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Provenance and Paleoclimate Analysis of Sandstone from Meluhu Formation in Kendari, Southeast Sulawesi.

Analisis Sumber Batuan dan Iklim Purba Batupasir Formasi Meluhu di Lintasan Kendari, Sulawesi Tenggara.

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Abstract - The Meluhu Formation consists of quartz sandstone, red shale, siltstone, and mudstone at the bottom part, and alternating black shale, sandstone, and thin limestone in the upper part. Petrographic components composition can reveal the litho-tectonic setting of a region. The composition of sandstone can be done by determining and counting the proportion of a quartz minerals, feldspar, and rock fragment from thin sections using petrographic analysis. This result can guide to depositional setting and paleoclimates of a region. The Provenance and paleoclimates studies of Meluhu Sandstone are still relatively new. The purpose of this study was to find out the provenance and paleoclimate of sandstone of Meluhu Formation which is exposed in 14 sites along Kendari and adjacent area. The method used to make petrographic observations followed by data processing using the point counting method. The sandstone in this study area was classified into sublitharenite, lithic arenite, arkose, subarkose, and greywacke. The origin of rock was interpreted as located in the recycled orogenic province, interior craton, and undissected arc. The paleoclimate that occurred in the formation of these siliciclastic rocks was arid to humid.

Keywords: Meluhu Formation, provenance, paleoclimate, sandstone.

***Abstrak** – Formasi Meluhu terdiri dari batupasir kuarsa, serpih merah, batulanau, dan batulempung di bagian bawah, serta serpih hitam, batupasir, dan batugamping tipis berselang-seling di bagian atas. Komposisi komponen petrografi batuan dapat mengungkapkan posisi lito-tektonik suatu wilayah. Komposisi batupasir dapat didapatkan dengan menentukan dan menghitung proporsi mineral kuarsa, feldspar, dan fragmen batuan dari lapisan tipis menggunakan analisis petrografi. Hasil analisis tersebut dapat memandu penentuan sistem pengendapan dan iklim purba. Kajian sumber batuan dan iklim purba pada batupasir formasi Meluhu masih terhitung baru. Tujuan penelitian ini adalah untuk mengetahui sumber batuan dan iklim purba batupasir Formasi Meluhu yang tersingkap pada 14 lokasi di lintasan Kendari dan sekitarnya. Metode yang digunakan adalah analisis petrografi dilanjutkan dengan pengolahan data menggunakan metode point counting. Batupasir di daerah penelitian ini diklasifikasikan menjadi sublitharenite, litik arenit, arkose, subarkose, dan greywacke. Asal batuan batupasir di daerah penelitian diinterpretasikan berasar dari recycled orogenic province, interior craton, dan undissected arc. Iklim Purba yang terjadi pada pembentukan batuan silisiklastik ini adalah arid hingga humid.*

***Katakunci:** Formasi Meluhu, sumber batuan, iklim purba, batupasir*

INTRODUCTION

The Meluhu Formation which is located along the Kendari trajectory is composed of quartz sandstone, red shale, siltstone, and mudstone at the bottom, alternating black shale, sandstone, and limestone at the top. (Rusmana *et al.,* 1993). This formation is unconformably overlain by metamorphic rocks and unconformably overlaid by the limestone unit of the Tampakura Formation (Rusmana *et al.*, 1993).

Sandstone petrographically components composition can reveal sandstone classification and litho-tectonic provenance setting (Christopher *et al.,* 2017). This composition is mainly the proportion of quartz minerals, feldspars, and rock fragments. The parent-rock assemblages of this sandstone could possibly be identified from the variety of quartz-grain varieties enclosed in the siliciclastic rock-like sandstone (Basu *et al.*, 1975). This detrital mode detects information of provenance, depositional environment, and paleoclimates (Boggs, 2006; Critelli, 2018).

Previous research about Meluhu Formation in Kendari has been conducted such as by Surono (2013) who interpreted the Meluhu Formation as the age of the Triassic, while the newest research from Fahruddin *et al.* (2020) using the palynologianalysisisis approach suggested the age of this formation is Middle to Late Miocene. This significant age difference must be confirmed by the tectonics event of each age.

The provenance and paleoclimates studies of Meluhu Sandstone are still relatively new. The purpose of this study was to find out the provenance and paleoclimate of sandstone from the Meluhu Formation which are exposed in Kendari and adjacent areas (Figure 1).This information can be tailored to add an understanding of the tectonic setting in the region.

REGIONAL GEOLOGY

Physiography

Physiographically, the research area is located on the southeastern arm of Sulawesi which is shown in the red box in Figure 2 (Hall & Wilson, 2000). This region is divided into three parts namely the northernmost, the central part, and the southern tip. The northern tip of Palopo in Tolo Bay consists of ophiolite while the central part, which is the widest in the region is mainly formed mainly by Mesozoic metamorphic and sedimentary rocks. Regionally there are three distinctive geological mandalas that are close to each other, namely the Buton Island, Muna, and the Tukangbesi Plateform (Davidson, 1991). Based on Surono (2013), the Southeast arm shows the morphology of mountains, hills, plains, and karst.

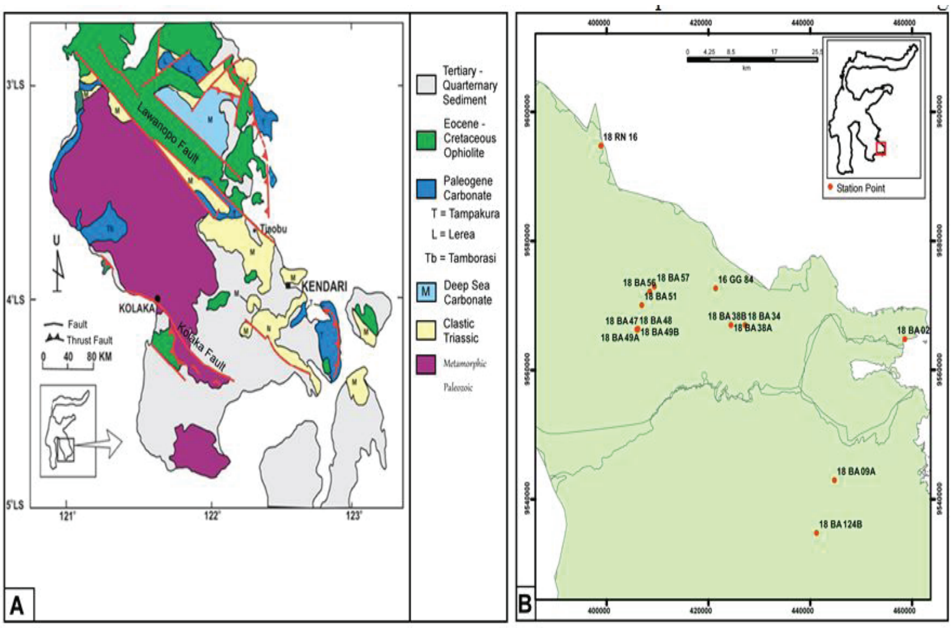


Figure 1. A) Geological map of the southeastern arm of Sulawesi (simplified and modified from Rusmana & Simandjuntak, 1993). B) Location map of the study area in Konawe and adjacent areas.

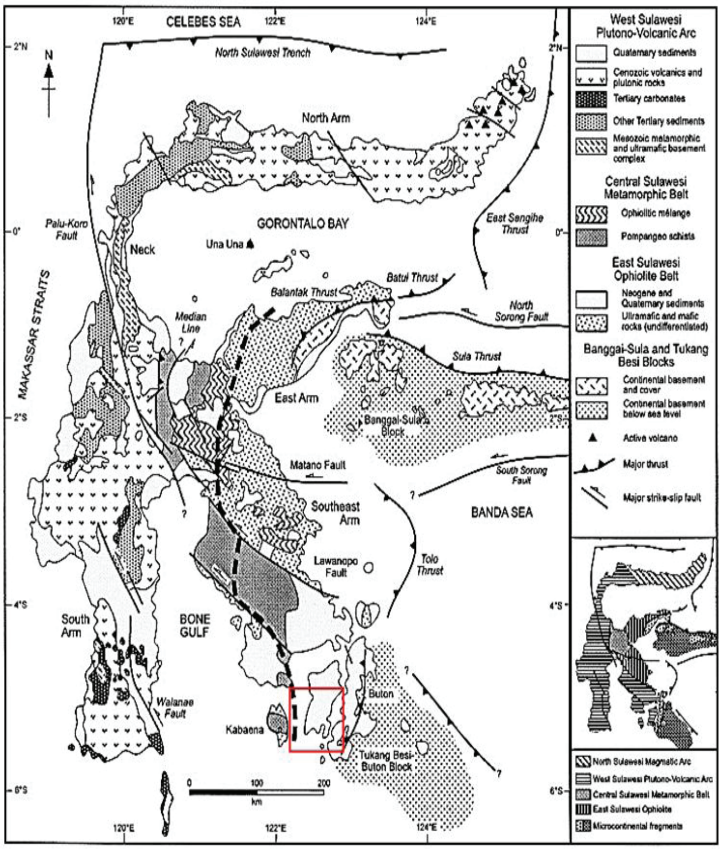


Figure 2. Physiography of Sulawesi (Hall and Wilson, 2000). The research area is shown by the line rectangle.

Tectonostratigraphy

According to Hall & Sevastjanova (2012), the initial process started as a result of the irregullar geometry of the Northern Australia boundary resulting in a diachronic collision between Australia and Southeast Asia (Figure 3). The Sula Spur formed a prominent feature on the Australian boundary and was the cause of the initial collision with the North Sulawesi Volcanic arc soon after 25 Ma. In the Early Miocene, there was a continental crust of Australia from East Sulawesi and Southeast Sulawesi through the Sula Spurs to the bird's head of New Guinea. The convergence between Australia and Eurasia continued in the early Miocene, with subduction of the Indian Ocean crust in the Java Trench, subduction of the South China seas counter clockwise broad rotation of Sundaland, internal Sundaland deformation, contraction, uplift, and erosion in East Sulawesi and Southeast Sulawesi (Hall, 2011). Sparkman & Hall (2010) provided a tectonic reconstruction of a subducted mantle with subduction rollback and crustal deformation with a particular extension. This led to the expansion of the Australian continental crust which had been in Southeast Asia since the Cretaceous and the fragmentation of the Australian Continental crust that arrived in the early Miocene as part of the Sula Spur. The Initial phase of extension resulted in the opening of the Northern Banda Sea between 12.5 and 7 Ma (Hinschberger *et al.*, 2000) and the stretching and fragmentation of crustal fragments from East and Southeast Sulawesi and the Sula Spur. Dredges sample from the Banda Ridges showed that they are supported by basaltic arc volcanic rocks, Neogene andesite, and continental crust similar to those found in Buton, East Sulawesi, Seram, Misool, and Banggai-Sula (Honshaas *et al*., 1998).

RESEARCH METHODS AND DATA

Microscopic petrography was executed on the 14 studied samples of Meluhu Sandstone from outcrop in Kendari and adjacent area. Microscopic observation in thin sections was done at the laboratory of petrology-petrography, geological department, Institut Teknologi Sumatra. The petrographic method was used to observe the characteristics of the constituent components of 14 samples of sandstone of the Meluhu Formation in the study area.

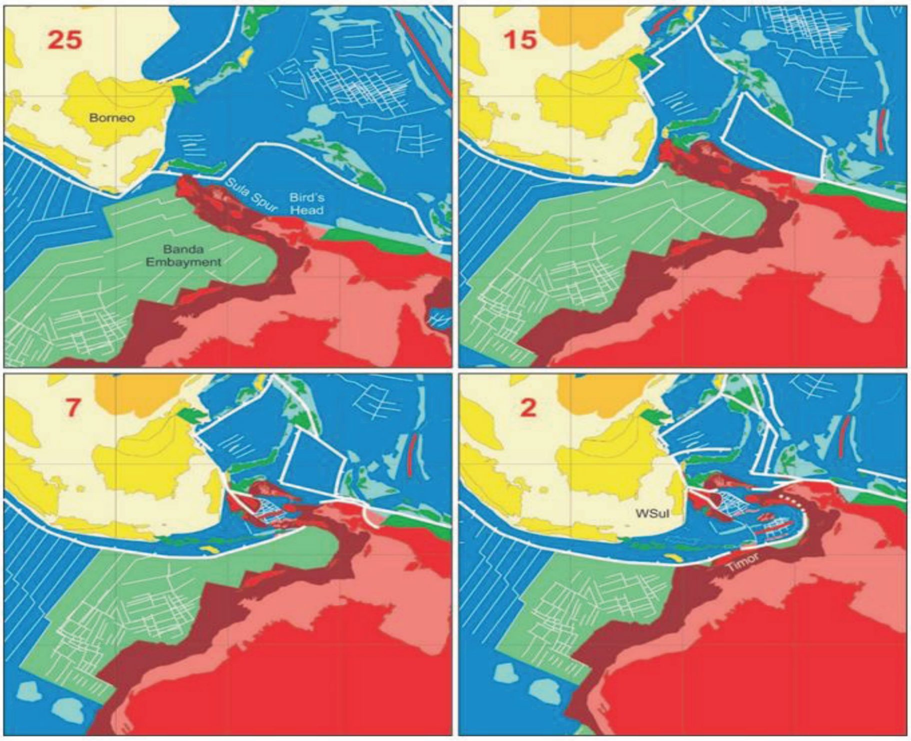


Figure 3. Tectonic reconstruction showing the Australia-Southeast Asia Collision in the Miocene when the Sula Spur collided with the North Sulawesi Volcanic Arc (Hall & Sevastjanova, 2012). The subduction rollback started at 15 Ma into the Jurassic Band bay causing the extension of the Sula Spur. The first stage of expansion formed the North Banda Basin between 12 and 7 Ma and the remnants of the Sula Spur was carried to the southeast on the subduction hinge.

The observed sandstone characteristics include sorting, packing, compaction, degree of roundness, and mineral composition of this sandstone using the point counting method introduced by Gazzi (1966) and Dickinson (1970) as many as 500 points counting on each thin slice sample. Identification of sandstone classification according to Pettijohn *et al.* (1987) which is based on the percentage of grain components, including quartz, feldspar, and lithic. Determination of rock origin/provenance using a discriminant triangle diagram of quartz, feldspar, and lithic (QFL) from Dickinson *et al.* (1983). Meanwhile, paleoclimate analysis used discriminant diagrams of quartz, feldspar, and rock fragment (QFR) and texture determination using Folk diagrams (1951).

RESULTS AND DISCUSSION

Sandstone Classification

The sandstone of the Meluhu Formation in this study generally has petrographic features with a dominance of poorly to moderately sorted, open fabric, angular to slightly rounded grains, and a dominant concave-convex to longitudinal grain contacts. The detail of the identification of the petrographic components is presented in Table 1. After having plotted based on the percentage of the presence of quartz, feldspar, and lithic minerals using a diagram of Pettijohn *et al.* (1987), the sandstone unit could be characterized into 5 units, namely sublitharenite, lithic arenite, arkose, subarkose, and greywacke (Figure 4).

1. Sublitharenites

Sublitharenite was found in two samples of 18 BA 56 and 18 BA 38B. This unit has medium grain size, with poorly to moderately sorted, slightly rounded, and long contact to concave-convex contact. Based on Folk (1974) the level of texture maturity is categorized as mature (Figure 5).

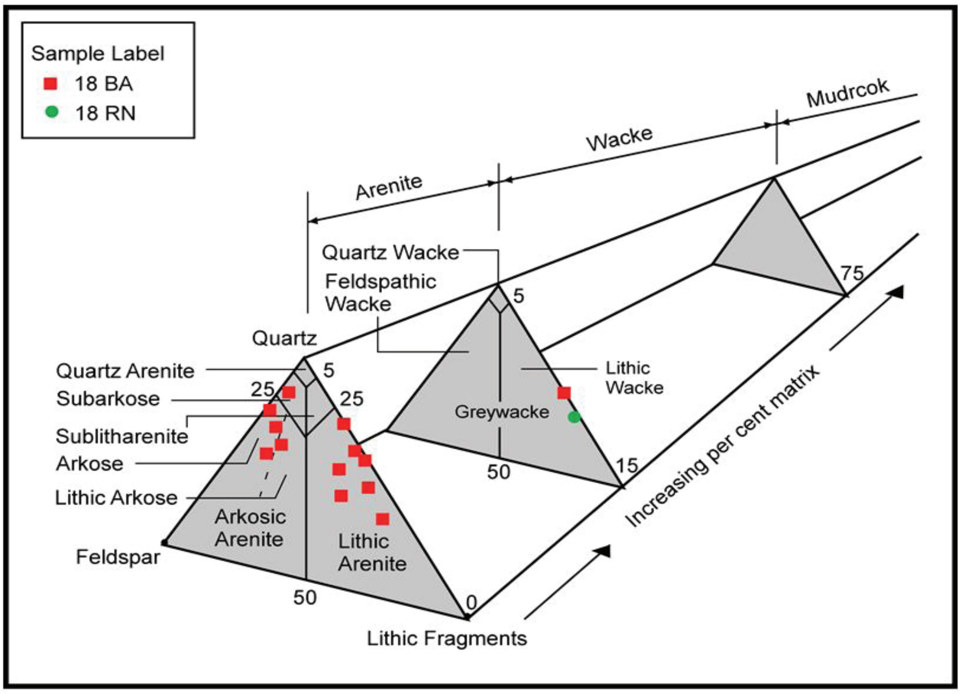
2. Lithic Arenite

Lithic arenites were found in eight samples, namely 16 GG 82A, 16 GG 84, 18 BA 38A, 18 BA 47, 18 BA 48, 18 BA 49A, 18 BA 51, and 18 BA 57. This unit has a fine to medium grain size with the dominance of medium size, well sorted, slightly rounded to rounded, concave-convex to long contact of grain. The level of texture maturity is sub-mature to mature (based on Folk, 1974; Figure 6).

Table 1. Detail of point counting of a petrographic component from sandstone Meluhu Formation

Description	18 RN 16	18 BA 09A	18 BA 34	18 BA 38A	18 BA 38B	18 BA 47	18 BA 48	18 BA 49A	18 BA 49B	18 BA 51	18 BA 56	18 BA 57	18 BA 124B	18 BA 02
Sorting	M - W	M - W	P	P	M	P - M	M	M - W	P - M	M	P - M	M	M	M
Grain Size (mm)	0,5-1	0,25-1	0,1-0,5	0,1-0,5	0,5-1	0,1-1	0,025-0,5	0,025-0,5	0,5-1	0,025-0,5	0,25-0,5	0,1-0,5	0,1-0,5	0,5-1,5
Roundness	SA	SR	SA	SA	SR	SR	R	SR	R	SA	R	SA	R	R
Contact	CC-LC	CC-LC	FC-CC	CC-LC	LC-CC	CC	FC	FC	CC-LC	CC-LC	LC	LC	FC	CC-LC
Maturity	SM	M	I	M	M	M	M	M	SM	M	M	M	M	SM
Quartz Mono	115	199	130	217	256	201	163	114	238	145	214	184	216	195
Quartz Poli	114	28	94	91	63	65	79	184	15	71	4	105	0	25
Feldspar	0	49	0	7	3	0	12	16	36	10	22	17	11	34
Litik	105	0	118	140	115	132	140	134	0	108	0	111	0	0
Muscovite	5	11	2	9	1	0	0	5	0	4	2	6	0	0
Opaque	2	12	10	0	2	1	3	9	9	8	5	17	6	25
Matriz	111	0	104	31	52	101	55	29	0	74	0	39	0	126
Cement	30	38	14	5	8	0	48	2	49	68	84	21	95	30
Pore	18	163	28	0	0	0	0	7	153	12	169	0	172	83
Total	500	500	500	500	500	500	500	500	500	500	500	500	500	518
Rock Classification Name	LG	A	LG	LA	SLA	LA	LA	LA	A	LA	SLA	LA	SA	A

Abbreviation:	P	: Poor	R	: Rounded	CC	: Concavo-convex	M	: Mature	LG	: Lithic Greywacke
	M	: Moderate	SR	: Sub-Rounded	LC	: Long Contact	SM	: Sub-Mature	A	: Arkose
	W	: Well	SA	: Sub-Angular	FC	: Floating	I	: Immature	SA	: Subarkose
									SALE	: Sublitharenite
									LA	: Lithic Arenite



Source: Pettijohn et al., (1987).

Figure 4. The results of plotting diagrams show samples divided into 5 rocks classification.

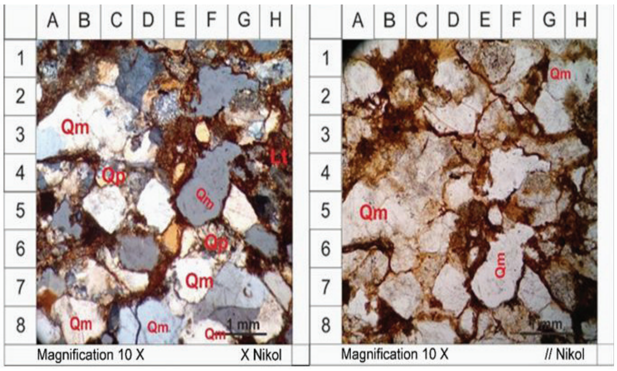


Figure 5. Example of sub-litharenite on a thin section from site 18 BA 56.

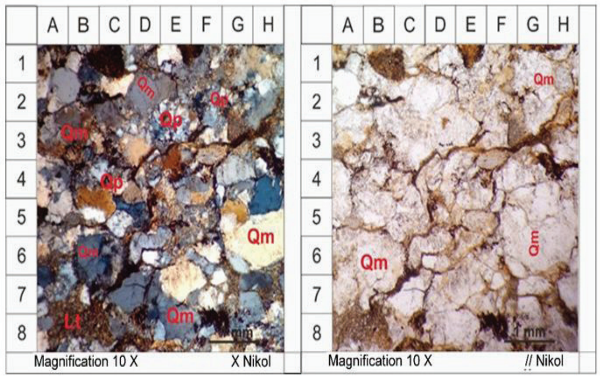


Figure 6. Example of lithic arenite on a thin section from site 18 BA 57.

3. Arkose

Arkose was found in three samples, 18 BA 02, 18 BA 09A, and 18 BA 49B. This unit has a medium to coarse grain, moderate–well sorted, slightly rounded to rounded, compaction types are long contact, suture contact, and concave-convex. The level of texture maturity based on Folk (1974) is sub-mature to mature (Figure 7).

4. Subarkose

Subarkose was found in one sample 18 BA 124B. This unit has a medium grain, grain supported and grain contact found were floating, concave-convex, and long contact. The level of texture maturity was mature (Folk, 1974) (Figure 8).

5. Greywacke

Greywacke was found in two samples, namely 18 RN 16 and 18 BA 34. The grain size is mostly medium grain, poorly sorted, slightly angular to slightly rounded, open fabric, grain contact dominance floating contact. This unit is interpreted as a sub-mature – mature category based on Folk (1974) (Figure 9).

Provenance

The determination of the source of the sandstone grain was obtained by plotting the discriminant diagram of Dickinson *et al*. (1983). The result indicated that the origin of sandstone grains from the Meluhu Formation in the study area came from the undissected arc province, recycled orogenic province, and the interior craton province based on the QFL diagram. The QmFLt diagram in more detail showed that the origin of the sandstone grain was lithic recycled, transitional recycled, and interior craton (Figure 10). In another diagram, Yerino & Maynar (1984) (Fig 11) showed the origin rock was in the form of fore arc-island arc, strike-slip, and passive margin with the dominance of the strike-slip system. The recycled orogen province is affected by a horizontal fault movement. Then, based on the discriminant diagram by Dickinson (1985) shows that the QFL result indicated a source from oceanic subducted, continental thrust belt, and collision belt. Diagram QmFlt presented the recycled orogen and continental block province (Figure 12). So it can be seen that the dominance of the source of the grains is related to the recycled orogen province, which means that the constituent siliciclastic sediments are in the form of altered rock that has previously been deposited and then transported and eroded and weathered so that it is re-deposited and become the rock that we studied here.

Paleoclimate

Paleoclimate interpretation was determined based on the calculation of the composition of quartz, feldspar, and lithic based on several diagrams used. Based on Basu's (1985) QFL diagram and Suttner et al. (1981), the paleoclimate was believed that in the form of metamorphic source arid climate and metamorphic source humid climate (Figure 13). The paleoclimates determination based on Suttner & Dutta (1986) and Weltje *et al*. (1998) showed a nearly connected result. It showed the humid to semi-humid on Suttner & Dutta's Diagram while the Weltje Diagram represented the metamorphic with high weathering intensity (Figure 14).

Throughout the Neogene which started from the Early Miocene, the geographical conditions of the island of Sulawesi experienced changes related to uplift and subsidence that affected the width of the basin formed (Nugraha & Hall, 2018) after collision with Australia, Sula Spur which formed Molasses (Neogene clastic sediments; Klompe, 1954). With the Southeast Asian margin of Sulawesi (Hall, 1996, 2002, 2012a). As a result of the collision also formed a high mountain area dominated by ophiolitic rocks, especially ultramafic, in the eastern part of Sulawesi there was an expansion of the area. Then, the Middle Miocene sediments in the Southeast Sulawesi Arm went on hiatus followed by erosion with a long period of subaerial tropical weathering (Schellmann, 1983; Butt & Cluzel, 2013). The weathering period is related to the geographical location of Sulawesi Island which is close to the equator, characterized by getting sunlight throughout the year with a fairly high intensity of weathering due to rain and rivers. In connection with the paleoclimate of the study area in the Middle to Late Miocene, the clastic sedimentary rocks of Meluhu formation with a predominance of composition rich in quartz minerals that are resistant to high weathering, formed from the metamorphic origin with a dry climate (arid) and also sandstones with a predominance of relatively fewer quartz minerals are formed from rocks of metamorphic origin in humid climatic conditions.

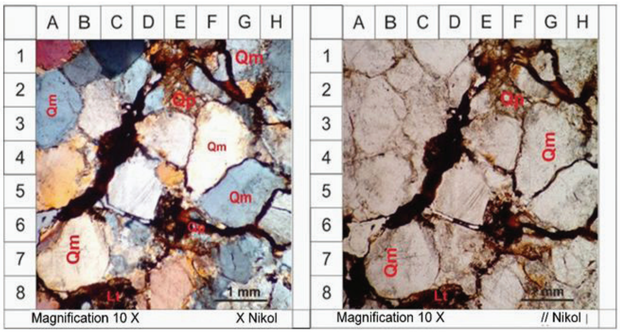


Figure 7. Example of arkose on a thin section from site 18 BA 02.

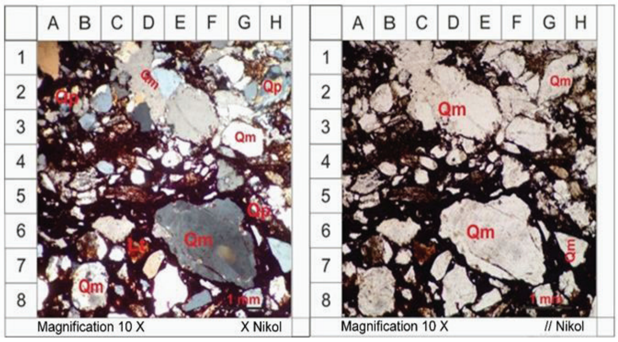


Figure 8. Example of sub-arkose from a thin section from site 18 BA 124B

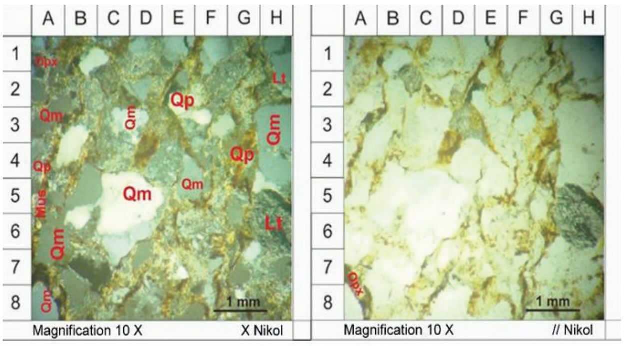
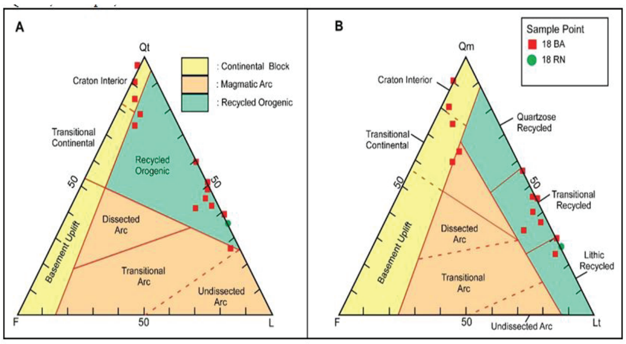
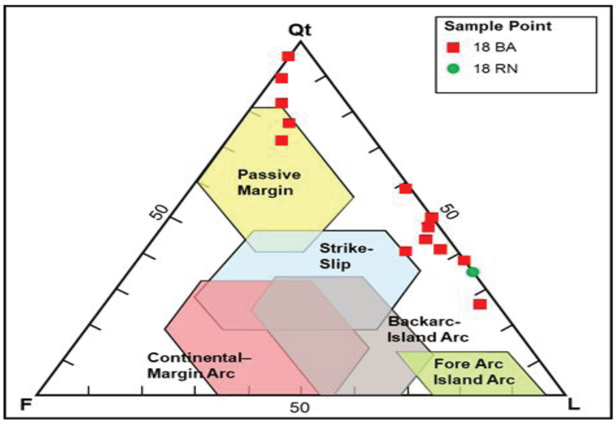


Figure 9. Example of lithic greywacke from a thin section from site 18 BA 34.



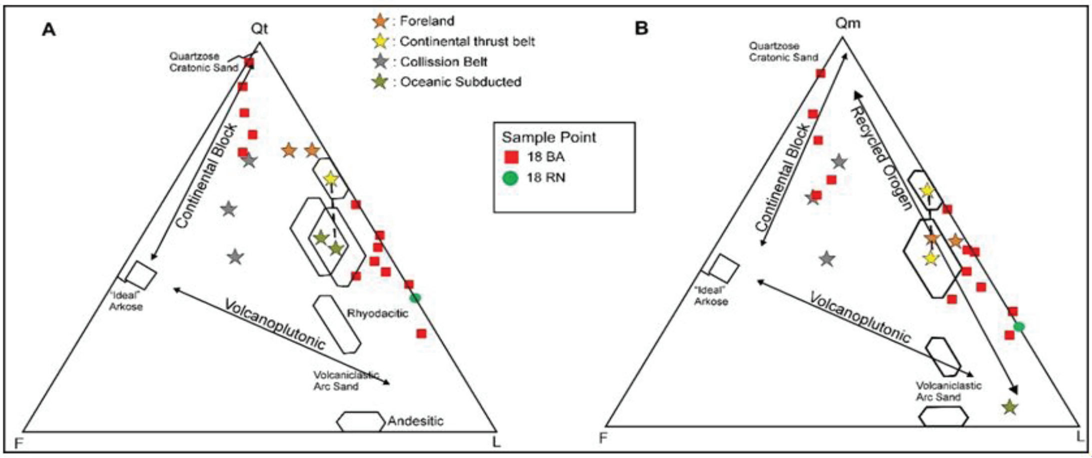
Source: Dickinson et al., (1983)

Figure 10. Discriminant Diagram (A). A plot of origin rock based on QFL; B. Origin rock plots based on QmFLt.



Source: Yerino and Meynar, (1984).

Figure 11. Discriminant plot of origin rock based on QFL



Source: Dickinson et al., (1985).

Figure 12. Discriminant Diagram (A). A plot of origin rock based on QFL; B. Origin rock plots based on QmFLt.

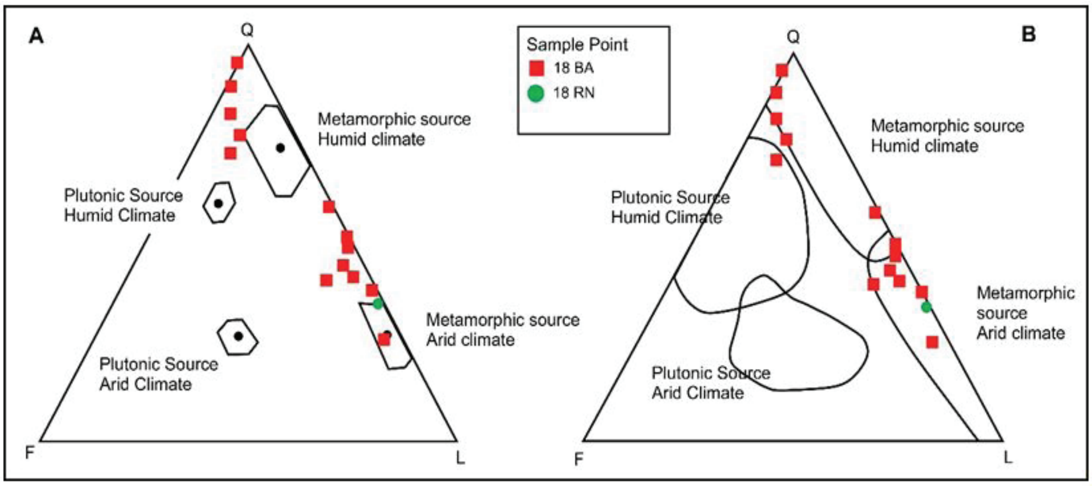


Figure 13. Discriminant Diagram of paleoclimates (A). QFL Based on Basu (1985); (B). QFL of Suttner *et al*. (1981).

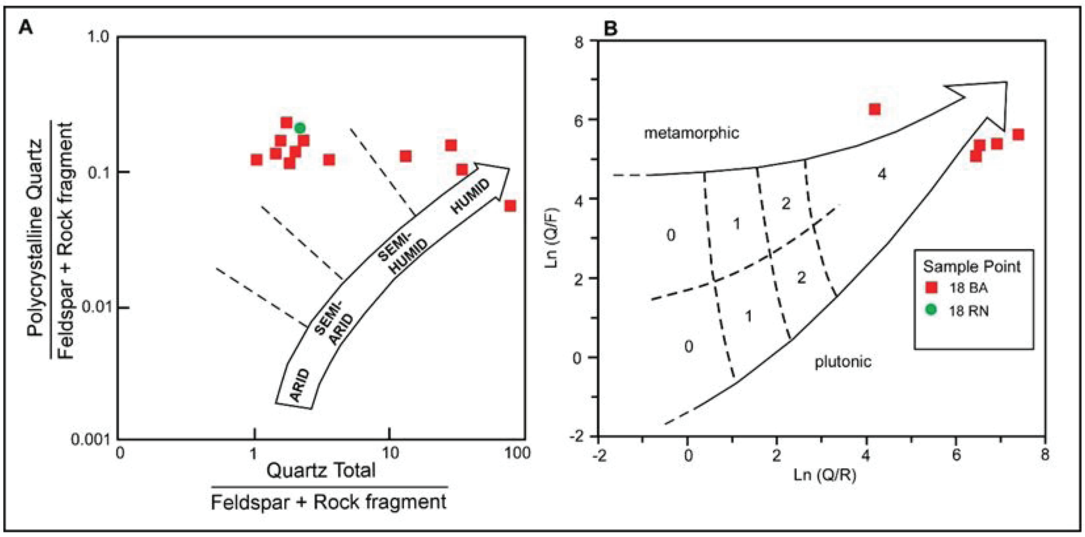


Figure 14. Discriminant Diagram of paleoclimates (A). Suttner & Dutta (1986); (B). Weltje *et al*. (1998).

CONCLUSION

The sandstone samples of Meluhu Formation from the study area have the characteristics of a dominant moderate sand grain, poorly to well sorted, subrounded, and grain contact dominance long to concave-convex. The sandstone is classified as greywacke, sublitharenite, lithic arenite, arkose, and subarkose.

The origin of the sandstone source that forms the Meluhu Formation in the study area was interpreted from the craton interior tectonic setting, undissected arc, transitional arc, and recycled orogenic.

The ancient sandstone climate of the Meluhu Formation in the study area is an arid climate to a humid climate which affects the dominance of the constituent minerals in the form of quartz which is quite abundant.

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