

PROBLEMS IN USING ICHNOFACIES FOR DEPOSITIONAL ENVIRONMENT INTERPRETATION CASE STUDY: THE CISAAR FORMATION, SUNGAI CISAAR, SUMEDANG DISTRICT, WEST JAVA, INDONESIA

PERMASALAHAN DALAM PENGGUNAAN ICHNOFACIES UNTUK INTERPRETASI LINGKUNGAN PENGENDAPAN STUDI KASUS: FORMASI CISAAR, SUNGAI CISAAR, KABUPATEN SUMEDANG, JAWA BARAT, INDONESIA

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(Received 05 September 2021; in revised from 29 September 2021; accepted 25 October 2021)

DOI: 10.32693/bomg.36.2.2021.731

ABSTRACT : Although numerous researchers have used trace fossils method to determine depositional environment, this method is still considered less robust. This is due to the finding of several similar trace fossils in two or more diverse environments, leading to irrelevancy in environmental interpretation.

Therefore, we conducted this study in order to verify how powerful the trace fossil analysis is, by applying this method to interpret the depositional environment of the Cisaar Formation in the Cihanyir Tonggoh area, Sumedang Regency, West Java. We combined trace fossil study with foraminiferal assemblage analysis and vertical succession of related sedimentary units. For this study, 19 rock samples that have been collected from outcrop along 16 m traverse and 14 m measured stratigraphic sections were examined.

The result of the study shows that shallow marine trace fossils which were developed at the edge of the shelf, were transported into the basin by gravitational mass flow and re-deposited as deep marine turbidites. Trace fossils were generally found in sandstones, while planktonic foraminifers were found in claystones-sandstones interbeds. This study concludes that to avoid inconsistency in the interpretation of the depositional environment, performing trace fossils method must be integrated with other methods, e.g. analysis of lithofacies and biofacies.

Keywords: trace fossil; ichnofossil; ichnofacies; turbidite, depositional environment.

ABSTRAK: Meskipun banyak peneliti telah menggunakan fosil jejak untuk menentukan lingkungan pengendapan, metode ini masih dianggap belum cukup kuat. Hal tersebut dikarenakan adanya penemuan beberapa fosil jejak yang bentuknya mirip di dua atau lebih lingkungan pengendapan yang berbeda-beda. Sehingga timbul ketidaksesuaian dalam interpretasi lingkungan. Oleh karena itu kami melakukan studi ini dengan tujuan untuk memahami seberapa kuatkah metode fosil jejak, dengan mengaplikasikan metode ini untuk menentukan lingkungan pengendapan Formasi Cisaar yang terdapat di daerah Cihanyir Tonggoh, Kabupaten Sumedang, Jawa Barat. Kami menggabungkan studi fosil jejak dengan analisis foraminifera dan suksesi vertikal unit sedimennya. Dalam studi ini, analisis dilakukan terhadap 19 sampel batuan yang diambil dari singkapan sepanjang 16 m lintasan dan 14 m penampang stratigrafi terukur.

Hasil dari studi ini menunjukkan bahwa fosil jejak laut dangkal yang berkembang di tepi paparan, terangkut ke dalam cekungan melalui aliran massa gravitasi dan diendapkan kembali sebagai turbidit laut dalam. Fosil jejak umumnya dijumpai dalam batupasir dan foram planktonik dijumpai dalam perselingan batulempung-batupasir. Studi ini menyimpulkan bahwa untuk menghindari ketidakkonsistenan dalam interpretasi lingkungan pengendapan, metode fosil jejak perlu diintegrasikan dengan metode lain seperti analisis litofasies dan biofasies.

Kata kunci: fosil jejak, ichnofossil, ichnofacies; turbidit, lingkungan pengendapan

INTRODUCTION

This research is motivated by complexity in trace fossils analysis for environmental interpretation, particularly in turbidite deposits. Some results indicated inconsistent findings lead to perplexity and indecision of the method's potency. For example, several observations have been made to the trace fossil features in turbidite deposits, such as in turbidite deposits of Cisaar Formation, Tapak Formation and Cinambo Formation, which display similar characteristics to the trace fossil shapes found in shallow marine sediments (shoreface).

Turbiditic sedimentary rocks of Cisaar Formation are well exposed as outcrops, occur within the Cihanyir Tonggoh area, Sumedang Regency, West Java, Indonesia (Djuhaeni and Martodjojo, 1989). Trace fossils, which have yet to be analyzed thoroughly, occur within these rocks. Therefore, we conduct a detail study on this formation, focusing on using trace fossils to determine the environment of deposition.

Several regional stratigraphic studies were previously conducted in Sumedang - Majalengka area (Djuri, 1973; Martodjojo, 1984; Djuhaeni and Martodjojo, 1989) (Figure 1). According to the Ardjawinangun Regional Geological Map Sheet (Djuri, 1973), sedimentary strata in the study area belong to the upper Cinambo Formation, composed of claystone with sandstone interbeds, limestone, calcareous sandstone, and tuffaceous sandstone. Five formations occur in Sumedang - Majalengka area: Cinambo Formation, Halang Formation, Subang Formation, Kaliwangu Formation, and Citalang Formation, from older to younger, respectively (Figure 1). Some part of Citalang Formation is covered unconformably by alluvial and volcanic deposits (Djuri, 1973). More recently, Djuhaeni and Martodjojo (1989) subdivided the stratigraphy of the area into (in order from the oldest to the youngest): Cisaar Formation, Cinambo Formation, Cantayan Formation, Bantarujeg Formation, Subang Formation, Kaliwangu Formation, and Citalang Formation (Figure 1).

Grimm and Follmi (1994) stated that tracemakers can be allochthonous, meaning transported from their original habitat to other places, commonly associated with gravity flow deposits. Thus, to use trace fossils as an indicator for determining depositional environment, it must consider sedimentation mechanisms, lithology, and microfossil (foraminifera). Accordingly, trace fossils analysis will reveal better result if combined with lithology and microfossils content analyses, as we are doing in this research.

MATERIALS AND METHODS

This study was conducted at the Cihanyir Tonggoh Village, approximately 60 km in the northeast of Bandung. Administratively, this region belongs to Jatigede Subdistrict, Sumedang District, West Java Province, Indonesia. It is located at the geographic

coordinates of 108.12517710° - 108.17064020° E and 6.800410490° - 6.845316900° S (Figure 2).

19 rock samples were collected in the field along a 16 m traverse and 14 m measured stratigraphic sections (Figure 3). To those samples, we conducted analysis of lithofacies, trace fossil ichnofacies, and microfossil biofacies. Lithofacies analysis to interpret sandstone depositional environment, was based on Posamentier and Walker (2006), Howell and Nomark in Scholle and Spearing (1982), and Shanmugam (2006). Ichnofacies analysis was based on Seilacher (1967); Frey et al. (1978; 1990), Pemberton (1992), and biostratigraphy analysis was based on Blow (1969).

Age		Blow Zonation (1970)	Djuri (1973)	Martodjojo (1984)	Djuhaeni & Martodjojo (1989)	
						Period
Pleistocene		N 23	Young Volc. Product	Volcanic Breccia	Volcanic Breccia	
		N 22	Old Volc. Product	Citalang Formation	Citalang Formation	
Pliocene		N 21	Tilted Breccia	Kaliwangu Formation	Kaliwangu Formation	
		N 20	Citalang Formation			
		N 19	Kaliwangu Formation	Subang Formation		
		N 18	Subang Formation			
Miocene	Late	N 17	Upper Member	Jatigede Member	Cinambo Formation	
		N 16				
		N 15				
		N 14				
		N 13				
	Middle	N 12	Lower Member	Halang Formation	Cinambo Formation	Bantarujeg Formation
		N 11				Cantayan Formation
		N 10				Cinambo Formation
		N 9				Cinambo Formation
		N 8				Cinambo Formation
Early	N 7	Upper Member	Cinambo Formation	Unexposed	Cisaar Formation	
	N 6	Lower Member				
	N 6	Lower Member				

Figure 1. Comparison of the study area stratigraphy based on previous studies (translated from Nova et al, 2018)

The methods used in this study can be divided into two phases: 1) data collection phase and 2) laboratory analyses phase. Data collection phase includes measuring stratigraphic sections, observation and description of trace fossils data along the traverse, and sediment samplings. Laboratory analyses phase includes trace fossil description, foraminiferal sample processing and analyses, and stratigraphic section analyses.

RESULTS

3.1 Lithofacies

Rock units found in the study area are composed of sandstones and sandstone-claystone interbeds. The size fraction of sandstone is fine to very fine with parallel laminae and graded bedding sedimentary structure. The sandstone thickness varies from 8 to 200 cm, while the interbedded sandstone and claystone ranges

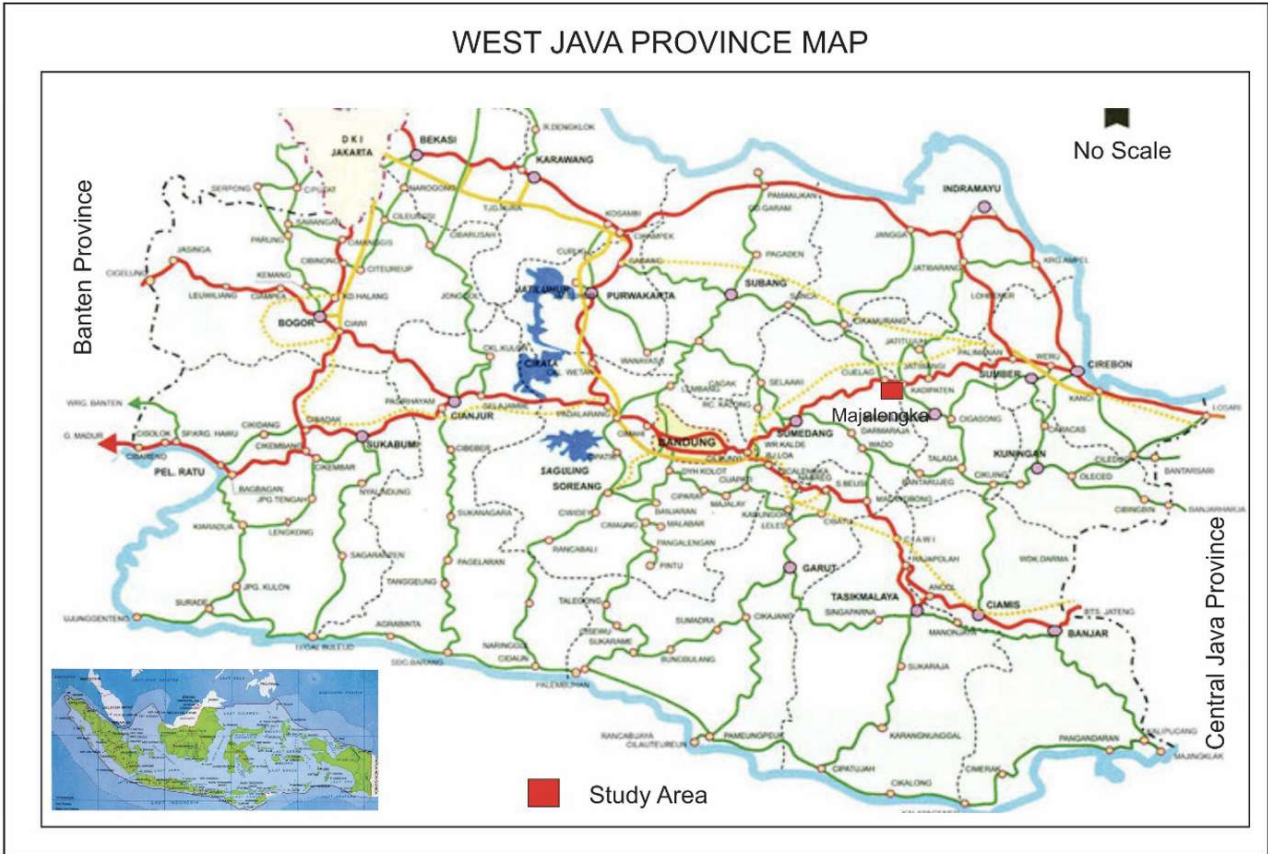


Figure 2. Location map of the study area (108.12517710° - 108.17064020° E and 6.800410490° - 6.845316900° S)

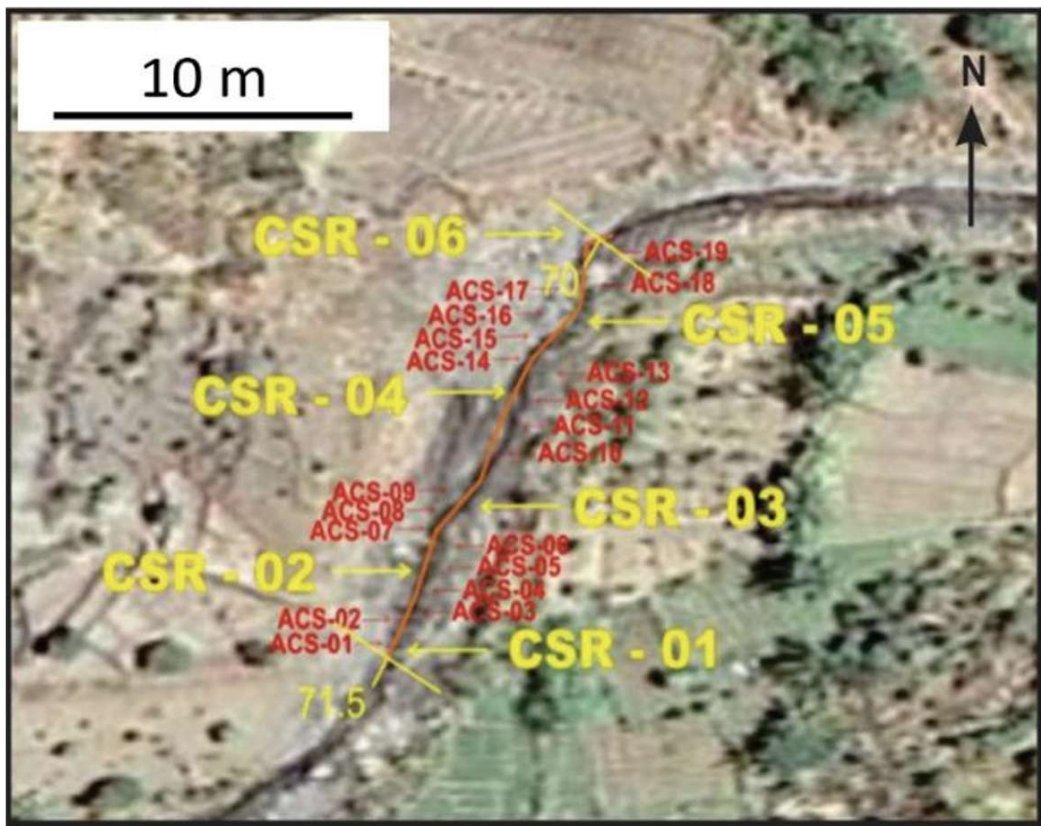


Figure 3. location of traverse line, observation site (yellow color), sampling location and sample number (red color) in Cisaar River

Stratigraphy column of the Research Area

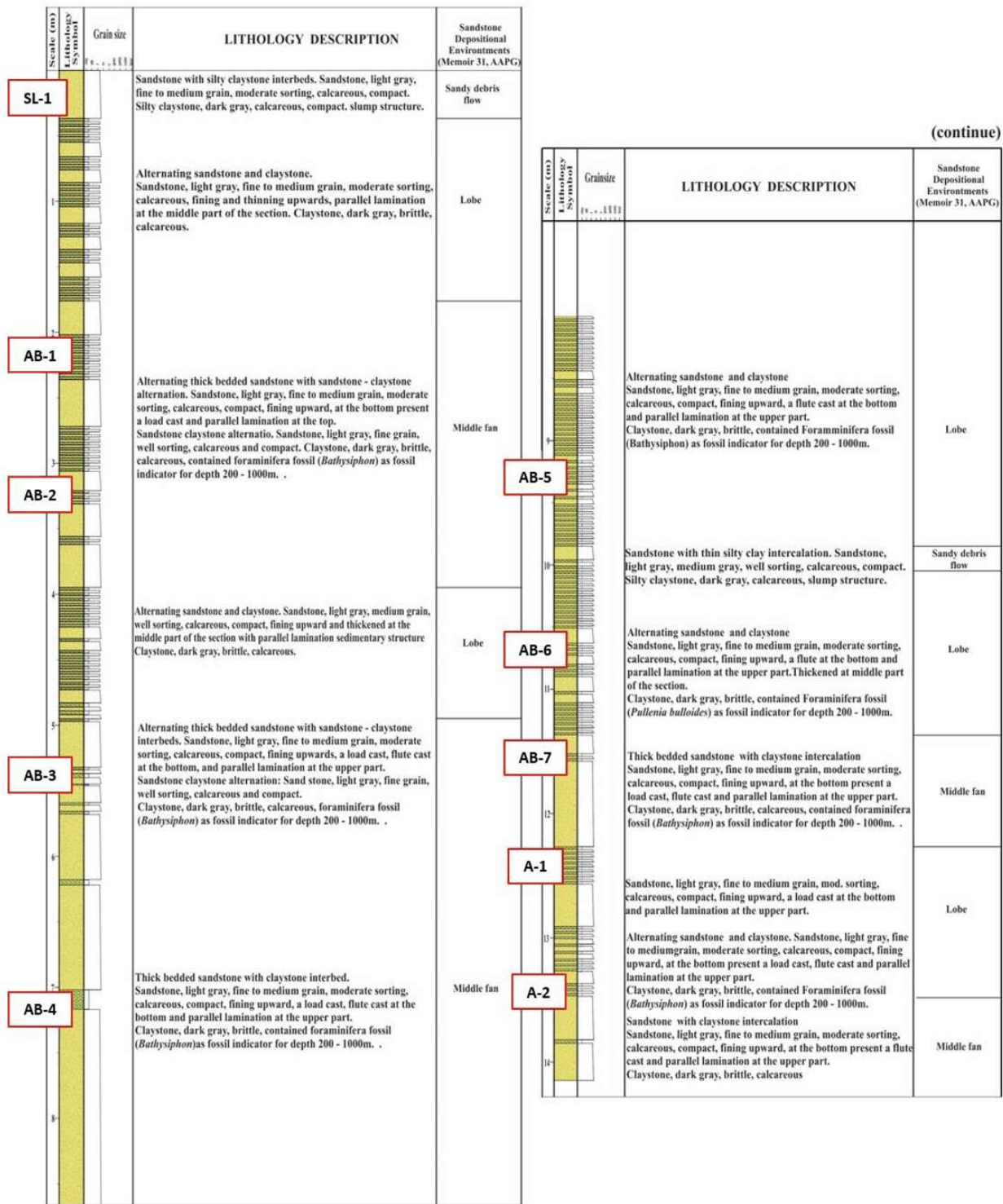


Figure 4. Detailed description of the stratigraphic section in the study area. Sandstone depositional environments interpretation based on Howell and Nomark in Scholle and Spearing (1982). Microfossils sampling locations for. Table 1 shown inside red box.

from 2-15 cm thick. Figure 4 shows the detailed description of the stratigraphic section.

Lithology of the lower part of Cisaar traverse consists of sandstone, alternating with sandstone-claystone interbeds (Figure 5a). The interbedded

sandstone-claystone sequences have a considerably diverse range of thicknesses (30 cm to 1 m), and are bounded by sandstone layers ranging in thickness between 50 cm and 2.5 m. The stratigraphic succession feature is similar to depositional patterns characteristic of submarine

fan successions, particularly in the middle fan, channel, and lobe sub-environments. Flute casts occur on the bases of sandstone layers above interbedded sandstone-claystone layers (Figure 5b), which indicate relatively rapid sedimentation process on an uncompacted layer (Kelling and Walton, 1957).

Fining upward sandstone successions are consistent with gravity-driven, waning flow processes, which are common in turbidite successions. Coarser sediments are deposited initially, due to waning flow and loss of carrying capacity, followed by finer grained sediment as the flow slows down and ceases (Figure 6a). Claystone intraclasts or mud drapes occur in some layers and are typically overlain by parallel lamination towards the top of the bed. The intraclasts occur as lags floating in the sandstone matrix (Figure 6b). The change of lithology from sandstone containing mud drapes to sandstone with parallel lamination structure is estimated as the limit of changes in depositional currents from turbid to traction currents. Asymmetrical ripple marks (current ripple

marks) occur locally at the top of this sandstone layer (Figure 7).

3.2 Trace Fossils

In general, ichnofossils (trace fossils) occur more abundant in the lower part of each thick sandstone layer (Figure 8) compared to that in the interbedded sandstone and claystone successions. In the interbedded sandstone and claystone layers, ichnofossils features composed of *Thalassinoides* and *Planolites*. *Thalassinoides* was commonly found in a vertical position and cutting the claystone layers, while *Planolites* is located on the sandstone beds' sole surfaces (Figure 8). We have identified six ichnogenera at the Cisaar River traverse as summarized below:

Ophiomorpha

Ophiomorpha is a burrow system recognized by an almost smooth inner lining and a rough outer lining, characterized by pelletal agglutination. Pellets on the external surface of *Ophiomorpha* ichnofossils occur as

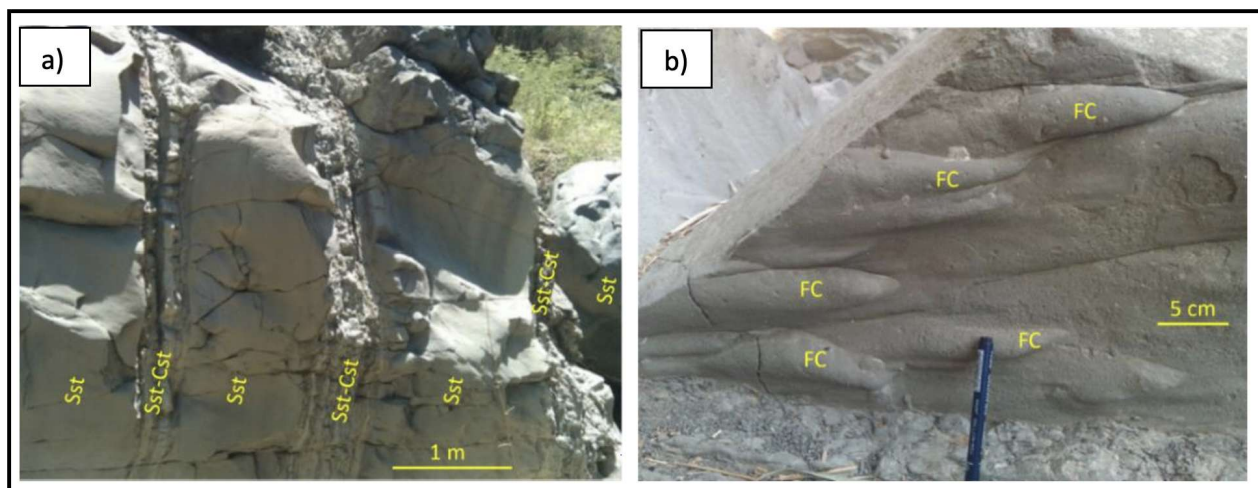


Figure 5. a) Sandstone (Sst) and interbedded claystone (Cst) and sandstone layers at CSR-01 location. b) Flute casts (FC) on the base of a sandstone layer at CSR-01 location.

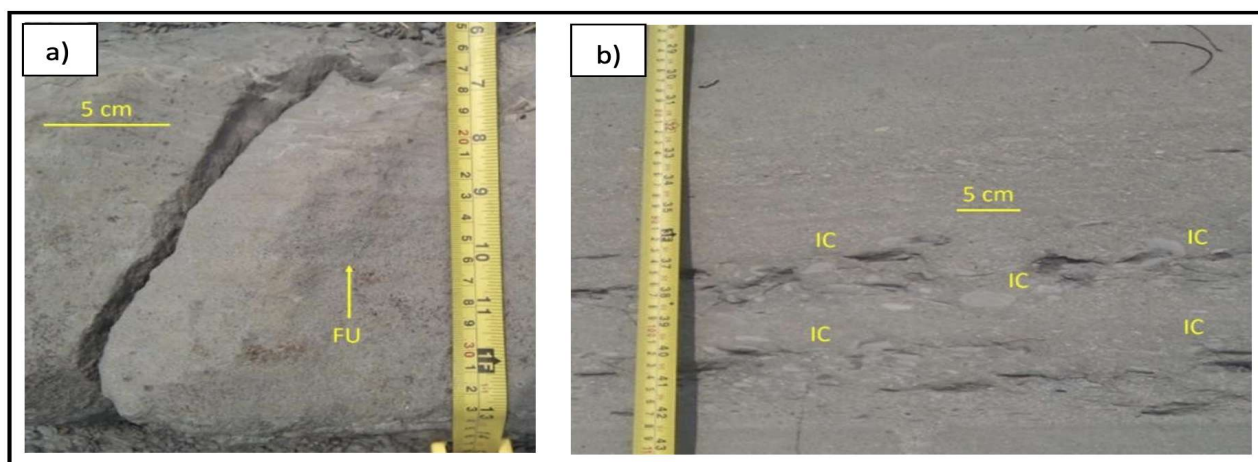


Figure 6. a) Fining upward (FU) succession within sandstones resulted from gravity-driven processes deposition. Photo was taken at the lower part of a sandstone layer at CSR-02 location. b) Mud drape pseudo layers overlain by parallel lamination at CSR-02 location.

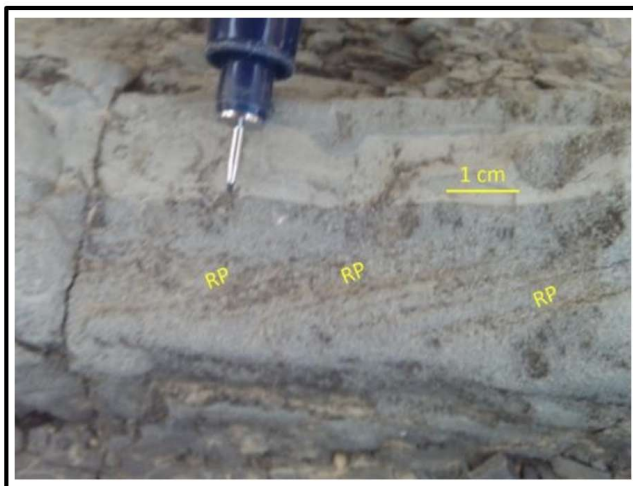


Figure 7. Ripple (RP) marks on a sandstone layer at CSR-05 location.

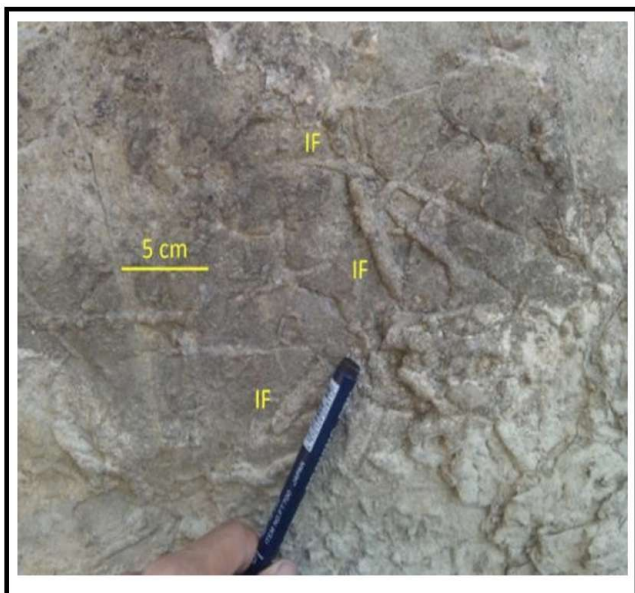


Figure 8. Ichnofossils (IF) at the bottom of the sandstone layer at CSR-02 location.

disc, oval, conical, mastoid, bilobate or irregular forms (Figure 9.a). *Ophiomorpha* morphological features were previously discussed by Frey et al. (1978). They argued that *Ophiomorpha* represents the burrow of decapod crustaceans including some of Thalassinidean shrimp species.

Planolites

Planolites is characterized by curved, smooth-walled burrow with circular or elliptical cross-sections and diverse dimensions and configurations (Pemberton and Frey, 1982) (Figure 9.b). *Planolites* is characterized by unstructured filling with lithological character distinct from its host rock. It is distinguished from *Thalassinoides* through its geometry, lack of a lining and the burrow size; and from *Palaeophycus* by its lack of a lining. The infill in *Planolites* burrows consist of sediment processed

by organisms during foraging and feeding activities (infaunal sediment process-feeders) by vermin-form organisms. *Planolites* occurs in almost all environment types, from fresh water and marginal marine to deep marine.

Chondrites

It is a complex burrow system for feeding mechanism, resembling roots that are neither anastomotic (continuous) or intersecting. *Chondrites* is a branching vertical to subvertical burrow network constructed during infaunal food-foraging (Figure 9.c). *Chondrites* is interpreted to represent the feeding activity of sipunculid worms (annelids), callianasid decapods, palaeotaxodont bivalves and small tetrapods with tunnel networks (Fernández & Pazos, 2012). It is commonly found in the *Cruziana*. Monospecific occurrences of *Chondrites* are inferred to indicate zones with low oxygen content (Mángano et al., 2002).

Skolithos

Skolithos are solitary, vertical to sub-vertical unbranched burrows (Figure 9.d). The trace is usually straight but may be slightly wavy, producing generally smooth walls and structureless filling. This genus represents the dwelling burrows of suspension-feeding or predatory organisms, that can be produced by various organisms, including *Polichaeta*, *Sabellaria*, *Arenicola*, *Onuphis*, *Phoronopsis*, and insect larvae. *Skolithos* are generally associated with marine or brackish environments. However, it can also be found in various environmental types ranging from marine to lacustrine, and various non-aquatic environments because it can be produced by a wide variety of organisms (Vinn & Wilson, 2013).

Thalassinoides

Thalassinoides are sizeable burrow systems with cylindrical components and are typically smooth walled. They commonly have Y or T bifurcations with expansions at the bifurcation point (Figure 9.e). The dimensions of the burrow vary within a particular system as well as the cross section. It may be cylindrical, half-moon shape to ellipsoidal. They contain vertical, subvertical, and horizontal components with slight irregular inclination. The fill of *Thalassinoides* is typically unstructured to plane parallel laminae or graded fill. *Thalassinoides* are considered to be the dwelling burrows of decapod crustaceans that may occur in large commensal communities. Chambers and expansions at bifurcations are utilized by organisms to reverse their direction or to be a place for reproducing.

Thalassinoides is commonly associated with the *Cruziana* ichnofacies in lower shoreface to uppershore environments (Nielsen et al., 1996, Yanin & Baraboshkin, 2013). It can also be found in low diversity turbid water complexes.

Rhizocorallium

Rhizocorallium are straight to curved U-shaped burrows with spreite (growth lines) between the causative tubes. The ratio between tube diameter and spreite width is typically ~1:5 (Figure 9.f). The burrow infill is generally similar to the rock matrix, though in some cases it may be filled by finer grains.

Fürsich (1974) divided *Rhizocorallium* into three ichnospecies based on morphological features, i.e.: *R. Jenese*, represents a less straight and short oblique spreiten burrow; *R. Irregulaire*, characterized by long, sinus, planispiral and branched forms; and *R. Uliarensis*, distinguished by a trochospiral spreiten burrow. Although interpreted initially as traces of corals, sponges, or algae, the occurrence of scratch marks on burrow walls support the hypothesis that crustaceans are the likely trace makers.

Rhizocorallium is commonly associated with shallow to deep marine environments and the *Cruziana* ichnofacies, furthermore, it can also be found on some *Glossifungites* ichnofacies (Knaust, 2013).

The association results reveal that ichnofacies changed four times through the study interval, respectively from the oldest to the youngest are: *Cruziana*, *Skolithos*, *Glossifungites* and back to *Cruziana* ichnofacies. These changes indicate environmental changes which affect the distribution of living organisms within the various environments.

3.3. Microfossils

Samples were obtained from several stratigraphic locations (Figure 4) for foraminiferal analysis. We assessed the proportion of planktonic and benthic

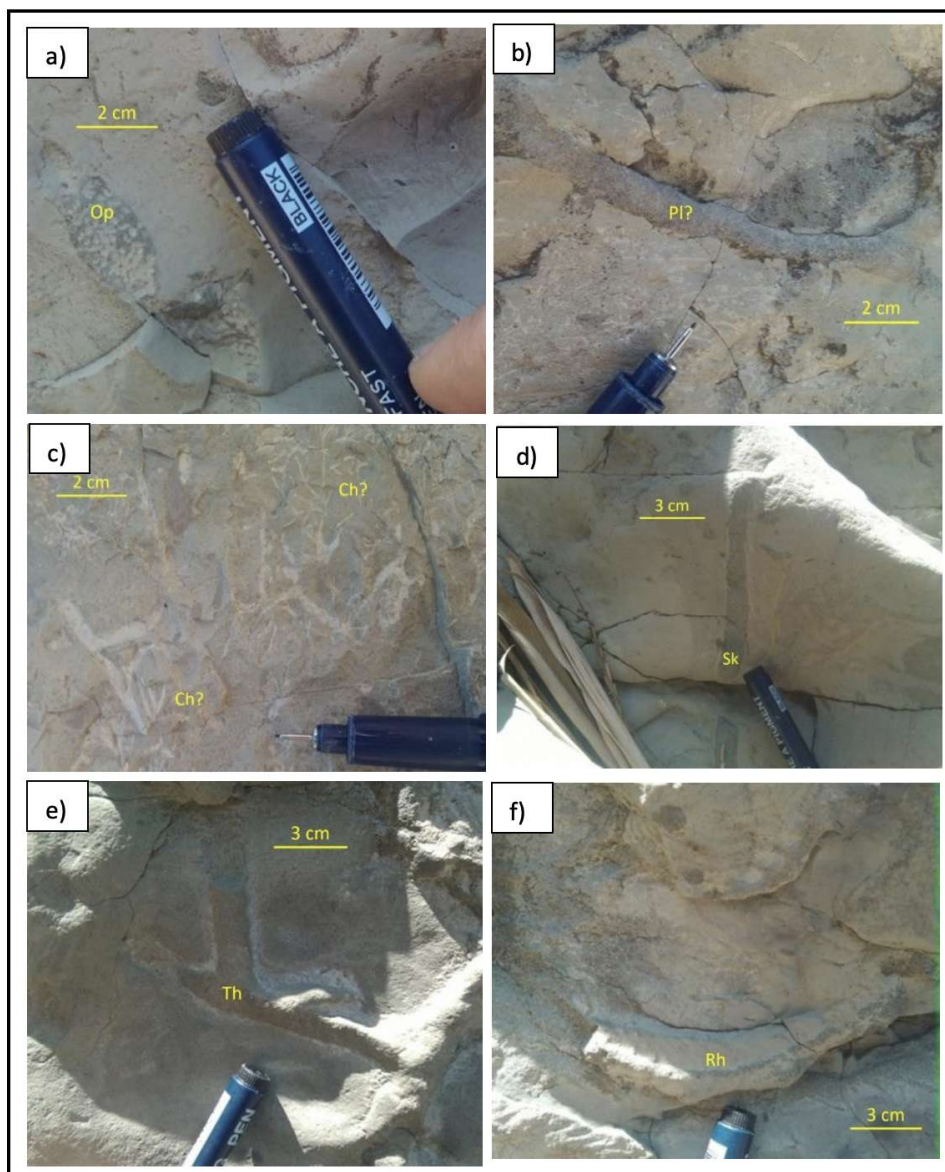


Figure 9. a) *Ophiomorpha* (Op) on sandstone layer at CSR-05 location. b) *Planolites* (Pl) in a sandstone layer at CSR-03 location. c) *Chondrites* (Ch) on a sandstone layer at CSR-06 location. d) *Skolithos* (Sk) on a sandstone layer CSR-04 location. e) *Thalassinoides* (Th) on a sandstone layer at the CSR-02 location. f) *Rhizocorallium* (Rh) on a sandstone layer at CSR-02 location.

foraminifers. Table 1 summarizes the results of microfossils analysis, which are sorted by stratigraphic position from the oldest to the youngest. Bathymetry interpretation were reconstructed according to the microfossils assemblages and abundances.

Slump structures found in several layers on the Cisaar River traverse are interpreted as part of density flows, followed by the formation of sandy debris flow layers (Figure 12). These beds are the result of a rotational movement between stable layers and moving masses,

Table 1. Qualitative foraminiferal abundance and bathymetric interpretation. Sampling location refer to Figure 4.

Sample Position	Fossil Name																						Depth															
	Planktonic											Benthic																										
	<i>Globigerina bulloides</i>	<i>Globigerinoides ruber</i>	<i>Globigerinoides sacculifer</i>	<i>Orbulina universa</i>	<i>Globorotalia continuosa</i>	<i>Globigerinella siphonifera</i>	<i>Globigerina selli</i>	<i>Globorotalia menardii</i>	<i>Foraminifera fragments</i>	<i>Pararotalia sp.</i>	<i>Rotalia canui</i>	<i>Pullenia bulloides</i>	<i>Marsipella elongata</i>	<i>Bathysiphon filiformis</i>	<i>Botellina labyrinthica</i>	<i>Cassidulina obtusa</i>	<i>Arenoturrispirulina Sp</i>	<i>Oolina emaciata</i>	<i>Rotorbis auberii</i>	<i>Tubinella funalis</i>	<i>Dentalina filiformis</i>	<i>Protobotellina cylindrica</i>	<i>Textularia sp. 3</i>	<i>Loeblichopsis cylindricus</i>	<i>Nodulina dentaliniformis</i>	<i>Dentalina ittai</i>	<i>Pyrgo murrhyna</i>	<i>Siphogenerina striata</i>	Coral fragments	0 - 20m	20 - 100m	100 - 200m	200 - 1000m	1000 - 4000m				
A-1	3	3	3	2					1	1		1																								+		
A-2	1	1	1	1								1					2																				+	
AB-7	3	3	3	2				2				1		1																							+	
AB-6	2	2	2		2							1		2	1	1																					+	
AB-5	3	3		2		2						1			2		1	1	1	3																	+	
AB-4	2	2		2										2	1						1																+	
AB-3		3		2	1		1				1			2							1	1															+	
AB-2	2	3					1	2														1															+	
AB-1	3	3		2																	1		1	2	2								1				+	
SL-1	3	3		2										1								2				1	1	1									+	

Explanation: 1 - Rare (<5); 2 - Medium (6 – 10); 3 - Abundant (>11)

3.4 Analysis

Comparison of the Cisaar River section with successions described by Bouma (1962) supports the interpretation that the Cisaar River rock layers were deposited by turbidity currents mechanism. Critical observations include fining upwards sandstone depositional units, intraclast lags at the bases of beds and partial Bouma sequences Td-Tc-Tb-Ta. The occurrence of conformable sandstone-claystone interbeds above the sandstone layer may be interpreted as a product of low-density turbidity currents (Tc; (Lowe, 1982). The stacking pattern of Cisaar River section is also consistent with deposition in a submarine fan depositional environment indicated by the features of turbidite channels and fan lobes in a middle fan setting. The stacking pattern of thick sandstone beds, deposited above the interbedded sandstone-claystone units, exhibit thickening upward and thinning upward patterns in different parts of the section (Figure 10). This pattern is similar to the depositional pattern in the submarine fan lobe and submarine fan channel as previously illustrated by Shanmugam (2006) (Figure 11).

while sandy debris flow units represent a continuous process spectrum between cohesive and non-cohesion debris flow, plastic, characterized by laminar current and are commonly found in fine-grained sandstone layers (Shanmugam, 1996).

Figure 13 shows a consistent correlation between changes in lithologic stacking pattern and changes in ichnofacies. As the depositional environment shifts from submarine fan lobe to submarine fan channel, ichnofacies also change from *Cruziana* ichnofacies to *Skolithos* ichnofacies. This occurrence repeatedly occurs through the studied interval.

The study interval is interpreted to be deposited in a submarine fan setting, which was likely located in bathyal zone. This interpretation is supported by the lithofacies stacking pattern and microfossil analyses. The occurrence of microfossils benthic foraminifera *Bathysiphon* and *Pullenia bulloides* in almost every sample indicate a deep-marine depositional environment of the claystone. In contrast, ichnofacies analysis suggests that these lithofacies were deposited in littoral to neritic zones, possibly even up to the shoreface zone.

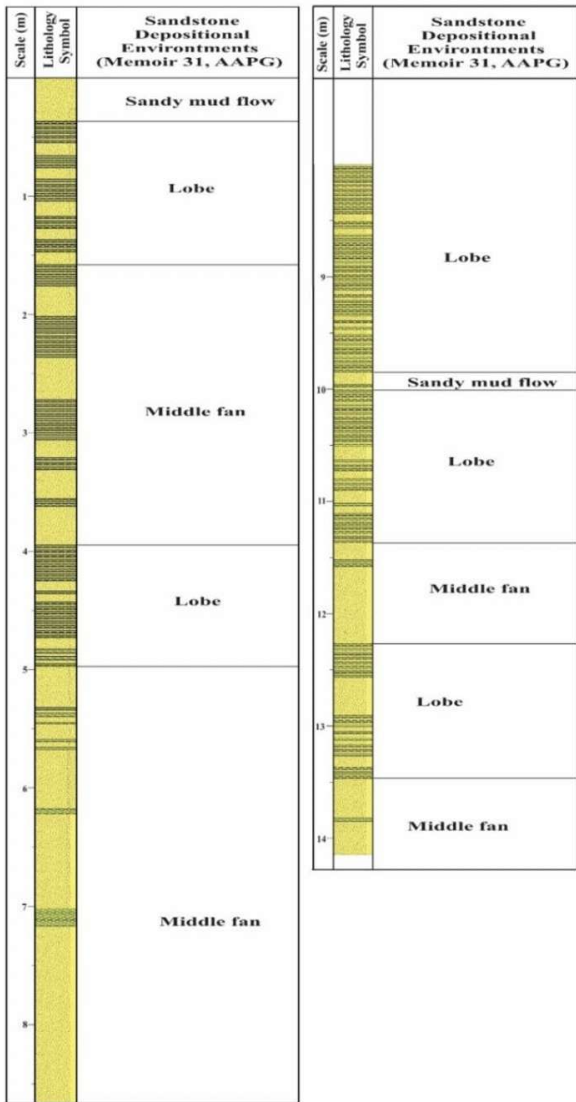


Figure 10. The Cisaar Formation sandstones in the study area and their depositional environments based on Howell and Nomark in Scholle and Spearing (1982).

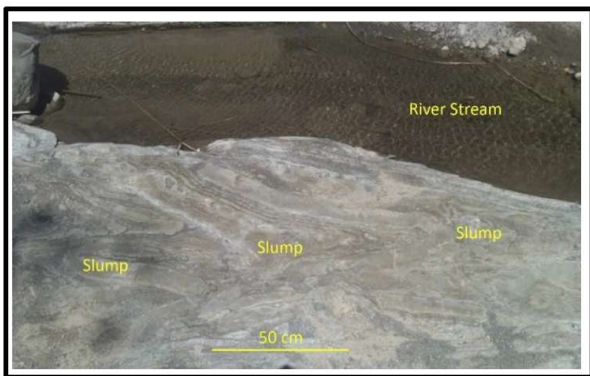


Figure 12. Slump structures at CSR-06 location.

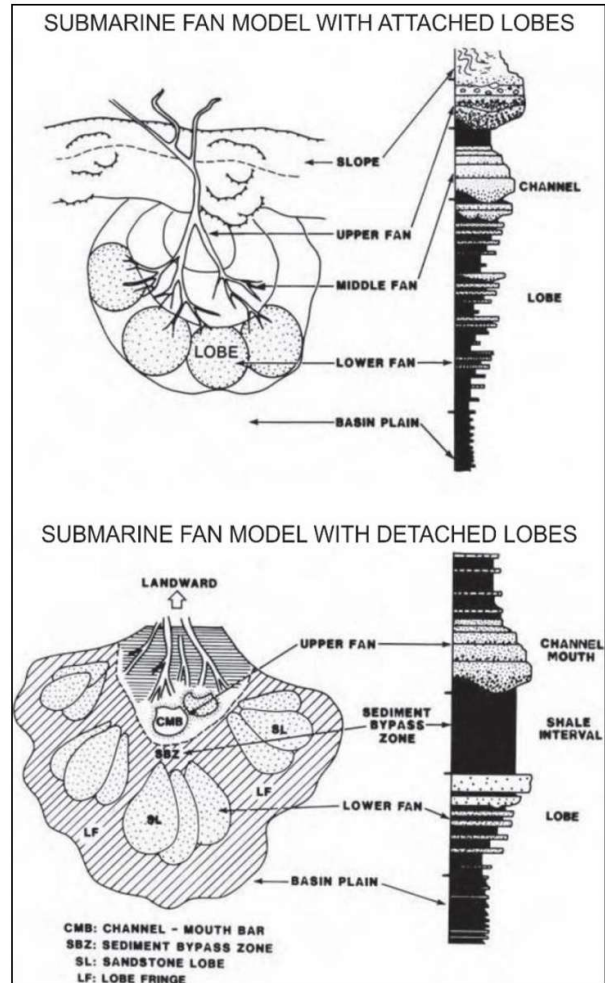


Figure 11. Depositional model of submarine fans (Shanmugam, 2006).

DISCUSSION

Ichnofossil analyses indicate three (3) ichnofacies preserved at Cisaar River include the *Cruziana*, *Skolithos* and *Glossifungites* ichnofacies. Ichnofacies interpretation based on the work of Pemberton (1992) and Seilacher (1967), suggests that the study interval was deposited in sublittoral as semi consolidated substrate (beach) to sandy backshore, and then shifted back to sublittoral environments. The analysis indicates the existence of shallowing and deepening processes that are most likely caused by sea level fluctuation, interpreted from the iterative succession of changes in the depositional environment of the middle fan and lobe.

However, Regarding the correlation between ichnofacies and bathymetry, Frey et al. (1990); Ekdale (1988); and Byers (1982) suggested that the correlation between bathymetry and the presence of relevant trace fossils might need to be reviewed, because there are certain ichnofacies that are not found in their original habitat. Frey and Pemberton (1985) stated that succession of ichnofacies can be used properly under normal conditions. Frey (1971) even described that we should not be surprised to find nearshore assemblages in offshore

DETAIL STRATIGRAPHIC SECTION OF CISAAR RIVER

SCALE (m)	LITHOLOGY	Mud Sand	Sandstone Depositional Environments Memot 31, AAPG	DEPOSITION ENVIRONMENTAL					Ichnofacies	OUTCROP	MICROFOSSIL
				Bathymetry	Ch	Op	Pr	Rb			
10											
15											
20											
25											
30											
35											
40											
45											
50											
55											
60											
65											
70											
75											
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85											
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150											
155											
160											
165											
170											
175											
180											
185											
190											
195											
200											

continue

SCALE (m)	LITHOLOGY	Mud Sand	Sandstone Depositional Environments Memot 31, AAPG	DEPOSITION ENVIRONMENTAL					Ichnofacies	OUTCROP	MICROFOSSIL
				Bathymetry	Ch	Op	Pr	Rb			
205											
210											
215											
220											
225											
230											
235											
240											
245											
250											
255											
260											
265											
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360											
365											
370											
375											
380											
385											
390											
395											
400											

Figure 13. Detailed description of the whole stratigraphic section with photographs of ichnofossils, outcrops, and microfossils.

sediments, and vice versa, if these accumulated under conditions like those preferred by the trace-making organisms.

In this study we found a striking difference in bathymetric interpretation derived from ichnofossil analysis, lithologic and microfossil analyses. Ichnofossil analysis suggests that the sedimentary environment of the rock layers in the Cisaar River lies in the sublittoral-

sandy shore zone, in contrast lithologic and microfossil analysis interpret that the rock layer was deposited in 200-1000 m depth range (upper bathyal - bathyal). The stacking pattern of the rock layers in the Cisaar River indicates that the rock layers are deposited on the middle fan zone with its environmental change order, from the oldest to the youngest, are submarine fan channel - submarine fan lobe - submarine fan channel.

Given the highly significant differences in bathymetry, it can be estimated that there were errors in the analysis or incompatibility between our analysis compared to the references. We assumed there is possibility that those differences might be due to several factors such as reworked fossil, which are commonly found in micropaleontology studies, as well as debris flow or sedimentological/stratigraphical landslide.

According to the data and the analysis results, the possibility of planktonic or benthic fossils being transported or reworked is very unlikely, especially when the lithological analysis interpret that turbid currents is the dominant depositional currents. The possibility of fossils transportation by a landslide block does not correspond to the visible condition because the rock layers are continuous or lateral vertical, in contrast the landslide block is discontinuous. The Slump structures are formed due to the movement of semi-consolidated rock layers in relatively steep areas. This movement is generally due to the influence of gravity in the form of medium-speed sandy debris flow and causes folding of the moving layer (Figure 14).

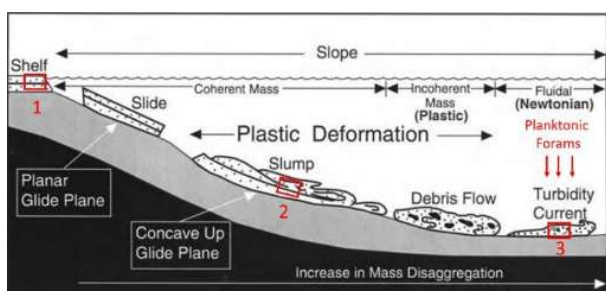


Figure 14. Schematic diagram of four common types of processes that transport sediment to the deep-water environment and are affected by gravity (Shanmugam et al., 1994).

All the results revealed above suggest that there is alternative possibility to explain the discrepancy of bathymetry interpretation between lithological analysis (supported by microfossil analysis) and ichnofacies interpretation, which are:

The trace producing organisms are depth tolerant

An organism that has a depth, water pressure, oxygen level and salinity tolerance could migrate between zones which makes traces of these organisms could be found literally on every environmental zone. This possibility was hard to accept because *Planolites* and *Cruziana* ichnofossil were produced by soft-bodied organisms with minimum tolerance to pressure, as Follmi and Grimm (1990) stated. The author argued that lack of ichnogenera *Chondrites*, *Planolites* and *Zoophycos* on their doomed pioneer trace fossil concept was due to low to zero survival rate of those organisms because their lack of exoskeleton.

Block landslide

Block landslide will cause a shallow water organism trace can be found in depth water bathymetry zone because those traces were formed before the landslide occurs and transports the shallow water block. The lithological data displayed by both traverses suggest no occurrence of landslide with blocky properties, hence this possibility must be ruled out.

The organisms were transported along the sediment materials

After producing traces in certain environment, organism may be transported along with the sediment material whereas upon its arrival in the new environment, these organisms once again produce similar traces. This possibility also could not be confirmed, since the ichnofossil data shows that the trace producing organisms such as *Cruziana* are not organisms with high water pressure tolerance (Follmi and Grimm, 1990).

Same trace was produced by different organisms

Though different species and occupy different habitats, several organisms within one genus could possibly produce similar traces. This is the most plausible possibility because current ichnofossils research can only determine trace-producing organisms only by its genus level. Although it was already researched previously by Pemberton (1992), Seilacher (1967), and others, however, the species recognition still cannot be done until the present. Therefore if an ichnofossil still cannot be identified by its previous classification, it is not quite surprising. Furthermore, currently, it is confirmed that there are living organisms within the same class or genus manage to live in a completely different environment.

Biological scientific naming/binomial nomenclature explains that the most specific way to describe an organism is its species (Thompson, 2003). Within a similar family or genus, various species could represent a diverse type of habitat, nutrient source, and level, or growth rate, for example, Tubeworm (*Lamellibrachia* genus), as a sea dwelling worm which commonly found in deep waters, *Lamellibrachia luymesii* inhabit 500-800 m water depth, while *Lamellibrachia satsuma* is another *Lamellibrachia* which inhabit the shallow marine zone (approximately at 82 m water depth), at Kagoshima Bay, Japan (Miura et al., 1997). However, they possess similar body size and may produce similar traces. In fact, the *Lamellibrachia satsuma* can only survive a maximum of up to 100 m water depth, conversely, *Lamellibrachia luymesii* cannot survive within shallow marine including on 82 m water depth. Shallow marine littoral and deep marine bathyal zone are differentiated by different pressure levels, oxygen content, light penetration, salinity, and nutrient supply. Consequently, almost no organism could tolerate these high variabilities of environmental parameters that allow them to migrate between both zones.

Furthermore, both lithological and ichnofacies analyses indicate similar shallowing and deepening sea level patterns suggests no misinterpretation. Derived from all data and facts have been discussed above, we could only argue that ichnofacies analysis might be better to be performed together with other analyses e.g. lithological analysis, microfossil analysis, etc., instead of being conducted as single analysis.

CONCLUSION

Based on the integrated analysis and discussion on lithology, ichnofossils, and microfossils, we can conclude as follows:

The rock formation in Cisaar is belongs to the Cisaar Formation. Lithological analysis shows that the depositional system was dominated by gravity influenced turbid currents, indicated by the occurrence of load cast, graded bedding, rip up clast, and ripple mark on sandstone layer and slump structure followed by sandy layer of debris flow sediment structure. These features generally occurs in the submarine fan zone. Similar to the lithofacies analysis, microfossil analysis result also suggests that depositional bathymetry for Cisaar River rock layers are between 200-1000 m water depth (deep marine) derived from the presence of *Pullenia bulloides* and *Bathysiphon* fossils.

In contrast, bathymetrical interpretation derived from ichnofossil analysis indicate relatively shallow marine environment. Ichnofossil which found in the Cisaar River are *Ophiomorpha*, *Planolites*, *Chondrite*, *Skolithos*, *Thalassinoides*, and *Rhizocorallium*, which are then classified into three ichnofacies, in sequences from the oldest to the youngest are *Cruziana*, *Glossifungites*, and *Skolithos*. According to the ichnofacies, bathymetrical changes interpretation are (in order): sublittoral – semi consolidated substrate (beach) - sandy shore – sublittoral depositional environment.

Discrepancy in bathymetrical interpretation revealed from lithology, ichnofossil, and microfossil analyses, most likely due to various species of organism which live in different habitat, though could produce similar traces, lead to environmental misinterpretation. Therefore, it is necessary to perform several analyses together instead of single ichnofacies analysis.

ACKNOWLEDGEMENTS

Here we would like to say thank you very much to Prof. Dr. John-Paul Zonnefeld from University of Alberta – Canada and Prof. Dr. Yahdi Zaim from Geological Department of ITB, for discussion and correction of the manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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