PROVENANCE AND DISTRIBUTION OF MIDDLE BAONG SAND IN THE MALACCA STRAIT AND ITS SURROUNDING

PROVENANS DAN SEBARAN BATUPASIR BAONG TENGAH DI SELAT MALAKA DAN SEKITARNYA

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ABSTRACT: The Middle Baong Sand Formation has long been ascribed to the Malay Peninsula. However, this contradicts the results of chronostratigraphic correlation and rare earth element (REE) analysis, which indicate another source from the south. This research was conducted in North Sumatra, especially in Pertamina's onshore and offshore work areas. The comparison area is located in Kutacane-Karo and the Malay Peninsula. The objective of the study is to understand the provenance of the Middle Baong Sand Formation in North Sumatra. Data from four wells and 32 outcrops are used to evaluate the provenance and distribution of Middle Baong Sand in the study area. Besides that, secondary data from three outcrops are also used to support the analysis. The methods used in this study are chronostratigraphic correlation and REE analysis. The results showed that the provenance of the Middle Baong Sand onshore is estimated to originate from southwest Sumatra, contrary to general assumptions. Validation was carried out by comparing Malay Peninsula data with Kutacane research data and wells using REE analysis. The analysis results showed that the Middle Baong Sand Formation in the onshore area has a different provenance from the Middle Baong Sand Formation in the offshore area, which contradicts other research conducted so far. Based on this study, it is concluded that the paleogeography of the North Sumatra basin undergoes deepening symmetrically in the central basin since 10.46 million years ago (Mya).

Keywords: Middle Baong Sand, rare earth element (REE), provenance, paleogeography, North Sumatra Basin

ABSTRAK: *Formasi Pasir Baong Tengah telah lama dianggap berasal dari Semenanjung Melayu. Namun hal ini bertentangan dengan hasil korelasi kronostratigrafi dan analisis unsur tanah jarang (UTJ) yang menunjukkan adanya sumber lain dari arah selatan. Penelitian ini dilakukan di Sumatra Utara khususnya di wilayah kerja Pertamina darat (onshore) dan lepas pantai (offshore). Daerah pembanding terletak di Kutacane-Karo dan Semenanjung Melayu. Tujuan penelitian adalah untuk mengetahui asal usul Formasi Pasir Baong Tengah di Sumatra Utara. Empat data sumur dan 32 data singkapan digunakan untuk mengevaluasi sumber dan penyebaran Pasir Baong Tengah di daerah penelitian. Selain itu, tiga data singkapan sebagai data sekunder juga digunakan untuk mendukung analisis. Metode yang digunakan dalam penelitian ini adalah korelasi kronostratigrafi dan analisis UTJ. Hasil penelitian menunjukkan bahwa provenans Pasir Baong Tengah yang berada di darat diperkirakan berasal dari barat daya Sumatra. Hal ini bertentangan dengan asumsi umum. Validasi kemudian dilakukan dengan membandingkan data dari Semenanjung Melayu dengan data penelitian Kutacane dan data sumur menggunakan analisis UTJ. Hasil analisis menunjukkan bahwa Formasi Pasir Baong Tengah di area darat memiliki provenans yang berbeda dengan Formasi Pasir Baong Tengah di area lepas pantai. Hasil ini bertentangan dengan penelitian-penelitian lain yang telah dilakukan selama ini. Pemetaan dan analisis data yang komprehensif menyimpulkan bahwa paleogeografi Cekungan Sumatra Utara pada 10,46 juta tahun lalu (jtl) menunjukkan pendalaman di sekitar Selat Malaka.*

Kata Kunci: *Pasir Baong Tengah, unsur tanah jarang (UTJ), provenans, paleogeografi, Cekungan Sumatra Utara*

INTRODUCTION

The research area is located in the North Sumatra Basin (NSB), as shown in Figure 1, with the main focus in the Pertamina onshore and offshore work areas. The outcrop as comparative data is in the Kutacane-Karo area and its surroundings, as primary data, and the Malay Peninsula area, as secondary data.

The Middle Baong Sand (onshore) Formation (MBS) is assumed to have been originally deposited from the Malay Peninsula and later shifted from the south during the Bukit Barisan uplifting period. This assumption is supported by the absence of volcanic fragments (tuffaceous) found in the sediments from the Paleogene and Neogene ages. Consequently, the direction of currents and paleogeography in the basin are described towards the south, with sediment sources originating from the north. In lithostratigraphic correlation, this understanding is readily accepted since the age is of less importance or not considered.

Nowadays, with an increasing amount of drilling in North Sumatra, wells containing hydrocarbons reveal the pattern and spread of the MBS section. The pattern extends along the direction of Sumatra, specifically in the southern part of the North Sumatra coastline. However, in the northern region, sandstone sediments do not develop, even with a four-way dip closure trap. Usman et al. (2023) explained that, based on borehole image data describing several results of the current direction, it was discovered that this sediment was deposited from the east and south to the north (Figure 2). This finding contradicts previous research, which generally suggested that the sediment's provenance originated from the Malay Peninsula.

Therefore, this research is important to define the provenance and distribution of the MBS, both onshore and offshore. So far, Neogene deep sedimentary rocks in NSB, both onshore and offshore, have been widely discussed. These rocks consist of formations, including the Yetai Formation, the Baong Formation with the MBS Unit inside it, and the Keutapang Formation. Researchers such as Kamili et al. (1973), Mulhadiono et al. (1978), Cameron et al. (1980), Mulhadiono et al. (1982), Davies (1984), Anderson et al. (1993), Syafrin (1995), Fuse et al. (1996), Daly et al. (1987), Panguriseng et al. (2011), Bahesti et al., Banukarso et al. (2013, 2014), Ambarwati et al. (2017), and Syarifudin et al. (2018) have extensively discussed both the sedimentology and stratigraphic arrangement of these formations. However, the provenance of these formations, especially when using the rare earth element (REE) approach, has rarely been explored.

In particular, the MBS turbidite marine formation has been widely discussed by Riadhy et al. (1998). They confirmed that the source of the MBS is from the Malay

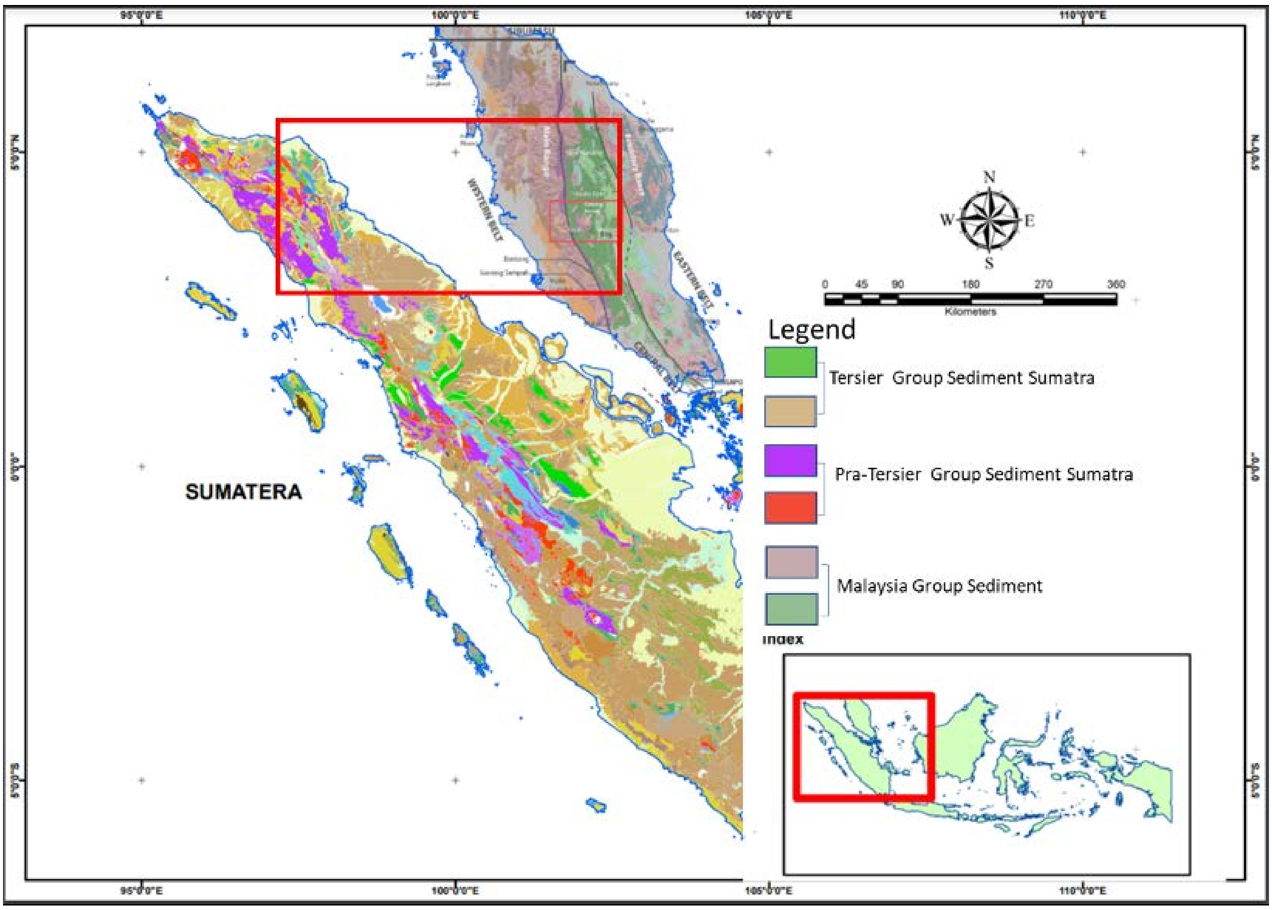

Figure 1. Study area and regional geology map, after Cameron et al. (1981a, 1981b), Keats et al. (1981), and Cameron et al. (1982)

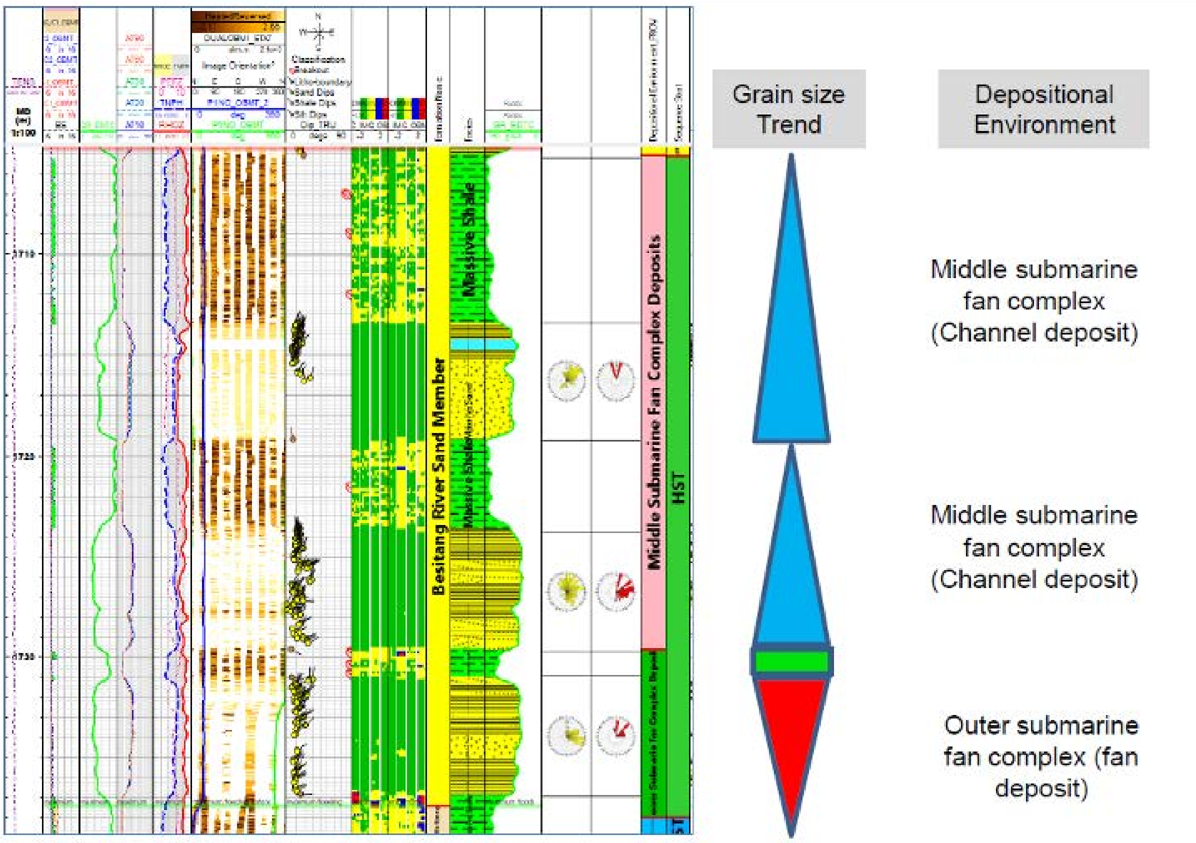

Figure 2. Borehole imaging well data at NSB (Usman et al., 2023)

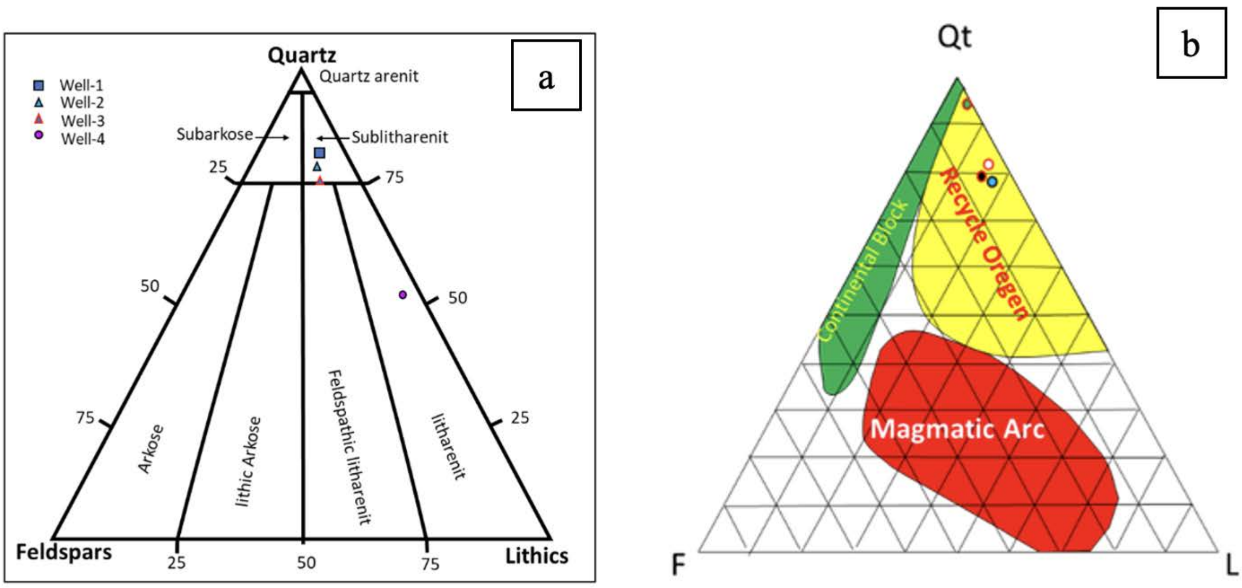

Figure 3. (a) The MBS mineralogical data based on Folks (1974) and (b) Dickinson (1979) diagram (Usman et al., 2023)

Peninsula, which changed from the south during the Bukit Barisan uplifting. This understanding is supported by the fact that sediments in the Paleogene and Neogene ages do not contain volcanic sediments (tuffaceous).

The current direction and paleogeography in the basin are described as moving towards the south, with sedimentary origins from the north. Based on petrology and mineralogy data analysis, Usman et al. (2023) explained that the MBS includes feldspathic litharenite sandstone (Figure 3.a), whose associated petrographic image is as shown in Attachment 3. Furthermore, Qt-F-L diagram after Dickinson's (1979) suggests that the MBS was formed from recycled orogen, meaning it was derived from existing sedimentary rocks (Figure 3.b).

Based on chronostratigraphic data and REE analysis from previous research (Usman et al., 2023), it is necessary to comprehensively map and analyze the existing data. This will facilitate the determination of the sediment origin of the MBS, assuming that clastic sediments came from igneous rocks, sedimentary rocks, or metamorphic rocks that undergo weathering and were transported into the basin.

METHODS

In this study, we used four wells and 32 outcrops of data to evaluate the provenance and distribution of the MBS. Besides that, three outcrops used as secondary data are also utilized to support the analysis. Based on the hypothesis that sediments came from sedimentary rocks, igneous rocks, or metamorphic rocks, it is important to consider that the further the sediments are away from their source of origin, the finer they will become as energy and deposition decrease. Hence, understanding the provenance of sediment is crucial.

To determine the rock origins, several methods can be employed, depending on the availability of data. In this study, the following methods are applied:

a. The chronostratigraphic correlation method is used to find out where the basin center is and where the landward direction is.

b. The REE method is employed to establish the correlation of rock origins using the comparison method with discrimination diagrams from Pearce et al. (1984).

The REE analysis method, supported by the chronostratigraphic correlation method, was used to observe and verify the direction of sedimentation in the study area, both onshore and offshore. Based on the results, the author can determine where the land location was and predict where the sediment originated from. This data will compare the REE of the MBS obtained from well data (below sea level), current surface outcrop data, and previous research data on the Malay Peninsula.

The discrimination diagram (Pearce et al., 1984) will assist in grouping igneous rocks into four categories based on their genesis: volcanic-arc granite (VAG), collision granite (COLG), within-plate granite (WPG), and ocean-ridge granite (ORG). VAG is typically found in the active continental margins and oceanic arcs (Pearce et al., 1984). By determining which group the MBS belongs to, comparisons can be made with the rock group assumed to be the original source. Based on these analyses, a conclusion can be drawn and the origin of the MBS and its paleogeographic form can be determined.

RESULTS

Based on the hypothesis, the MBS on the onshore is predicted from the southwest of the wells. This interpretation is based on the results of borehole image measurements from wells in the onshore NSB, which show sedimentation came from the southwest direction of the well area (Figure 2). In addition, the existence of *Globigerina Siakenesis (T)* at 10.46 Mya within the MBS on BTR, WP, and KB wells shows that sediments deepened towards the northeast, namely from neritic to bathyal (Figure 4).

Based on this data, it is described that the source of the MBS came from the southwest of Bukit Barisan. However, this assumption contradicts other research that mentioned the source of the sediments coming from the Malay Peninsula. On the other hand, the offshore well data show that the provenance rock came from the north to the south.

For offshore data, it is already established that the source provenance was from the Malayan Peninsula.

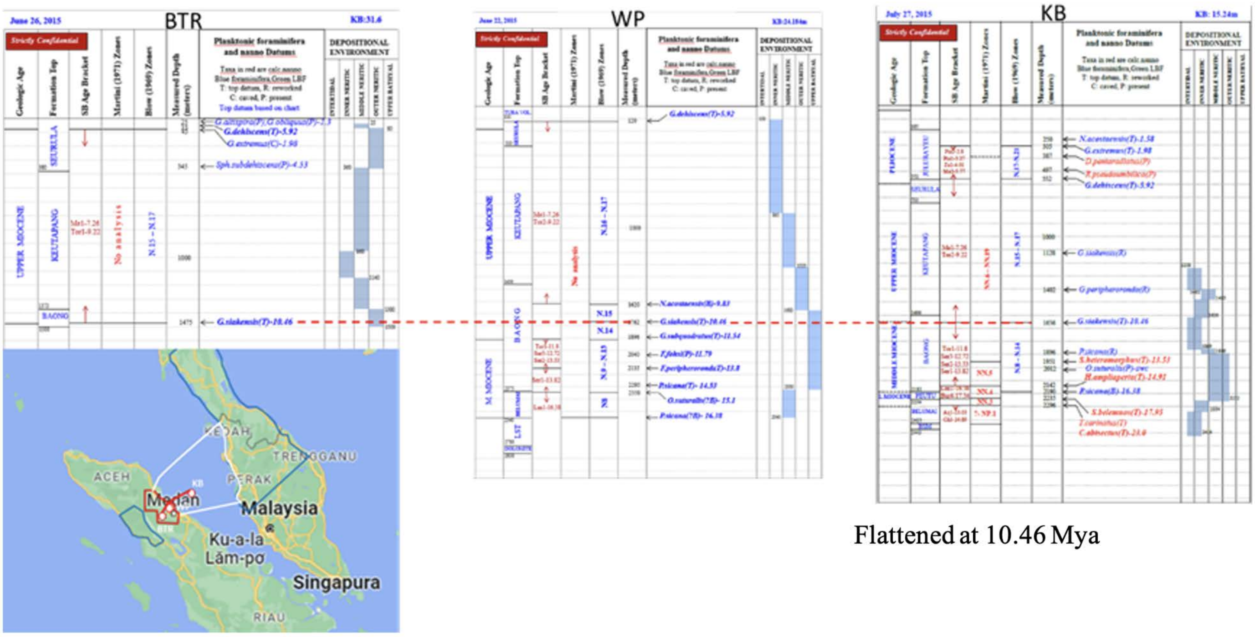

Figure 4. Paleoecological well correlation with Globigerina Siakensis (T) as the marker. (data attached: Attachment 1a-1c)

However, to strengthen the prediction of onshore wells originating from the south, validation was conducted using the comparison method with REE. For this purpose, well data from the onshore area and the Malay Peninsula were compared with well and outcrop data from the southern part of the well area, specifically the region around Kutacane. These comparisons were adjusted based on the prediction results from well borehole image data, as well as rare trace element data from the Malay Peninsula (Pertamina, 2016). The comparison method involves using a graph chart of elements Y vs. Nb (Figure 5).

Based on the data above, it is estimated that the MBS onshore originates from a VAG system. This is consistent with the samples from the southwest Sumatra region in the NSB. In contrast, the data from the Malay Peninsula indicates a WPG system. These findings show that there are two provenances in the NSB area. The data is more likely to be closer to coming from the southwest, represented by samples from the southwest Sumatra region (the NSB, or Kutacane Area), while the data from the Malay Peninsula is believed to be from a different source.

DISCUSSIONS

Based on this evaluation, it can be interpreted that as we move offshore in the north of Belawan, the sedimentary deposit tends to be shaly, indicating a deep sea environment. Similarly, as we move from the north offshore to the south towards the coast, the depth increases. Therefore, it can be predicted that Belawan Beach, located in the northern terrain, was the deepest basin where the MBS sediment was deposited, specifically in the bathyal environment (Figure 6).

The condition is almost similar to the present condition, except that during the time of *Globigerina Siakensis (T)* at 10.46 Mya, the environment along the Belawan coast was outer neritic, as was the area of the Strait of Malacca. It can be estimated that the southern onshore area at the time of the Plio-Pleistocene experienced a very strong uplift compared to the Strait of Malacca. As a result, the current onshore area, which was once outer neritic, became land, while the Strait of Malacca remained as sea.

This result is almost similar to the present-day paleogeographic conditions, where the position of the basin is in the Strait of Malacca. However, during the time of *Globigerina Siakensis (T)* at 10.46 Mya, the internal position was on the border of the area around the current coast, with a deeper depth of bathyal compared to the internal present-day position, which is east of the Strait of Malacca.

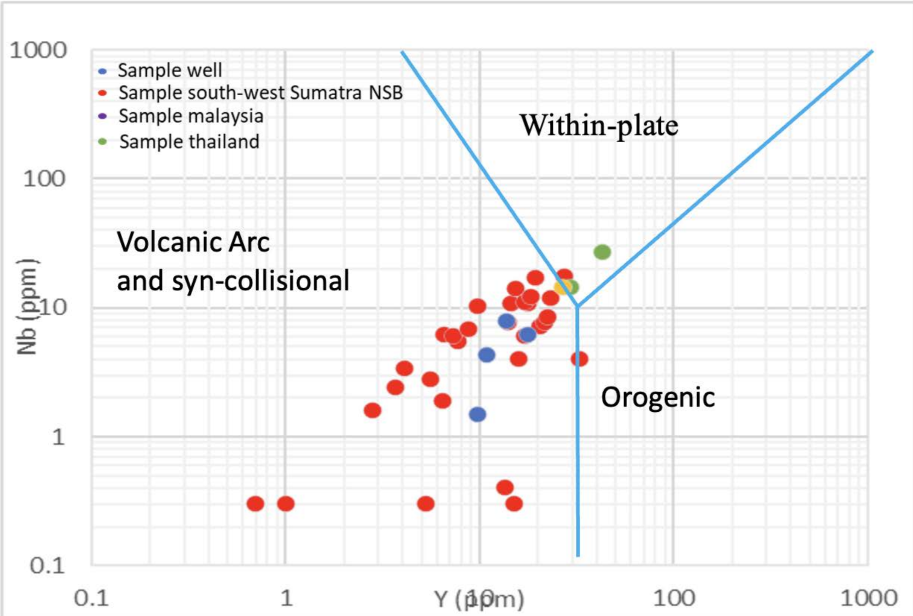

Figure 5. Elements Y vs. Nb discrimination diagram in North Sumatra and surroundings area (data attached: Attachment 2)

Thus, it shows that the position in the NSB was around the Strait of Malacca during the formation of the MBS, which has been in existence since 10.46 Mya. This contradicts the results of research from Riady et al. (1998) and Ambarwati et al. (2017), which stated that the source provenance onshore was the same as that offshore, i.e., originating from the Malay Peninsula. Therefore, it can be concluded that the opening of the NSB to the south occurred at the age of 10.46 Mya and the new Strait of Malacca was formed during the Bukit Barisan uplifting, specifically during the Plio-Pleistocene, when the Idi Formation was deposited.

CONCLUSSIONS

The MBS is described based on petrological and mineralogical data as feldspathic litharenite-

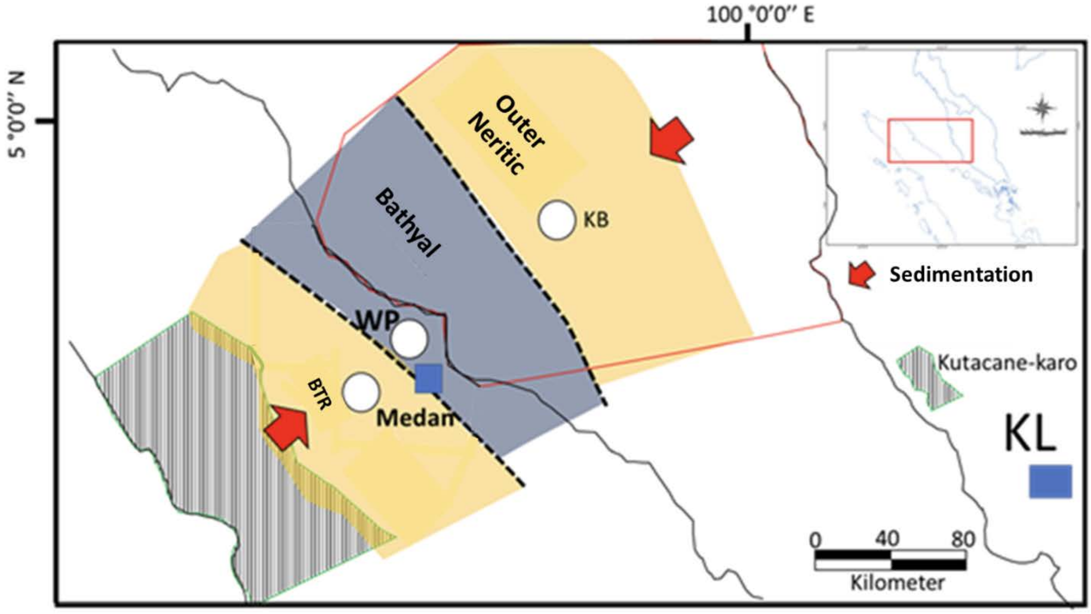

Figure 6. Paleogeography area research based on borehole image data chronostratigraphy and REE comparison (Y vs. Nb): WP= West Pakam, BTR= Batara, KB=Kambuna, KL=Kuala Lumpur

sublitharenite. In contrast, the MBS offshore can be distinguished based on REE data and benthos foram data. It shows that from south to north, the MBS is deeper towards the coast, transitioning from outer neritic to bathyal; while towards the Malay Peninsula, from the coast to the north, it becomes shallower.

Based on the analysis result, there are two sources of the formation. The MBS onshore comes from the south. On the other hand, the MBS offshore comes from the Malay Peninsula. The Strait of Malacca has existed since 10.46 Mya as an interior. However, during the deposition of the MBS (10.46 Mya), this strait took the form of a bathyal interior with a central interior around the Belawan Coast. Currently, it is in the form of a shallow strait.

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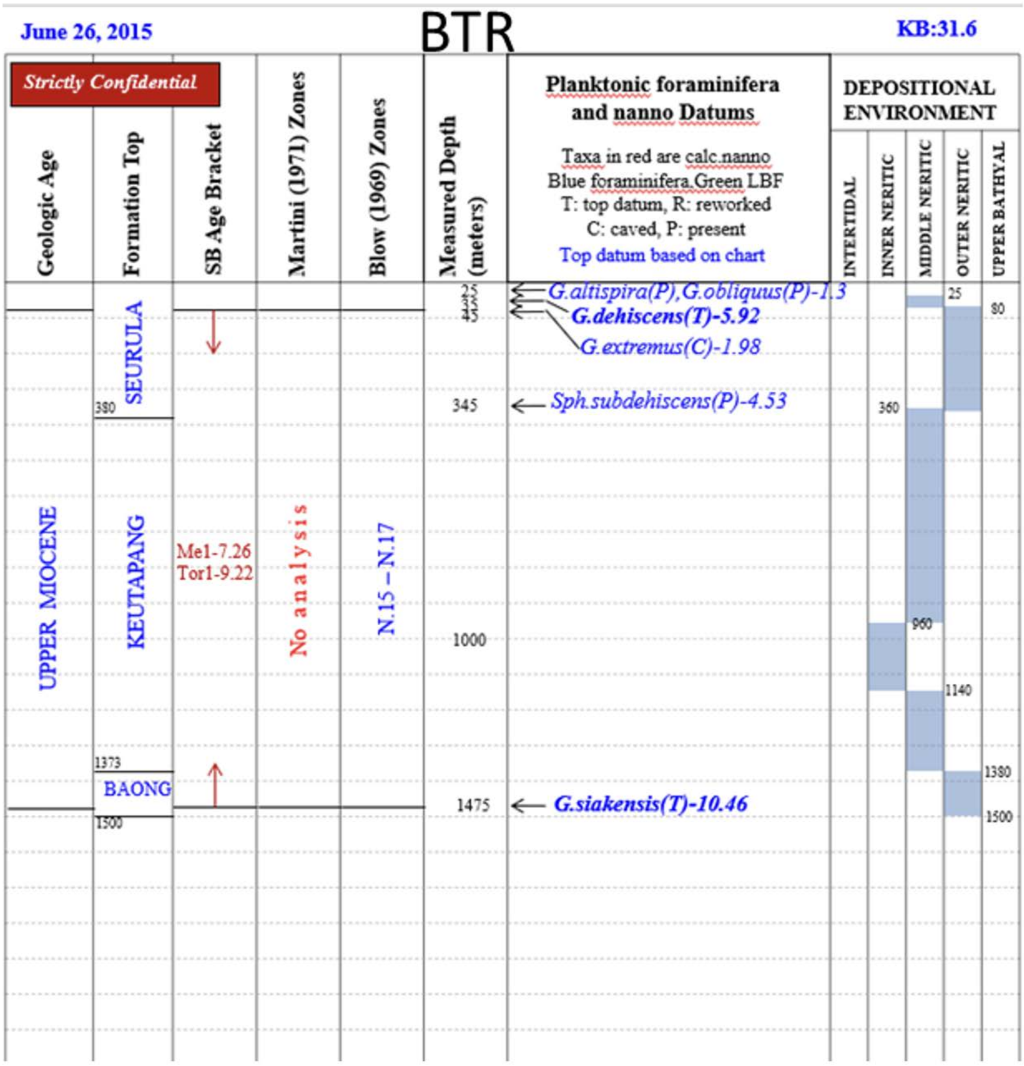
Attachment 1a (Pertamina, 2015)



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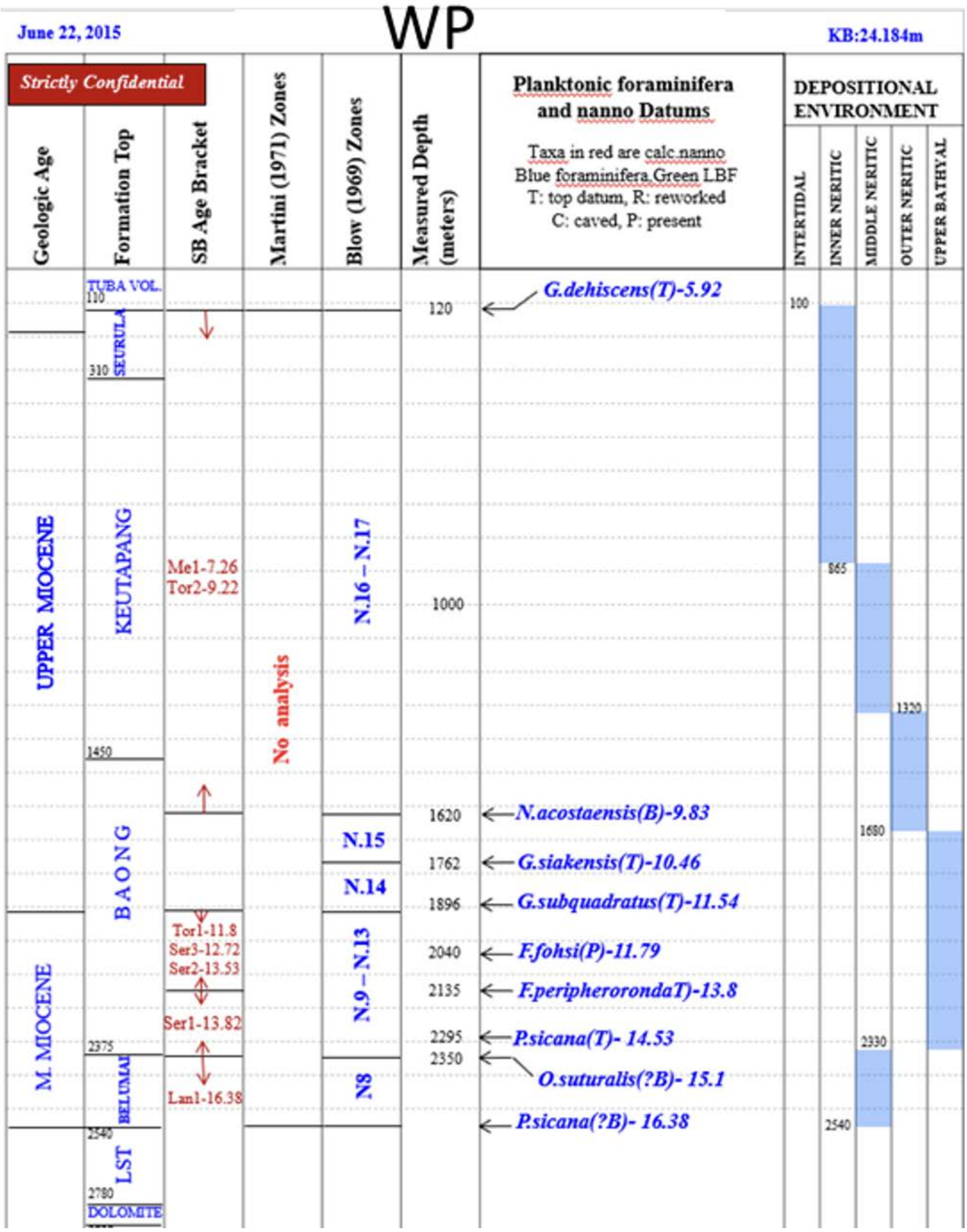
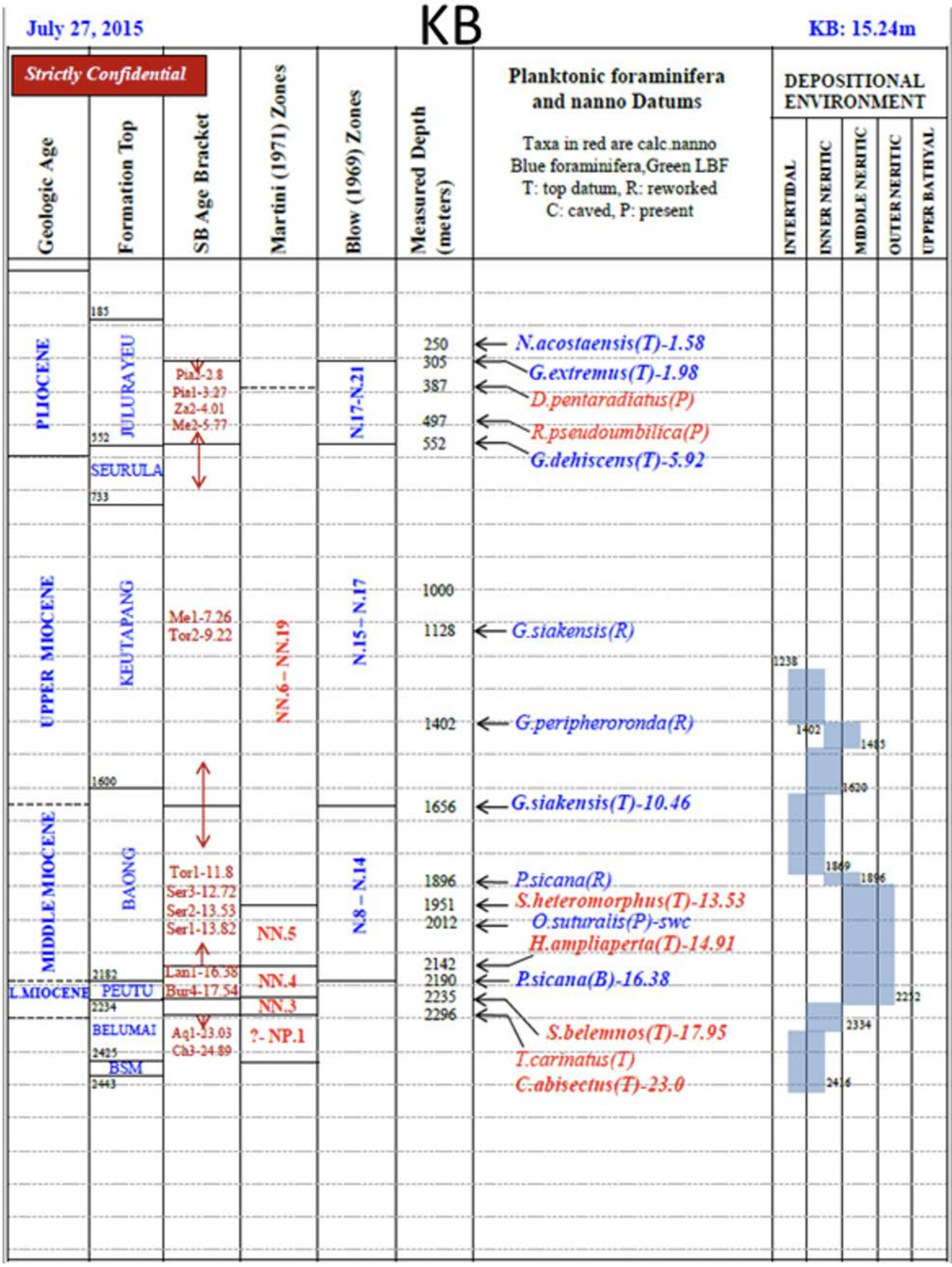


Attachment 1c (Pertamina, 2015)

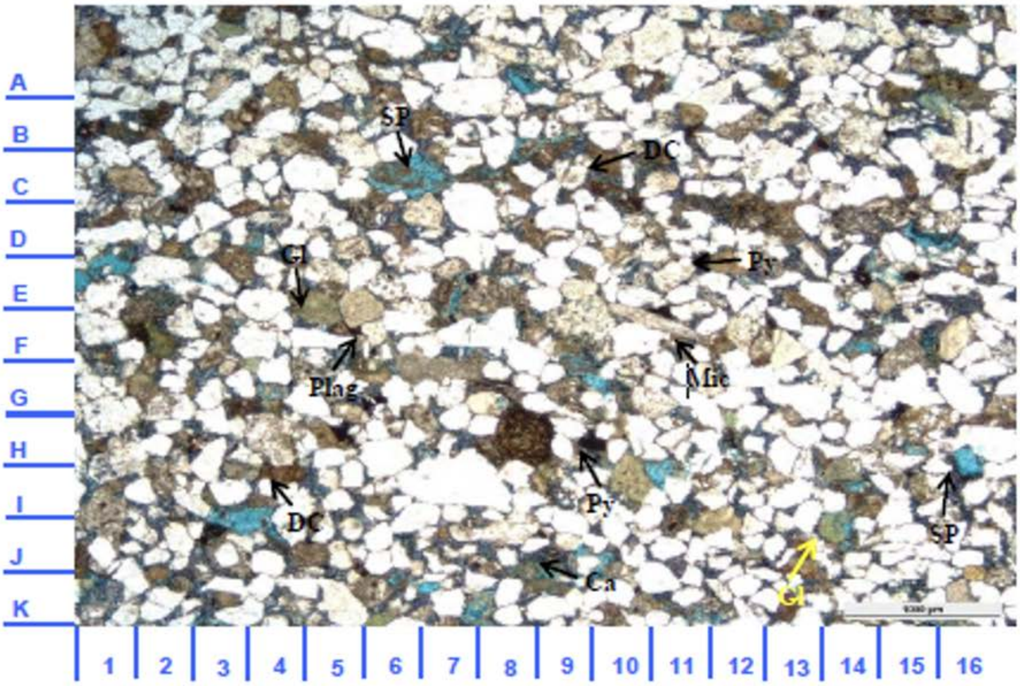


Attachment 2

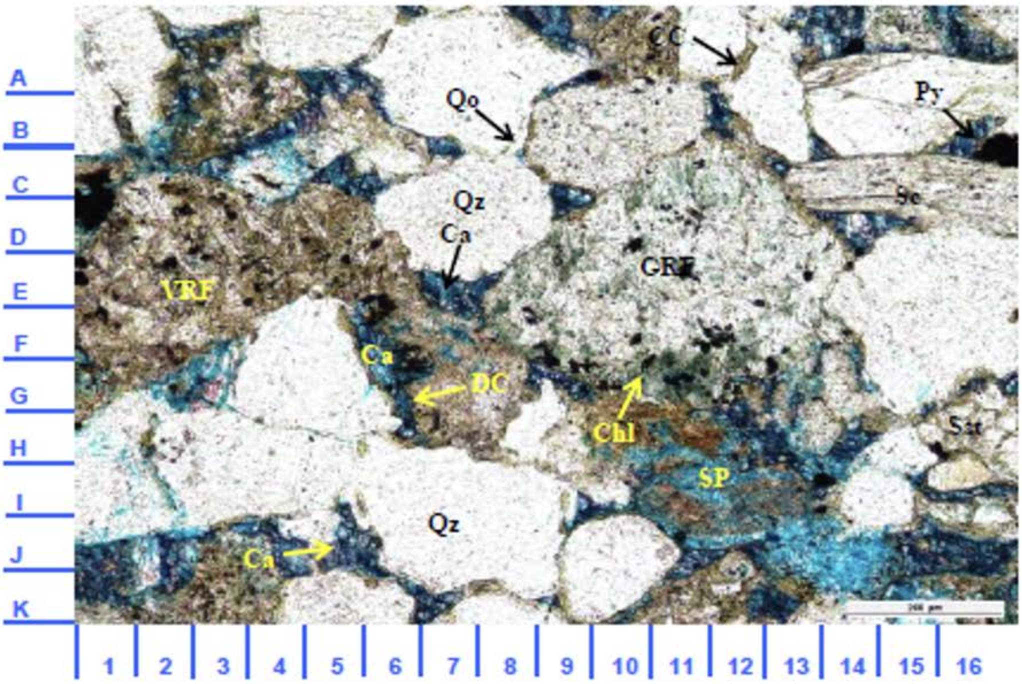
	Y	Nb
	PPM	PPM
	0.1	0.1
	4A/MS	4A/MS
well-1	10.8	4.3
well-2	13.8	7.9
well-3	9.8	1.5
well-4	17.8	6.2
SW-NSB-1	7.7	5.5
SW-NSB-2	14.1	7.7
SW-NSB-3	14.6	10.9
SW-NSB-4	17.6	10.7
SW-NSB-5	6.5	6.2
SW-NSB-6	13.4	0.4
SW-NSB-7	2.8	1.6
SW-NSB-8	9.8	10.2
SW-NSB-9	15.2	14.2
SW-NSB-1	17	11.1
SW-NSB-1	23	11.8
SW-NSB-1	1	0.3
SW-NSB-1	7.3	6.1
SW-NSB-1	3.7	2.4
SW-NSB-1	18.2	12.3
SW-NSB-1	4.1	3.4
SW-NSB-1	17	6.1
SW-NSB-1	0.7	0.3
SW-NSB-1	15.9	4
SW-NSB-2	19.2	17.2
SW-NSB-2	20.4	7.1
SW-NSB-2	5.3	0.3
SW-NSB-2	32.5	4
SW-NSB-2	6.4	1.9
SW-NSB-2	27.5	17.7
SW-NSB-2	8.7	6.9
SW-NSB-2	21.7	7.7
SW-NSB-2	15.1	0.3
SW-NSB-2	22.5	8.4
SW-NSB-3	5.6	2.8
mly-1	29.5	14.6
mly-2	43	27
tha-01	27	14.6
	1000	1000

Attachment 3. Calcareous sandstone, feldspathic litharenite

Depth 1646.3 m **Calcareous sandstone, Feldspathic litharenite** **Plate 1a**



Magnification X20 ||pol



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A low magnification image shows ~~that~~ moderately sorted sandstone composed of angular to rounded particles, identified as quartz (Qz), feldspar (F) and rock fragments (RFs). Unstable grain has partially dissolved and results in secondary pore (SP), and also partially replaced by calcite (Ca). Some grain is locally coated with clay (CC). Primary pores are occasionally filled by detrital clay (DC) and Ca. Visible porosity is moderate and the dissolution pore types are dominant. Restricted primary intergranular (IP) type is also recognized.