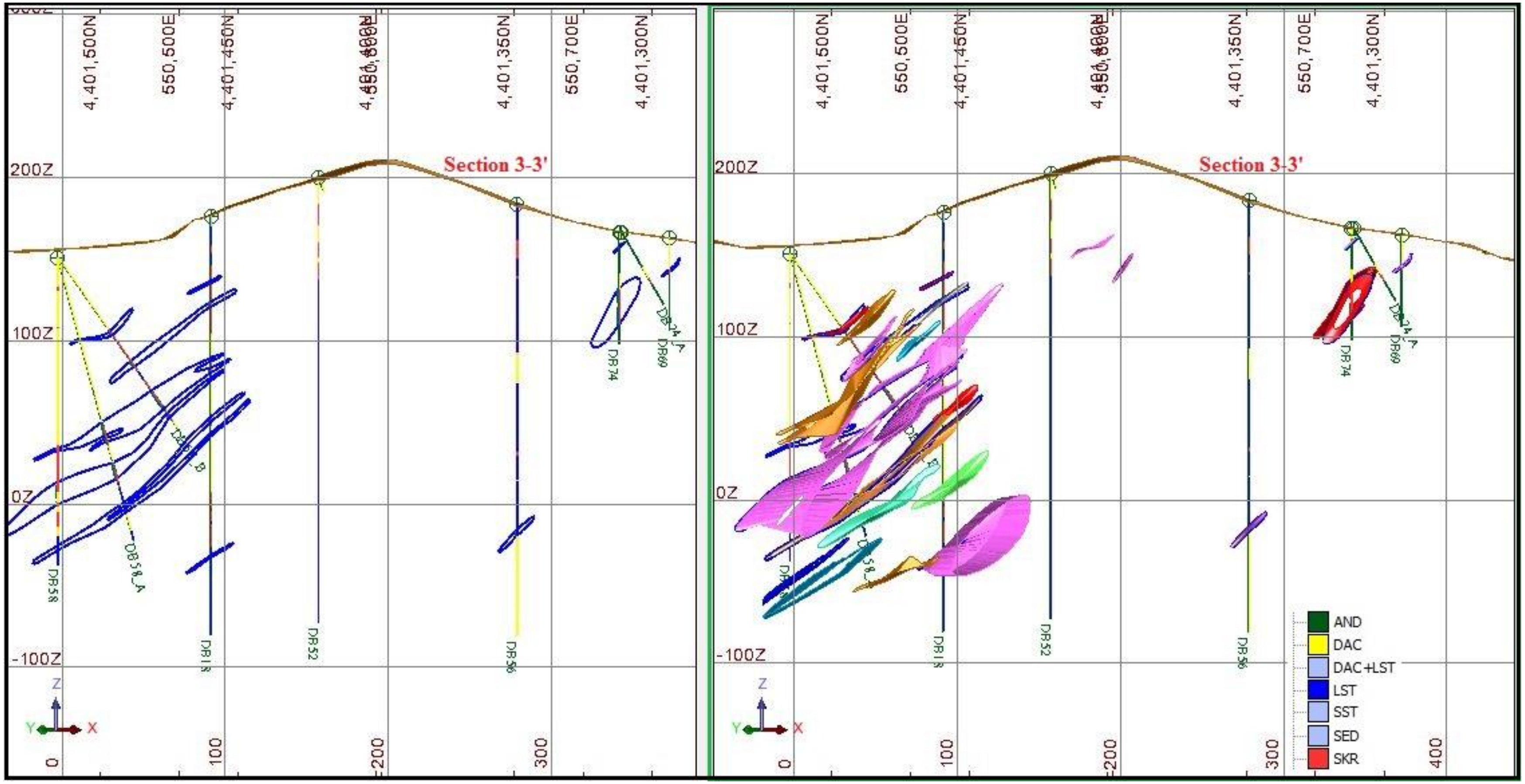

Figure B.3 : Section 3-3' view of ore strings and solid models.

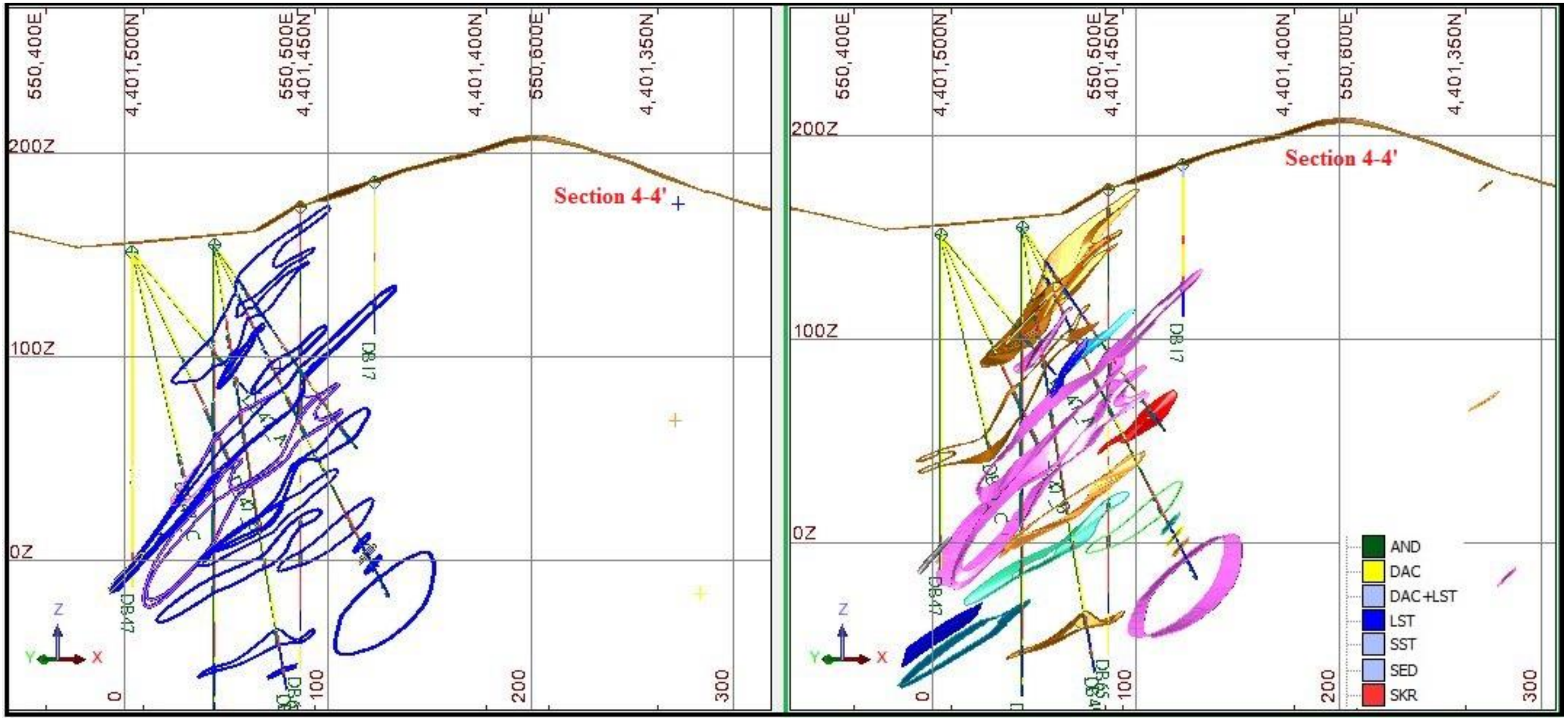

Figure B.4 : Section 4-4' view of ore strings and solid models.

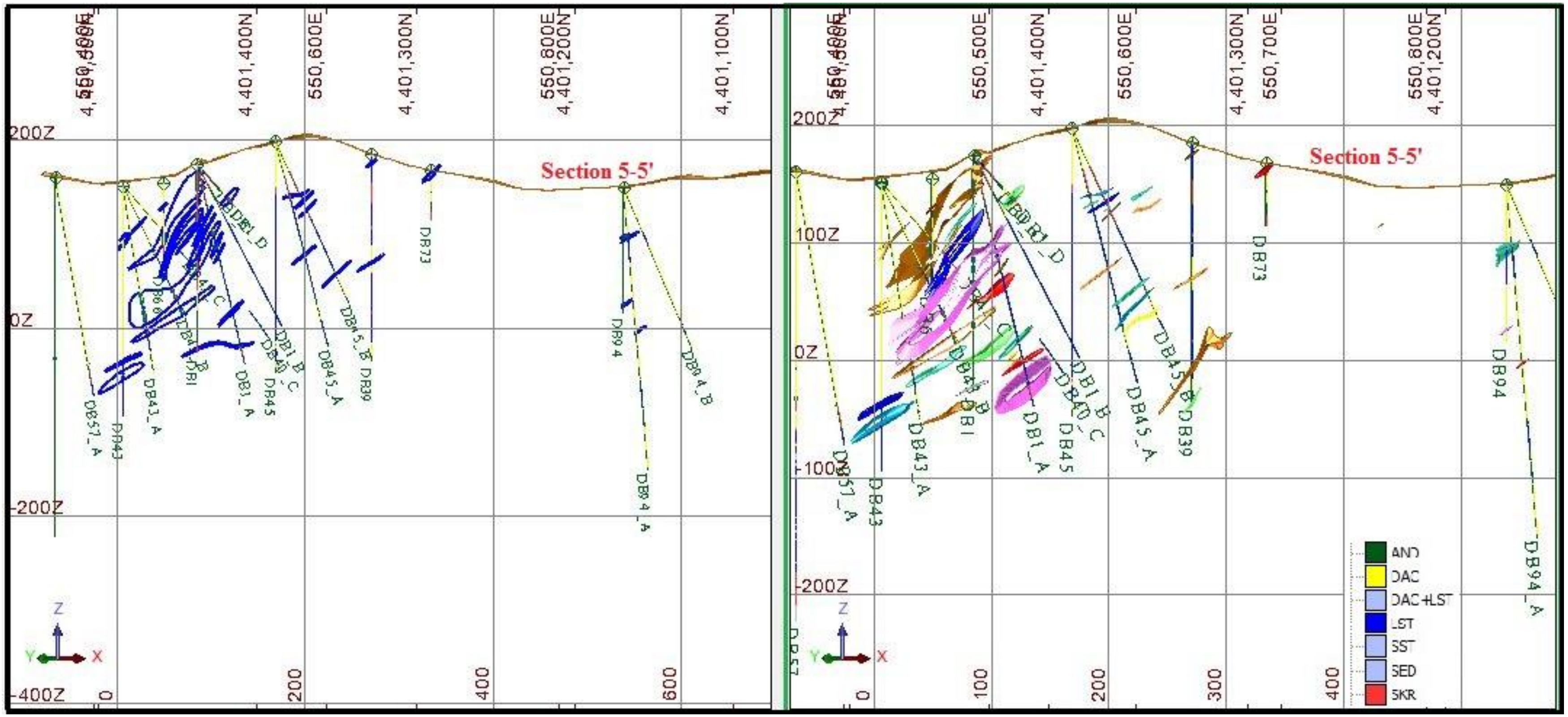

Figure B.5 : Section 5-5’ view of ore strings and solid models.

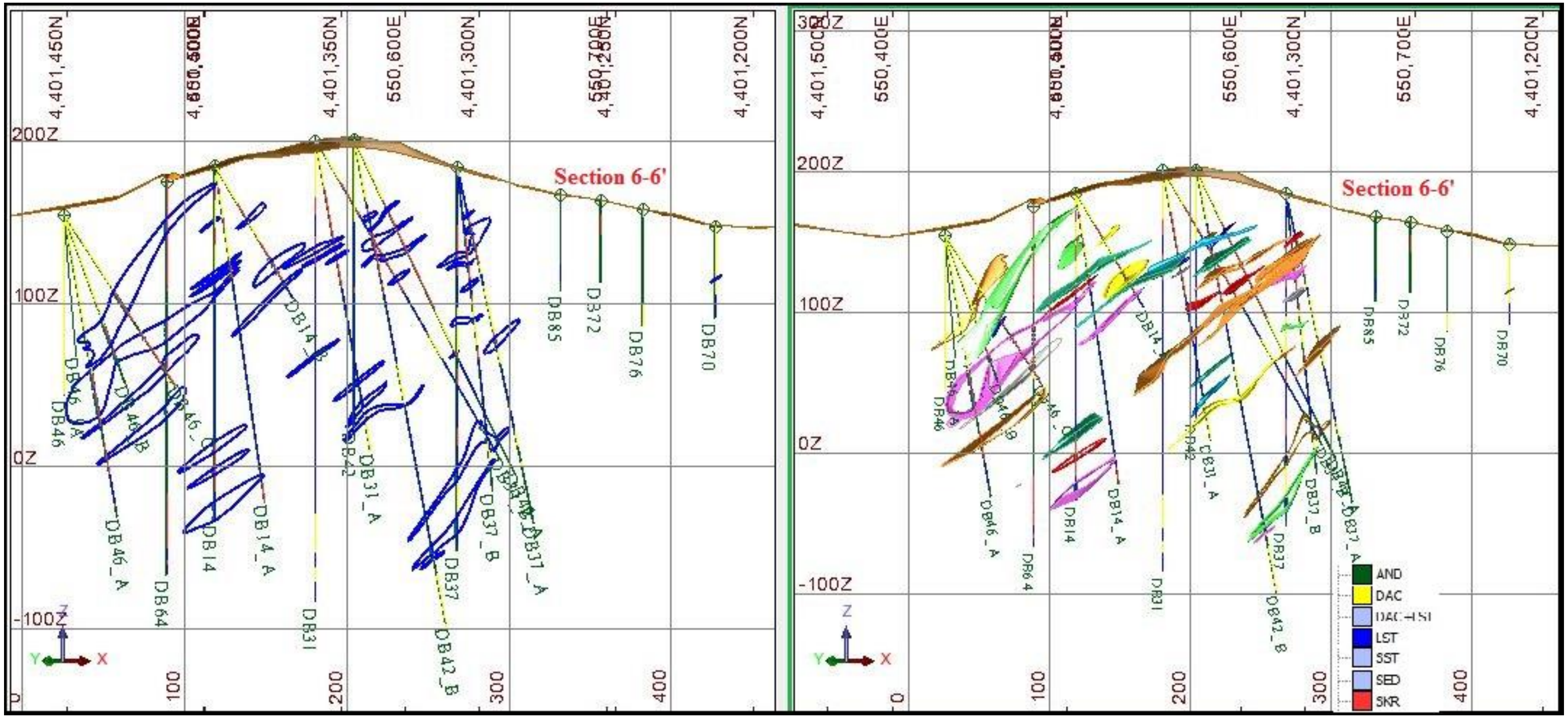

Figure B.6 : Section 6-6’ view of ore strings and solid models.

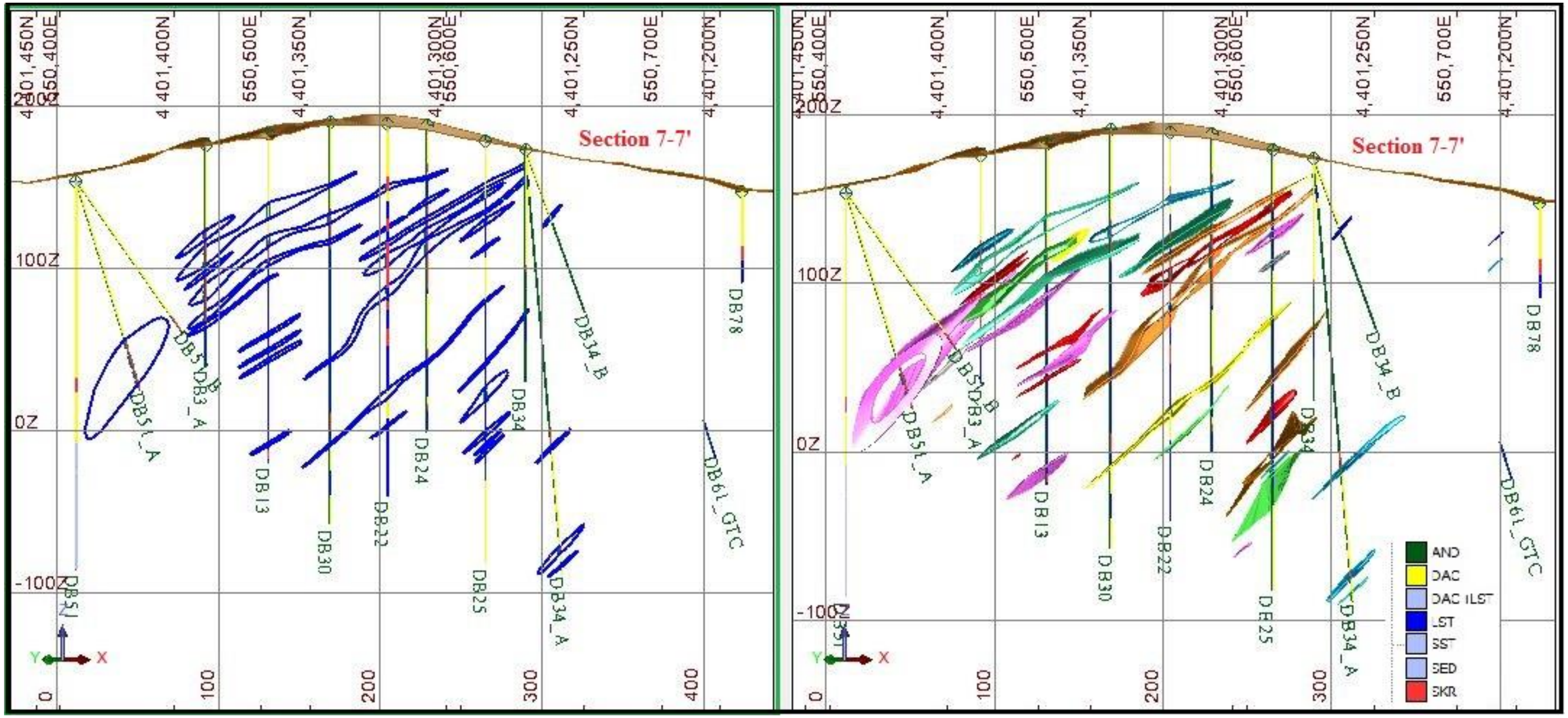

Figure B.7 : Section 7-7' view of ore strings and solid models.

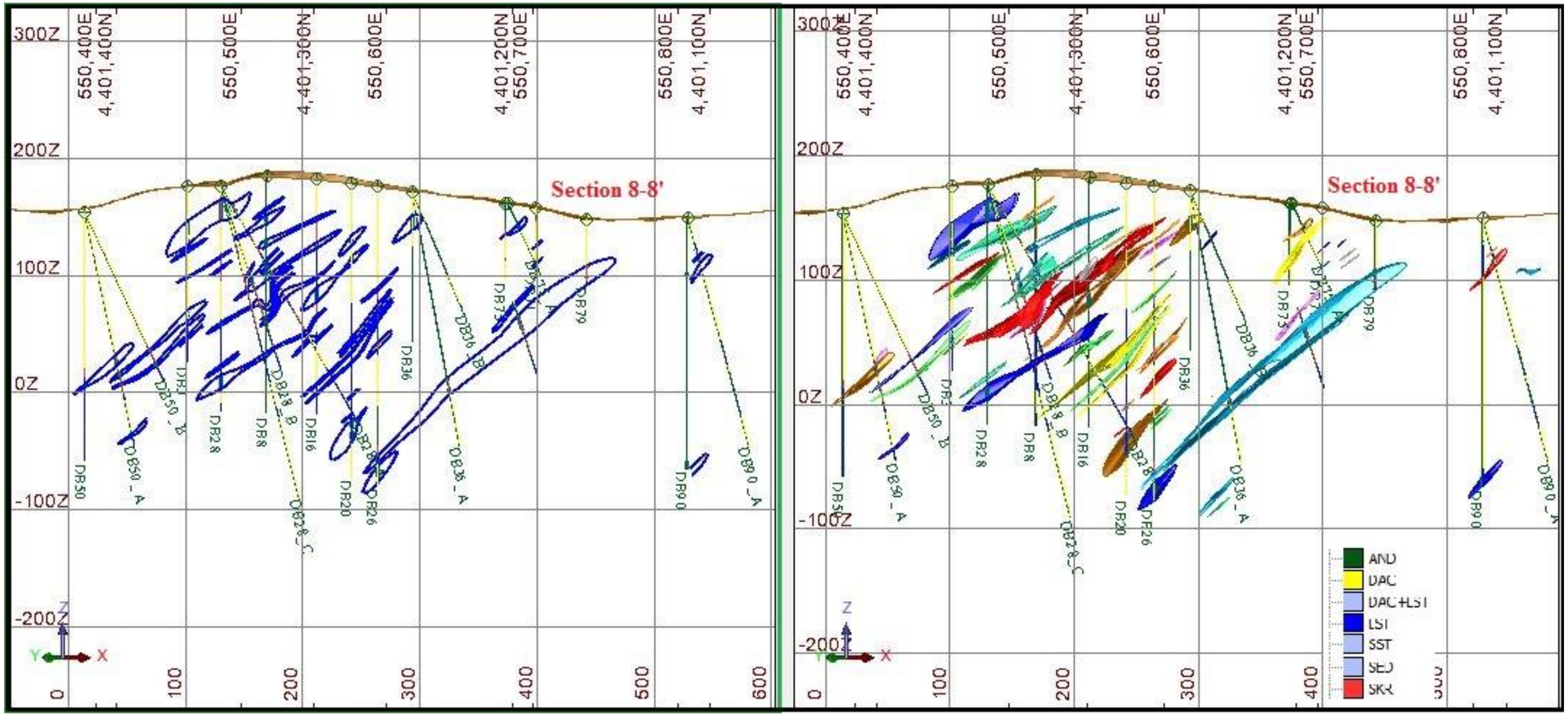

Figure B.8 : Section 8-8’ view of ore strings and solid models.

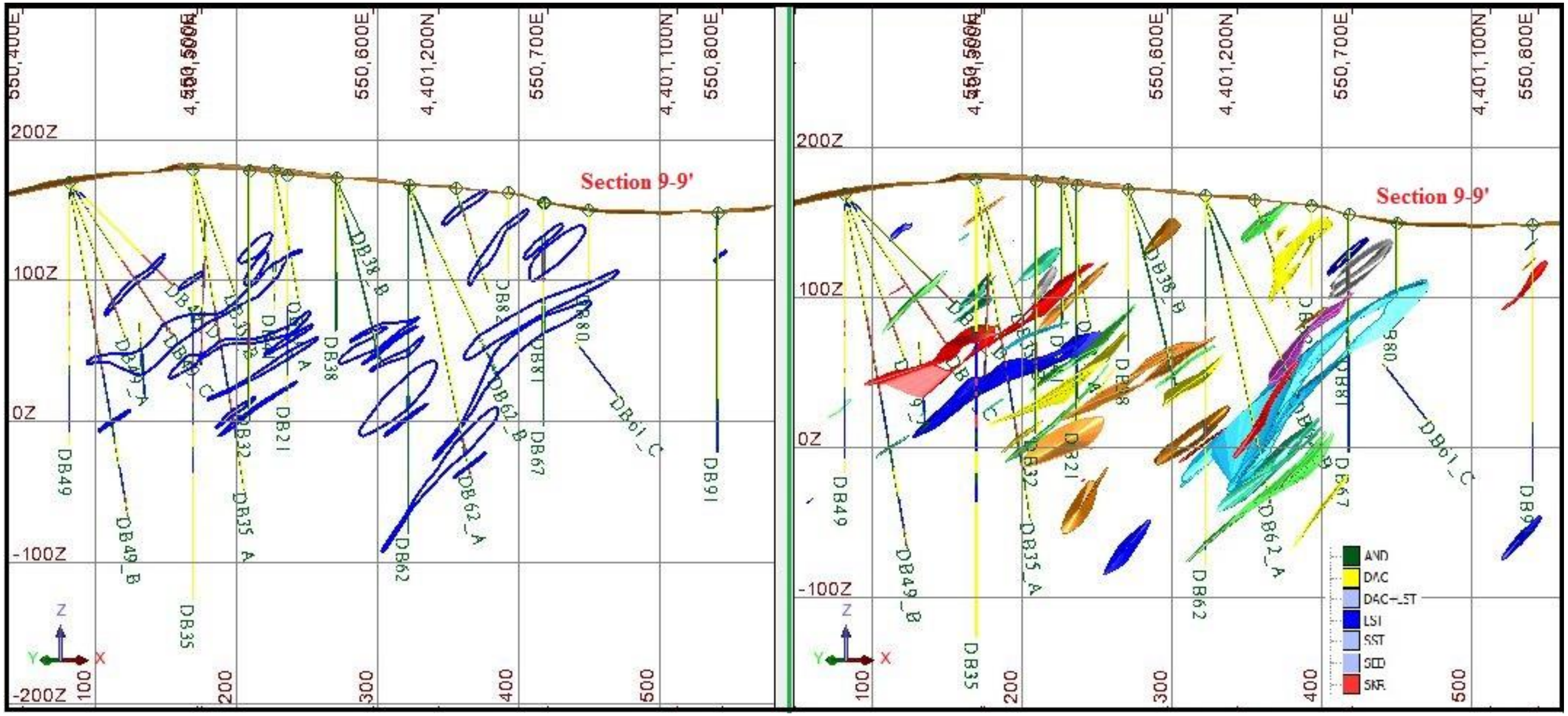

Figure B.9 : Section 9-9’ view of ore strings and solid models.

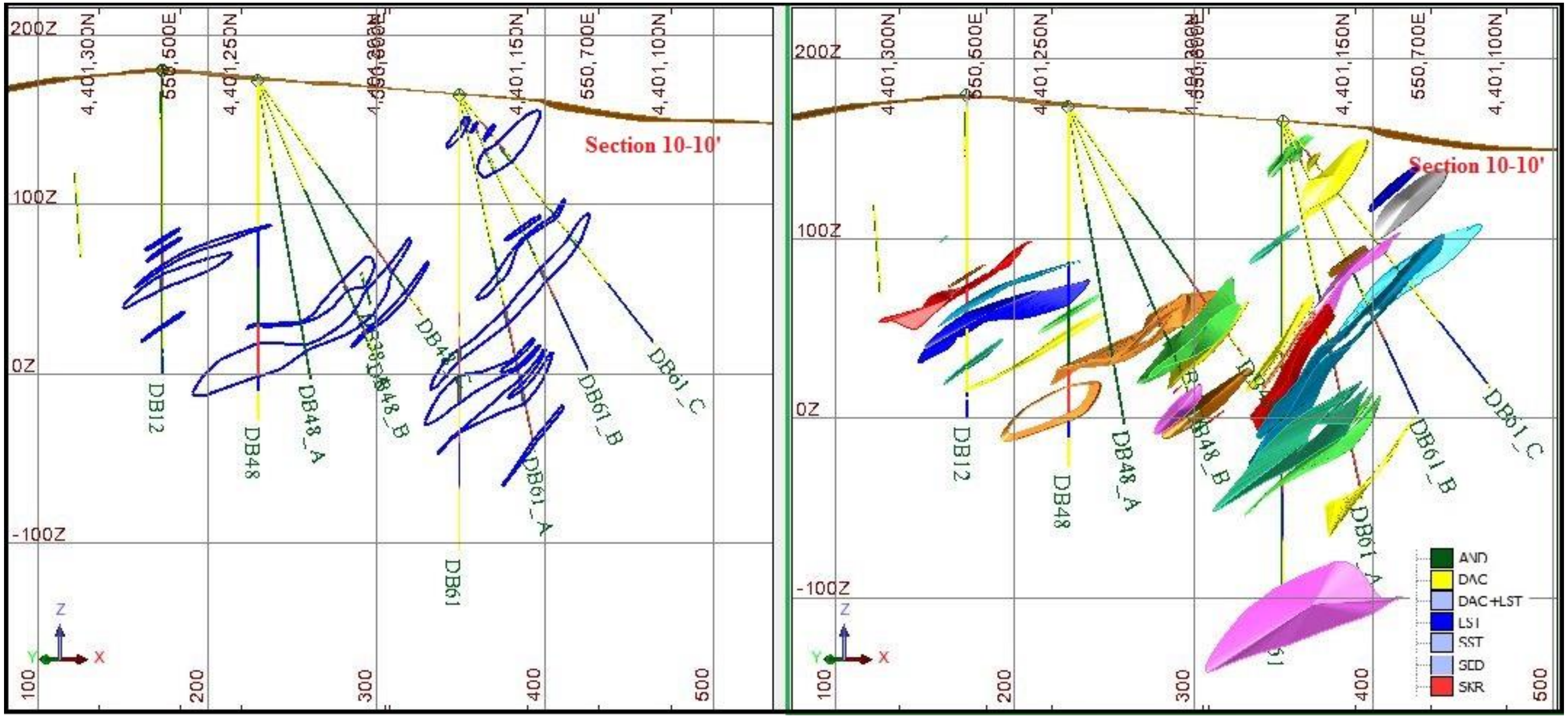

Figure B.10 : Section 10-10' view of ore strings and solid models.

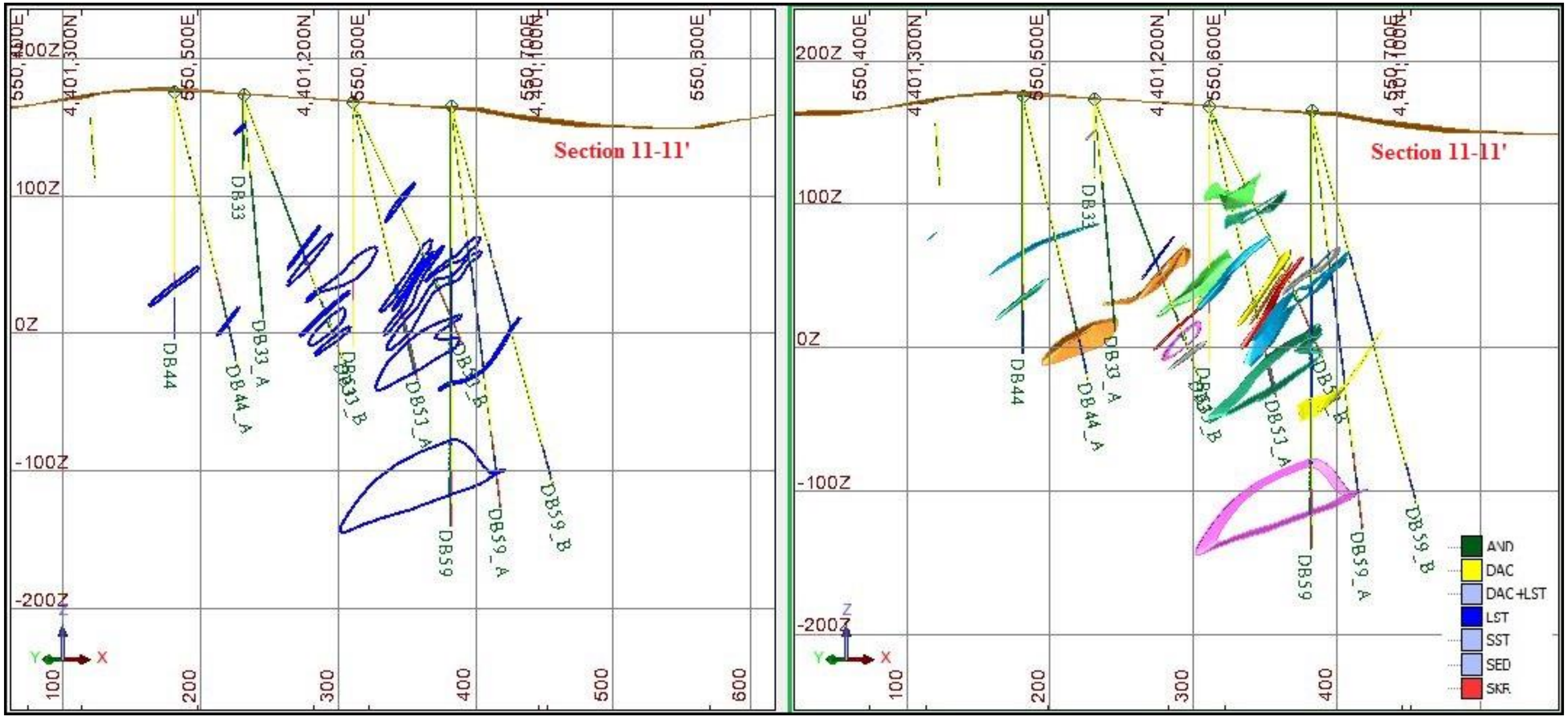

Figure B.11 : Section 11-11' view of ore strings and solid models.

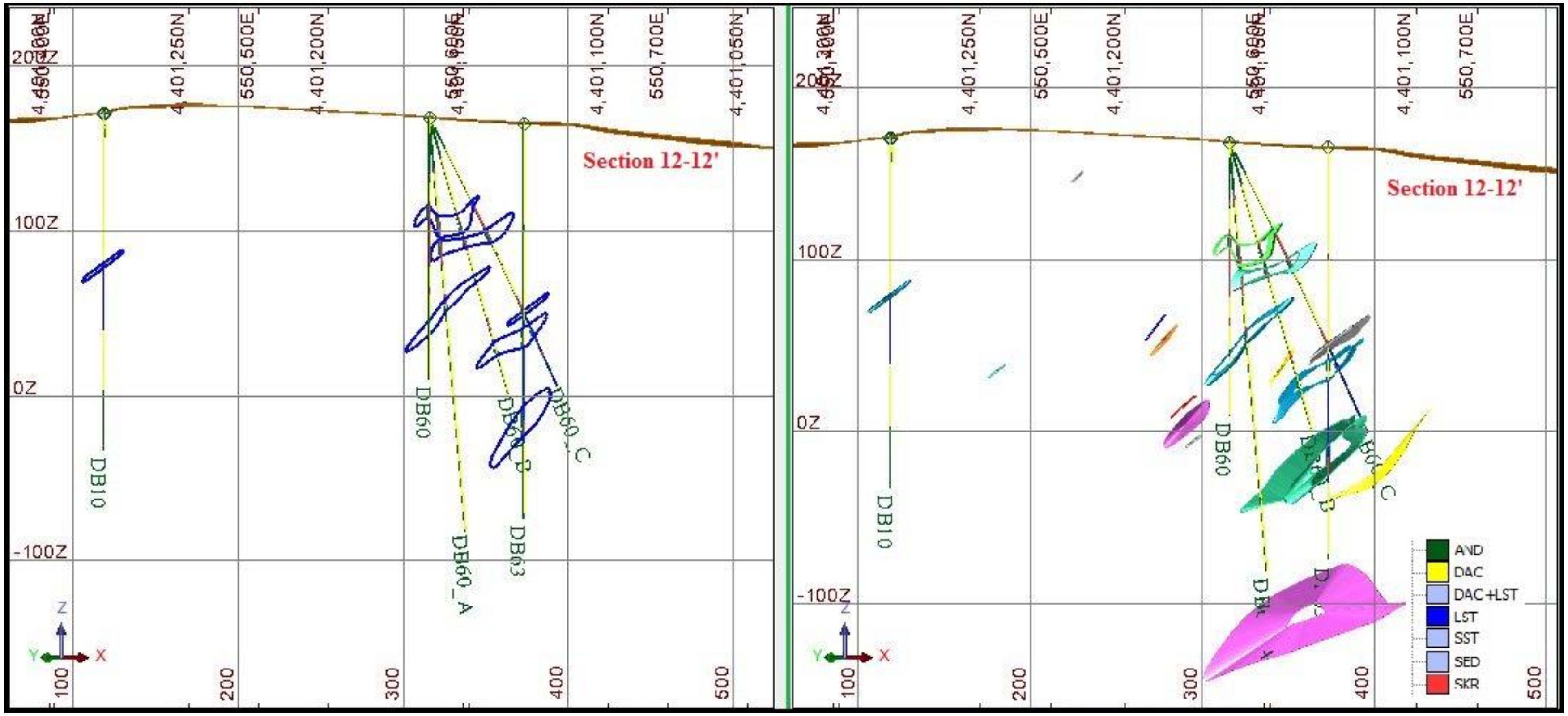

Figure B.12 : Section 12-12' view of ore strings and solid models.

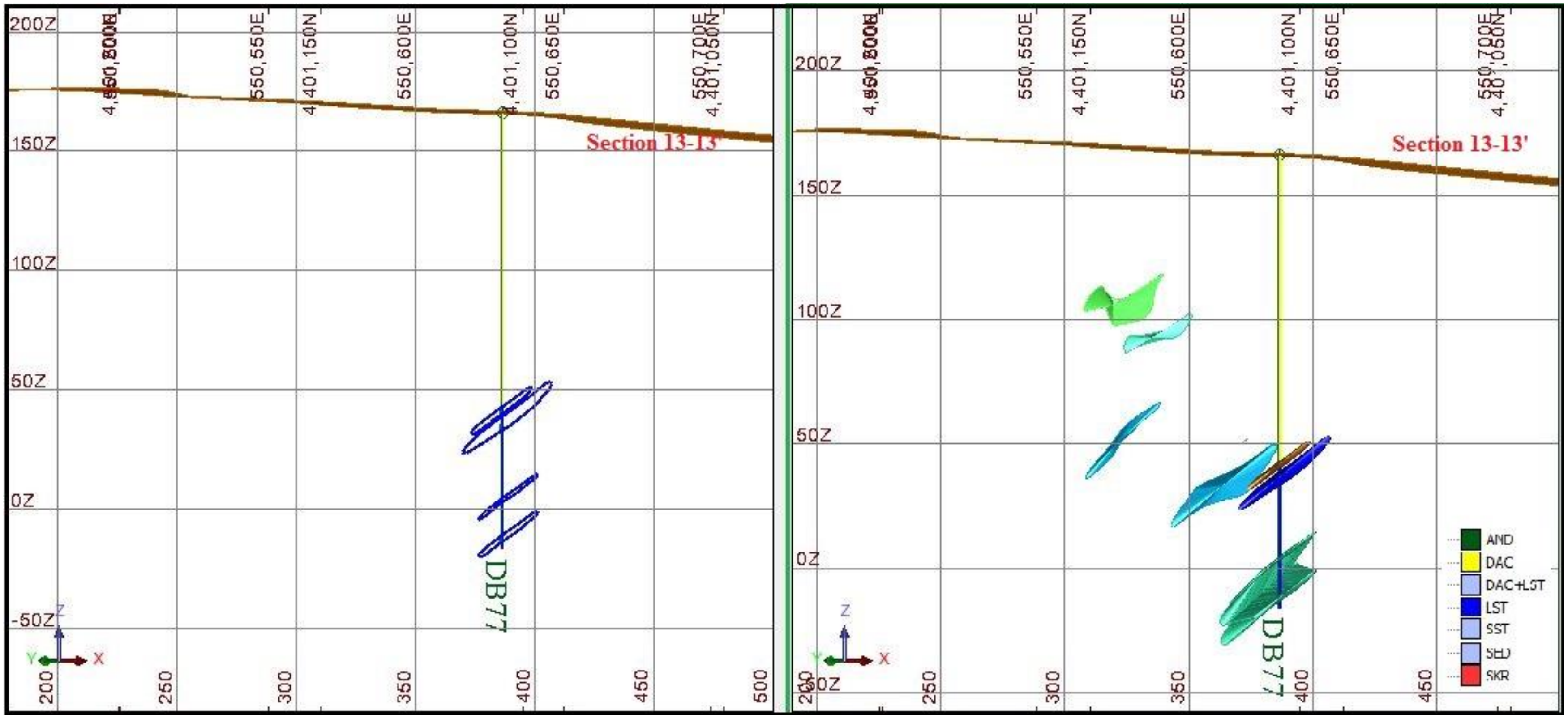

Figure B.13 : Section 13-13’ view of ore strings and solid models.

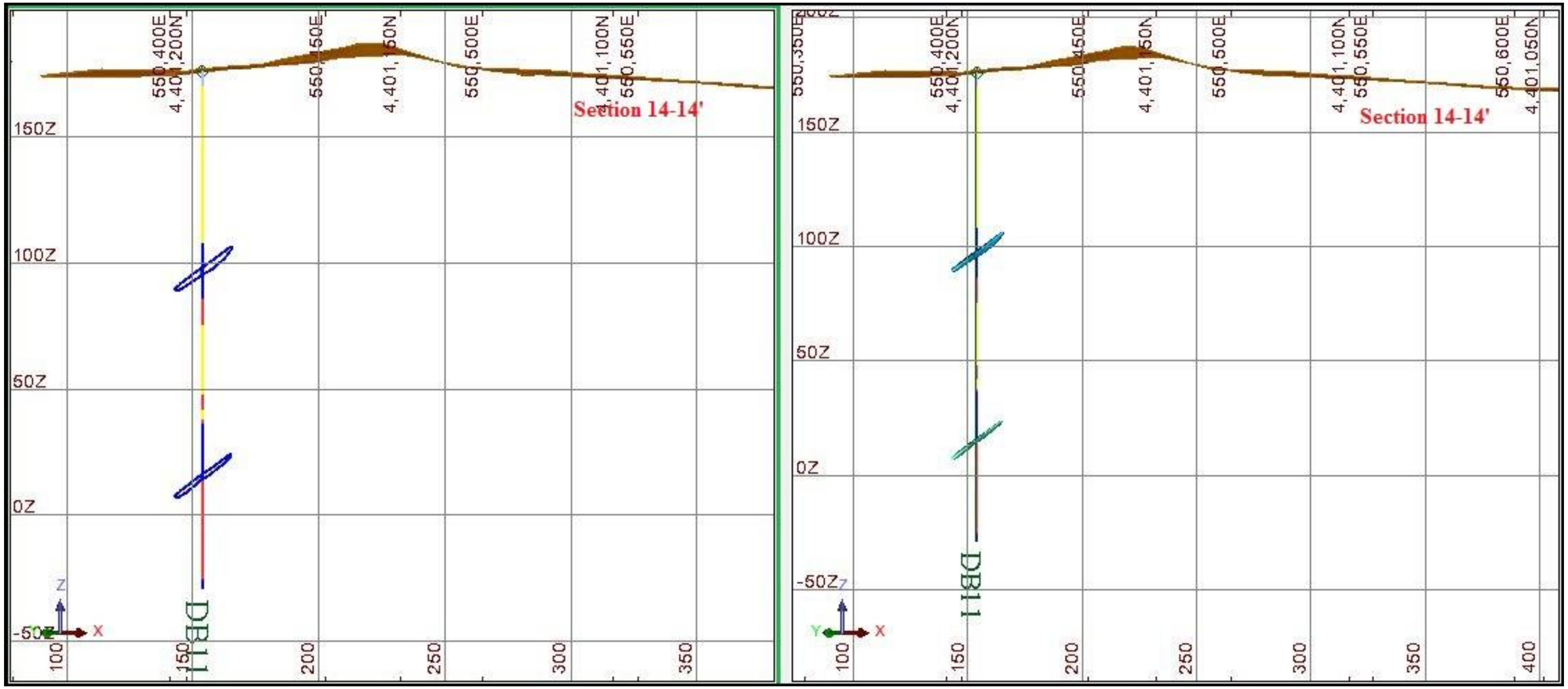

Figure B.14 : Section 14-14’ view of ore strings and solid models.

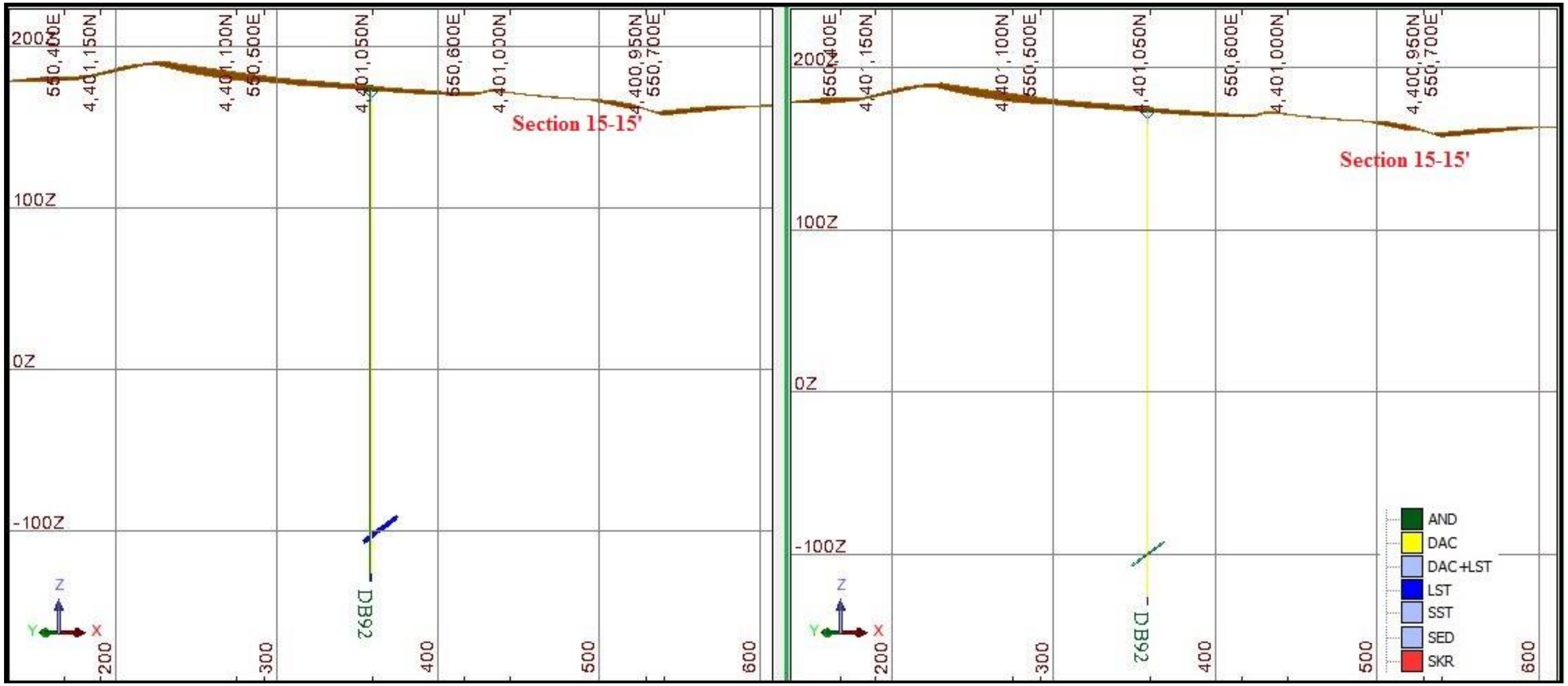

Figure B.15 : Section 15-15’ view of ore strings and solid models.

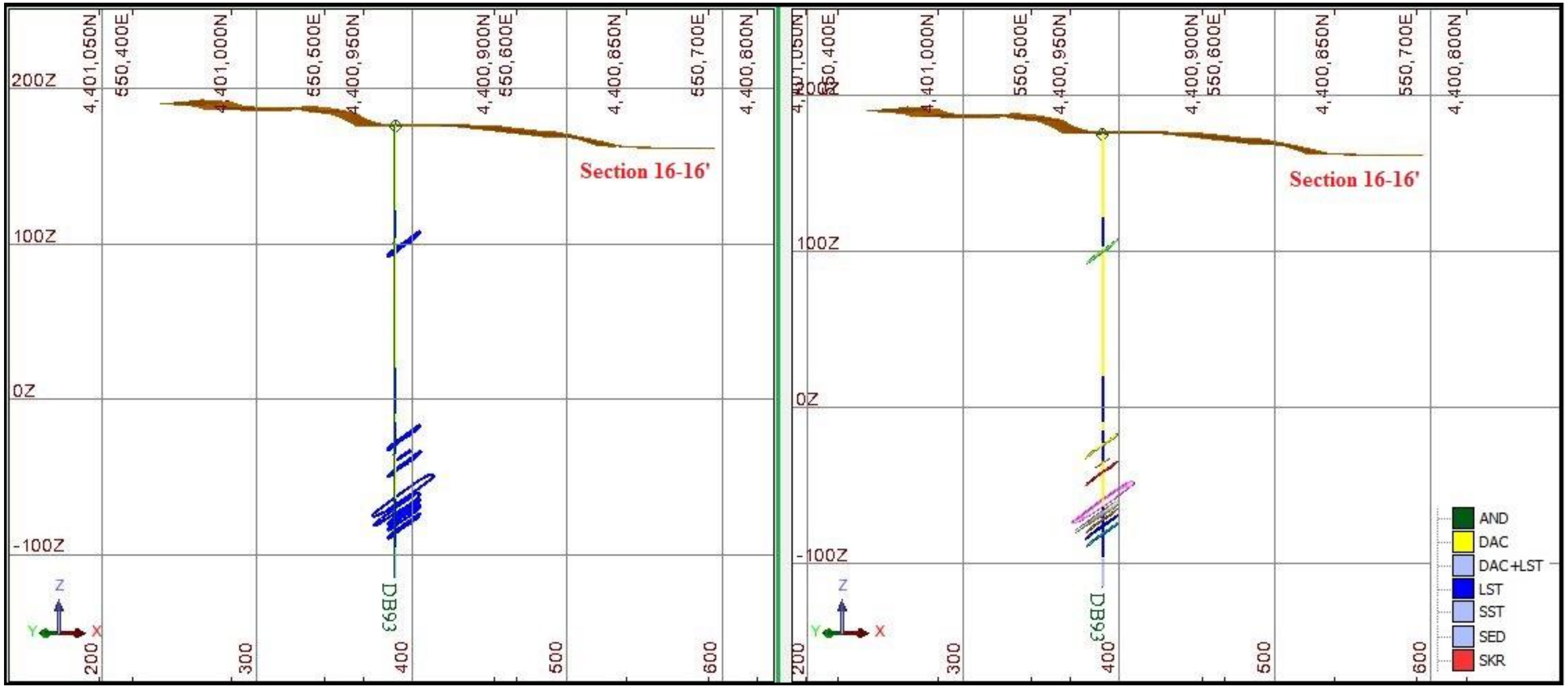

Figure B.16 : Section 16-16’ view of ore strings and solid models.

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