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Limestone reserve calculation for engineering purposes for the Nfayil Formation (middle Miocene) in Bahr Al-Najaf Depression, Iraq

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Abstract

Limestones have considerable commercial importance because they are used as building stones and are widely used for flooring and interior and exterior facings. On the other hand, the reserve calculation reveals the economic effectiveness of the investigation. This study aims to calculate the reserve of the middle Miocene limestone for engineering purposes. The limestone beds of the Nfayil Formation in Central Iraq have been studied over 15 outcrop sections. The Nfayil bed has an average thickness of about 1.64 m, while the overburden has an average of about 0.93 m. The average bulk density of limestone is 2.1 gm/cm^3 . Kriging and triangulation method has been adopted and used in the calculation and assessment of reserve. The industrial layer was calculated based on the American classification, where the assessment is from the inferred reserve, which is according to the geological characteristics of the industrial layer, as well as the presence of a few wells obtained for the studied area (15 wells). The industrial bed's total reserve (tonnage) is 253,245,195 tons, which is acceptable for accuracy and reliability compared to the American system. These values are acceptable for the number of the studied wells.

Keywords: Limestone, Reserve, Kriging, Triangulation, Najaf

حساب احتياطي الحجر الجيري للاغراض الهندسية في تكوين نفايل - بحرانجف - العراق

شذى فتحي حسن

قسم علم الارض، كلية العلوم، جامعة بغداد

الخلاصة

الصخور الجيرية لها أهمية تجارية كبيرة وذلك بسبب استخدامها كحجر بناء وهي تستخدم على نطاق واسع في الأرضيات والوجوه الخارجية والداخلية الخ... من جهة أخرى، ان حساب الاحتياطي يكشف الفعالية الاقتصادية للاستكشافات. ان الهدف من هذه الدراسة هو لحساب الاحتياطي من الصخور الجيرية من عصر الميوسين الأوسط للاغراض الهندسية. تم دراسة طبقات الحجر الجيري في تكوين نفايل (وسط العراق) على مدى 15 مكشف. حيث متوسط سمك طبقة نفايل 1.64 متر ، بينما متوسط سمك الغطاء الصخري هو 0.93 متر. متوسط الكثافة الكلية لصخور الحجر الجيري هو 2.1 جم/سم³. وقد اعتمدت طريقة الكريكنك والتثايبث

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في حساب وتقييم الاحتياطي. تم إجراء حسابات تقدير احتياطي الطبقة الصناعية وفقاً للتصنيف الأمريكي ، حيث يكون التقييم من صنف الاحتياطي المستدل ، الذي يستند إلى الخصائص الجيولوجية للطبقة الصناعية ، فضلاً عن وجود عدد قليل من الآبار التي تم الحصول عليها لمنطقة الدراسة (15) بئر، بلغ إجمالي الاحتياطي للطبقة الصناعية التي تكون فيها الدقة والموثوقية مقبولة بالمقارنة مع النظام الأمريكي 253,245,195 طن. وهذه القيم مقبولة بالنسبة لعدد الآبار المدرجة في الدراسة.

Introduction

Limestones are widely used in Iraq as one of the building materials. They are used in building houses and residential units as raw stone, ceilings and building faces, and a cement industry base [1]. Also used in arbitration ruins railway or used as a class basis or under the basis of the roads. Many researchers studied limestones due to their great importance. In this paper, a reserve calculation was proposed.

The Miocene succession of western and southern Iraq is represented by the Euphrates, Jeribe, and Nfayil formations and their equivalent, the Nfayil Formation, the Fatha Formation in the Hit area, which is distinguished by the existence of primary gypsum beds limestone. The Nfayil Formation is mainly deposited in restricted and shallow open marine conditions [2].

Previously in the study area, Nfayil Formation was included in the Euphrates Formation [3]. The type section of the Nfayil Formation is of composite type [4]. In the study area, the lower and middle cycles of the Lower Member of the Nfayil Formation were considered two members of the Euphrates [3].

The studied area is located in the middle of Iraq, west of Najaf Governorate (Bahr Al-Najaf depression) and between two longitudes in the east ($44^{\circ} 02' 33'' - 44^{\circ} 01' 44''$) and two latitudes in the north ($31^{\circ} 58' 22'' - 31^{\circ} 58' 01''$) (Figure 1).

The present study aims to calculate the limestone reserve in the Nfayil Formation for engineering projects, buildings and industry.

Location of the study area:

Geological settings

The area generally includes the Quaternary deposits of the Pleistocene rocks and the latest Holocene deposits, including aeolian sediments, flooding plain, marshes, lacustrine, and wadi fill sediments. The aeolian sediments were distributed at many sites in the study area. In terms of stratigraphically, the erosion processes have eroded and exposed succession of the marine and continental sediments, ranging in age from the Paleocene to Pleistocene. The formations which are exposed near Al-Najaf from the oldest are Dammam Formation (Early - Late Eocene), Euphrates Formation (Early -Middle Miocene) and Nfayil Formation (Middle Miocene), Injana Formation (Late Miocene), Zahra Formation (Pliocene-Pleistocene), and Dibdibba Formation (Pliocene-Pleistocene) [5].

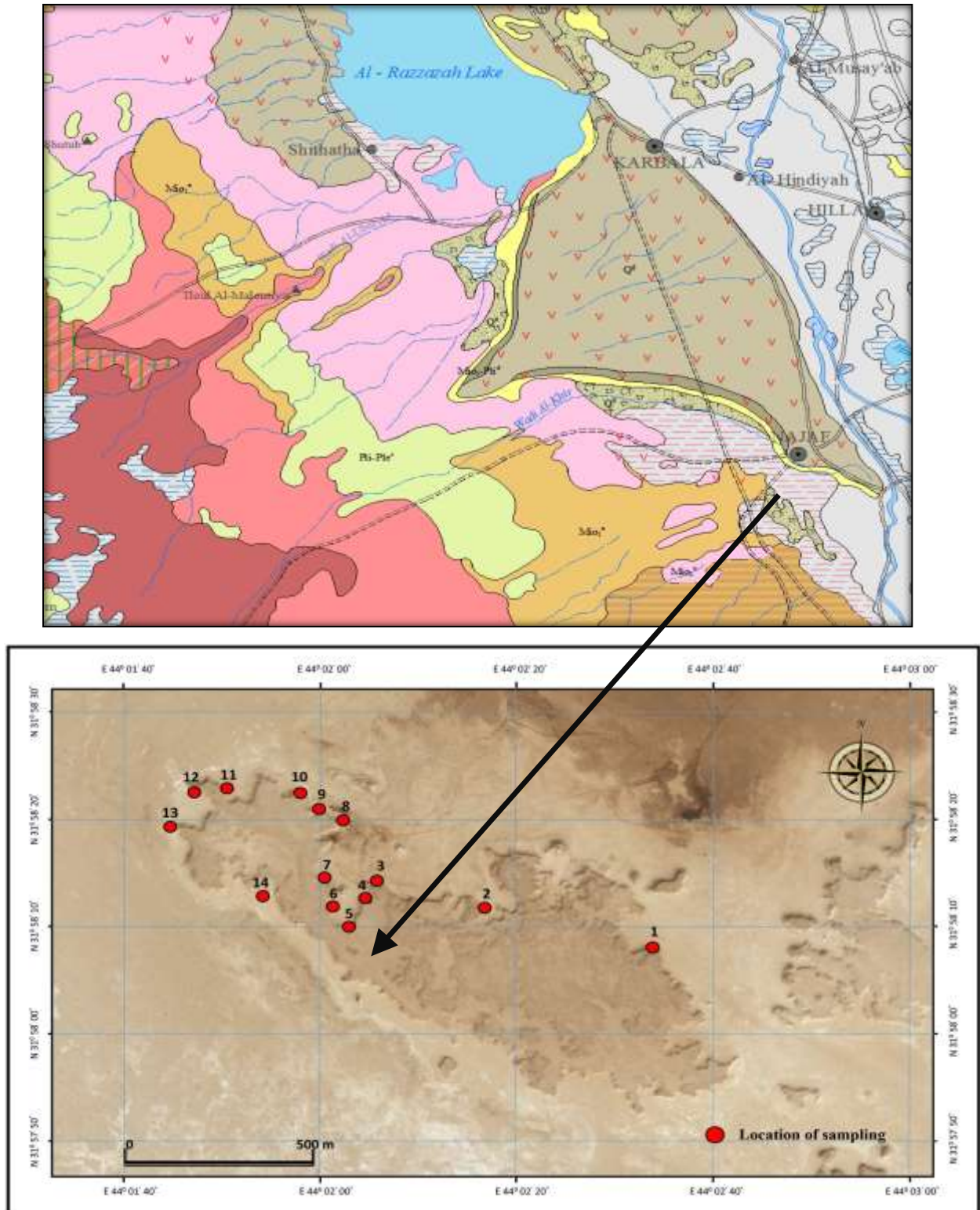


Figure 1-location map shows the sampling sites and general geological setting in the study area.

Physical properties tests

The basic physical properties are important to evaluate limestone rocks, giving an integrated description of the quality and extent of validity for the rocks as construction materials.

Bulk density: Density is defined as the sample's weight to the total volume [6].

$$\rho_b = \frac{W_{dry}}{V_t} \dots\dots\dots (1)$$

$$V_t = \frac{W_{sat} - W_{sub}}{\rho_w} \dots\dots\dots (2)$$

Whereas:

- ρ_b Total density (g / cm³)
- ρ_w Water density (g/cm³)
- W_{dry} Dry Form Weight (g)
- W_{sub} Weight of a submerged model (g)
- W_{sat} Water saturated form weight (g)
- V_t Total volume (cm³)

As density increases, the value of the mechanical properties of rocks will increase [7]. Such as the volume stability and heat capacity[8]. Ten limestone samples were tested for bulk density. They range from 1.8 gm/cm³ to 2.6 gm/cm³ whereas the average value is 2.1 gm/cm³. These values are compatible with the common densities of industry.

Engineering Properties

Uniaxial compressive strength: Compressive strength is defined as rock resistance to its stress. It is measured by applying continuous stress on the material in opposite directions until failure occurs. The stress represents the material resistance, and its unit of measurement is m2 / N or Pa (Pa), depending on the rock mineral composition, hardness, texture, and water content [7]. The uniaxial compressive strength shows the materials' stability in construction and their resistance to crushing, which mostly happens during transport.[8]

Uniaxial compression strength according to ASTM C170-90 and according to the following formula: -

$$q_u = W/A \dots\dots\dots(3)$$

Where:

- q_u Compression strength.
- W Projected load upon collapse.
- A Calculated surface area projected load upon collapse.

Estimation of Reserve

The reserve estimation shows the economic efficiency of investigation and provides the necessary information to evaluate through the geological exploration work [9]. The geologic exploration for natural resources is too expensive; however, it opens new opportunities and challenges. The geologic investigation follows a series of multidisciplinary activities: explorations, reconnaissance, prospecting, and economic mining. The investigation concept looks for the unique stratigraphic age of committed favourable rocks [10].

Mineral Deposit Geometry

The mineral deposits geometry means the location of these mineral deposits in the earth's crust, shape and size. They have irregular geometric forms depending on complex geological and sedimentary conditions, which have led to their three-dimensional origin. The two dimensions are the horizontal area (length and width), while the third dimension is the thickness of the mineral deposits Figure 2. [11]

The three factors (length, width, and thickness) are significant in studying mining operations because of their effect on choosing the method of mining used in ore extractions. The main objectives of geological studies and explorations of mineral deposits are to identify the sediment thickness and side extensions to be transferred to the coming after phase of detailed studies and mineral assessments, which is a reserve account for mineral deposits.

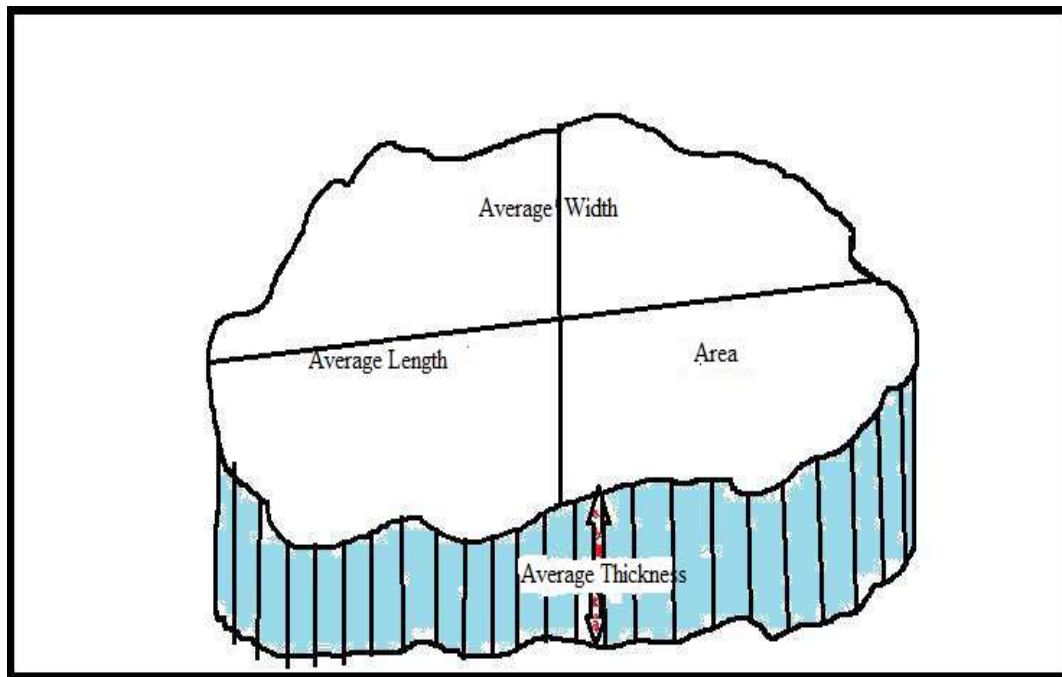


Figure 2-3D Mineral Deposit Geometry

Kriging Method

This method represents insertion data that gives predictions at the unsampled sites by using a linear combination of the observations at nearby sampled sites. The influence of each observable feature on the kriging prognostic is controlled by several factors:

- 1- the geographical proximity to the unsampled location.
- 2- the spatial arrangement of all observations.
- 3- the pattern of spatial correlation of the data.

Developing kriging methods and models is meaningful only when data are spatially correlated. The advantages of the kriging method are:

- 1- Providing the measurement of the uncertainty attached to the results.
- 2- The accounts for direction-dependent relationships.
- 3- Weights were assigned to observations based on the spatial correlation of data and information.
- 4- Kriging prognostics do not constrain the ranges of the observations used for interpolating.
- 5- The measured data can be combined and changed over different spatial supports [12].

Triangulation Method

The triangulation method is based on using multiple methods or data and information from the sources in qualitative research to develop a comprehensive understanding of phenomena [13]. It is also a qualitative strategy to test data validity and information from different sources. [13] Four types of triangulation are approved: (a) theory triangulation, (b) investigator triangulation, (c) method triangulation, and (d) data source triangulation. In the triangles method, the area is divided into triangles by connecting the adjacent columnar sections with straight lines and computing the data and information area for each mathematical triangle. The studied area is a semi-triangle area. This method divides the study area into 19 triangles to estimate the limestone reserve (Figures 3&4). Each triangle represents three sections. The triangle sides are unequal, and the angle is unequal at 60° . The correction factor is recommended to correct the thickness of limestone beds in each triangle according to [11], [14], [15] and [16]. It was presented in (Table 1) and achieved as follows:

$$\text{Correction factor (C. F.)} = \frac{\text{Angle of the triangle peak}}{60^\circ} \dots\dots\dots (4)$$

The reserve (tonnage) was calculating by the below equation:

$$R \text{ (ton)} = A \text{ (m}^2\text{)} \times \text{ACT (m)} \times \text{BD (g/cm}^3\text{)} \dots\dots\dots (5)$$

Where

- A The total area.
- ACT Average of Corrected Thickness.
- BD Bulk Density Average.

The average of the correcting thickness for each triangle in the studied area was calculated by the following equation:

$$\text{ACT} = \frac{A(T1 \times F1) + (T2 \times F2) + (T3 \times F3)}{n} \dots\dots\dots (6)$$

Where:

- ACT: Average of corrected thickness for triangle (m).
- T1, T2 and T3: Thickness of the industrial bed in sections.
- F1, F2 and F3: Factors of correction for each triangle.
- n: Section numbers of and which equal 3

Table 1-Total thickness and coordinates of the studied locations

Sam ple No.	Longitu de	Latitude	Decima l Longitu de	Decima l Latitud e	Eastin g UTM	Northin g UTM	Elevati on	Tot al Dep th (m)	Thickne ss of Overbur den	Thickn ess of Nifile Bed
1	44°1.914	31°58.20 7	44.1914	31.5820 7	42327 8	349440 0	48	2.0	0.5	1.5
2	44°1.908	31°58.21 5	44.1908	31.5821 5	42322 1	349441 0	46	2.0	1	1
3	44°2.562	31°58.13 6	44.2562	31.5813 6	42942 6	349427 8	48	2.0	0	2
4	44°2.276	31°58.19 6	44.2276	31.5819 6	42671 3	349436 3	45	5.1	3	2.1
5	44°2.1	31°58.23 6	44.2100	31.5823 6	42504 3	349442 0	51	2.0	0.5	1.5
6	44°2.084	31°58.20 8	44.2084	31.5820 8	42489 1	349439 0	48	3.0	1.5	1.5
7	44°2.041	31°58.17 1	44.2041	31.5817 1	42448 3	349435 2	48	2.5	0.5	2
8	44°2.024	31°58.20	44.2024	31.5820 0	42432 1	349438 5	45	2.0	1	1.5
9	44°1.998	31 58.251	44.1998	31.5825 1	42407 5	349444 3	45	3.0	2	1
10	44°2.026	31°58.32	44.2026	31.5832 0	42434 1	349451 8	44	3.0	1	2
11	44°2.001 2	31°58.34 2	44.2001	31.5834 2	42410 4	349454 4	39	2.0	0	2
12	44°1.97	31°58.36	44.1970	31.5836 0	42381 0	349456 6	30	2.5	0	2.5
13	44°1.842	31°58.37 9	44.1842	31.5837 9	42259 6	349459 6	36	2.5	0	2.5
14	44°1.796	31°58.37 6	44.1796	31.5837 6	42215 9	349459 6	35	3.0	2	1
15	44°1.76	31°58.31 7	44.1760	31.5831 7	42181 7	349453 3	37	1.5	1	0.5

The area of triangle is in unit of m^2 , based on the fellow equation:

$$A = 1/2 B \times H \quad \dots\dots\dots (7)$$

Where:

A The triangle area,

B Base of the triangle and

H Triangle height.

The total reserve (tonnage) for the industrial bed computed by the triangle method is 253,245,195 tons (Table 2).

Table 2- The reserve of the limestone industrial bed calculated by the triangles method.

Tr. No.	Sections No.	Th (m)	CF (degree)	CT (m)	ACT (m)	Area (m ²)	BD (gm/c ³)	Reserve (ton)
1	S13	2,5	1.75	4.4	2.3	11,360,00	2.1	5486880
	S14	1.0	1.75	1.75				
	S15	1,5	0.75	1.1				
2	S15	0.5	0.75	0.4	1.8	65,210,00	2.1	24649380
	S13	2.5	1.75	4.4				
	S2	1.0	0.5	0.5				
3	S13	2.5	0.58	1.6	2.1	81,690,00	2.1	36025290
	S12	2.5	1.6	4				
	S2	1.0	0.75	0.7				
4	S12	2.5	0.75	1.9	1,8	43,180,00	2.1	16322040
	S9	2.0	1.5	3.0				
	S2	1.0	0.58	0.6				
5	S9	2.0	0.58	1.2	1,2	23,950,00	2.1	6035400
	S8	1.0	0.75	0.8				
	S2	1.0	1.6	1.6				
6	S8	1.0	0.58	0.6	1,5	13,970,00	2.1	4400550
	S7	1.5	1.6	2.4				
	S2	1.0	0.75	0.8				
7	S7	2.0	0.75	1.5	1,3	32,520,00	2.1	8877960
	S2	1.0	1.6	1.6				
	S1	1.5	0.58	0.8				
8	S8	1.0	0.75	0.8	1.6	13,520,00	2.1	4542720
	S7	2.0	1.6	3.2				
	S6	1.5	0.58	0.9				
9	S7	1.0	1.5	1.5	1.6	26,410,00	2.1	8873760
	S6	2.0	0.75	1.5				
	S4	2.1	0.75	1.6				
10	S7	2.0	0.75	1.5	1.1	48,210,00	2.1	11136510
	S4	2.1	1.5	3.2				
	S1	1.5	0.75	0.8				
11	S4	2.1	0.58	1.2	1.7	14,995,00	2.1	5353215
	S3	2.0	1.6	3.2				
	S1	1.5	0.75	0.8				
12	S10	2.0	0.75	1.5	2.1	77,050,00	2.1	33979050
	S4	2.1	1.5	3.2				
	S3	2.0	0.75	1.5				
13	S10	2.0	1.8	3.6	1.9	52,230,00	2.1	20839770
	S5	1.5	0.58	0.9				
	S4	2.0	0.58	1.2				
14	S6	1.5	0.75	0.8	1.5	22,570,00	2.1	7109550
	S5	1.5	1.6	2.4				
	S4	2.0	0.58	1.2				
15	S10	2.0	0.75	1.5	1.6	14,410,00	2.1	4841760
	S6	1.5	1.75	2.6				
	S5	1.5	0.5	0.8				

Tr. No.	Sections No.	Th (m)	CF (degree)	CT (m)	ACT (m)	Area (m ²)	BD (gm/c ³)	Reserve (ton)
16	S10	2.0	0.75	1.5	1.7	31,310,00	2.1	11177670
	S8	1.0	1.75	1.8				
	S6	1.5	0.5	0.8				
17	S10	2.0	0.58	1.2	1.7	13,470,00	2.1	4808790
	S9	2.0	1.6	3.2				
	S8	1.0	0.75	0.8				
18	S11	2.0	0.75	0.8	1.6	96,910,0	2.1	32561760
	S10	2.0	1.5	3.0				
	S9	2.0	0.58	1.2				
19	S12	2.5	0.58	1.5	2.2	13,470,00	2.1	6223140
	S11	2.0	0.75	1.5				
	S9	2.0	1.75	3.5				
Total reserve								253,245,195

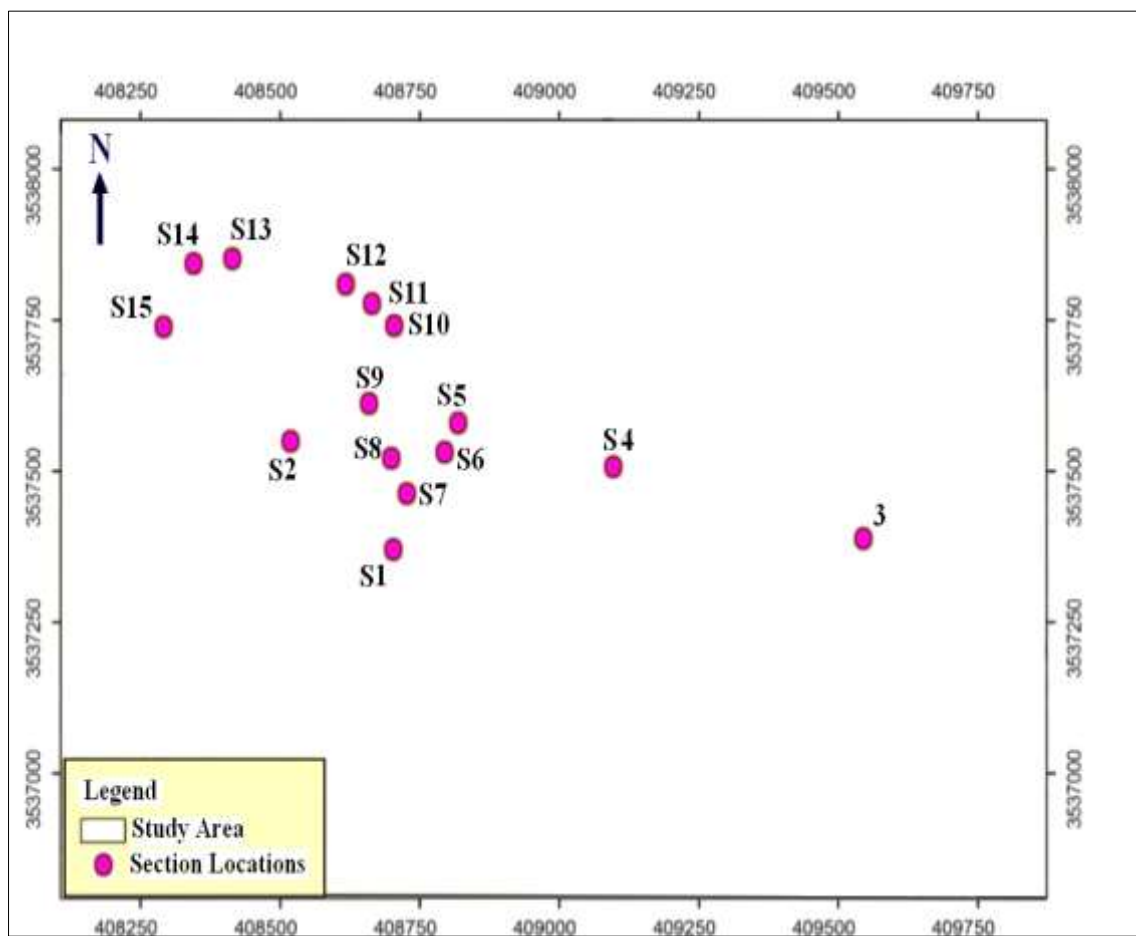


Figure 3-Location map shows the area of the industrial bed.

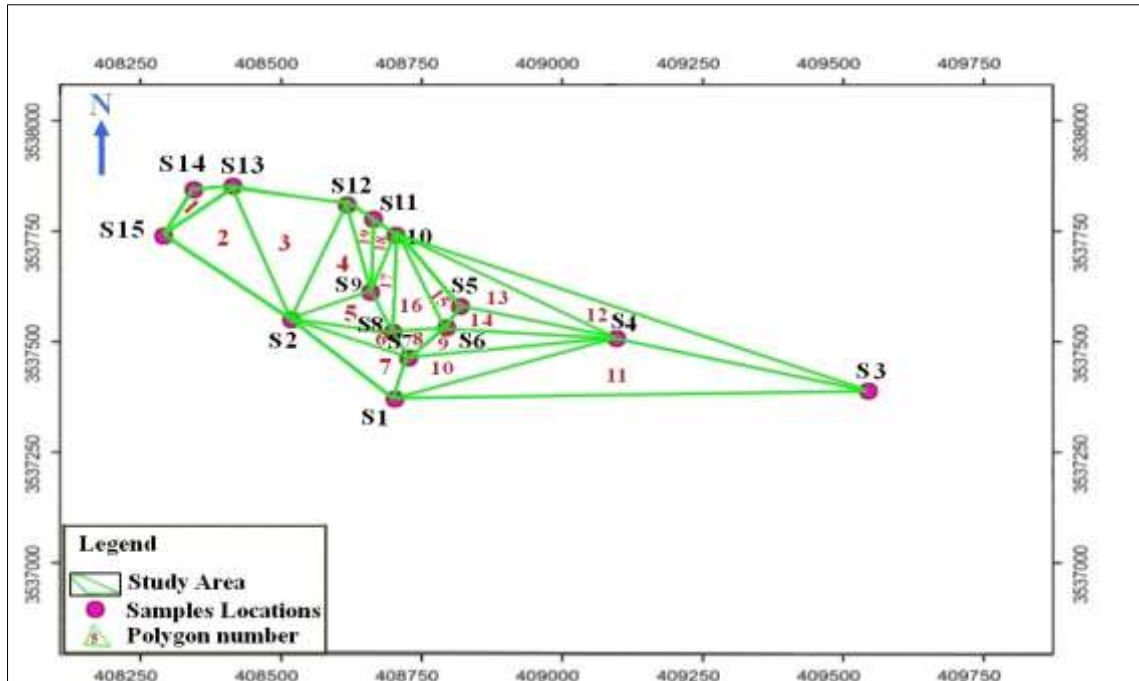


Figure 4- Reserve calculation based on the triangles method

Results:

RockWorks 2D Volumetric Report for Nifile Bed

- Minimum accepted thickness values..... 0.0 meters
- Maximum accepted ratio of stripping 5.0
- "Proven Reserves" distance of cutoff 50.0 meters
- "Probable Reserves" distance of cutoff 100.0 meters
- "Inferred Reserves" distance of cutoff..... 500.0 meters

Raw Data (XYZ Input)

- X-Minimum value (western most coordinate) 421,817.0 meters
- X-Maximum value (eastern most coordinate) 429,426.0 meters
- Y-Minimum value (southern most coordinate) 3,494,278.0 meters
- Y-Maximum value (northern most coordinate) 3,494,596.0 meters
- Z-Minimum value (minimum thickness observed) 0.5 meters
- Z-Maximum value (maximum thickness observed) 2.5 meters

Grid Dimensions

- X-Minimum value (western most node) 421,800.0 meters
- X-Maximum value (eastern most node) 429,600.0 meters
- X-Spacing value (east/west node spacing) 200.0 meters
- Y-Minimum value (southern most node) 3,494,200.0 meters
- Y-Maximum value (northern most node) 3,494,600.0 meters
- Y-Spacing value (north/south node spacing) 200.0 meters

Initial Thickness Model: 19,317,021.0 Tons (8,398,704.8 Cubic meters)

- Minimum node value 0.8 meters
- Minimum node value > 0 ... 0.8 meters
- Maximum node value 2.1 meters
- Mean node value 1.7 meters
- Sum of all node values ... 210.0 meters
- Standard Deviation 0.3 meters
- Null nodes 0.0 meters

After Applying Thickness Filter: 19,317,021.0 Tons (8,398,704.8 Cubic meters)

- Minimum node value 0.8 meters

Minimum node value > 0 ... 0.8 meters
 Maximum node value 2.1 meters
 Mean node value 1.7 meters
 Sum of all node values ... 210.0 meters
 Standard Deviation 0.3 meters
 Null nodes 0.0 meters

After Implementing Stripping Ratio Filter: 19,317,021.0 Tons (8,398,704.8 Cubic meters)

Minimum node value 0.8 meters
 Minimum node value > 0 ... 0.8 meters
 Maximum node value 2.1 meters
 Mean node value 1.7 meters
 Sum of all node values ... 210.0 meters
 Standard Deviation 0.3 meters
 Null nodes 0.0 meters

Distance-Qualified Reserves using kriging method:

Proven Reserves 749,712.0 Tons (325,961.8 Cubic meters)
 Probable Reserves ... 1,087,403.5 Tons (472,784.1 Cubic meters)
 Inferred Reserves ... 10,787,884.0 Tons (4,690,384.3 Cubic meters)
 Unclassified 6,692,021.5 Tons (2,909,574.6 Cubic meters)

Discussion and Conclusion

Kriging method, one applications of Rockwork-15 which uses to calculate reserve. The expanding area is used according to the application of the extension rule to the impact site of the models. In this way, the statistical processing of wells is used to calculate the reserve and estimate its effect on distances from the studied well locations or sections. The average area thickness in each triangle is estimated, consisting of three wells located at the vertices of each triangle. The extension of the triangle datum covers the studied area. The effect of each triangle on the study area where the thicknesses of the industrial layer were relied upon (Table 2).

The geostatistical method, called the Kriking method, is one of the modern methods of calculating and estimating the reserves of the geological beds. At any location within the geological formation or the bedrock, it takes into account the location of each sample concerning the other in any location, as well as the relationship with each other within the extensions of the geological bed and even outside the sample location or boundaries of those extensions.

In this study, the sample location and thickness were obtained. There is an extension of the bed thickness beyond the location of each sample, and for a certain distance that is estimated by the program depending on the sample value and the extent of each sample distance and their relationship. Therefore the method is used geostatistical in addition to other areas outside the boundaries of the sites up to the study area boundary according to the coordinates (Figure 3). The reserve calculated based on this method is 749,712.0 confirmed tons. The reason for the exaggeration of the value of the reserve is due to the addition of these areas depending on the relationship of the extent of influence area of the locational impact of the samples within the study area.

Table 2 represents the data and reserve values calculated using the triangulation method, which depends on dividing the study area into triangles. The sample location from the peak of the triangles and the correction factor was calculated to re-evaluate the extent of the positional influence of each sample in the case of large angles.

In this method, the reserve for the Nfayil Formation was calculated manually depending on the triangle area multiplied by the weighted thickness value to get the reserve volume for each triangle. Then they are collected to obtain the volume of the total reserve. The volume is

multiplied by the density rate to obtain the total reserve in tons. With the triangle method, a lower value for reserve estimation is obtained due to not adding areas outside the limits of the sampling sites, so this method gives a certain reserve, and this is the reason for the difference in the data obtained in calculating the reserve using these two methods.

The reserve estimation of the industrial class was calculated according to the U.S. classification. The estimation of the inferred reserve class depends on the geologic characteristics of the industrial layers, as well as the presence of fifteen wells. The accuracy and reliability are acceptable in comparison to the weighted reserve class used in the American system. The standard deviation ranges from about 0.3 m to the number of the studied wells.

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