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LITHOFACIES AND ICHNOFACIES OF TURBIDITE DEPOSITS, WEST JAVA, INDONESIA

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Abstract: This study focuses on the analysis of sedimentary facies and ichnogenus variations to determine the palaeogeographic setting of turbidite deposits that are clearly exposed in the surroundings of Majalengka area, West Java, Indonesia. Lithofacies variation in turbidite deposits, identified from detailed stratigraphic sections, were visually presented as a composite log and indicated a thickening and coarsening pattern due to a regressive event. Trace fossils exposed in all stratigraphic levels consist of *Thalassinoides*, *Chondrites*, *Cruziana* and *Planolites*. They are commonly found in a series of thin to medium bedded fine grained turbiditic sandstones intercalated with shales. Hereinafter, the integration analysis in between sedimentology and ichnology data, the sediment shed into the basin in the submarine channelized related to slope system. Such findings cast no doubt as to whether integrated sedimentary facies and ichnofacies analysis can be viewed as precise methods for sedimentary basin interpretation, in which external parameter, for example magmatic processes, also are considered to play a role.

Key words: *Cruziana* ichnofacies, *Thalassinoides*, turbidite system, Majalengka, West Java

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Introduction

Turbidite facies are extensively well exposed in Majalengka, West Java, Indonesia. These sediment facies spread outwards in the middle-part of West Java, in an elongated manner parallel with Java Island itself. Among these basins, the Bogor Trough is filled with sedimentary rocks that tilted and folded tightly (Van Bemmelen 1949). Regionally, the Bogor Trough is bordered by two geologic terranes, the Northwest Java Basin to the north and the Southern Mountains to the south. The study area is situated in the eastern part of the Bogor anticlinorium located at Majalengka, Sumedang, West Java, Indonesia (Text-fig. 1).

The Miocene to Pliocene lithostratigraphy of the study area is conventionally divided into three formations, namely, Cisaar (at the bottom), Cinambo and Cantayan (at the top) Formation. The Cantayan Formation is composed of two members, i.e., the Halang and Bantarujeg members. The second formation is composed mostly of very fine to medium sand intercalated with siltstone and shale. According to biostratigraphic analysis, the succession can be divided into two parts: (1) the lower part consists of two formations (Cisaar and Cinambo formations), and (2) the upper part is composed of Cantayan Formation. The lower section consists predominantly of sandstone intercalation between siltstone and shale, the upper part, however, is dominated by medium to coarse grained material interbedded with very coarse grained.

The geology of the study area has been studied by many researchers since the last decades of the 19th century. The results of their studies were summarized and well documented by Van Bemmelen (1949), who explained the regional geology of Indonesia. Furthermore, Martodjojo (1984) carried out comprehensive research on the entire Bogor Trough, and described it into his dissertation. Satyana and Armandita (2004) made a summarization of turbidites in Java in relation to the possibility of hydrocarbon occurrence. Djuhaeni and Martodjojo (1989) presented a new systematic classification of the lithostratigraphic units in Majalengka (Text-fig. 2). Soeria-Atmadja et al. (1994) explained magmatism in Java during the Tertiary by the use of K-Ar dating methods on igneous rock samples to determine magmatism evolution. Djuri et al. (1973) made a geological map of Majalengka and the surrounding area. Muljana (2006, 2012) defined the provenance interpretation based on tectonics and sediment sources. However, such information is often limited to lateral and vertical continuity of facies, especially those integrated between sedimentary facies and ichnofacies.

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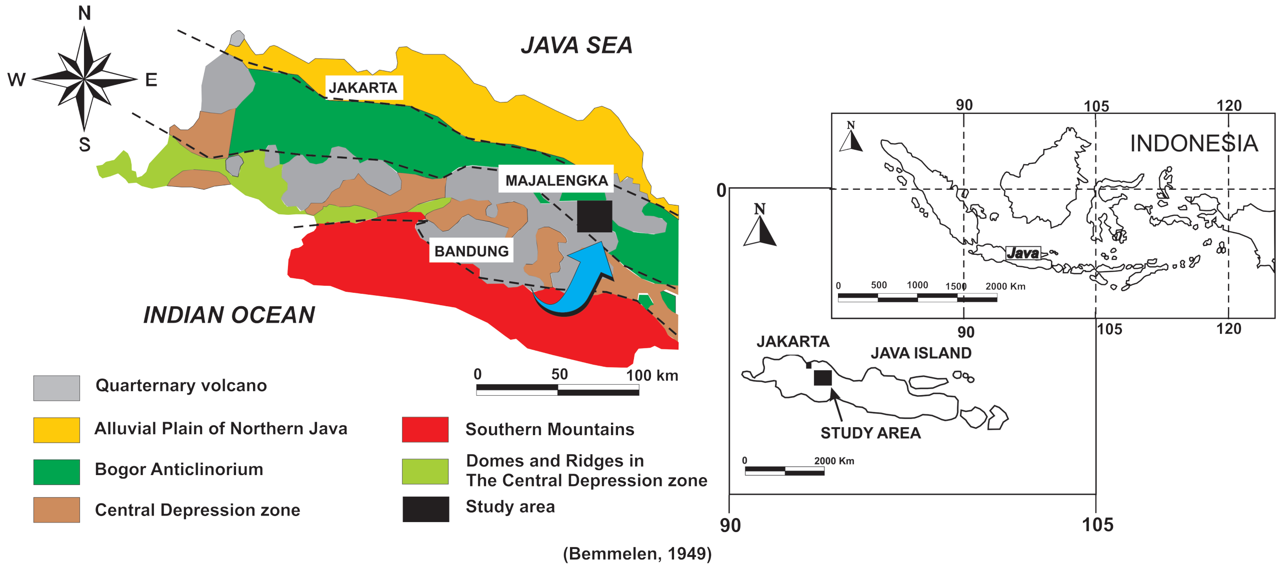
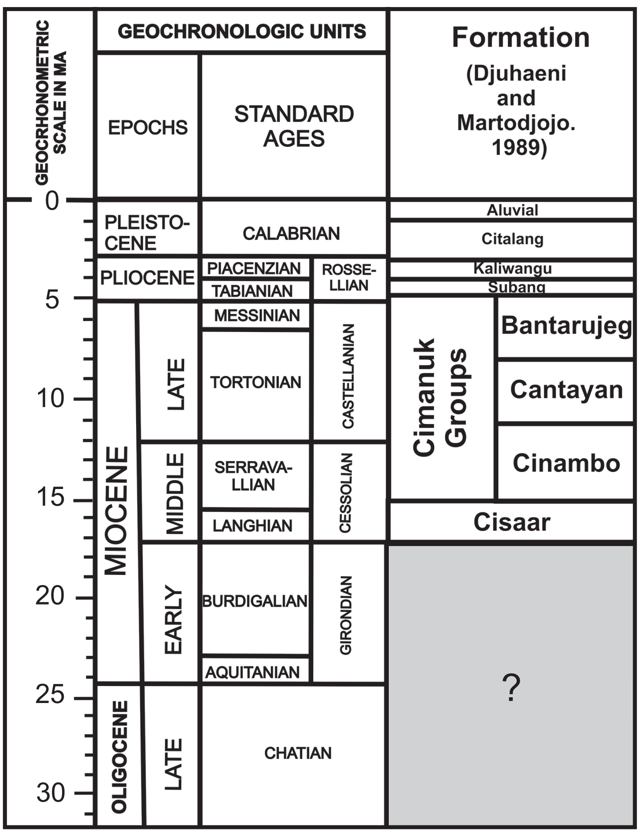


Text-fig. 1. Location of study area within Majalengka, West Java, Indonesia.



Text-fig. 2. Distribution of different rock units in the turbidite facies in Majalengka area, West Java, Indonesia.

It is more than three decades since Martodjojo (1984), concluded in his dissertation that all turbidite facies in Majalengka area were accumulated in the deep water zone during the Miocene. Therefore, the primary objective of this paper is to describe lithofacies and trace fossil occurrences in turbidities in order to develop a new interpretation and a framework which can assist in understanding the depositional environment. Furthermore, we try to explain how the sea level and other external parameters, such as magmatism processes, may influence lithofacies and ichnofacies variation.

Biostratigraphy

The nannofossil assemblages were collected from all lithostratigraphy units. The preservation state of samples from the Middle Miocene to Pliocene was frequently poor. Similarly, in the rare planktonic foraminiferal microfossils assemblages, preservation state in all intervals is approximately medium to bad. For his dissertation, Muljana (2012) collected several samples and concluded that the biostratigraphy interval of the study area is Middle Miocene to Pliocene on lower bathyal to outer neritic of bathymetry zone.

Methods

The field-study involved assessment of the turbidite succession using stratigraphic logging. Facies analysis of the sedimentary rocks in the study area was carried out following the concepts of Collinson and Thompson (1982). Facies are defined by lithology, stratification, texture and also sedimentary structures (Mutti and Ricci Lucci 1975). Furthermore, sedimentary facies association was grouped in order to identify the depositional environment. It was arranged in 37 log sections with a thickness of almost 4.5 km.

Trace fossils were mapped bed-by-bed in several areas. Special attention was paid to regular alternations of sandy and shale layers and the sedimentary context of particular trace fossils. The morphological structures and the behavior of trace makers were identified in order to determine the ichnofacies. Outcrop studies of turbidite units integrated into sedimentary facies and ichnofacies analysis were carried out in order to define palaeoenvironmental characteristics with a more precise interpretation. The turbidite facies in Majalengka area were previously sampled to study the nannofossil and planktonic foraminifera assemblages (Muljana 2012). They were collected to determine details of the bathymetry column and biostratigraphic ages.

Results

Sedimentary facies, description and interpretation

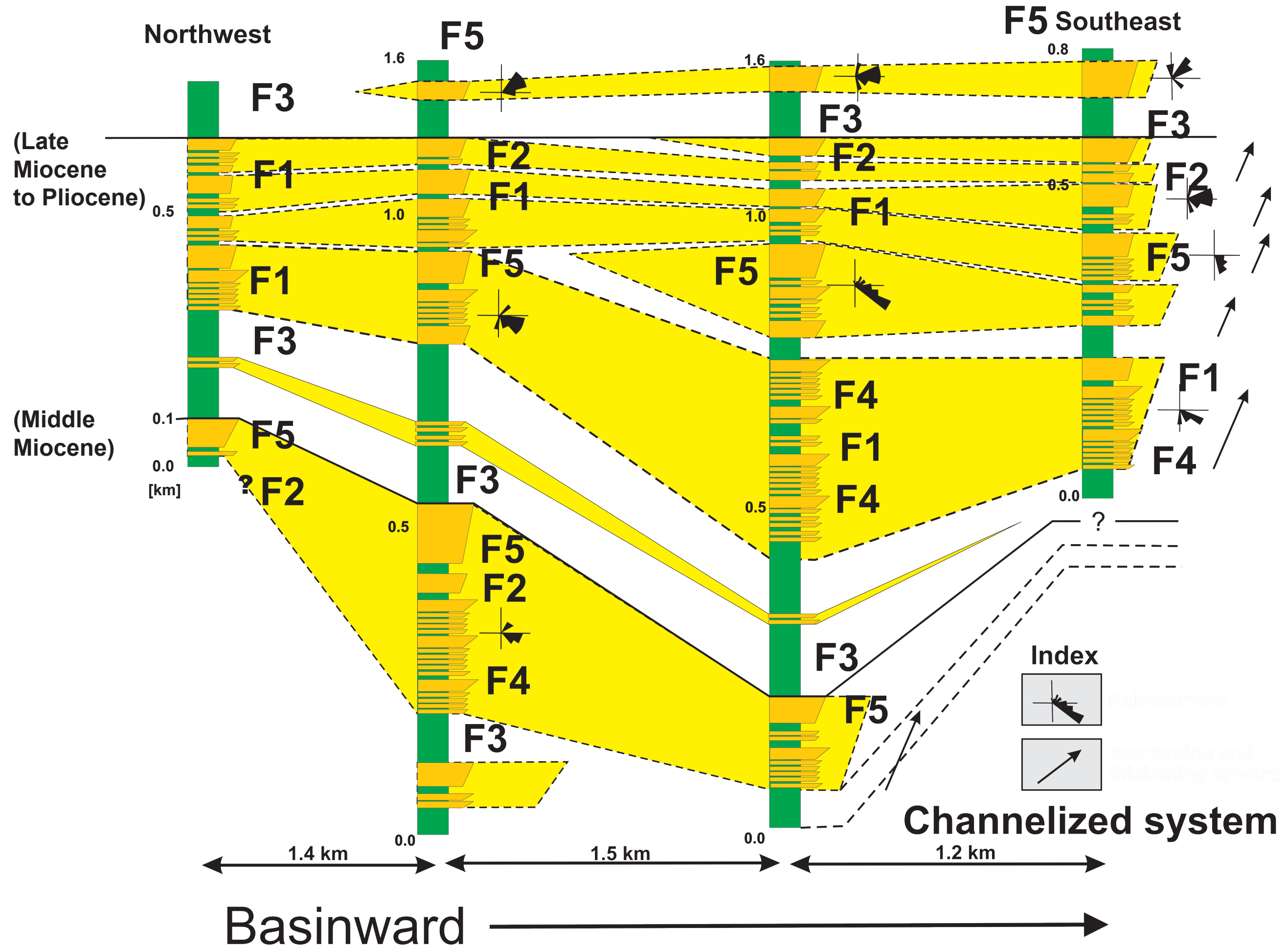
Facies analysis of the studied outcrop which consisted of intercalation between sandstone and mudstone is reflected by turbidite facies, whereas the lower sandstone boundary is mostly indicated by a sharp bonding surface. Furthermore, the results of the field study indicate that the turbidite series in the study area can be categorized into five facies types: heterolithic sandstone-mudstone 1, heterolithic sandstone-mudstone 2, mudstone, heterolithic fine sand and mudstone, and conglomerate to massive sandstone (Text-fig. 3).

Facies 1: Heterolithic sandstone-mudstone facies 1

D e s c r i p t i o n . The heterolithic sandstone-mudstone facies 1 is formed of dark-yellowish fine to medium-grained sandstone very thickly and regularly interbedded with siltstone and dark-grey mudstone. Carbonaceous clay interbeds occur occasionally. The facies indicated very high sand-shale ratios and an average thickness laterally of 20 to 60 cm. The Bouma sequence such as graded-bedding (Ta), parallel lamination (Tb) and low angle of cross-lamination (Tc) is frequently found in some places, glauconite also occurs. The sandstone thickness either laterally or vertically is inconsistent. The sandstones are generally well-bedded with sharp contacts and sometimes an erosive base is between individual beds, forming tabular or sheet-like beds. This pattern in basin scale is fining and thinning upwards.

Flute casts are also important structures of the sandstone unit in this facies, and palaeocurrent measurement reveals information that the sediment dispersed generally into the basin from northwest to southeast.

I n t e r p r e t a t i o n . This facies was produced by a high-speed suspension deposition event. The sediment flow is generated from turbidity currents in lower grade deposition. In the sedimentary cycle in outcrop-scale, the facies normally indicated a thickening upwards. It is interpreted as a channel to channel margin or lobe deposit inward in a deep marine environment. According to Mutti and Ricci Lucci’s (1975) classification, these heterolithics belong to Facies C, but according to Walker and James (1992) and Berggren (1978) it is classical turbidite.



Text-fig. 3. Outcrop cross section of the turbidite facies distribution in the Majalengka, correlated northwest to southeast. The progradation pattern indicated by thickening of sandstone into the basin area are shown. F1 – heterolithic sandstone-mudstone 1; F2 – heterolithic sandstone-mudstone 2; F3 – mudstone facies; F4 – heterolithic fine sand and mudstone; F5 – conglomeratic to massive sandstone facies (Muljana 2012).

Facies 2: Heterolithic sandstone-mudstone facies 2

Description. The heterolithic sandstone-mudstone facies 2 is characterised by intercalation of very thin fine sand to silty and grey yellowish shale. In most of this facies, graded bedding (Ta) and parallel lamination (Tb) of the Bouma sequence are commonly found in various parts of the stratigraphic section. Vertical and lateral bed thickness are variable and as in heterolithic sandstone-mudstone facies 1, the bedding boundary of heterolithic sandstone-mudstone 2 has sharp contact. The facies is arranged as monotonously intercalation of very thin sand to silty in fining to thinning upward pattern. In the lower part of the stratigraphic section very dark carbonaceous shale was frequently found.

Interpretation. The heterolithic sandstone-mudstone 2 facies is interpreted as a product of a high-speed sand influx during a quiet phase in long time periods in which channel-margin deposits were laid down distally. A turbidity current was indicated by low-velocity and density and thick suspension current. That is indicated that its more distally than the heterolithic sandstone-mudstone 1 facies.

Facie 3: Mudstone facies

Description. The mudstone facies is composed of dark-grey mudstone to carbonaceous shale intercalated with very thin laminations of fine-sand or silt, having an irregular to wavy base in the lower part of the sections. Internal sedimentary structures were not found in mudstone units, in contrast, however, very thin parallel lamination (Tb) were frequently found within very fine sand. Similar thickness characteristics as in the heterolithic sandstone-mudstone 2, the mudstone bed however was thicker than the fine-sandstone units. These facies outcropped extensively in Cisaar, Cilutung River in Bantamerak and Cimaningtin, and all of them are within the lower part of the turbidite deposits.

Interpretation. The mudstone facies can be interpreted predominantly as sediment suspension in a quiet current or low-energy environment, deposited in the distal-zone, and relatively structureless. These facies belong to the channel-margin related to proximity of overbank deposits (Mutti and Ricci Lucci 1975).

Facies 4: Heterolithic fine sand and mudstone

Description. Heterolithic fine sand is characterised by irregular strata of fine to medium sand and mudstone interbeds. The fine sandstone units often contained a few of the lower grade Bouma sequence, for example, graded bedding (Ta), parallel lamination (Tb) and small-scale cross lamination (Tc) or some essentially structureless layers. The secondary sedimentary structures such as bioturbation tend to be more uncommon than in the heterolithic sandstone-mudstone facies 2. The mudstone beds are frequently thicker than the fine sandstone beds. Sharp contact with an erosive base was indicated within several outcrops. Some lithologies included in slumps are largely those of heterolithic fine sand facies. This facies comprises folded fine sandy to muddy deposits with low-angle reverse faults. The thickness variation of slump deposits is between 50 to 150 cm and increases with the downdip trend at two directions, south to southeast and east. A single bed of fine sand of 8 to 10 cm thickness, could occasionally be found and is a sedimentary water-escape structure. An irregular bedding boundary in the lower and upper part are frequently found.

Interpretation. The sandstone and mudstone succession was originally produced as an over bank deposit due to the continued deposition in the elevated area before lithification, or a slumping mass leading into a channel or deposited in more distal parts. Over-pressure during sediment accumulation (liquefaction) which formed pore-fluid pressure upwards (water-escape sedimentary structure) was a frequent result. A different facies classification which was developed by Mutti and Ricci Lucci (1975) indicated these belong to facies F or a slumped bed unit.

Facies 5: Conglomeratic to massive sandstone facies

Description. Conglomeratic facies are characterised as an individual bed, composed of coarse sand to gravel, particles are sub-angular with the mean grain diameter greater than 4 mm (according to the Wentworth grain size scale), often disorganized or very minimally organized. The grain character is mostly grain-supported with an absence of sediment structure in the upper part of the section. However, in the lower part there is more normal graded bedding and which has sharp planar to irregular contact with overlying and underlying beds. Moreover, an imbrication pattern in which the long-axis of the fragment that lies perpendicular to the bedding plane, was a commonly found trend. Andesite (AF), clay (CF) and coarse-sand (SF) fragments were frequently discovered in all stratigraphic intervals of these facies. Sedimentary structure was dominantly graded bedding (Ta) on the bottom side of bedding plane. The thickness average is around 1 to 1.5 meters and distributed laterally. Based on Mutti and Ricci Lucci's (1975) classification, this facies belongs to Facies A.

Interpretation. The massive sandstone was characterised by fine to medium grain size grey to yellowish sandstone, well-sorted and well-organized fragment distribution. Coarse fragments of medium to cobble size were found randomly disseminated in the power side. Carbonate, glauconite and coal fragments were occasionally found, floating in the bed. It is assumed that shallow-marine deposits have a role of play as a sediment source. The irregular sharp contact on the lower side of the bedding is an erosional boundary and similar to the palaeo-flow structure. Trace fossils in moderate to high abundance on the lower side of the bedding-plane with horizontal to sub-sinuous and occasionally branching pattern are common features.

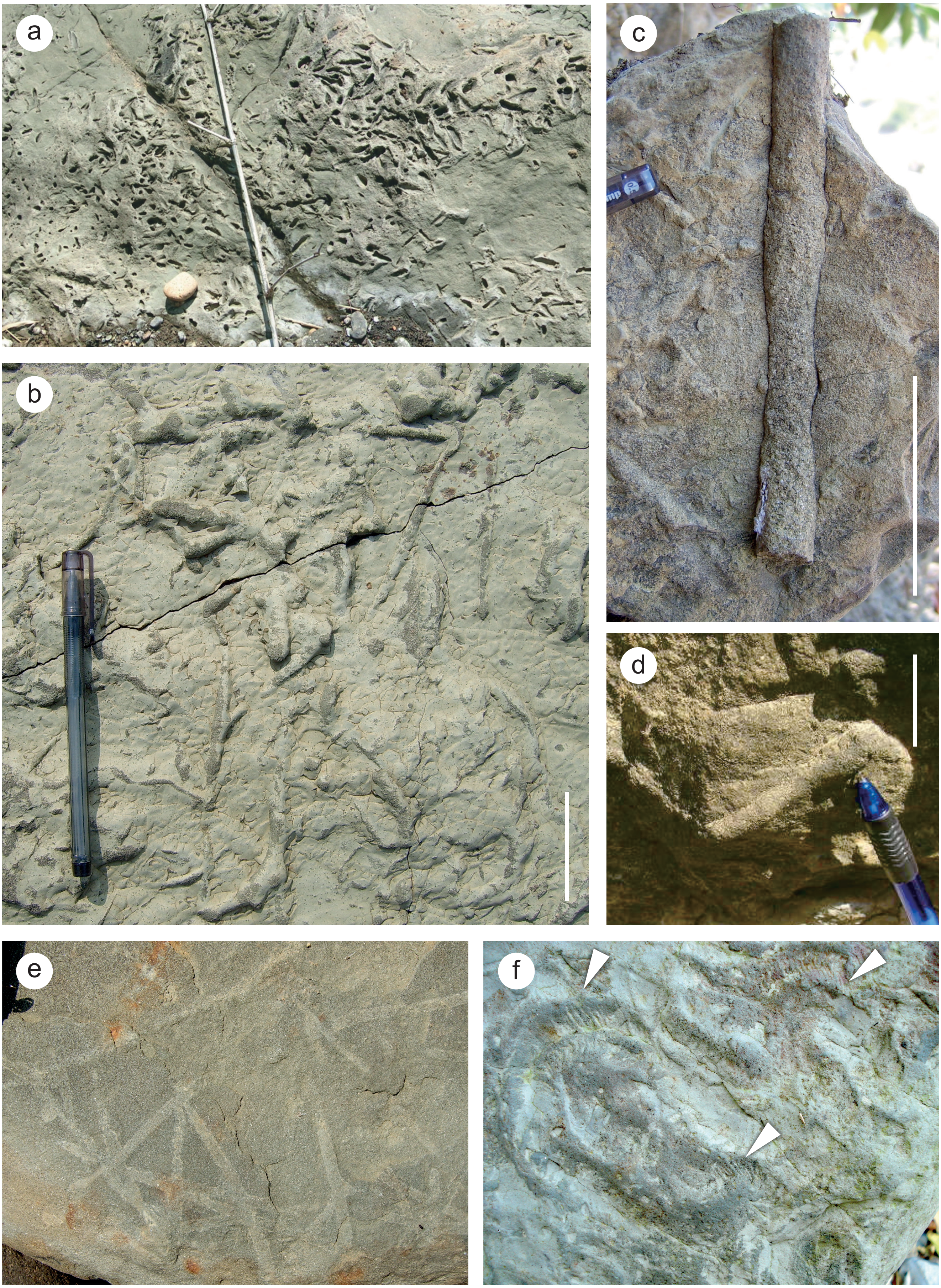
The fine-grain and low-viscosity properties which make sediment spread out across the basin is considered as an agent of transportation. A reduction in viscosity value due to mixing up of sediment enables the development of a traction-current. Low viscosity characterised by low concentration and high velocity due to a transition zone between and shallow marine and deep marine as indicated by fragments such as coal and carbonate. Text-fig. 4 shows the representative of outcrop scale of lithofacies.

Trace fossils analysis

When carrying out field investigation in order to correctly interpret the palaeogeography of turbidite, one

Text-fig. 4. a: Conglomeratic to massive sandstone facies 1, facies A are composed of Andesit (AF), Clay (CF) and Sandstone (SF) fragments lain on medium-sandstone. b: Conglomeratic to massive sandstone facies, outcropping of massive sandstone facies comprises of fine to medium grain size of grey to yellowish sandstone. c: Heterolithic sandstone-mudstone facies, intercalation of fine sand with silt and shale as type form of heterolithic sandstone mudstone as indicated by a high sand/shale ratio. d: Example outcrops of heterolithic sandstone-mudstone 2 indicated by low sand/shale ratio. e: Heterolithic fine sand and mudstone and mudstone facies, intercalation of thin sandstone and shale. f: Representative of slump deposits outcrops belong to conglomeratic to massive sandstone facies, which is indicated by the intercalation of sandstone and shale and some disturbed beds or layers as seen in slump deposits. The facies type is normally deposited within the basin floor, channel margin or as a product of the overbank deposits. In this figure the slump deposit is shown as internal bedding, some occurred on the bedding-plane. Trend slope measurement of the fold-axis revealed values N 135°E and N 108°E.

of the advantages is finding trace fossils preserved in situ in contrast with macrofossil usually found allochtonous (Starek and Šimo 2015). Trace fossils are the behavioral reaction undefined animal activity in ancient sedimentary rocks. There are four main factors controlling the reaction to animal activity: (1) depositional rate, (2) lithology of



Text-fig. 5. Several trace fossil types found within turbidite facies in Majalengka area (Muljana 2012). (a) *Chondrites*, (b) *Planolites*, (c–e) *Thalassinoides*, (f) *Cruziana*?. Scale bar 5 cm.

substratum, (3) energy regime and (4) food availability. These factors are controlled by water depth (Ekdale 1982, Ekdale and Mason 1988, Frey et al. 1990, Knaust 1998, Heard and Pickering 2008, Lima and Netto 2012). According to studies of trace fossils in various lithologies, the distribution of trace community could be divided into four types of ichnogenera, namely, *Thalassinoides*, *Chondrites*, *Cruziana* and *Planolites* (Text-fig. 5).

Thalassinoides

Thalassinoides, characterised by regularly branching cylindrical burrows and forming a horizontal network, can be observed on the bottom of the bedding plane of fine to medium-grained structureless massive sandstone. The trace fossils are very easily determined because they are normally found as a tube-shape extending to form a T or Y shape, very thin walls, no structure in the sediment or only a limited amount of parallel lamination. This ichnogenus, reflecting fodibichina-domichina types within a shallow-marine environment (Ekdale et al. 1984) or ancient deep-marine environment (Vaziri and Fürsich 2007), are produced as a result of variatious behavior in dwelling or feeding burrow types. For example, infaunal activity of crustaceans during transportation of substrate from shallow to deep marine due to rising sea level. The variation in behavior types normally develops in the lower shore-face to offshore zone, and occasionally in the brackish environment (Knaust and Bromley 2012). Outcrops are mostly common in the medium to thick bedded fine to very fine sands of turbidite.

Chondrites

The trace fossils' body is characterised by a root-like structure or a regularly branched burrow system, that became slightly curved and appears like an overturned tree. Several specimens were encountered in the upper part of the stratigraphic succession, for example in mudstone and siltstone predominantly. They were produced as deep worm-like trace makers. In the study area, *Chondrites* is formed as a highly branched burrow system of deposit feeders from an unknown endobenthic source.

Chondrites generally reflects specialized feeding behaviors (Bromley 1996). These trace fossils, that had broad oxygen tolerances, normally occur in fine to medium grained sandstone under low O_2 conditions in deep marine or anaerobic zones (reducing environment) or as an oxygenation indicator (Bromley and Ekdale 1984, Savrda and Bottjer 1986, Goldring 1993). They may be able to live in an anoxic interface as a chemo-symbiotic organism that pumps methane and hydrogen sulphide from the sediment. According to Seilacher (2007), Ekdale et al. (1984), Bromley and Ekdale (1984) and Martin (2004), they have populated different sediment accumulations that began in a littoral to abyssal environment.

Cruziana

Cruziana is characterised by an almost straight to loosely meandering ridge of uniform width. Their surface tracking is a characteristic density covered by distinct oblique ridges and usually branch out within a substrate fine to very fine sand. *Cruziana* is considered as the feeding trace or locomotion-feeding burrow of trilobites (Seilacher 1974, 2007). The burrow in combination with locomotion and feeding strategy, indicate that these trace fossils must have required a significant amount of energy in order to represent an expression of real locomotory behavior. A high rate of sedimentation limited the colonization window of bedform and resulted in a generally low degree of bioturbation.

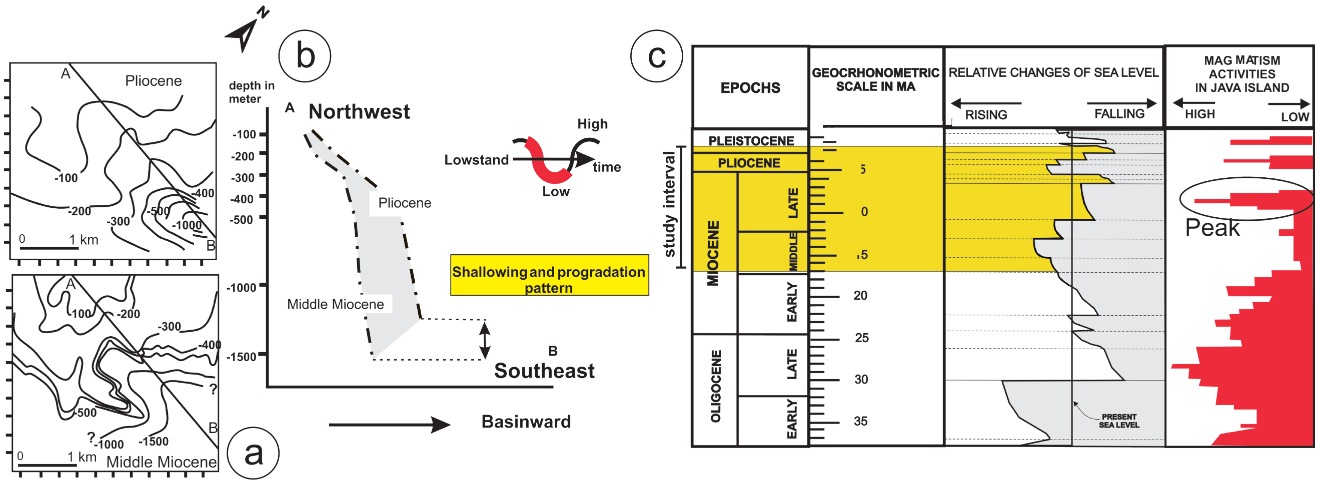
Planolites

Planolites is formed as a subhorizontal to occasionally oblique or sinuous burrow and are unbranched, smooth to irregular or rarely with an annulated wall structure. The burrows form mostly smooth walls but rarely may show irregular ornamentation, whereas the tunnels shape are filled with sedimentary material, clearly contrasting to the adjacent rock matrix. The burrow structure indicates the organism's activity during sediment feeding caused texture reformation, the sediments having textural characteristics which differ from the host rock (Pemberton and Frey 1982). In one case, a sandstone reservoir belonging to the Upper Cibulakan Formation in the Northwest Java Basin, Indonesia, appears to have increased permeability and porosity values due to trace fossils activities within the sedimentary textures. The occurrence of this ichnogenus is commonly found throughout sedimentary rocks successions, particularly those with a high mud content and is normally associated with *Chondrites.*

Discussion

The objective of palaeoenvironmental interpretation in this study is to construct a depositional model based sedimentology and ichnology. The first turbidite facies model introduced by Bouma (1962) was used as a basis for model sedimentation from bottom to top. The submarine fan models introduced by Mutti and Ricci Lucci (1972) serve as the basis for turbidite system interpretation. Seilacher (1974) and Frey and Seilacher (1980) principally studied turbidite facies containing a rich collection of trace fossils.

The turbidite system in the Majalengka area demonstrates a cyclic intercalation of sandstone, silt and shale. Frequently numerous very fine grain size organic particles are found in the lower part and this changes to a gradually coarsening to thickening trend in the upper part. According to sedimentology, five sedimentary facies were defined which were interpreted as gravity flow products. Furthermore, they formed the stratigraphic succession representing an overall shallowing-upward succession which was well exposed laterally. The depositional trend indicated this was a progradation movement. These processes known as a regressive event are considered as the main agent for sedimentation which was the result of a sea-level drop in response to a single relative sea level cycle (third order) between the Middle to Late Miocene (Muljana and Noeradi 2009, Muljana 2012, Muljana and Watanabe 2012). In a previous study, Muljana and Watanabe (2012), using provenance and palaeocurrent analysis, interpreted that sediment delivery into the basin was from north. Wherein, submarine-channelized systems formed, related to slope zone, which prograded to the southern part of



Text-fig. 6. Shallowing pattern during the Middle Miocene to Late Miocene/Pliocene due to increasing magmatic activity as an external parameter. a: palaeobathymetry map during the Middle Miocene to Pliocene; b: sea level change curve indicating a shallowing pattern; c: relative changes of sea level and magmatic activity curve (Haq et al. 1987, Soeria-Atmadja et al. 1998, Muljana 2012).

the study area. These depositional zones were dominated by shelf-edge sediment flow into the basin from several origins including transitional to shallow marine sediment such that coal and limestone fragments could be found (Mutti and Normark 1991, Muljana and Watanabe 2012).

Moreover, several facies associations could be recognized as slope sediment, e.g., the slump deposit in the southern side of study area (Muljana and Watanabe 2012, Muljana 2012). Even though, the facies continuity was occasionally interrupted due to the discontinuous nature of the outcrop, the stratigraphic correlation in a north to south direction could be easily traced and we can interpret that the deepest part of sedimentary basin to have been situated in the southern part (Muljana and Watanabe 2012). The lower boundary of these turbidite systems in the outcrop is indicated by very thick shale beds, revealed as transgressive events Muljana and Watanabe (2012) Mutti and Ricci Lucci (1972).

A short break in sea level change is indicated at the top of the shale beds by coarse sand that implied a new cycle of sedimentation.

The ichnofossil content of the stratigraphic succession in the study area may be characterised, as follow:

a. Moderate to low diversity of trace fossil in each stratigraphic interval.
b. From bottom to top indicated the difference in trace marking variations from horizontal to subhorizontal.
c. Dominated by four ichnogenera, namely *Chondrites*, *Thalassinoides*, *Planolites* and *Cruziana*.
d. Ethological categories show a wide variety, but dominated by sediment feeding trace fossil.
e. Smooth transition from background epichnia to event bed endichnia connected with lithofacies change.
f. Almost no colonization on all the bed events.

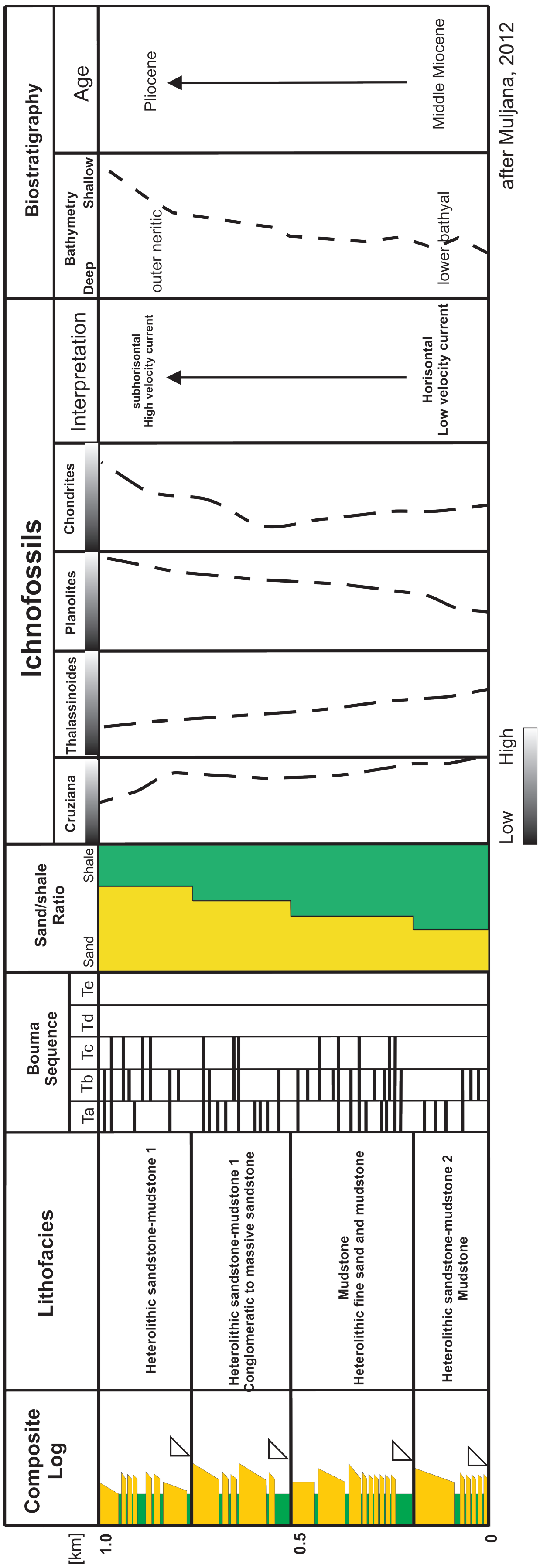
Trace fossil domination is typical of the *Cruziana* ichnofacies which typically occur in shore face and offshore sediments. These ichnofacies usually develop below the normal wave base, but occasionally influence of storms is the most dominant. Therefore, being truncated upward by erosion due to high energy levels is considered as a main factor for the uneven distribution of trace fossils. It is a very low oxygen content zone (below 1 to 0.5 ml/L) and for survival some organisms penetrated below into the mixed layer.

According to lithofacies and ichnofacies studies, we can conclude that the Miocene turbidite facies in Majalengka area were accumulated within the submarine channel fan system related to the slope zone (Tab. 1). This differs from previous research by Martodjojo (1984) who interpreted all turbidite facies as deposited within the deep marine zone. As discussed above, vertical changes in lithofacies and ichnofacies are probably associated with variations in sea level which control many environmental parameters during a regressive event (Text-fig. 6). All of the parameters influencing the distribution of trace makers tend to modify increasingly with the increasing or decreasing of water depth. On the other hand, the sediment accumulation, i.e., in which beds it is deposited, is successively basin-ward due to sediment supply exceeding available space. Therefore, the shoreline position migrated into the basin during progradation episodes. Furthermore, the magmatic activity during that time period was considered as an external factor that caused lithofacies and ichnofacies variation (Muljana 2012).

Conclusion

The present study, integrating sedimentological and ichnological analysis, demonstrates that the turbidite system was deposited within a submarine-channelized fan system related to the slope zone. In general, the stratigraphic succession represents an overall shallowing-upward succession. It is clearly exposed laterally due to a regressive event as indicated by the abundance of very fine grain of organic content in the lower part and thickening to coarsening trends in the upper part. Ichnological analysis, regarding ichnogenera distribution, indicates a distal to

Table 1. Cross section trend showing composite log, lithofacies, diversity of sedimentary structures, sand/shale ratio, ichnology and biostratigraphy (Muljana 2012). Cross section trend is from Northwest (NW) to Southeast (SE).



proximal *Cruziana* ichnofacies trends. Both of these data sets revealed a shallowing up pattern. On the other hand, analysis of lithofacies and ichnofacies within the outcrops are important parameters in the field which aid interpretation of palaeogeography and sea-level change in turbidite facies. Macrofossils are very rarely found in situ and are normally only in allochtonous positions in turbiditic sediment. On the contrary, facies and trace fossils are preserved in situ and can aid better understanding in palaeoecological interpretation. Therefore, the integration of ichnology into a sedimentological framework is a powerful method in recognizing lateral and vertical variations related to basin analysis. On the other hand, we have concluded that magmatism accompanied by orogenic events (regional uplifting and shallowing of sea level due to regressive processes) during the Late Miocene are considered as the main external parameter causing lithofacies and ichnofacies variations of turbidite deposits in Majalengka area, West Java, Indonesia.

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