Application of geostatistics to complete uranium resources estimation of Rabau Hulu Sector, Kalan, West Kalimantan

Roni Ciputra*, *Suharji* Suharji, *Dhatu* Kamajati, and *Heri* Syaeful

Center for Nuclear Mineral Technology of BATAN, Lebak Bulus Raya St. No. 9, Jakarta, Indonesia

Abstract. Kalan is one of the focus areas for uranium exploration in West Borneo that conducted by BATAN. Situated in the central part of Kalan, previous works in Rabau Hulu Sector consisted of surface geology and radiometric anomaly mapping, trenching, drilling, logging, and conventional uranium resource estimation. Nevertheless, the complete resource estimation of the previous work was still using 2D modeling, and the latest one using 3D modeling is a method-application case study in one orebody. To increase the confidence level and completing the uranium resource estimation of all orebodies in this sector, a geostatistical estimation with 3D orebody modeling using SURPAC mine planning software was conducted in this paper. Gamma-ray log data from 32 drill holes were collected and then interpreted to obtain uranium grade-thickness data. Based on the correlation of grade-thickness data according to surface orebody orientation, the orebody 3D modeling was done. It resulted in 26 orebodies with one control system of lithology as the mineralization only taken place in the quartzite unit. This 3D model then used as a constraint for block model with 4x4x2 m block size and 0.25x0.25x0.125 m minimum block size. Block model calculation was performed using ordinary kriging which generated the kriging efficiency attribute for the determination of the resource category. Within 25 meters searching radius, the calculation resulted in 408,480 tons of ore, while total uranium resource was 268 tons of uranium with 677 ppm average grade. There were 214 tons of uranium (79%) categorized as measured while the other 54 tons of uranium (21%) categorized as indicated.

Keywords: uranium resource, Kalan, Rabau Hulu, geostatistics, ordinary kriging

1 Introduction

It dated back to 1969 when Indonesia, through BATAN, conducted the uranium exploration in the country's territory. After the period of collaboration between BATAN and France's CEA in 1977, the exploration program focused on Kalan Area of Ella Hilir Region, West Borneo which had the most significant uranium mineralization indication.

Situated in the northern margin of the Schwaner Mountains as portrayed by Figure 1, Kalan geologically consists of Pinoh Metamorphic Group (PMG) rocks that were intruded by later granitic rocks of Sepauk Tonalite and Sukadana Granite in some parts. The Protolith of the Pinoh Metamorphic was the volcanogenic sediments that suggested to be formed during subduction at the Paleo-Pacific margin after the collision of South West Borneo to Sundaland in Early Cretaceous (130 Ma) [1]. These rocks then going through thermal metamorphism due to volcanic arc-related emplacement of I-type granitoid rocks from c. 120-80 Ma producing pelitic schists and hornfelses with occasional quartzites and metabasites [2]. he emplacement of the granitic rocks was also the source of uranium mineralization [3].

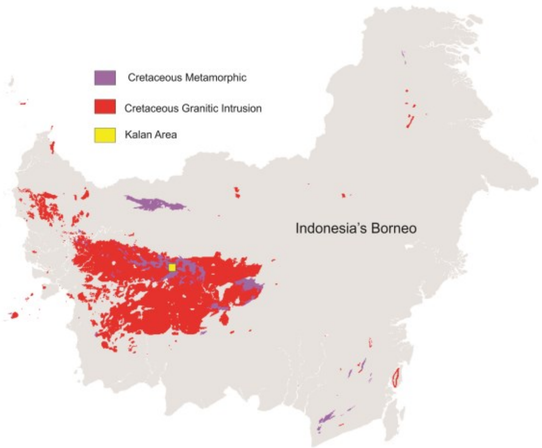

Fig. 1. Location of Kalan Area

The 16 uranium-potential sectors of Kalan Area are Remaja, Lembah Hitam, Lemajung, Semut, Rirang, Rabau Hulu, Sarana, Tanah Merah, Amir Engkala, Jeronang, Jumbang, Ketungau, Parembang Kanan, Ririt,

* Corresponding author: roni.cahya@batan.go.id

Dendang Arai, Bubu, and Kayu Ara. Figure 2 displays the geological map and uranium sectors of Kalan. Among these sectors, until 2018 Indonesia has reported 2029 ton of uranium measured resource from Remaja and Lembah Hitam Sector to the world's periodic uranium resource, production, and demand report called 'The Red Book', a joint-report between Organisation for Economic Co-Operation And Development (OECD) of Nuclear Energy Agency (NEA) and International Atomic Energy Agency (IAEA) [4].

Located in the central part of Kalan Basin, Rabau Hulu Sector uranium mineralization occurred in centimetric-decimetric tourmaline veins filling tectonic breccias and fractures on fine-grained quartzite host rock [5]. Previous works in Rabau Hulu Sector consist of radiometric anomaly mapping on the surface, trenching, core drilling, and non-core drilling. Utilizing gamma-logging data from 32 drill holes, uranium resource estimation has been conducted in 1991 and 1993 [6,7]. The first estimation which used the area of influence conventional method resulted in 338 tons of uranium [6]. The later resources estimation used 2D kriging interpolation for U3O8 grades and thickness and resulted in 294 tons of uranium [7]. The result was felt less satisfactory because the orebody geometrical parameter needed for estimation is expected in 3D. The latest work on the uranium resource of Rabau Hulu Sector was a case study of the application of geostatistic for resource category in one orebody (Orebody 15) with 3D modeling and Ordinary Kriging interpolation method on SURPAC mine planning software[8]. The case study was the first 3D application of geostatistics in Kalan Area concentrated in how applicable the method was for uranium estimation. However, a complete 3D application of geostatistics in uranium estimation of a sector in Kalan Area has not been done yet.

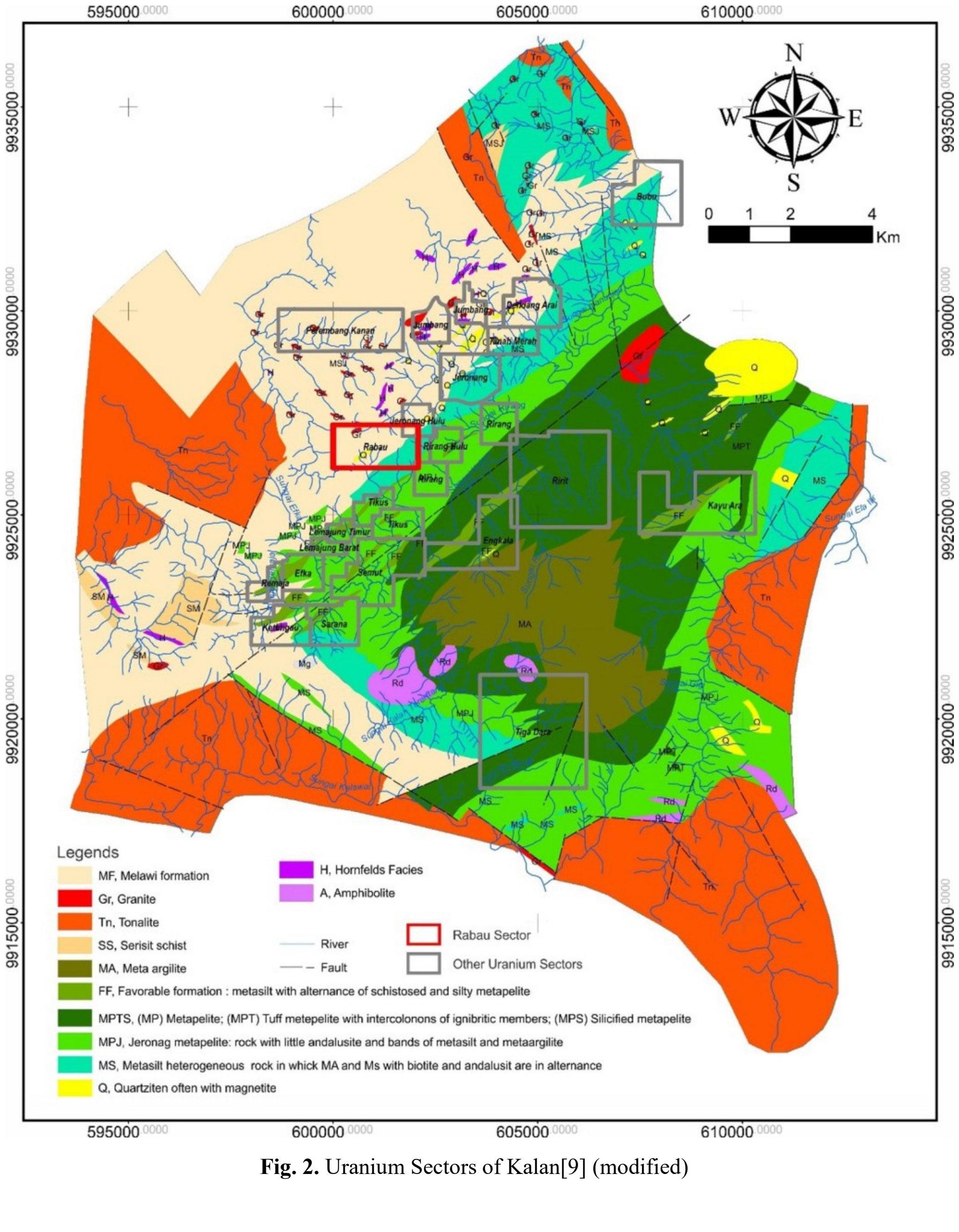

Fig. 2. Uranium Sectors of Kalan[9] (modified)

The objective of this paper is to estimate the uranium resource of all orebodies in Rabau Hulu Sector with the Ordinary Kriging method using SURPAC mine planning software. Using 3D orebody modeling, the result of this paper increased the confidence level of uranium resources of Rabau Hulu Sector from the previous work [7].Although applicating the geostatistical method used in the previous work [8], this paper estimated all of the orebodies in Rabau Hulu Sector. Therefore, the uranium resource estimation of Rabau Hulu Sector is completed. The result is expected to contribute to the inventory of uranium resources of Indonesia as a material for the stake holder's decision making.

2 Regional Geology of Kalan

Stratigraphy of Kalan, as displayed in Figure 2, consists of metamorphic group and felsic intrusions. The metamorphic group is andalusite metasiltstone (Melawi Formation), quartzite, metasiltstone, schistosic metapelite, sericite schist, amphibolite, hornfels, and metaargillite.

Intercalation between metasiltstone and schistosic metapelite is the regional uranium-favorable lithology. The lithology formed in lenses that oriented NE-SW scattered in Remaja, Lemajung, Ririang, Emir Engkala, and Kayu Ara [9].

The main period of tectonic deformation in Kalan are ductile and brittle deformation. The ductile deformation, observed from N 70º E fold plunging 30º NE, generated the schistocity plane slanted 70-80º to the north. The first brittle deformation resulted in open-mode fractures and schistocity planes. These fractures and schistocity planes filled by uranium-rich solution forming uranium veins, veinlets, and breccia mineralization. Later brittle deformation formed fractures that filled with calcite-gypsum solution afterward, forming centimetric-decimetric vein and veinlet cutting the uranium vein [3,10].

3 Geology & Uranium Mineralization of Rabau Hulu

Stratigraphy of the Rabau Hulu Sector consists of quartzite, feldspathic tuff, and hornfels. Figure 3 depicts the geological map and distribution of dill hole in the sector while Figure 4 A shows the West-East cross-section of the area and Figure 4 B shows the North-East cross-section. The quartzite as the favorable host rock of mineralization is fine-grained with quartz, muscovite, biotite, sericite, cordierite, andalusite, feldspar, tourmaline, epidote, zircon, monazite, chlorite, magnetite, pyrite, pyrrhotite, rutile, and ilmenite composition [11].

The quartzite lied East-West dipping 35º to North with thickness 45 – 85 m while uranium mineralization occurred in centimetric-decimetric tourmaline veins that filled tectonic breccias and fractures on the fine-grained quartzite host rock. The tectonic breccias and fractures lied N 260º E tilted 20-40º to North [5,11]. Based on the lithofacies, uranium mineralization associated tightly with the ferromagnesian or biotite zone in the quartzite.

The main radioactive mineral is uraninite associated with pyrite, chalcopyrite, sphalerite, molybdenite, lollingite, bornite, ilmenite, and magnetite. The tourmaline veins are suggested to be formed at the temperature of 325-400º C in the pegmatitic-pneumatolitic phase [12].

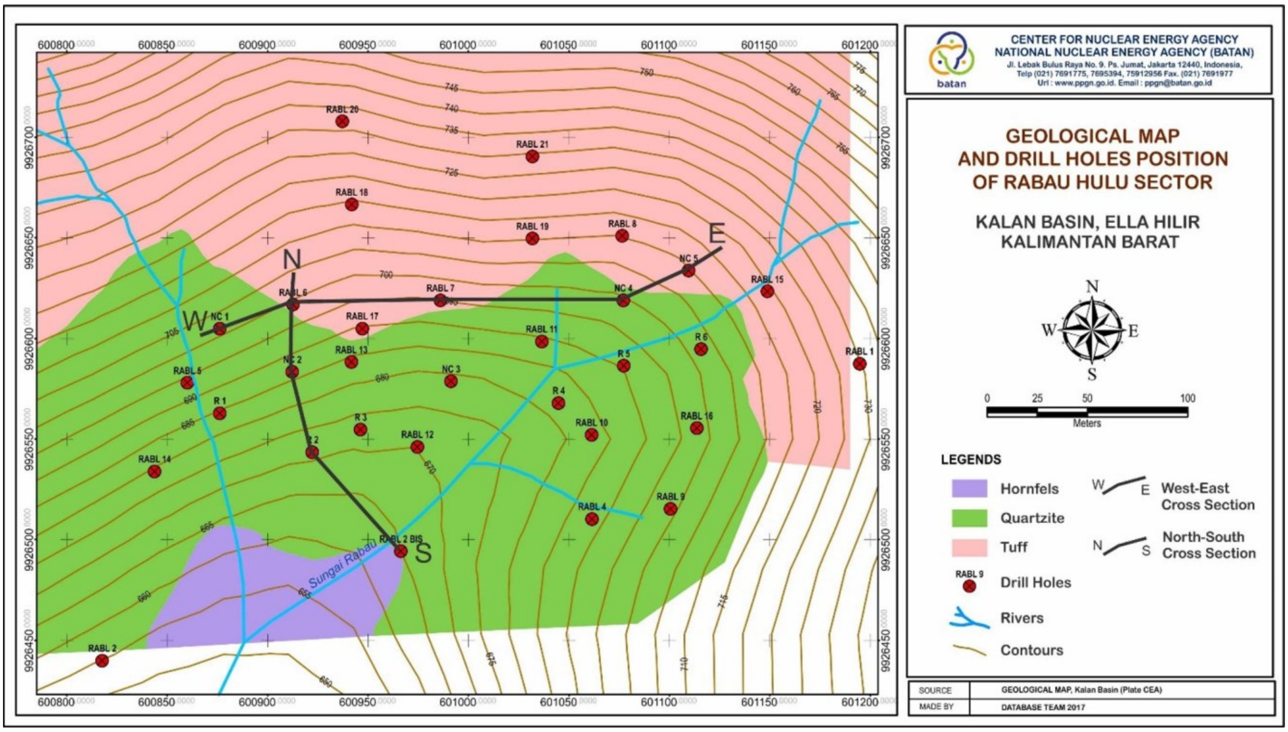

Fig. 3. Geological Map and Drill hole Location of Rabau Sector

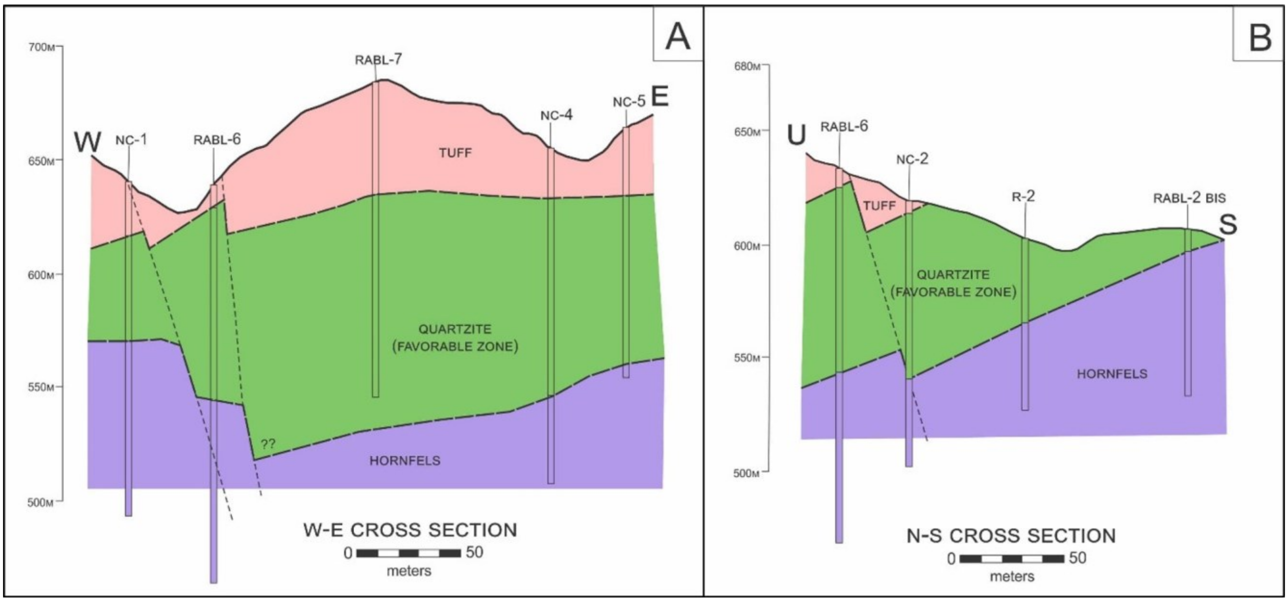

Figure 4. West-East and North-South geological cross-section of Rabau Hulu Sector cutting RABL-6 drillhole[11]

4 Methods

Three main parts of this estimation were arranged as:

4.1. Gamma-Ray Log Interpretation

Gamma-Ray log interpretation was conducted in 32 drill holes in Rabau Hulu Sector. The objective of this step was to generate uranium grade converted from gamma-ray log data[8]. Apparent thickness correction, the angle between the mineralized field and borehole reading, borehole correction factor calculation, corrected area calculation, apparent and average grade-thickness calculation, and corrected grade calculation was conducted to generate the uranium grade. The result was gathered alongside the drill holes data into a database.

4.2. Orebody Modeling

The drill hole and grade-thickness data from the database then displayed based on its borehole location and depth using SURPAC mine planning software 6.3 version as can be seen in Figure 5. The SURPAC mine planning software was used because it could fulfill the entire geostatistical analysis and estimation of grades[13]. Subsequently, as the orebodies in the sub-surface of Rabau Sector are similar with the N 260º E/30º orientation of the orebody measured from the surface outcrop and trenching, the 3D correlation between grade-thickness data in each borehole was conducted to model the orebody geometry. The uranium grade-thickness data only modeled if they were inside the quartzite unit in each drill holes as the mineralization controlled by lithology. Thus, the model only had one control system domain for the geostatistical estimation which was the quartzite lithology. The average distance between sections for the correlation was 25-50 m.

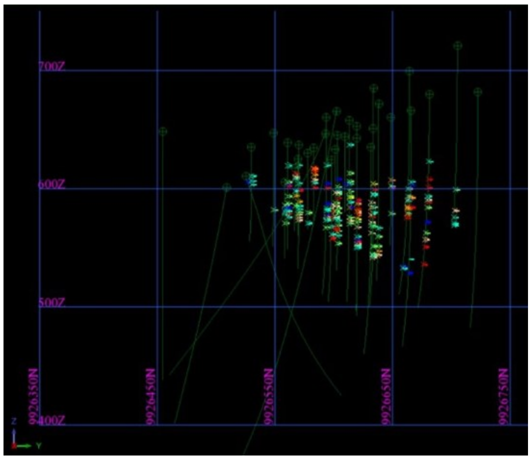

Fig. 5. Uranium grade (various colors) in the drill holes (greens), on X-Z display mode

4.3. Block model Estimation

This process consists of domain definition, downhole compositing, basic statistic, and grade-top cutting using 95% confidence interval, ellipsoid anisotropy visualization, variogram modeling, block model making, and estimation constraint definition, and finally the estimation of block model using a linear geostatistic method of ordinary kriging. Depends on the spatial correlation of the data, the weighting value in the geostatistic method of ordinary kriging is determined using a variogram. The method will excel inverse distance weighting because the spatial variability of the data, seen from the variogram, minimizes the error [13]. Although not all orebodies that have been modeled can be estimated using ordinary kriging method due to its minimum data requirements, the method was selected because the case study that has been done for Rabau Hulu Sector the method can provide attribute for determination of resource category [8]. The classification based on the attribute of Kriging Efficiency [14] can be seen in Table 1. This process also conducted with Surpac 6.3 mine planning software.

Table 1. Resource classification based on Kriging Efficiency [14]

Kriging Efficiency	Classification
<0.3	Inferred
0.3 – 0.5	Indicated
0.5 – 1	Measured

Block size that used had 4x4x2 m block size and 0.25x0.25x0.125 m minimum block size with N 260° E and plunge 60° rotation as well as the orebody geometry orientation. The tonnage of orebody resulted from volume gained from block model calculation with a density adjustment of 2,77 g/cm^3. The tonnage then multiplied with uranium grade to obtain uranium tonnage.

5 Result And Discussion

5.1. Orebodies and Anisotropy

The correlation acquired 26 orebodies of the Rabau Sector. These orebodies having various sizes and thickness but their direction was the same. Among these orebodies, only 16 orebodies had sufficient data for ordinary kriging estimation. The thickest orebody with the most amount of grade data was Orebody 15. Anisotropy of the orebodies that used for ordinary kriging estimation showed a various range of major/minor ratio adjusting to their maximum thickness, but the maximum search radius is set to the same value of 25 m. The value was half of the maximum distance between the correlation sections.

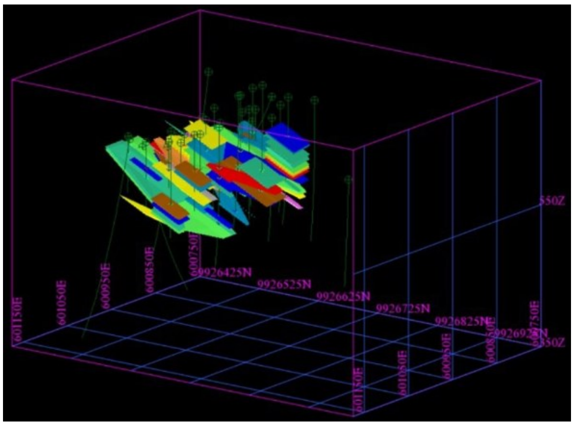

Fig. 6. Orebodies of Rabau Sectors (colors as distinctive style for one orebody to others

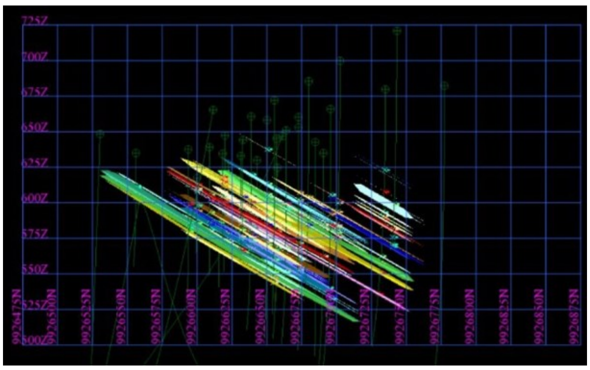

Fig. 7. Orebodies of Rabau Sector viewing direction of N 260° E/0°

5.2. Ordinary Kriging Result

Ordinary kriging method was performed to calculate the grade of the blocks, using orebodies' geometry as a constraint. Figure 6 displays uranium grade distribution on Orebody 17 as a result example.

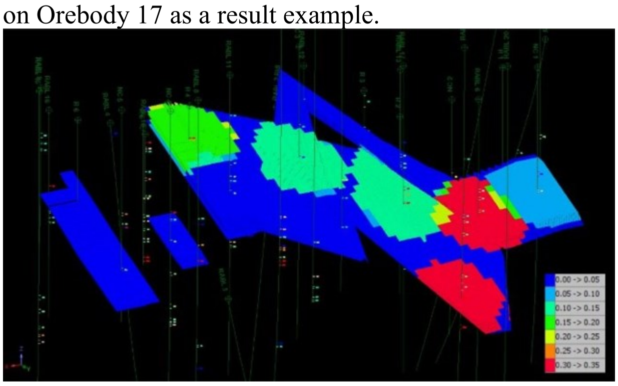

Fig. 8. Uranium grade distribution of Orebody 17 blocks resulted from ordinary kriging estimation

The complete result for each orebody is presented in Table 2. Total ore resulted from the estimation was 408,480 tons while total uranium resource was 268 tons U with 0.0677% or 677 ppm uranium grade. Kriging Efficiency showed value above 0.3 indicating classes for resource category resulted are Measured and Indicated Resources. There were 214 tons of uranium (79%) categorized as a measured resource while the other 54 tons of uranium (21%) categorized as an indicated resource.

Table 2. Ordinary Kriging result for uranium resource estimation of Rabau Sector

Orebody	*Ore Tonnage (tons)*	*Grade (%)*	*Uranium Tonnage (tons)*	*Kriging Effici-ency*	*Category*
OreBody 8	7297	0.029	2.1	0.518	Measured
OreBody 11	7257	0.111	8.1	0.407	Indicated
OreBody 12	25467	0.050	12.6	0.794	Measured
OreBody 13	11114	0.085	9.4	0.823	Measured
OreBody 14	61001	0.087	53.2	0.613	Measured
OreBody 15	59742	0.099	59.4	0.588	Measured
OreBody 16	32629	0.055	17.9	0.383	Indicated
OreBody 17	16796	0.060	10.0	0.333	Indicated
OreBody 18	3302	0.128	4.2	0.361	Indicated
OreBody 19	28888	0.053	15.4	0.592	Measured
OreBody 20	28647	0.040	11.3	0.62	Measured
OreBody 21	24259	0.063	15.4	0.553	Measured
OreBody 22	44819	0.029	13.2	0.525	Measured
OreBody 23	25108	0.060	15.0	0.615	Measured
OreBody 24	22864	0.063	14.5	0.439	Indicated
OreBody 25	9283	0.071	6.6	0.746	Measured
Measured			214	tons	(79.62 %)
Indicated			54	tons	(20.38 %)
Grand Total	408,480		268	tons	(100 %)
Average Grade			0.0677	%	

Figure 9 displays a comparison between each orebody in terms of ore tonnage in tons. Among 16 orebodies that calculated, orebody 14 and 15 had the largest amount of ore tonnage. This case corresponds to the amount of uranium grade from the drill hole inside the orebody geometry and the maximum orebody thickness of orebody 14 and 15 which had the highest values for these parameters among other orebodies.

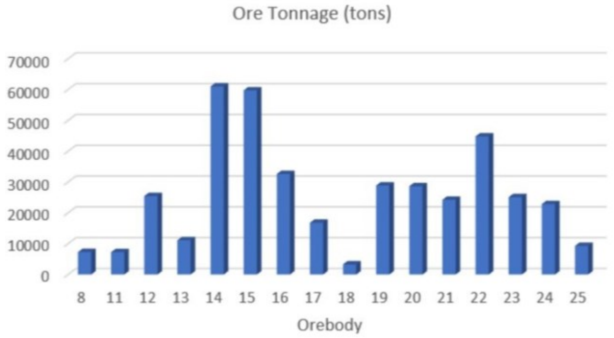

Fig. 9. Ore tonnage of each orebody comparison in tons

Figure 10 portrays a comparison between each orebody in terms of their grade. Uranium grade of Rabau Sectors ranged from 0.029 to 0.128 %. Orebody 8 and 18 had grade above 0.1% or 1000 ppm but their ore tonnage is relatively low, thus they would not contribute much in total uranium resource.

Figure 10

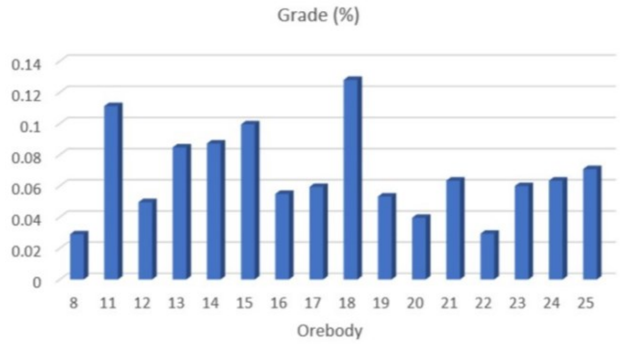

Fig. 10. The average grade of each orebody comparison in percent

Figure 11 presents the comparison between each orebody in terms of their uranium tonnage. Among the total of 268 tons of uranium, almost 113 tons or 42% were from orebody 14 and 15. This is because these orebodies had the highest value of ore tonnage and their average grade was above 0.08 or 800 ppm.

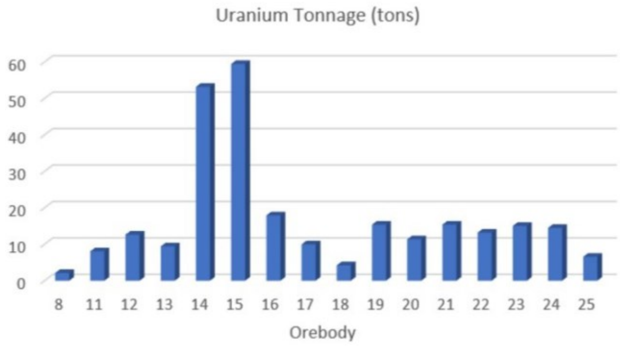

Fig. 11. Uranium tonnage of each orebody comparison in tons

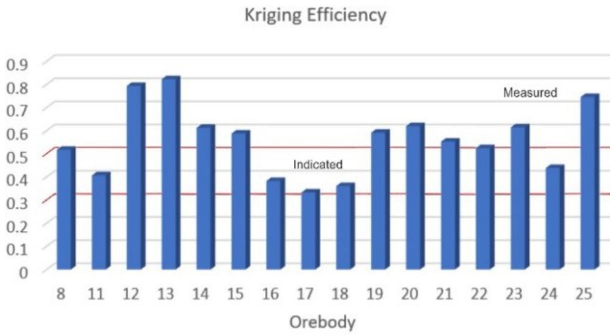

Figure 12 displays a comparison between each orebody in terms of their kriging efficiency attribute from the ordinary kriging performing. Among 16 orebodies, there were 11 orebodies classified as a measured resource since their kriging efficiency exceeded the value of 0.5 while the other categorized as indicated resource as their kriging efficiency were between 0.3 and 0.5 categorized. This difference may occur because the amount of data in each orebody was different, which led to the difference between their variograms.

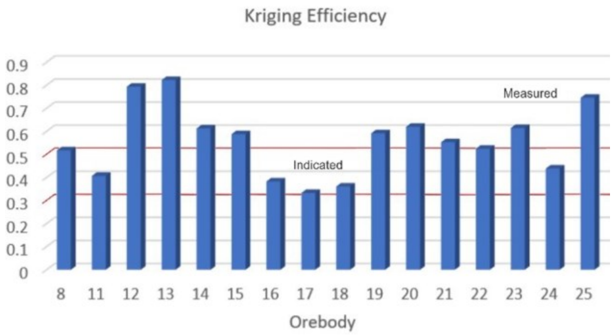

Fig. 12. Kriging efficiency attribute of each orebody comparison

In comparison to the 294 tons of uranium resulted from the previous estimation[7], the total uranium resource of this estimation showing the difference of 26 tons less. The difference is not very significant though the model that used was different. What should be noted is that the estimation using SURPAC mine planning software also accomplished the analysis of the kriging efficiency parameter that provides additional information to determine the resource category.

6 conclusion

It can be concluded that the total ore resulted from the estimation using ordinary kriging of Rabau Sector was 408,480 tons of ore. The total uranium resource was 268 tons of uranium with 677 ppm average grade. Based on the kriging efficiency attribute, there were 214 tons of uranium (79%) categorized as a measured resource while the other 54 tons of uranium (21%) categorized as an indicated resource.

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