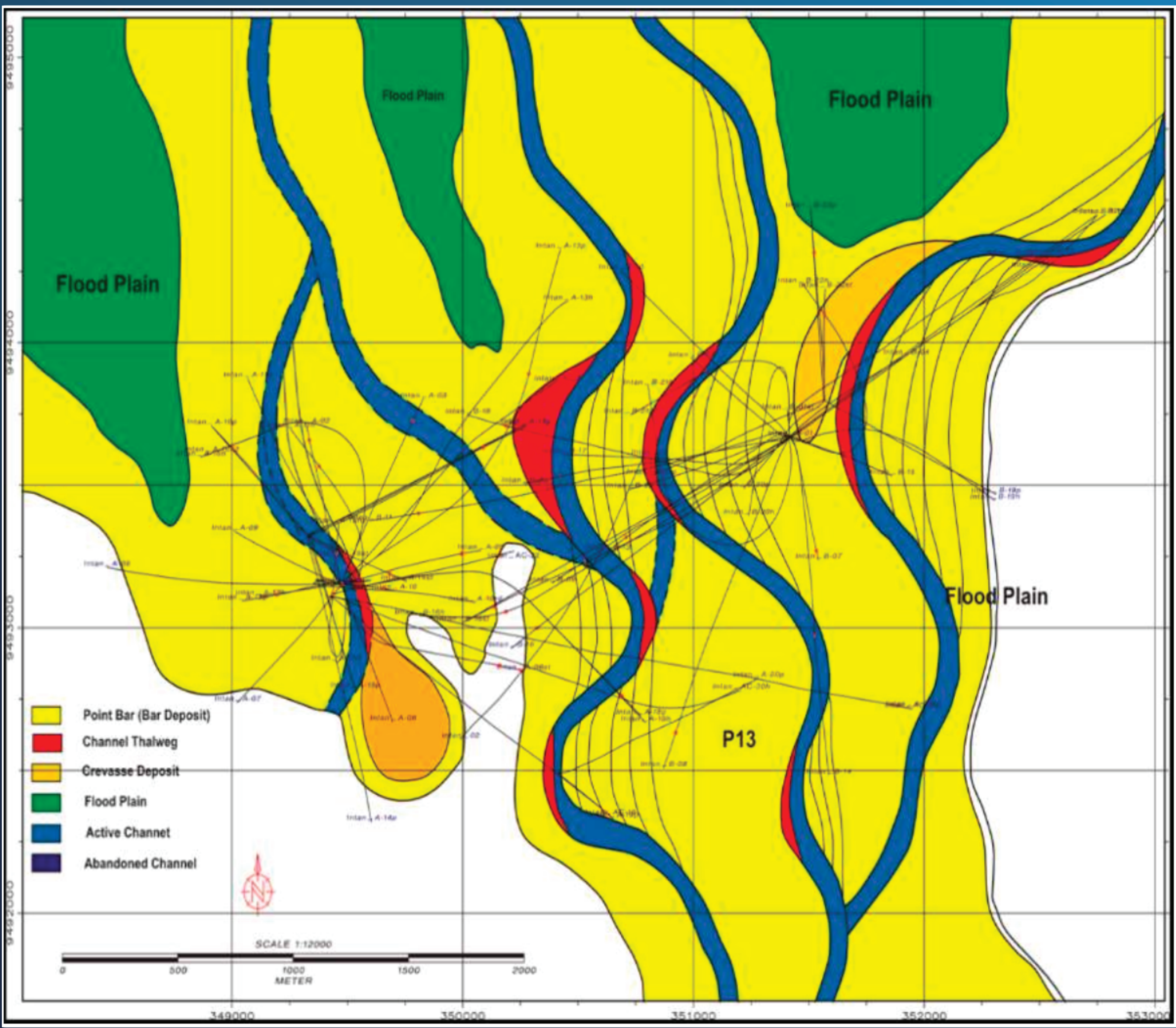
Bulletin of The Marine Geology

Volume 36, No. 2, December 2021

ISSN : 1410 - 6175



Sand facies interpretation of TAF reservoir

MARINE GEOLOGICAL INSTITUTE
RESEARCH AND DEVELOPMENT AGENCIES FOR ENERGY AND MINERAL RESOURCES
MINISTRY OF ENERGY AND MINERAL RESOURCES

PUSAT PENELITIAN DAN PENGEMBANGAN GEOLOGI KELAUTAN
BADAN PENELITIAN DAN PENGEMBANGAN ENERGI DAN SUMBER DAYA MINERAL
KEMENTERIAN ENERGI DAN SUMBER DAYA MINERAL

Bull. of The Marine Geology	VOL. 36	NO. 2	Page 57 - 107	BANDUNG Dec 2021	ISSN 1410- 6175

Accredited :
National Research and Inovation Agency
200/M/KPT/2020

BULLETIN OF THE MARINE GEOLOGY

Vol. 36, No. 2, December 2022

For communication of this publications, please contact :
MARINE GEOLOGICAL INSTITUTE
Dr. Junjunan 236, Bandung-40174, Indonesia
Telephone : +62-22-6032020, 6032201, Fax : +62-22- 6017887
E-mail : ejournal.p3gl@gmail.com

Preface

To end the year 2021, we proudly present Vol. 36, No. 2 of the Bulletin of Marine Geology (BoMG). Our honourable authors have kindly shared their knowledge, enriching further the development of marine science in Indonesia. Starting with the successful story of the rejuvenation of a mature oil field in the Asri Basin to increase oil production significantly again, then moving to a lesson from the UK on building a database of metal resources in Indonesia, and finally some topics regarding sedimentology for identifying paleotsunami deposits, interpreting depositional environments using ichnofacies, and assessing hydrodynamic processes between river and coastal areas based on grain size analysis.

With a variety of research scopes, we hope their results can be used as a driving force in determining national policies in terms of energy, mineral resources, or even those related to geohazard mitigation and society. Happy reading!

The Editorial Team of BoMG

ISSN 1410-6175

BULLETIN OF THE MARINE GEOLOGY

Vol. 36, No. 2, December 2021

CONTENTS

A SUCCESS CASE OF WIDURI AREA REJUVENATION, ASRI BASIN, OFFSHORE SE SUMATRA BLOCK, INDONESIA

PEMUTAKHIRAN KONSEP PENGEMBANGAN AREA WIDURI, CEKUNGAN ASRI, LEPASPANTAI BLOK TENGGARA SUMATRA, INDONESIA

Dwandari Ralanarko[1,2], Ildrem Syafri[2], Abdurrokhim[2], Andi Agus Nur[2]

[1] Pertamina Hulu Energi OSES, Menara Standard Chartered, Jl. Prof. Dr. Satrio No.26, Karet Semanggi, Setiabudi, Jakarta Selatan, DKI Jakarta 12950

[2] Post-Graduate Program, Faculty of Geological Engineering – Universitas Padjadjaran, Jl. Raya Bandung – Sumedang KM 21, Jatinangor, Jawa Barat 45363

Corresponding author: dwandari.ralanarko@pertamina.com / dwandari20001@mail.unpad.ac.id

(Received 18 May 2021; in revised from 23 August 2021; accepted 05 November 2021)

ABSTRACT: INTA/B Field is one of the most producing mature fields in Widuri Area, Asri Basin, Offshore SE Sumatera, Indonesia, therefore it is subjected to rejuvenation to enhance hydrocarbon production. INTA/B Field is distinguished from other fields from its featured anticlinal structures that have the northeast-southwest trending. This structure is heavily faulted mainly in the up-thrown south side of a major normal fault. Two structural configurations with various oil-water contact have successfully been identified within the field. The most of oil reserves are preserved in the western lobe in which Intan-1 sands. One of the most important reservoirs in this field is Talangakar (TAF) sand deposited as a meandering river system that streamed from the northwest to the southeast within the basin. Two main reservoirs, Gita-34A and Gita-34B are correlated throughout the field and interpreted as Miocene fluvio-channel sands. These two channels are thickened moderately from southwest to northeast which has descriptions as follows: fine-to-coarse grains, unconsolidated to friable, and low cementing materials.

INTA/B Field has been produced for 25 years and currently undergoing a watered-out phase. Therefore, an integrated study is subjected to overcome this issue for mature field rejuvenation. The integrated study ranged from geology (e.g., depositional environment and facies analysis), geophysics (e.g., revisiting and reprocessing of seismic attributes), petrophysical calculation, and reservoir engineering (e.g., water conformance plot and volumetric calculation).

This integrated study has successfully rejuvenated a mature field resulting and added a significant number in oil production with an average of 300 BPOD/well. The extended project is estimated to have a similar result to the forward pilot.

Keywords: mature field rejuvenation, integrated study, offshore SE Sumatra, water out phase

***ABSTRAK**: Lapangan INTA/B merupakan salah satu diantara lapangan tua yang masih produktif di Area Widuri, Cekungan Asri, Lepas Pantai Tenggara Sumatra, Indonesia, yang tentunya memerlukan peremajaan konsep pengembangan untuk terus memproduksi hidrokarbon. Lapangan INTA/B dapat dipisahkan dari lapangan lainnya dari keberadaan struktur antiklin berarah Timurlaut - Tenggara. Struktur ini terpatahkan sangat kuat terutama pada sisi naik bagian Selatan dari Sesar Normal utama. Dua konfigurasi struktur dengan beberapa variasi kontak minyak dengan air sudah berhasil diidentifikasi di lapangan ini. Cadangan minyak tersisa sebagian besar berada pada area Barat dimana lokasi pengendapan Intan-1 terjadi.*

Salah satu reservoir utama di lapangan ini adalah Batupasir Formasi Talangakar (TAF) yang diendapkan sebagai sistem sungai bermeander yang mengalir dari arah baratlaut menuju bagian tenggara dari cekungan. Dua reservoir utama, yaitu Gita-34A dan Gita-34B berkorelasi pada lapangan ini dan diinterpretasikan sebagai fluvial-channel sands yang terendapkan kala Miosen. Kedua interval tersebut menebal secara moderat dari baratdaya kearah timurlaut yang memiliki karakteristik fine - coarse grains, unconsolidated - friable, dan low cementing materials.

Lapangan INTA/B sudah diproduksikan selama 25 tahun dan saat ini sudah memasuki fase watered-out. Studi terintegrasi mutlak diperlukan untuk mengatasi permasalahan ini dengan peremajaan dan *pemutakhiran lapangan tua. Studi ini melingkupi aspek geologi (lingkungan pengendapan dan analisis fasies), geofisika (semisal memproses ulang atribut seismic), perhitungan petrofisika, dan reservoir engineering (semisal water conformance plot dan perhitungan volumetrik)*

Studi terintegrasi ini telah berhasil meremajakan dan memutakhirkan konsep pengembangan lapangan tua. Kelanjutan dari proyek ini tentunya perlu terus dilakukan dan diharapkan dapat juga memberikan hasil yang signifikan.

Kata Kunci: *peremajaan lapangan tua, studi terintegrasi, lepas pantai Tenggara Sumatra, watered out phase*

INTRODUCTION

Southeast Sumatra production sharing contract is located in Offshore Sumatra, operated by Pertamina Hulu Energi OSES. Three basins of Sunda, Asri, and Hera lie in an area of 11,046 sq. km of concession. Asri Basin was once thought to have low maturity of source rocks resulted in a low interest to be explored, during the early stage, from 1983 to 1987 (Wight *et. al.,* 1997). Approximately 9.7 km north of WIDA platform, INTA/B Field lies between VITA and NEIA field. The discovery well Intan-01 was drilled in 1987, up to 42 ft and 34.5 ft net oil pay from two sandstone units (namely Gita-34A and Gita-34B sand) from Early Miocene TAF. Oil-bearing sands in the Intan-1 well are stratigraphically similar to Gita-34 interval sandstone in surrounding structures, according to a correlation with the INDA and WIDA fields, which is well-defined by 3D seismic mapping. This extensive study in developing this reservoir type suggests no further delineation wells are necessary.

Asri Basin Regional Context

A Cenozoic extensional back-arc and half-graben rift of Asri Basin (Young and Atkinson, 1993) is situated in Offshore Sumatra, Indonesia, and covers an area of approximately 3500 sq. km. It comprises thick sediment from Paleocene to Pleistocene up to 16,000 ft thickness. It is bordered by a downthrown to the west, N-S trending faults to the East, and an NW-SE trending wrench system to the south (Ralanarko *et. al.,* 2020).

Three major tectonics are recognized: pre-rift, syn-rift, post-rift, which affected the structural style and depositional systems in the Asri Basin (Ralanarko *et. al.,* 2020). The basin acknowledged oil fields have a stratigraphic aspect that is influenced by moderate intra-basinal faulting and folding. Structural control on major axial drainage systems would exert tremendous influence on sand supply to any particular basin at any given time. Basin integration and its control on axial fluvial systems play an important role to fluvial deposition during basin evolution and fill.

The Lower Zelda and Upper Gita Members are the main components of the Oligocene TAF (Armon *et. al.,* 1995). In INTA/B Field, the Gita-33 series sand comprises the top sequence of Gita Member. One of those series is the Gita-33A sand consisting of sinuous meandering fluvial channel sandstones with northwest-southeast trending (Ralanarko *et. al.,* 2020). A fault with a throw of around 150 ft in the northwest juxtaposes sand against shale. It was collected in the same channel system as VITA field Gita-33 sand during a similar time.

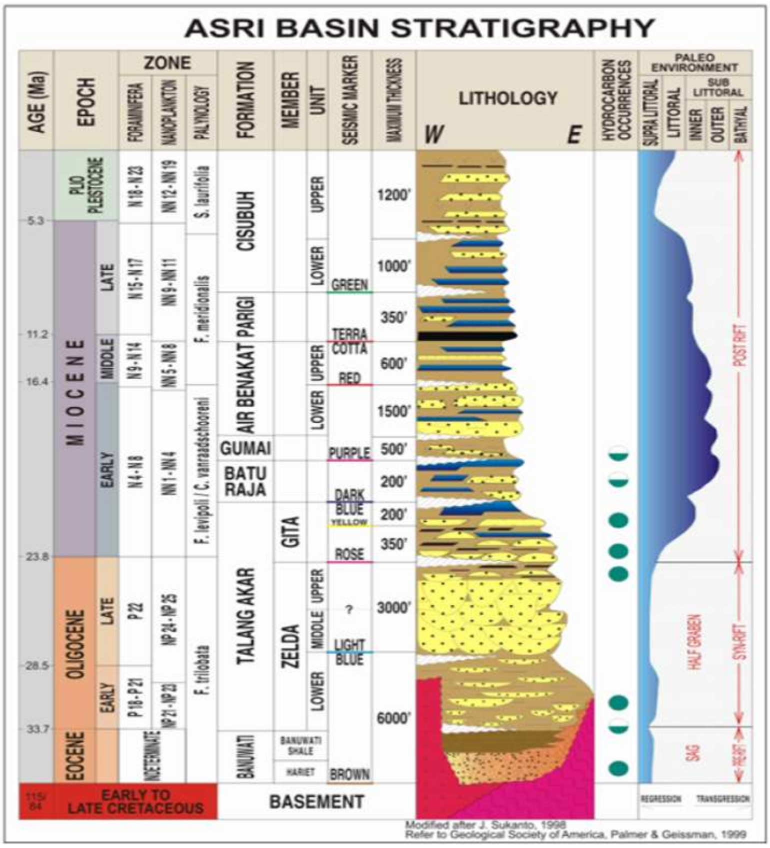


Figure 1. Asri Basin Regional Stratigraphy (modified after Sukanto, 1998)

METHODS

Earlier in 2015, review and analyses were conducted on all producer wells in the Asri Basin. After data gathered, it can be seen that watered out-wells potency from production well test before watered out reached about 1800 BPOD from 17 wells, where four wells of them are from INTA/B Field. This study covers various subjects including completion history and well perforation, production performance plot of the well, well-cased hole logging, seismic attribute analysis, a structural cross-section with offset well, facies distribution map,

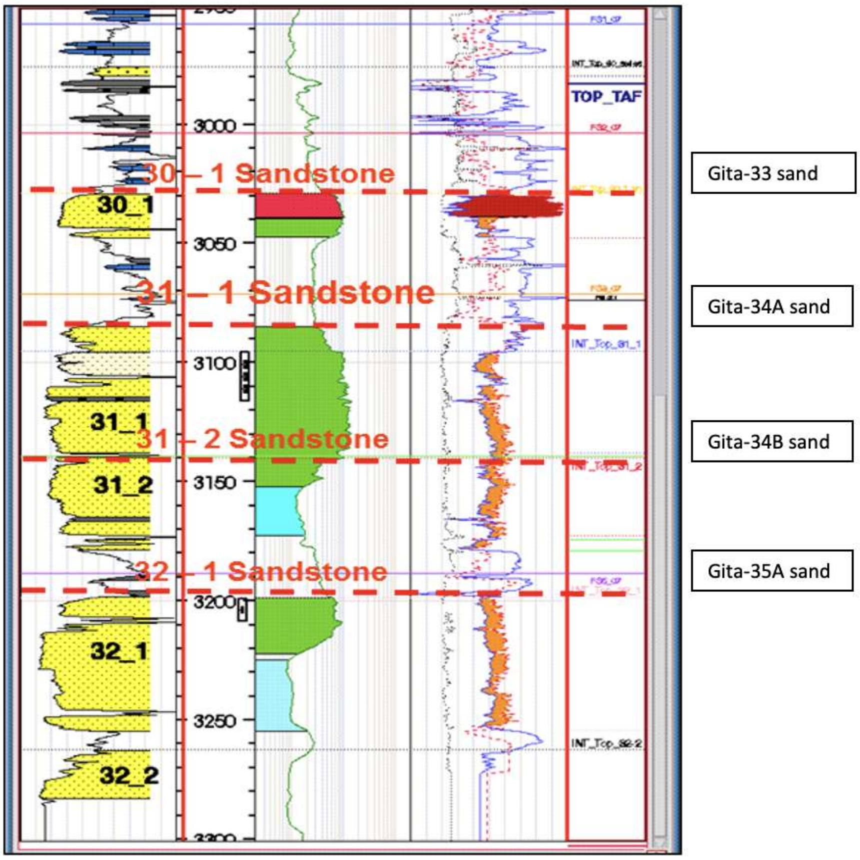


Figure 2. INTB-X Elan Log

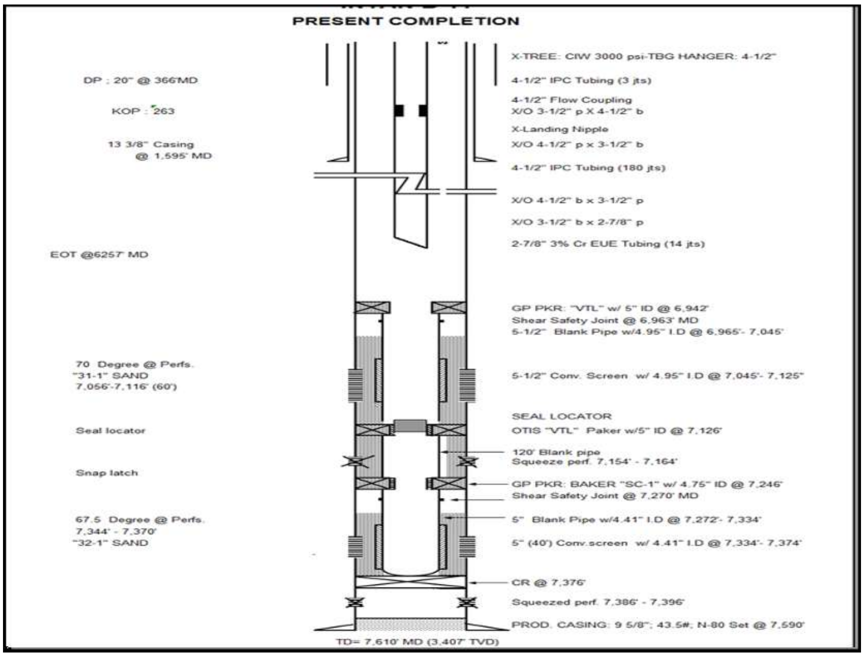


Figure 3. INTB-X Wellbore Diagram

production surveillance, and current recovery factor, and risk analysis.

One of the wells which successfully reactivated is INTB-X drilled in June 1995, encountered 21 ft net pay of Gita-35A sand, 52 ft net pay of Gita-34A sand, and 9.5 ft netay of Gita-33A sand (Figure 2).

INTB-X was completed in June 1995 in Gita-35A sand with interval perforation 7344' – 7370' MD using production casing 9-5/8" production casing (Figure 3). The initial pressure of this well from Gita-35A sand is 1336 psi meanwhile initial production is 1200 BPOD. Due to production decline, the Gita-35A sand was closed in December 1995 using a seal locator. INTB-X continues to produce from Gita-34A sand, with interval perforation 7056' – 7116' MD.

A seismic attribute used to observe Gita-34 series sand continuity in the INTA/B field is a root mean square (RMS) amplitude (Figure 4), one of the most common and powerful statistical measures of the magnitude of variation over a dataset. In particular, the RMS is constructive if

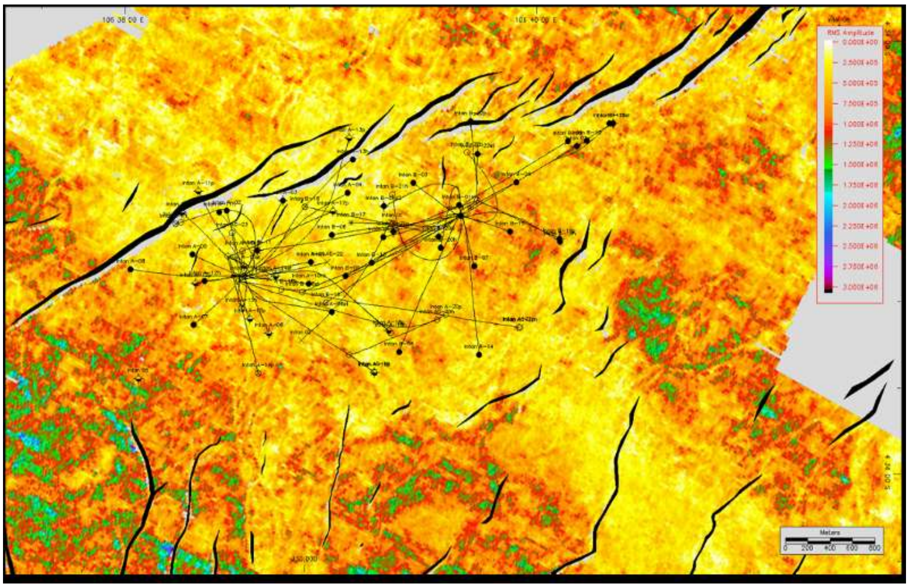


Figure 4. RMS Amplitude of Gita-34

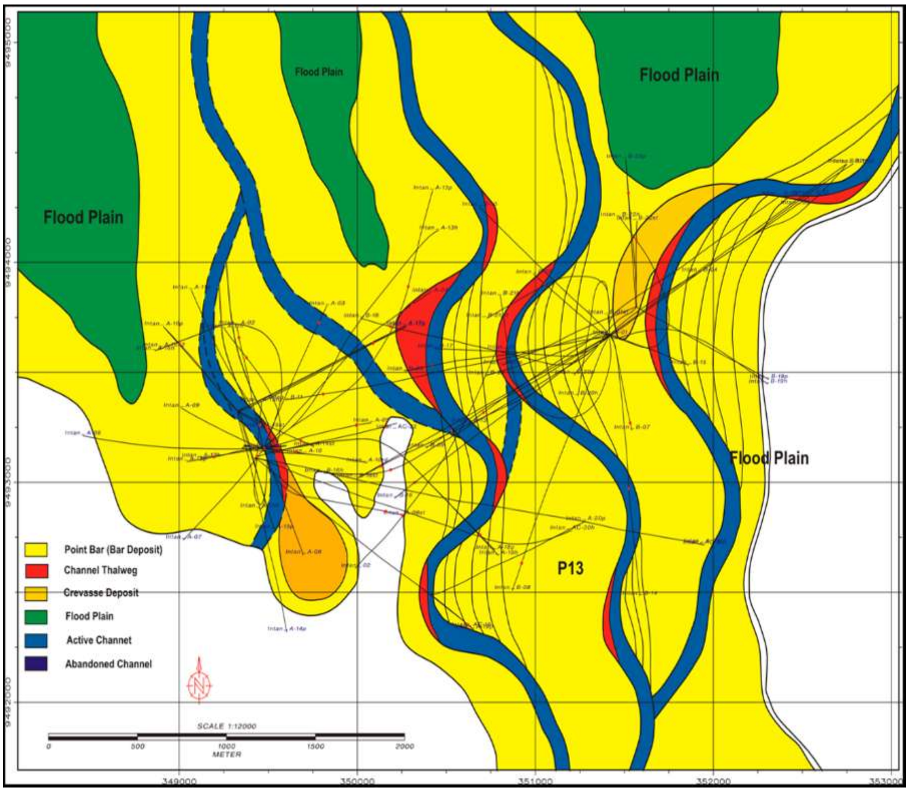


Figure 5. The Gita-34 Series Sand Facies Interpretation

positive and negative values such as sinusoids and seismic tracks are crossed. As a result, the RMS attribute emphasizes acoustic impedance variations over a given sample interval (Epgeology Website, 2015). This attribute's amplitude ranges from 0 to 1500000.

RESULTS

Intan - Widuri platform area forms the western flank of the Asri Basin which is cut by several series of NE-SW trending faults. This area became the focus of exploration after the Intan and Widuri discoveries in 1987 and 1988 (Young *et. al.,* 1991). The structure on this platform is generally a three-way dip closure bounded by down-to basin-margin series of en-echelon faults i.e., Intan closure, and a four-way dip closure as seen in the Widuri (Widuri is 3 way – fault bounded to NW) and Indri closure (Young *et. al.,* 1995).

The only productive area found to date in the Asri Basin is the Intan and Widuri platform on the NW flank of the basin (Primadani *et. al.,* 2018). All oilfields are currently producing from the syn-rift sandstones (Zelda Member) and early sag sandstones (Gita Member) reservoirs. The trapping mechanism in these fields is a large three-way dip-faulted closure (Intan and NE Intan) and four-way dip closures (Indri) except for the Widuri oil accumulation, which is a combination structural-stratigraphic trap (Ralanarko *et. al.,* 2020).

Reservoir distributions and properties in the Gita-34 sands has not been optimally defined and determined in previous field development campaigns. The Gita-34A and Gita-34B updated facies distribution maps are established using the RMS amplitude, combined with log and core data (Figure 5). The depositional environment of this Gita-34 series sand is interpreted as a meandering river system deposit, where some areas are associated with a crevasse splay deposit.

Structurally, the Gita-34A sand in INTB-X is 40 ft higher than INTA-S (248 m from INTB-X) and 55 ft higher INTB-E (397 m from INTB-X) (Figure 6).

DISCUSSION

The Initial production of the Gita-34A sand in INTB-X is 2873 BOPD, 4719 BFPD, 39% water cut with initial pressure 1357 psi. On June 7, 2004, INTB-X was watered

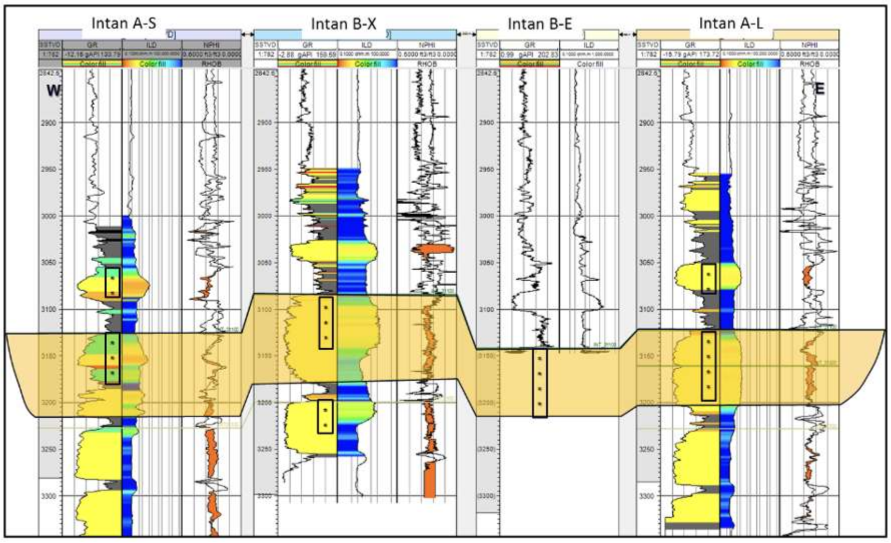


Figure 6. West to East Gita-34A Sand Structural Cross

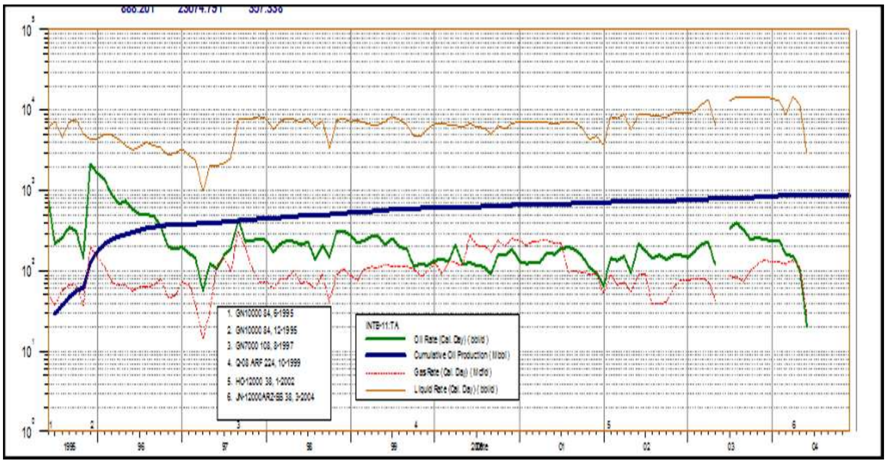


Figure 7. INTB-X Production Plot (1995-2004)

out (Figure 7). INTB-X cumulative production as of June 2004 is 811 MBO. In early 2015, INTA-S still produces 107 BPOD, 7667 BFPD with 98.6% water cut. INTB-E, another offset well of INTB-X, produces 101 BPOD, 20235 BFPD, and 99.5% water cut.

INTB-X reactivation is also analysed using MMRA development well chance success. Source components (quantity, quality, and maturation) have already been proven as the well has been already drilled and produced. Various factors including timing/ migration components (*e.g.,* timing of the closure, timing of expulsion, and effective migration pathway), reservoir components (*e.g.,* the reservoir presence, quality, and performance), and closure components (*e.g.,* map reliability, presence, and data quality) have similarity with the source components. The risk for Intan B-X reactivation will be preservation from spillage, depletion, and degradation (Table 1).

Table 1. INTB-X Reactivation Chance Success

DEVELOPMENT WELL(S) Chance Success	Ratings (0.01-1.00)
SOURCE COMPONENTS	Confidence of P99 Reserves: 118.13 MBO
Quantity/Volume (include Monetizable Product)	1.00
Quality/Richness	1.00
Maturation	1.00
MINIMUM FACTOR	1.00
TIMING/ MIGRATION COMPONENTS	Confidence of P99 Reserves: 118.13 MBO
Timing of Closure / Trap	1.00
Timing of Expulsion	1.00
Effective Migration Pathway	1.00
0	
MINIMUM FACTOR	1.00
RESERVOIR COMPONENTS	Confidence of P99 Reserves: 118.13 MBO
Presence	1.00
Quality	1.00
Reservoir Performance	1.00
MINIMUM FACTOR	1.00
CLOSURE COMPONENTS	Confidence of P99 Reserves: 118.13 MBO
Map Reliability & Control	1.00
Presence	1.00
Data Quality	1.00
MINIMUM FACTOR	1.00
CONTAINMENT COMPONENTS	Confidence of P99 Reserves: 118.13 MBO
Top / Base Seal Effectiveness	1.00
Lateral Seal Effectiveness	1.00
Preservation from Spillage or Depletion	0.90
Preservation from Degradation	0.90
MINIMUM FACTOR	0.90
DEVELOPMENT WELL(S) Chance Success	**0.90**

The integrated analysis has successfully reactivated the INTB-X well in February 2020, after considering its resource availability. The initial production of INTB-X after reactivation is 345 BPOD, 23021 BFPD, 98.5 water cut. After reactivation, INTB-X still has productivity index (PI) 634 BFPD/ psi. This PI indicates an excellent performance of the Gita-34A sand. The liquid rate of INTB-X has also been stable. This successful project later triggering rejuvenation concept opener for similar case studies in other mature oil fields in Widuri Area, Asri Basin, and Offshore SE Sumatra Block.

CONCLUSIONS

Among the many challenges of managing a mature oil field is the need to obtain as accurate as possible an understanding of its remaining recovery potential. Greater accuracy in assessing characteristics that influence recovery—geologic changes, rate of saturation, water cut; will enabling subsurface teams to make better decisions regarding mature field production optimization. With the right methods that take advantage of the wealth of reservoir data, geoscientists and reservoir engineers can more easily determine when, where, and how to improve well performance.

Mature fields have the inherent benefit of a long history of geologic and operational data, complemented by even larger volumes of recent surveillance data made available through increased oilfield instrumentation. When these data (seismic, cores, geology analyses, reservoir simulations, completion plans, production data, tracers, and well stimulations) are integrated, visualized, and analysed subsurface teams could be more accurately determine how much ultimate recovery potential has already been achieved and how much remains.

Further analysis can help determine the appropriate mature field optimization methods. The ability to identify and evaluate bypassed hydrocarbons and monitor fluid movement is vital in improving recovery in mature fields. Fortunately, the volume and details of reservoir data acquired in recent years can make it easier to identify bypassed pay. Time-lapse seismic surveys, reservoir fluid saturations, tracer data, and updated geocellular models can reveal previously undetected promising zones. Utilizing data that changes over time can see the extent and effectiveness of previous steam injections, as well as uncover zones that have not been swept and drained by current production wells.

Risk analysis and resource arrangement play a crucial role before reactivation execution. The probability of success is an important input parameter during the economic evaluation and profitability studies of mapped prospects. It is also an important tool in exploration and development strategy, especially when assessing the ranking of prospects and/or well candidates, i.e. which of a portfolio is most favourable with respect to the predicted volume of oil or gas, its chance of success and economic value.

ACKNOWLEDGEMENTS

The authors would like to thank the management of Pertamina Hulu Energi OSES, Pertamina EP, Pertamina Subholding Upstream (PHE), and SKK MIGAS, for their permission to publish this paper. Thank you to all Geosciences & Reservoir Team of the Subsurface Development Planning Department, PHE OSES and all lecturers of Post-Graduate Program, Faculty of Geological Engineering, Universitas Padjadjaran for several beneficial and constructive discussions.

REFERENCES

Aldrich, J.B., Pinehart, G.P., Ridwan, S., and Schuepbach. M.A., 1995. Paleogene basin architecture of the Sunda and Asri basins and associated non marine sequence stratigraphy, Proc. International Symposium on Sequence Stratigraphy, IPA, Jakarta, May 1995, 261-287.

Armon, J., Harmony, W. E., Smith, S., Thomas, B., Himawan R., Harmon B., Lukito, P., Gilmore, L., and Syarkawi I., 1995. *Complementary role of seismic and well data in identifying upper Talangakar stratigraphic sequences— Widuri Area, Asri Basin*, in: C.A. Caughey, D.C. Carter, J. Clure, M. J.

Primadani, G.S., I.M. Watkinson, Gunawan H., and Ralanarko D., 2018. *Tectonostratigraphy of the Asri Basin, SE Sumatera, Indonesia: Unlocking the Hidden Potential of Oligo-Miocene Reservoirs and Implications for Hydrocarbon Prospectivity*. Proc. 42nd Ann. Conv. Indon. Petroleum Assoc. (IPA), Jakarta, IPA18-19-G, 14p.

Ralanarko, D., Syafri, I., Abdurrokhim, and Nur, A.A., 2020. Seismic Expression of Paleogene Talangakar Formation, Asri & Sunda Basins, Java Sea, Indonesian Journal of Sedimentary Geology, ISSN 0853-9413, No. 46, 21-43.

Wight, A., Friestad, H., Anderson, I., Wicaksono, P., and Remington, C.H., 1997. *Exploration History of the Offshore Southeast Sumatra PSC, Java Sea, Indonesia,* in: Petroleum Geology of Southeast Asia, Fraser, Matthews, and Murphy (eds.), Geol.Soc. Sp. Pub. No. 126,p. 121-142.

Young, R., Harmony, W.E., Juniarto, Gunawan., Thomas, B., 1991. *Widuri Field, Offshore Southeast Sumatra: Sandbody Geometries and The Reservoir Model.* Jakarta, Prceeding 20th Annual Convention Indonesian Petroleum Association.

Young, R. and Atkinson, C.D., 1993. A Review of Talangakar Formation (Oligo-Miocene) Reservoirs in the Offshore Areas of Southeast Sumatra and Northwest Java. Clastic Core Workshop, Spec. Publication of the Indonesian Petroleum Association, 177-210.

Young, R., Harmony, W.E., and Thomas B., 1995. *The Evolution of Oligo-Miocene Fluvial Sand-Body Geometries and the Effect on Hydrocarbon Trapping: Widuri field, West Java Sea*, in A. G. Plint, ed., Sedimentary facies analysis: Oxford, Blackwell Science, Special Publication of the International Association of Sedimentologists 22, p. 355 – 380.

www.epgeology.com, Seismic Attribute root-mean-square, accessed date July 28, 2015.

NATIONAL DATABASE OF METAL IN COMPARATIVE PERSPECTIVES OF THE UNITED KINGDOM & INDONESIA

BASIS DATA NASIONAL UNTUK LOGAM DALAM PERSPEKTIF KOMPARASI ANTARA INGGRIS DAN INDONESIA

Rachma Puspitasari[1,3], Raldi Hendrotoro Seputro Koestoer[1,2]

[1] School of Environmental Science, Universitas Indonesia, Jakarta, Indonesia
[2] Coordinating Ministry for Economic Affairs, Jakarta, Indonesia
[3] National Research and Innovation Agency, Jakarta, Indonesia

Corresponding author: poespitsari@gmail.com

(Received 27 October 2021; in revised from 03 November 2021; accepted 16 December 2021)

DOI: 10.32693/bomg.36.2.2021.733

ABSTRACT: The ocean is a source of mega-biodiversity that is supposed to perform optimally for current and future generations. The health of the ocean must be evaluated by measuring heavy metals in sediment because they can be accumulated and stored in long term. This metal can be released and absorbed by an organism, and affect the ecological risk and human health. The purpose of this article is to share viewpoints and those in a comparative study in terms of the metal database of both countries, the UK and Indonesia. The methodology used in this paper is critical review and analysis to compare a success story about compiling metal data into a national database in the United Kingdom (UK). Indonesia already has an open public access database issued by the Ministry of Environment and Forestry. The further step is to strengthen collaboration between research institutes, universities, and government to assign a Standard Operational Procedure (SOP) to collect, analyze and report the data to a national depository. This database will be worthwhile to describe the pollution status in Indonesia and basic data for best practice decisions.
Keywords: database, Indonesia, metal, United Kingdom

***ABSTRAK**: Laut adalah sumber dari megabiodiversitas yang mendukung kehidupan saat ini dan generasi mendatang secara optimal. Kesehatan laut harus dievalusi dengan mengukur kadar logam berat dalam sedimen karena logam berat dapat terakumulasi dan tersimpan dalam sedimen dalam waktu yang lama. Logam dapat terlepas kembali dan terserap oleh organisme yang mempengaruhi risiko ekologis dan kesehatan manusia. Tujuan penulisan artikel ini untuk memberikan sudut pandang dalam bentuk studi komparasi database logam di dua negara yaitu Inggris dan Indonesia. Metode yang digunakan adalah telaah kritis dan analisis membandingkan kisah sukses dalam menyusun data logam menjadi database nasional. Indonesia sudah memiliki basis data publik yang dikelola Kementerian Lingkungan Hidup dan Kehutanan. Langkah selanjutnya adalah memperkuat kolaborasi antara Lembaga riset, universitas dan pemerintah untuk menyusun protokol standar terkait pengambilan, analisis dan laporan data logam ke dalam depositori nasional. Database ini akan sangat bermanfaat untuk menentukan status polusi di Indonesia dan data dasar untuk pengambilan berbagai keputusan lingkungan.*
***Kata Kunci:** basis data, Indonesia, logam, Inggris*

INTRODUCTION

Marine and coastal ecosystem is easily threatened by a contaminant that can reduce biodiversity, ecological and economic value, food security, affect livelihood, and also impacts human health (Ouali *et al*., 2018). The world's attention is focused on the ocean because of part of Sustainable Development Goals (SDGs) that target responsible consumption and production (SDG 12) and life below water (SDG 14) (United Nation, 2015). The ocean is also the main actor in the blue economy concept that a healthy ocean can support the food security and sustainability of fisheries (Vayer *et al*., 2020; Choudhary *et al*., 2021).

Indonesia is an archipelago with the world's fourth-longest coastline at 95,181 kilometers. As a result, Indonesia's coastline geomorphological traits are diverse and unique, particularly in northern Java (Bott *et al.,* (2021). Most of big cities in Indonesia located in coastal area and their topography is lowland deltas and high population city, which contribute to the high input land-based material to the ocean. Indonesia is predicted to receive a demographic bonus of 8% from 2020 to 2035 (Adyasari *et al*., 2021) resulting from the consequences of a decrease in environmental quality due to the influence of human activities such as increased sedimentation and contaminants from the mainland (Serrano *et al*., 2020). Ones of the chemicals discovered poses a risk to the ocean is heavy metal. Heavy metal is a toxic metal that can be sourced from natural or anthropogenic activities e. g. industrial and agricultural and provide a significant environmental and health risk to living organisms, particularly in aquatic environments (Khemis *et al*., 2017). Heavy metals are susceptible to being trapped by suspended particulate matter when they enter the water column then absorbed and deposited in the sediments (Zhang *et al*., 2021, Zhai *et al*., 2020). The ability of sediment to accumulate trace metal is well known, so they act the role as a carrier to an aquatic organism (Belabed *et al*., 2017; Franco-Fuentes *et al*., 2021, Ouali et al., 2018). Sediment-bounded heavy metals may be released again if there is a change of environment (Zhang *et al*., 2018; Liu *et al*., 2021). As a result, determining the level of heavy metal contamination in sediments is a critical point for ecological risk assessment and human risk assessment.

Maritime policies must be used to guarantee that human activities and a healthy ecosystem are harmonious. The use of contamination levels in abiotic environmental compartments, such as water and sediments, to monitor the water quality of marine ecosystems may aid in identifying the principal sources of pollution (la Colla *et al*., 2021). However, because metals in sediments have been increasing in recent years, water quality requirements are insufficient to preserve aquatic ecosystems. In Indonesia, (Adyasari *et al*., 2021) reported that the accumulation of heavy metals, organic pollutants, and other contaminants in sediments has increased in the last 20 years. Beside environmental database optimization, Adyasari *et al*. (2021) also recommend the requirement of Indonesia for plastics/microplastics, heavy metals, and organic contaminants regulation, due to they are found in higher concentrations in sediments than in water. Hereby, this review will reinforce the urgency to optimize the national database in Indonesia for further management coastal environment. The purposes of this article are to share viewpoints and those in a comparative study in terms of the metal database of both countries, the UK and Indonesia. The geology of the United Kingdom and Indonesia is the result of plate tectonic processes over a long period of time. Changing latitude and sea levels have influenced the nature of sedimentary sequences in both of countries. UK is chosen as a role model in this article because of their awareness and initiative to make a metal database for three decades. This is not a simple thing but no difficult to do if there are tight collaboration with the government and research institute.

METHODS

The methodology used in this paper is critical review and critical analysis to compare a success story about compiling metal data into a national database in the UK and Indonesia. A reputable and supportable journal was used for the literature review and be focused on Richir *et al*. (2021) as a main journal. UK has a database containing coastal and marine monitoring data that store in two databases: a) the Environment Agency (EA) and b) the MERMAN database managed by the British Oceanographic Data Centre (BODC) under the Clean Safe Seas Environmental Monitoring Programme (CSEMP) (CEFAS, 2012). This database consists of nine metals (As, Cd, Cr, Cu, Fe, Pb, Hg, Ni, and Zn) in a lot of sites during three decades.

RESULTS

Success Story of UK

Based on these databases, the UK can perform data mining for their data. For example, the background concentration for uncontaminated sediment could be determine based on their long period data and calculate the sediment quality index (Richir *et al*., 2021). The following are the example analysis based on the existing database. The EA-MERMAN databases were created by overlaying two data sets (EA and MERMAN), resulting in 45,962 data points (334 sites) for 29 chemicals during a 31-years (1983–2013). The nine metals (As, Cd, Cr, Cu, Fe, Pb, Hg, Ni and Zn) that are most often monitored were chosen (about 87 percent of all data) derived from coastal and open sea sites. The protocol of sediment samples collected by EA and MERMAN must be clear and follow the guidelines provided by CEFAS (2012). The total number of sites monitored achieved 796 sites for As, 1.210 sites for Cd, 1.070 sites for Cu, 1.073 for Zn during three decades.

From this database, UK can conduct data mining to assess their environment based on historical data. Further, the UK determined the natural background concentration based on the 20th percentile value of historical data. If there is lack of historical data, non-contaminated data, sedimentary rock abundance, and crustal composition are required. The Geoaccumulation Index (Igeo) and Contamination factor (CF) as the sediment quality index were also calculated. Igeo is assessment of the pollution levels in sediment of individual heavy metal wheter CF is evaluation of sediment quality to describe toxic substance (Kowalska *et al*., 2018). Based on two parameters, the Nemerov Pollution Index (PI) (Richir *et al*., 2021; Ciarkowska, 2018) is used to classify sediment quality from unpolluted or excellent (PI ≤ 0.7); clean (PI=0.7-1); slight pollution (PI=1-2); moderate pollution (PI=2-3) and heavy pollution (PI≥ 3). Pollution indices can be used as a tool and guide for determining the state of the soil environment using a comprehensive geochemical investigation (Kowalska *et al*., 2018). Mining sediment contamination databases from national public sources is a valuable tool for assessing the trend of contamination at challenging scales. Managers will be able to link ecosystem management techniques with multiple contamination levels that have large cumulative effects if coastal observatory networks are combined. Another country also assigns a national database for example Scotland has Marine Scotland Data and Denmark development International Council for the Exploration of the Sea (ICES) database.

All sites together

Pollution Level	I_{geo}	Colour scale	CF	As (796)	Cd (1,210)	Cr (sad) (842)	Cr (td) (201)	Cu (1,070)	Fe (sad) (676)	Fe (td) (198)	Pb (1,064)	Hg (1,126)	Ni (1,066)	Zn (1,073)
Unpolluted	0		<1.5	53.9	14.6	43.9	76.1	28.7	58.9	82.3	36.2	25.7	38.5	33.6
Unpolluted - moderate pollution	0-1		1.5-3	27.9	18.0	49.2	20.4	25.8	39.6	17.7	34.4	15.0	51.3	39.1
Moderate pollution	1-2		3-6	6.8	22.6	6.9	3.5	22.6	1.3	0	20.8	23.0	9.3	19.2
Moderate - strong pollution	2-3		6-12	5.9	25.0	0	0	11.6	0.1	0	6.8	23.5	0.9	5.1
Strong pollution	3-4		12-24	2.8	14.4	0	0	6.4	0	0	1.7	9.9	0	1.3
Strong - very strong pollution	4-5		24-48	0.8	2.9	0	0	3.1	0	0	0.2	1.9	0	0.9
Very strong pollution	>5		>48	2.0	2.5	0	0	1.9	0	0	0	1.1	0	0.7

Coastal sites

Pollution Level	I_{geo}	Colour scale	CF	As (706)	Cd (1,121)	Cr (sad) (842)	Cr (td) (112)	Cu (980)	Fe (sad) (676)	Fe (td) (112)	Pb (974)	Hg (1,037)	Ni (976)	Zn (981)
Unpolluted	0		<1.5	52.3	12.6	43.9	65.2	28.5	58.9	74.1	36.0	21.2	41.1	33.8
Unpolluted - moderate pollution	0-1		1.5-3	27.8	17.0	49.2	28.6	23.0	39.6	25.9	32.2	14.7	48.2	36.8
Moderate pollution	1-2		3-6	7.1	22.3	6.9	6.2	24.0	1.3	0	22.5	24.9	9.7	20.6
Moderate - strong pollution	2-3		6-12	6.7	26.8	0	0	12.4	0.1	0	7.3	25.4	1.0	5.5
Strong pollution	3-4		12-24	3.1	15.5	0	0	6.7	0	0	1.7	10.7	0	1.4
Strong - very strong pollution	4-5		24-48	0.8	3.1	0	0	3.4	0	0	0.2	2.0	0	1.0
Very strong pollution	>5		>48	2.3	2.7	0	0	2.0	0	0	0	1.2	0	0.8

Open sea sites

Pollution Level	I_{geo}	Colour scale	CF	As (90)	Cd (89)	Cr (sad) (0)	Cr (td) (89)	Cu (90)	Fe (sad) (0)	Fe (td) (86)	Pb (90)	Hg (89)	Ni (90)	Zn (92)
Unpolluted	0		<1.5	66.7	40.4	-	89.9	31.1	-	93	37.8	77.5	10	30.4
Unpolluted - moderate pollution	0-1		1.5-3	28.9	30.3	-	10.1	56.7	-	7	57.8	19.1	85.6	64.1
Moderate pollution	1-2		3-6	4.4	25.8	-	0	7.8	-	0	2.2	1.1	4.4	4.3
Moderate - strong pollution	2-3		6-12	0	3.4	-	0	2.2	-	0	1.1	2.2	0	1.1
Strong pollution	3-4		12-24	0	0	-	0	2.2	-	0	1.1	0	0	0
Strong - very strong pollution	4-5		24-48	0	0	-	0	0	-	0	0	0	0	0
Very strong pollution	>5		>48	0	0	-	0	0	-	0	0	0	0	0

I_{geo} = Geoaccumulation Index.
CF = Contamination Factor.
Number in brackets = number of sites monitored, on a yearly basis, over the 31-year time series.

Figure 1. An example the data mining of EA MERMAN database in UK.

Metal Contamination in Coastal Environment of Indonesia

Indonesia is an island nation located between the Pacific and Indian Oceans, with water covering 78 percent of its territory and more than 81,000 kilometers of coastlines (Adyasari *et al*., 2021). As a result of this phenomenon, Indonesia now possesses high biodiversity and is unique as a tropical coastal and marine habitat in the world. Unfortunately, the quality of Indonesian coastal water has been steadily degrading, especially in the densely populated coastal cities of Java. The heavy metal concentrations in Jakarta Bay are up to three times greater than in Bangkok (for sediment) and Manila (for seawater) when compared to other nations with similar environments (Adyasari *et al*., 2021; Velasques et al., 2002). The trend of Cu and Pb in Jakarta Bay, have increased 40 and 30 times between 1983 and 2014, respectively (Koropitan & Cordova, 2007). The most significant source of coastal water pollution in Indonesia is excess nutrients, organic compounds, and heavy metals from home wastewater, industry, mining, agriculture, aquaculture, and solid waste (Asian Development Bank, 2016). Based on Adyasari *et al*. (2021), nutrient pollution is the most pressing issue in Indonesia followed by heavy metals and organic pollutants during 1986 and 2021. As a result, the quality of Indonesia's coastal water is poor, and prompt action is required, such as restrictions for plastic debris, heavy metals, and organic contaminants, which are typically found in larger concentrations in sediments than in the water. The mining areas of Sulawesi, Papua, Buru Island (Maluku), and Sumbawa (Nusa Tenggara) are the source of pollution in Indonesia (Budianta, 2021). The hotspot area is Buyat Bay, Sulawesi that indicated the mercury level is 7 mg/kg in sediment and exceeds the safety limit of 2 mg/kg from WHO. The other possible source of metal pollution in the mining region is derived from natural factors such as volcanoes (Franco-Fuentes *et al*., 2021; Syakti *et al*., 2015), variability of the season (Siregar *et al*. 2016, Zhang *et al*., 2021), and interaction between contaminant (Purwiyanto *et al*., 2020), anthropogenic from marine or terrestrial source such as shipping activities, industry, wastewater discharge (Suteja *et al*., 2020; Amin *et al*., 2009; Sindern *et al*., 2016).

DISCUSSION

The Proposed of National Database in Indonesia

The literature study using was conducted by searching for keywords "Indonesia", "metal, "sediment" in "abstract, keywords and title" from Scopus database and Googlescholar. The most reported of heavy metal in keywords in Scopus Database is Pb (33 articles), Cu (32 articles), Zn (23 articles), Cd and Cr (19 articles), Fe (18 articles), Hg (14 articles) and Ni (11). From the 193 papers identified in the initial search results, limitation on journals published in the last 10 years (2011-2021) generated 145 articles, which were then subjected to a content analysis to determine the topic's eligibility. Data from Google Scholar related to non-essential metal is appended in Table 1 to resume research has been done in Indonesia and useful as a baseline data. Anthropogenic metal accumulation in sediments of Jakarta Bay (Zn, Cu, and Pb) began in the 1920s and intensified significantly from the 1970s until the end of the 1990s. Zn and Pb accumulation rates near the coastal industrialized area were consistent or decreased from the end of the 1990s to 2006 (Hosono *et al*., 2011). Harmesa *et al.* (2021) reported that the Cd concentration in Dasun estuary, Rembang was relatively high, and the source was presumed to be waste from the batik industry. Pb concentration ranged from 7.6 to 15.40 mg kg^{-1} dw in shrimp aquaculture in Central Java and showed moderate contamination, according to the ecological risk (geoaccumulation index (Igeo), contamination factor (CF), pollution load index (PLI), and potential ecological risk index (PERI)) determined in the sediments (Hidayati *et al.,* 2020). The average Cd compositions ranged from 0.13 to 0.89 mg/kg, while the average Cr compositions ranged from 0.09 to 96.0 mg/kg, according to the studies. Furthermore, average Cu compositions ranged from 3.00 to 148 mg/kg, whereas average Ni compositions varied from 1.00 to 37.4 mg/kg. Furthermore, Pb compositions ranged from 1.00 to 111 mg/kg on average. Finally, Zn compositions ranged from 4.00 to 595 mg/kg on average. The average highest metal of Ni was found in East Asia, whereas the highest metals of Cd, Cr, Cu, Pb, and Zn were found in Southeast Asian countries, according to the study's metal distribution areas (Fang *et al*., 2011). Cordova *et al*. (2016) reported that the concentration of Pb, Hg and Cd in Jakarta Bay sediments reached 21,77; 0,36 and 0,19 mg/kg, respectively. The study of metal levels in sediments is not as extensive as that of metal levels in water. Metal levels in water are positively correlated with metal levels in sediments (Franco-fuentes *et al*., 2021), so if it follows a pattern of heavy metal study trends in water that are high in hotspot areas due to industrial and mining, the study should be concentrated several locations.

As operational suggestion, it recommended to focus on heavy metal such as cadmium, copper, mercury, and chromium because of nonessential metal. Non-essential metals (e.g., Cd, Cr, Pb, Hg) play an unknown role in the biological system, are toxic, persistent, and tend to accumulate in organisms (Fatima *et al*., 2020). The first step to initiate the preparation of sediment quality standards is the collection of baseline data on metal contamination sediments (Table 1). As we know that Indonesia is an archipelago with diverse characteristic, we recommended for initial project, the location can be concentrated on coastal area because this region is economically important and highly dense population especially Jakarta and Semarang. For specific sites with high risk i.e mining and aquaculture also get high priority. Heavy-mining sites in Buyat Bay (Sulawesi), Buru islands (Maluku), Aijkwa estuary (Papua), and Sumbawa (Nusa Tenggara) are the focus of study on coastal heavy metal pollution in Indonesia (Adyasari *et al*., 2021).

A national database is urgently needed for collecting data related to contamination in Indonesia. The fact that Indonesia has various coastal characterization will be a consequence of the dynamic data will be very diverse (Tussadiah *et al*., 2021). The form of data not only primary data like concentration of metal in water, sediment, and organism but also the water quality like pH, DO, salinity, TSS, temperature. Further analysis of these data will be useful for monitoring, direction for the policymaker, a comprehensive study for students, and for compiling water and sediment quality standard. Principally, Indonesia has a competency to compile a national database because of the method, equipment like Atomic Absorption Spectrophotometer (AAS), Inductively Coupled Plasma Mass Spectrometry (ICP-MS), Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) and human resources are available. The challenge comes from the availability of accredited personnel and laboratory to make sure the data is accurate and valid, and the availability of Certified Reference Material (CRM) for quality of assurance and quality of control. This project needs collaboration between research institutes, universities, local government, and national government as a leader. Standard Operational Procedures (SOP) must be arranged to make sure the data is reliable and accurate as a depository database.

Based on current trends in big data storing and archiving worldwide, we recommend optimizing the environmental database. Indonesia already has an open public access database contain environmental data (water, air, waste) issued by the Ministry of Environment and Forestry (https://dataalam.menlhk.go.id/). It is a good initiative to make open public data source. This database has the potential to facilitate and expedite future

Table 1. Baseline data of metal contamination in sediment.

Location	Cd	Pb	Hg	Cr	References
Kahayan estuary (2005)	69.87	46.87	7.41	-	Siregar & Murtini, (2008)
Barito Estuary (2005)	73.9	90.94	21.46	-	Siregar & Murtini, (2008)
Perairan Ngemboh, Gresik, East Java	0.46	1.71	-	-	Eshmat *et al.* (2014)
Jakarta Bay (2010)	0.012-0.75	-	-	45.32-139.18	Permanawati *et al.,* (2013)
Teluk Jakarta	0.312-0.425	12.49-23.60	0,774-0.855	-	Barokah *et al.* (2019)
Teluk Jakarta	-	-	0,009-0,38	-	Murtini & Ariyani, 2005
Semarang (2010)	0.09	13.69	-	-	Rositasari & Lestari, (2013)
Semarang (2016)	0.24	8.16	-	-	Rositasari & Puspitasari, (2021)
Estuary Jakarta (2015)	0.28	28.8	0.47	-	Cordova *et al.* (2016)
Semarang	-	25.6		-	Widianarko *et al.* (2000)
Wonorejo estuary, East Java	-	4.22	-	70.8	Titah *et al.* (2020); Lutfthansa *et al.* (2021)
Dasun estuary, Rembang	0.21	5.36	-	3.39	Harmesa & Cordova, (2021)
Benoa Bay	-	-	-	1-24.6	Suteja *et al.* (2020)
Trimulyo, Semarang	-	-	-	20.4–45.8	Nuraini *et al.* (2017)
Segara anakan	-	-	-	17-73	Syakti *et al.* (2015)
Dumai	0.88	32.43	-	-	Amin *et al.* (2009)
Buru islands (2011)	-	-	>3	-	Male *et al.* (2013)
Buru islands (2013)	-	-	8.05-82.39	-	Reichelt-Brushett *et al.* (2017)
Ratatotok, North Sulawesi	-	-	40	-	Limbong *et al.* (2005)

ecological investigations by providing easy access to already investigated.

CONCLUSIONS

From a case study in the UK, it is important to prepare a database of metals in sediment in Indonesia as national basis data. The database contains a history of baseline information of metals and helps the manager to choose best practices based on an environmental framework. As an initial step, it is recommended to explore the Java Sea especially Jakarta and Semarang, and several hotspots of mining because of the high risk of heavy metal contamination for collecting the database. This would facilitate the monitoring and utilization of data for various purposes. A government agency, the Ministry of Environment and Forestry, and National Research and Innovation Agency (NRIA) should take a lead that can coordinate the database update mechanism to other sectors.

ACKNOWLEDGEMENTS

We thank to anonymous referee for their useful suggestion

REFERENCES

Asian Development Bank. 2016. *Indonesia: Country Water Assessment*. Manila. Asian Development Bank, Philippines.

Adyasari, D., Pratama, M. A., Teguh, N. A., Sabdaningsih, A., Kusumaningtyas, M. A., & Dimova, N. 2021. Anthropogenic impact on Indonesian coastal water and ecosystems: Current status and future opportunities. *Marine Pollution*

Bulletin, 171. https://doi.org/10.1016/j.marpolbul.2021.112689

Amin, B., Ismail, A., Arshad, A., Yap, C.K., Kamarudin, M.S. 2009. Anthropogenic impacts on heavy metal concentrations in the coastal sediments of Dumai, Indonesia. *Environmental Monitoring Assessment*. 148 (1–4): 291–305.

Barokah, G. R., Dwiyitno, & Nugroho, I. 2019. Kontaminasi Logam Berat (Hg, Pb, dan Cd) dan Batas Aman Konsumsi Kerang Hijau (*Perna viridis*) dari Perairan Teluk Jakarta di Musim Penghujan. *Jurnal Pasccapanen dan Bioteknologi Kelautan dan Perikanan*. 14(2): 95-106.

Belabed, B.E., Meddour, A., Samraoui, B., Chenchouni, H. 2017. Modeling seasonal and spatial contamination of surface waters and upper sediments with trace metal elements across industrialized urban areas of the Seybouse watershed in North Africa. *Environmental Monitoring Assessment*. 189 (6): 265. https://doi.org/10.1007/s10661-017-5968-5.

Bott, L. M., Schöne, T., Illigner, J., Haghshenas Haghighi, M., Gisevius, K., & Braun, B. 2021. Land subsidence in Jakarta and Semarang Bay – The relationship between physical processes, risk perception, and household adaptation. *Ocean and Coastal Management*, *211*. https://doi.org/10.1016/j.ocecoaman.2021.105775

Brady, J.P., Ayoko, G.A., Martens, W.N., Goonetilleke, A. 2015. Development of a hybrid pollution index for heavy metals in marine and coastal sediments. *Environmental Monitoring Assessment*. 187, 306. https://doi.org/10.1007/s10661-015-4563-x

Budianta, W. 2021. Heavy metal pollution and mobility of sediment in Tajum River caused by artisanal gold mining in Banyumas, Central Java, Indonesia. *Environmental Science and Pollution Research,* 28. https://doi.org/10.1007%2Fs11356-020-11157-5

Cefas, 2012. *CSEMP Green Book*. http://cefas.defra.gov.uk/media/510362/greenbookv15.pdf.

Cole, M., Lindeque, P., Halsband, C., & Galloway, T.S. 2011. Microplastics as contaminants in the marine environment: a review. *Marine Pollution Bulletin.* 62 (12): 2588–2597.

Choudhary, P., Subhash, V., Khade, M., Savant, S., Musale, A., Kumar, R. K., Chelliah, M. S., & Dasgupta, S. 2021. Empowering blue economy: From underrated ecosystem to sustainable industry. *Journal of Environment Management,* 291, https://doi.org/10.1016/j.jenvman.2021.112697

Ciarkowska, K., 2018. Assessment of heavy metal pollution risks and enzyme activity of meadow soils in urban area under tourism load: a case study from Zakopane (Poland). *Environmental Science and Pollution Research*. 25, 13709–13718 https://doi.org/10.1007/s11356-018-1589-y

Cordova, M. R., Purbonegoro, T., Puspitasari, R. & Hindarti, D. Purbonegoro. 2016. Assessing Contamination Level of Jakarta Bay Nearshore Sediments Using Green Mussel (*Perna viridis*) Larvae. *Marine Research in Indonesia*, 41(2), 67-76

Eshmat, M. E., Mahasri, G. & Rahardja, B. S. 2014. Analisis Kandungan Logam Berat Timbal (Pb) dan Cadmium (Cd) Pada Kerang Hijau (*Perna viridis* L.) di Perairan Ngemboh Kabupaten Gresik Jawa Timur. *Jurnal Ilmiah Perikanan dan Kelautan.* 6(1): 101-108

Fatima, S., Muzammal, M., Ismail Khan, D., Aqsa Rehman, P., Saqib Ali Rustam, P., Khan, I., Zainab Shehzadi, P., Mehmood, A., Waqar, M., Rehman, A., Ali Rustam, S., & Shehzadi, Z. (2020). Water pollution of heavy metals and its effects on fishes. *International Journal of Fisheries and Aquatic Studies*, 8(3), 06-14. http://www.fisheriesjournal.com

Franco-Fuentes, E., Moity, N., Ramirez-Gonzales, J., Andrade-vera, S., Hardisson, A., Gonzales-Weller, D., Paz, S., Rubio, C., & Gutierrez, A. J. 2021. Metals in commercial fish in the Galapagos Marine reserve: Contribution to food security and toxic a risk assessment. *Journal of Environmental management*, 286. https://doi.org/10.1016/j.jenvman.2021.112188

Harmesa & Cordova, M. R. 2021. A preliminary study on heavy metal pollutants chrome (Cr), cadmium (Cd), and lead (Pb) in sediments and beach morning glory vegetation (*Ipomoea pescaprae*) from Dasun Estuary, Rembang, Indonesia. *Marine Pollution Bulletin*, 162, 111819. https://doi.org/10.1016/j.marpolbul.2020.111819

Hosono T., Su C.C., Delinom R., Umezawa Y., Toyota T., Kaneko S., & Taniguchi, M. 2011. Decline in heavy metal contamination in marine sediments in Jakarta Bay, Indonesia due to increasing environmental. Regulations. *Estuarine, Coastal and Shelf Science*, 92, 297-306

Hidayati, N. V., Prudent, P., Asia, L., Vassalo, L., Torre F., Widowati, I., Sabdono, A., Syakti, A. G. & Doumenq, P. 2020. Assessment of the ecological and human health risks from metals in shrimp aquaculture environments in Central Java, Indonesia. *Environmental Science and Pollution Research*, 27, 41668-41687. https://doi.org/10.1007/s11356-020-09967-8

Khemis, I.B., Aridh, N.B., Hamza, N., M'Hetli, M., Sadok, S. 2017. Heavy metals and minerals contents in pikeperch (*Sander lucioperca*), carp (*Cyprinus carpio*) and flathead grey mullet (*Mugil cephalus)* from Sidi Salem reservoir (Tunisia): health risk assessment related to fish consumption. *Environmental Science Pollution Research*. 24 (24), 19494–19507. https://doi.org/10.1007/s11356-017-9586-0.

Koropitan, A.F., Cordova, M.R. 2017. Study of heavy metal distribution and hydrodynamic simulation in green mussel culture net, Cilincing water-Jakarta Bay. *Makara Journal of Science*. 89–96.

Kowalska, J. B., Mazurek, R., Gasiorek, M., & Zalesk. T. 2018. Pollution indices as useful tools for the comprehensive evaluation of the degree of soil contamination–A review. *Environmental Geochemical Health*. 40: 2395–2420. https://doi.org/10.1007/s10653-018-0106-z(0123456789().,-volV)(0123456

La Colla, N. S., Botté, S. E., Simonetti, P., Negrin, V. L., Serra, A. V., & Marcovecchio, J. E. 2021. Water, sediments and fishes: First multi compartment assessment of metal pollution in a coastal environment from the SW Atlantic. *Chemosphere*, 282. https://doi.org/10.1016/j.chemosphere.2021.131131

Liu, H., Liu, G., Yuan, Z., Ge, M., Wang, S., Liu, Y., & Da, C. 2019. Occurrence, potential health risk of heavy metals in aquatic organisms from Laizhou Bay, China. *Marine Pollution Bulletin*, *140*, 388–394. https://doi.org/10.1016/j.marpolbul.2019.01.067

Liu, J., Peng, A., Deng, S., Liu, M., Liu, G., & Li, C. 2021. Distribution of heavy metals and radionuclides in the sediments and their environmental impacts in Nansha Sea area, South China Sea. *Marine Pollution Bulletin*, 166. http://dx.doi.org/10.1016/j.marpolbul.2021.112192

Limbong, D., Kumampang, J., Ayhuan, D., Arai, T & Miyazaki, N. Mercury Pollution Related to Artisanal Gold Mining in North Sulawesi Island, Indonesia. *Bulletin of Environmental Contamination and Toxicology*.75: 989-996

Lutfthansa, U. M., Titah, H. S., & Pratikno, H. 2021. The Ability of Mangrove Plant on Lead Phytoremediation at Wonorejo Estuary, Surabaya, Indonesia. *Journal Ecological Engineering.* 22(6): 253–268. DOI: https://doi.org/10.12911/22998993/137675

Male, Y. T., Reichelt-Brushett, A. J., Pocock, M., & Nanlohy, A. 2013. Recent mercury contamination from artisanal gold mining on Buru Island, Indonesia – Potential future risks to environmental health and food safety. *Marine Pollution Bulletin*, 77: 428-433

Murtini, J.T. dan Ariyani, F. 2005a. Kandungan logam berat kerang darah (*Anadara granosa*) dan kualitas perairan di Tanjung Pasir, Jawa Barat. *Jurnal Penelitian Perikanan Indonesia*. 11 (8): 39–45.

Nuraini, R. A. T., Endrawati, H., & Maulana, I. R. 2017. Analisis Kandungan Logam Berat Kromium (Cr) pada Air, Sedimen dan Kerang Hijau (*Perna viridis*) di Perairan Trimulyo Semarang. *Jurnal Kelautan Tropis*. 20(1): 48–55

Ouali, N., Belabed, B. E., & Chenchouni, H. 2018. Modelling environment contamination with heavy metals in flathead grey mullet *Mugil cephalus* and upper sediments from north African coasts of the Mediterranean Sea. *Science of the Total Environment*, 639: 156–174. https://doi.org/10.1016/j.scitotenv.2018.04.377

Permanawati, Y., Zuraida, R., & Ibrahim, A. 2013. Heavy Metal Content (Cu, Pb, Zn, Cd, and Cr) In Sea Water and Sediment in Jakarta Bay. *Jurnal Geologi Kelautan*, 11 (1): 9-16

Purwiyanto, A.I.S., Suteja, Y., Trisno, Ningrum, P.S., Putri, W.A.E., & Rozirwan. 2020. Concentration and adsorption of Pb and Cu in microplastics: case study in aquatic environment. *Marine Pollution Bulletin*. 158, 111380.

Rositasari, R., & Lestari. 2013. Evaluasi Lingkungan Perairan Pesisir Semarang. *Jurnal Ilmu dan Teknologi Kelautan Tropis*. 5(1):112-121

Reichelt-Brushett, A. J., Stone, J., Howe, P., Thomas, B., Clark, M., Male, Y., Nanlohy, A., Butcher, P.2017. Geochemistry and mercury contamination in receiving environments of artisanal mining wastes and identified concerns for food safety. *Environmental Research*. 152: 407-418

Rositasari, R., & Puspitasari, R. 2021. The ecological vulnerability of Semarang's coastal waters, a brief review. The 4th International Symposium on Marine and Fisheries Research IOP Conf. Series: Earth and Environmental Science 919 (2021) 012028. doi:10.1088/1755-1315/919/1/012028

Richir, J., Bray, S., McAleese, T., & Watson, G. J. 2021. Three decades of trace element sediment contamination: The mining of governmental databases and the need to address hidden sources for clean and healthy seas. *Environment International*, 149. https://doi.org/10.1016/j.envint.2020.106362

Sindern, S., Tremohlen, M., Dsikowitzky, L., Gronen, L., Schwarzbauer, J., & Siregar, T.H. 2016. Heavy metals in river and coast sediments of the Jakarta Bay region (Indonesia)—Geogenic versus anthropogenic sources. *Marine Pollution Bulletin*. 110 (2): 624–633.

Siregar, T.H., Priyanto, N., Putri, A.K., Rachmawati, N., Triwibowo, R., & Dsikowitzky, L. 2016. Spatial distribution and seasonal variation of the trace hazardous element contamination in Jakarta Bay, Indonesia. *Marine Pollution Bulletin*. 110 (2): 634–646.

Siregar, T. H & Murtini, J. T. 2008. Kandungan Logam Berat pada Beberapa Lokasi Perairan Indonesia pada tahun 2001 sampai dengan 2005. *Squalen*. 3(1):7-15

Suteja, Y., Dirgayusa, I.G.N.P., & Purwiyanto, A.I.S. 2020. Chromium in Benoa Bay, Bali-Indonesia. *Marine Pollution Bulletin*. 153, 111017.

Syakti, A., Demelas, C., Hidayati, N., Rakasiwi, G., Vassalo, L., & Kumar, N. 2015. Heavy metal concentrations in natural and human-impacted sediments of Segara Anakan Lagoon, Indonesia. *Environmental Monitoring Assessment*. 187 (1), 4079.

Titah, H. T. & Pratikno, H. 2020. Copper Accumulation by *Avicennia marina* at Mangrove Eco-forest in Wonorejo, Surabaya. The 5th International Conference on Energy, Environmental and Information System (ICENIS 2020) E3S Web of Conferences 202, 05004.

Tussadiah, A., Sujiwo, A. S., Andesta, I., & Daeli, W. 2021. Assessment of coastal ecosystem services and its condition for policy management plan in East Nusa Tenggara, Indonesia. *Regional Studies in Marine Sciences*, 47. https://doi.org/10.1016/j.rsma.2021.101941

United Nations. 2015. *Transforming our world: the 2030 Agenda for Sustainable Development*

Widianarko, B., Verweij, R. A., Van Gestel, C. A. M., & Van Straalen, N. M. 2000. Spatial Distribution of Trace Metals in Sediments from Urban Streams of Semarang, Central Java, Indonesia. *Ecotoxicology and Environmental Safety.* 46, 95-100

Velasquez, I.B., Jacinto, G.S., Valera, F.S. 2002. The speciation of dissolved copper, cadmium and zinc in Manila Bay, Philippines. *Marine Pollution Bulletin*. 45 (1), 210–217.

Voyer, M., Farmery, A. K., Kajlich, L., Vachette, A., & Quirk, G. 2020. Assessing policy coherence and coordination in the sustainable development of a Blue Economy. A case study from Timor Leste. *Ocean and Coastal management*, 192, https://doi.org/10.1016/j.ocecoaman.2020.105187

Zhai, B., Liu, Z., Wang., X., Bai, F., Wanga, L., Chen, Z., & Zhang, X. 2020. Assessment of heavy metal contaminations in surface sediments in the western Taiwan Straits. *Marine Pollution Bulletin,* 159. https://doi.org/10.1016/j.marpolbul.2020.111492

Zhang, H., Liu, S., Wu, K., Cui, J., Zhu, A., Zhang, Y., Mohamed, A. A., R., & Shi, X. 2021. Distribution and assessment of heavy metal contents in surface sediments of the wetern sediments Sunda Shelf. *Marine Pollution Bulletin*, 168. https://doi.org/10.1016/j.marpolbul.2021.112433

Zhang, Z., Lu, Y., Li, H., Tu, Y., Liu, B., Yang, Z. 2018. Assessment of heavy metal contamination, distribution and source identification in the sediments from the Zijiang River, China. *Science of Total Environment*. 645, 235e243.

IDENTIFICATION OF SUSPECTED PALEOTSUNAMI DEPOSITS STUDY FROM KARAPYAK BEACH, PANGANDARAN AREA, WEST JAWA, INDONESIA

STUDI IDENTIFIKASI ENDAPAN PALEOTSUNAMI DI PANTAI KARAPYAK, PANGANDARAN, JAWA BARAT, INDONESIA

Aswan* and Yan Rizal*

*Geological Engineering Study Program, Faculty of Earth Sciences and Technology, Institut Teknologi Bandung (ITB), Jl. Ganesha 10 Bandung, Indonesia (40132).

Corresponding author: aswan_gl@gl.itb.ac.id

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

DOI: 10.32693/bomg.36.2.2021.727

ABSTRACT : Identifying and determining paleotsunami deposits can be a vital tool for establishing the periodicity of earthquakes and their associated tsunami events beyond historical records. However, their deposits can be difficult to establish and to date. In this study, we used the characteristics of the 2006 Pangandaran tsunami deposit as a reference to identify paleotsunami deposits in Karapyak Beach, Pangandaran area, West Java, Indonesia. Similar to the 2006 Pangandaran tsunami deposit, the Karapyak Beach paleotsunami deposit is characterized by light brown loose sand materials overlying a dark brown paleosol layer with erosional contact. A thin layer of tsunami deposit, although varies in thickness, is locally found just above erosional contact. The deposit reveals non-laminated coarse grain size in the lower part that gradually changes into medium to fine sand in the upper part. The base of this lower part is rich with broken mollusc shells and corals. The mid to top of the lower part may contain several still-intact mollusc shells and corals, rock fragments, and anthropogenic products (roof tiles). Those types of fragments are absent in the upper part of this thin tsunami deposit. Grain size analysis shows a mixture of fine and coarse grains in the lower part of the 2006 tsunami deposits, as well as in the suspected paleotsunami deposits, suggesting an uprush of high energy flow during the sedimentation. The fining upward sequence above the mixed grain layers reflects a waning flow in pre-backwash deposition. Foraminifera analysis also shows a mixture of shallow and deep marine foraminifera in both recent tsunami and paleotsunami deposits. Based on the characteristics of the 2006 tsunami deposits, there are at least four paleotsunami deposits identified in Karapyak Beach, Pangandaran area.
Keywords: tsunami; paleotsunami; deposit; Pangandaran; Indonesia

ABSTRAK*: Identifikasi dan determinasi endapan paleotsunami merupakan hal yang penting dalam usaha untuk menetapkan periode gempa bumi (earthquake periodicity) yang menyebabkan tsunami-tsunami di luar catatan sejarah. Namun endapan paleotsunami ini masih sulit dipastikan dan diketahui kapan terbentuknya. Dalam penelitian ini, kami menggunakan ciri-ciri endapan tsunami Pangandaran 2006 sebagai standar untuk mengidentifikasi endapan-endapan paleotsunami di Pantai Karapyak, Pangandaran, Jawa Barat, Indonesia. Seperti halnya pada endapan tsunami 2006, endapan paleotsunami memiliki karakteristik berupa pasir lepas-lepas berwarna coklat terang yang posisinya berada di atas lapisan paleosol berwarna coklat gelap dengan kontak erosional. Lapisan tipis endapan tsunami dengan ketebalan yang bervariasi dijumpai di atas kontak erosional. Bagian bawahnya berbutir kasar dan tidak berlapis, dan semakin ke atas berubah secara gradasi menjadi berbutir sedang sampai halus. Dasar dari lapisan bagian bawah ini kaya akan pecahan cangkang moluska dan pecahan koral, dan semakin ke bagian tengah lapisan dijumpai fragmen moluska yang utuh dan koral, fragmen batuan dan bahan antropogenik (pecahan genteng). Fragmen-fragmen ini tidak ditemukan lagi pada bagian atas lapisan endapan tsunami. Hasil analisis ukuran butir menunjukkan adanya indikasi percampuran butir halus dan kasar pada bagian bawah endapan tsunami dan paleotsunami. Hal ini mengindikasikan adanya pengaruh arus berenergi relatif kuat selama pengendapannya. Klastik yang semakin menghalus pada bagian atas endapan tsunami/ paleotsunami merefleksikan melemahnya arus selama pengendapan pre-backwash. Analisis foraminifera*

juga menunjukkan adanya percampuran antara foraminifera laut dangkal dan laut dalam, baik pada endapan tsunami 2006 maupun endapan paleotsunami. Berdasarkan asosiasi ciri-ciri endapan tsunami 2006 ini, paling tidak dapat dikenali empat endapan paleotsunami di Pantai Karapyak, daerah Pangandaran.
Kata kunci: tsunami; paleotsunami; endapan; Pangandaran; Indonesia

INTRODUCTION

Earthquakes and their resulting tsunamis have had a devastating effect on the Indonesian Pangandaran coastline, killing 650 people, displacing hundreds of people, and costing more than US$5 million in the destruction of infrastructure (Ambarjaya, 2006). What is needed is a better understanding of the pattern of tsunami events to predict more accurately these devastating events (Rhodes et al., 2006; Prendergast et al., 2012). The timing of earthquakes and their associated tsunami events can be established by constraining paleotsunami deposits (De Martini et al., 2012; Jackson, 2008; Løvholt et al., 2012; Nentwig et al., 2018; Aswan et al., 2017; Rizal et al., 2019). The resulting chronologies can be used to establish the periodicity in which these earthquakes and subsequent tsunami events occur. However, paleotsunami deposits must first be identified. Generally, their characteristics are relatively loose unconsolidated sediments with a light-colored carbonate layer of sand overlying a darker-colored paleosol layer or remnant former soil (Yawsangrat et al., 2012; Rhodes et al., 2006; Aswan et al., 2017). The overlying layer contains light-colored molluscs, corals and organic materials, deposited from beach and shallow marine environments. Paleotsunami deposits are also characterized by fining-upward sequences with more variable fragments at the bottom parts which are due to high energy transportation capacity by a non-gravitational mass flow (Naruse et al., 2012; Cuven et al., 2013; Schicchitano et al. 2010 and Hawkes et al. 2007). Occasionally, parallel laminations occur only if there is lower velocity deposition during the backwash process.

Tsunami deposits formed by high energy depositional current will show a mixed environment from which the sediments pass through (Hawkes et al., 2007; Yudhicara et al., 2013; Pilarczyk et al., 2020; and Lespez et al., 2021). The sediments may contain a mixture of shallow marine and deep marine faunal benthic foraminifera (Hawkes et al., 2007; Dahanayake and Kulasena, 2008; Aswan et al., 2017; Pilarczyk et al., 2020; and Lespez et al., 2021) and grain size ranges that reflects more than one ocean current systems (Yawsangratt et al., 2012; Aswan et al., 2017). As tsunami events regularly occur in Pangandaran area (with the last event occurring as recently as 2006), the observation sites offer a good opportunity for finding potential paleotsunami deposits.

In this study, a comparison to verify the status of the suspected deposits against the 2006 tsunami deposits was carried out. The parameters comprise characteristics of the outcrops, grain size analysis, and inferring depositional environment based on foraminifera analysis. Fieldworks were conducted on May 26, 2015, and on January 17, 2018.

METHODS

The excavation site in Pangandaran area is located about 50 meters from the shore line of Karapyak Beach and falls on 7°41'44.21"S, 108°45'42.47"E (Figure 1). The observation and sampling location points are along small and short walls of river estuaries that lead to the sea. Most of the time, the locations are dry except when it rains. The height of this river wall is about 1.5 meters from the riverbed (Figure 2).

The paleotsunami deposit identification is carried out by comparing their outcrop characteristics to the 2006 tsunami deposits, such as their contact with the underlying paleosol or other deposits, the color difference to the underlying sediments, and their constituent fragments. Fragments to observe in those typical tsunami deposits are rock fragments, anthropogenic materials (e.g., roof tiles), molluscs, and/or coral fragments, commonly found at the bottom part of tsunami deposits and usually embedded in a non-laminated matrix. Several characteristics of the suspected paleotsunami deposit were observed in the field, including grain size variation (done through grain size analysis) to find out any evidence of a mixture between shallow (0 – 20 m) and deep marine sediments (20 – 200 m).

Sediment sampling for foraminifera content and grain size analyses was conducted on each layer, suspected as tsunami and paleotsunami deposits. A 100 g sediment from each layer was then analyzed for faunal content,

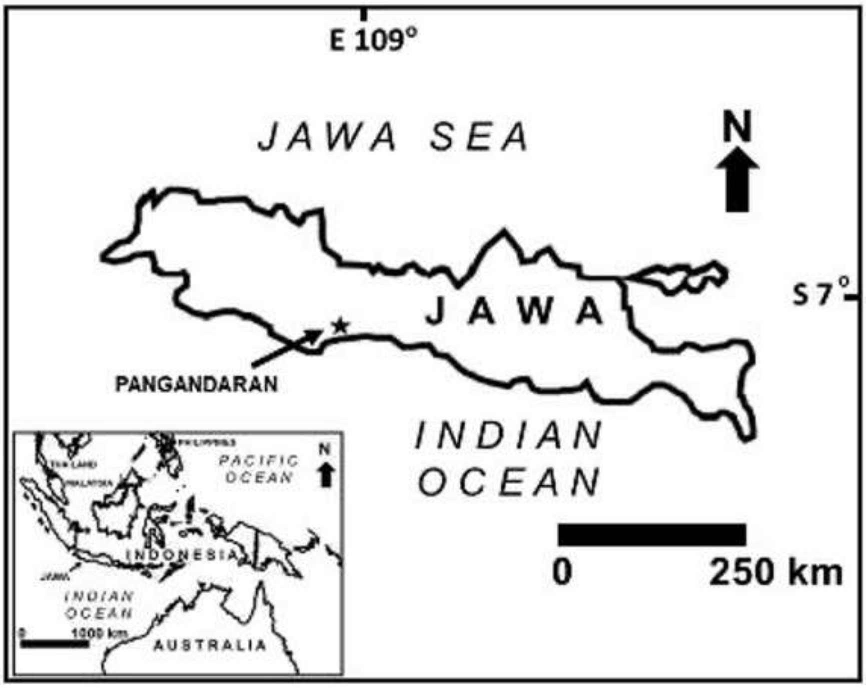


Figure 1. Location map of the Pangandaran tsunami and paleotsunami deposits in Java Island, Indonesia (star sign: 7°41'44.21"S; 108°45'42.47"E).

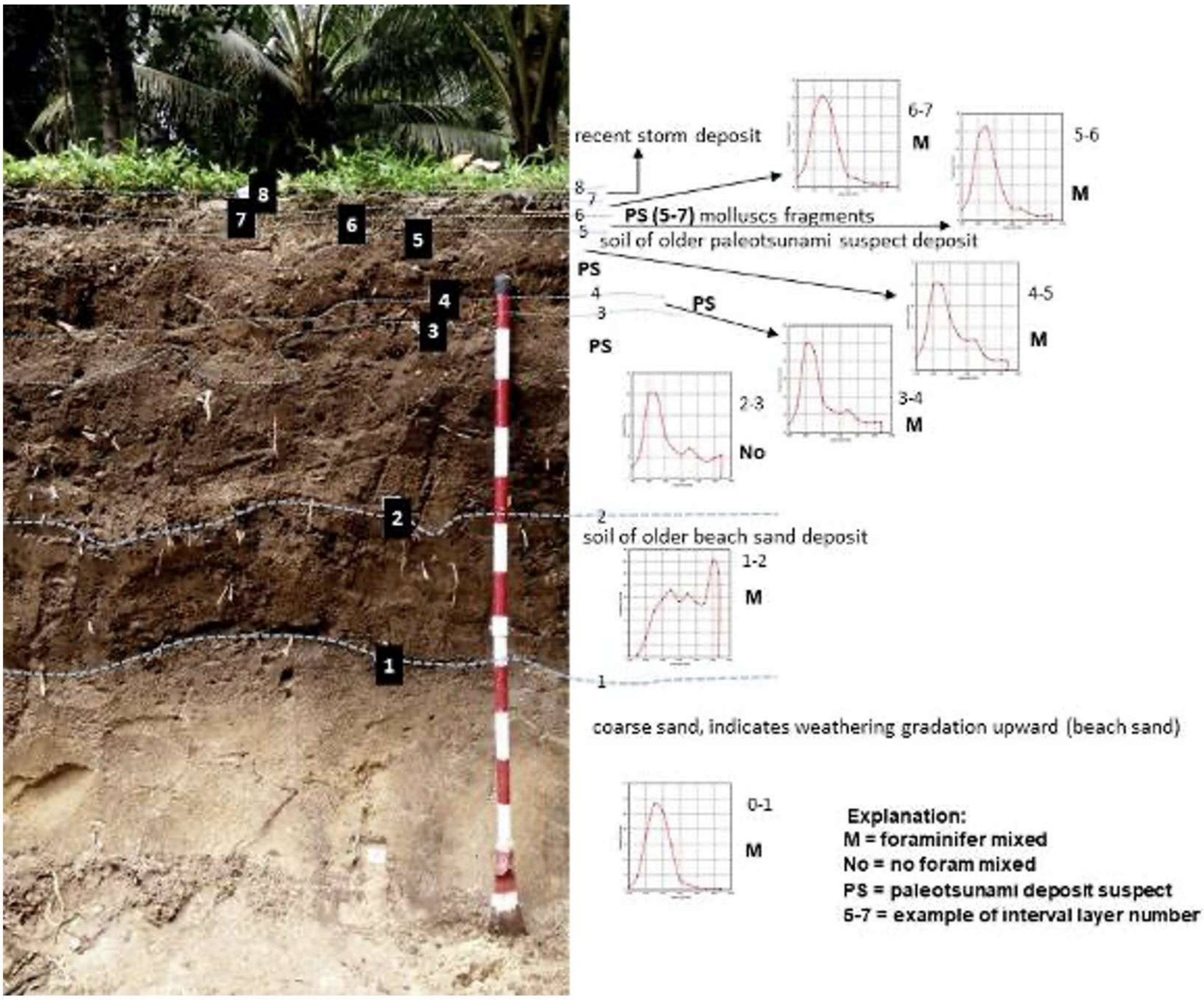


Figure 2. Stratigraphic profile of tsunami and paleotsunami deposits in Karapyak Beach, Pangandaran area. Grain size distribution curves for each layer are shown on the right-hand side. One scale bar in the red-and-white stick is 10 cm-long.

pounded, and soaked for one day in 0.1 M hydrogen peroxide to accelerate the disintegration process to get sample residues. After this process, the powder was washed several times through 74 – 125 µm sieves. The wet residues were dried in the oven for six hours. Faunal content was identified from the dry residues using a Nikon SMZ15000 binocular microscope. The results of faunal analysis were used to determine the depositional paleoenvironment based on benthic foraminifera content (Adisaputra et al., 2010) and on bathymetric reference (Tipsword et al., 1966). It was also used to determine whether a mixing had occurred between shallow marine (less than 20 m depth) and deeper marine (20 – 200 m depth) fauna.

Grain size analysis was carried out to understand the processes of paleotsunami sediment deposition (Visher, 1969) and to assess whether the sedimentation was influenced by one or more ocean current systems (Yawsangratt et al., 2012). Total sediments weighing 100 grams were sieved to 4760-44 µm fractions and were weighed for each designated fraction. The weight was normalized against the total amount of sediments, and by then the resulting grain sizes were plotted to generate a grain size distribution curve.

RESULTS

The 2006 Tsunami Deposit

The 2006 tsunami deposit is characterized by light brown loose sand with thicknesses varying from 7 to 3 cm (Layers 5-7 in Figure 2), overlying a dark brown paleosol layer with erosional contact. A thin layer that varies in thickness is locally present just above the erosional contact, with coarser grain embedded in a non-laminated matrix in the lower part of the layer that gradually changes into medium to fine sand-size in the upper part. The lower part contains several unbroken mollusc shells of *Neritina* sp. (Figure 3) and coral clasts, igneous rock fragments, and anthropogenic products (roof tiles). The grain size distribution curves

Figure 3. A 2006 tsunami deposit layer in Pangandaran, characterized by light brown color with still-intact mollusc clasts of *Neritina* sp. (M) and lithic fragments (L). The top of deposit layer is marked with number 7 label. Scale bar = 5 cm.

for the bottom part are slightly bimodal and become unimodal at the top. According to Adisaputra et al. (2010), analysis of the tsunami deposit origins based on foraminifera study suggests a mixture of materials from inner neritic (0 – 20 m), middle neritic (to a depth of about 60 m) and outer neritic (100 – 200 m) as indicated by the presence of benthic foraminifera *Ammonia* sp., *Lagena* sp., *Bulimina* sp., *Bolivina* sp., and *Gyroidina* sp.

Paleotsunami Deposit

The stratigraphic section presented in Figure 2 is delineated as follows:

Layer 1-2 (Figure 2) comprises lighter brown materials (compared to the underlying paleosol layer), shows erosional contact with the paleosol layer below, and locally contains fine-sized molluscs and coral clasts at the contact area. This layer got more intensely weathered upwards and formed paleosol, on which the next sediments were deposited. The layer thicknesses vary on average by about 35 cm thick with a polymodal grain size distribution curve. Benthic foraminifera analysis indicates a mixture of materials from inner neritic (0 – 20 m) and shallow middle neritic (20 – 50 m), carried from the ocean to the coast. Index benthic foraminifera found in this layer are *Ammonia* sp. and *Bolivina* sp.

Layer 2-3 (Figure 2) contains lighter brown materials (compared to the underlying paleosol layer) and shows erosional contact at the bottom. Fine-sized molluscs and coral fragments are found in some bottom parts of the contact area. This layer was more intensely weathered upwards and forming paleosol, on which the next paleotsunami deposits were deposited. The average thickness of the layer varies from 35 to 40 cm with a polymodal grain size distribution curve. Benthic foraminifera analysis shows no evidence of paleotsunami material mixing from different bathymetric levels. Foraminiferal test in this layer is composed mainly of *Ammonia* spp. without the presence of other index foraminifera. The result indicates that some parts of the deposits are erosional products in the inner neritic environment (less than 20 m depth). Nevertheless, a large amount of still-intact mollusc shells (genus *Turbo* sp. in Figure 4) and coral fragments (Figure 5) is found floating in a coarse sand-sized matrix.

Figure 4. A mollusc clast (still-intact; genus *Turbo* sp.) is embedded in a paleotsunami deposit (Layer 2-3).

Layer 3-4 (Figure 2) shows bottom erosional contact and the materials have lighter brown color compared to the paleosol layer below. It locally contains fine-sized broken mollusc shells, coral clasts, and rock fragments, embedded in a coarse sand-sized matrix at the bottom of its contact area. This layer was more intensely weathered upwards to form paleosol, on which the next paleotsunami deposits were deposited. The average thickness of the layer is about 5 – 7 cm with a bimodal grain size distribution curve. Benthic foraminifera analysis indicates a mixture of paleotsunami deposit materials from inner neritic (0 – 20 m) and outer neritic (100 – 200 m) of the bathymetric zones. Index benthic foraminifera found in this layer are an association of *Ammonia* sp., *Dentalina* sp., and *Gyroidina* sp.

Layer 4-5 (Figure 2) reveals lighter brown materials with an erosional contact to the underlying paleosol layer. Fine-sized mollusc clasts and coral fragments are locally found in the bottom of the contact area. This layer became more intensely weathered upwards to form paleosol, on which the next layer was deposited. The average thickness of the layer is 10 – 15 cm with a bimodal grain size distribution curve. Benthic foraminifera analysis implies a mixture of paleotsunami material origins from inner neritic (0 – 20 m) and shallow middle neritic (to a depth of about 60 m). Foraminifera found in this deposit layer are *Ammonia* sp. and *Lagena* sp. Anthropogenic products (e.g., roof tiles) and rock fragments are found floating in a medium to coarse sand-sized matrix.

Figure 5. A coral fragment floating in a paleotsunami deposit. Number 2 label is the bottom contact of paleotsunami deposit (overlain, lighter color) upon the underlying paleosol (darker color).

DISCUSSION

Characteristics comparison with the 2006 tsunami deposit in Karapyak Beach, Pangandaran leads to exposing four suspected paleotsunami deposits that share similar characteristics. They comprise coarse sand materials with a lighter color appearance, compared to the underlying paleosol layers. Some areas of the bottom part of the layers contain fine particle sizes of broken mollusc shells and coral fragments. They have different thicknesses and each layer shows lateral thickness variations with bottom erosional contacts. Similar to the 2006 tsunami deposit, several layers in paleotsunami deposits contain still-intact mollusc shells and rock fragments that are floating in a coarse sand-sized matrix. Benthic foraminifera analysis on Layer 2-3 shows no evidence of mixing of paleotsunami materials from various bathymetric levels and is assumed to be transported from a depth of less than 20 m. Nevertheless, Layer 2-3 shows similarities to those of the 2006 tsunami deposit with regard to their outcrop characteristics, the still-intact mollusc shells and coral fragments that locally found in the layer, and their grain size distribution curves.

CONCLUSION

Based on the comparison to the 2006 tsunami deposits, four suspected pre-2006 paleotsunami deposits can be identified at Karapyak Beach, Pangandaran area. They share similar characteristics yet still can be observed and distinguished. The deposits consist of loose sand materials overlying dark brown paleosol layers and show bottom erosional contacts. Their overall thicknesses vary, showing lateral changes from the thinnest variation of 5 – 7 cm (Layer 3-4) to the thickest one of 35 – 40 cm (Layer 2-3). The bottom parts of the deposits contain coarse grains that gradually change into medium to fine sand-sized grains in the upper parts. Fine-sized broken mollusc shells, embedded in a non-laminated (homogeneous) matrix, are locally present at these bottom parts. Coral and rock fragments, as well as anthropogenic products (e.g., roof tiles), may also be found. The upper parts of the deposits, however, generally lack those types of fragments. Grain size analysis indicates a mixture of fine and coarse grains, as shown by bimodal grain size distribution curves, inferring that poor sorting at the lower part of tsunami and paleotsunami deposits was due to high energy flow. The fining upward sequences in the upper part of tsunami and paleotsunami deposits are regarded as having been deposited by a waning flow during pre-backwash deposition. Similarly, benthic foraminifera analysis indicates a mixture of materials from shallow and deep marine environments, i.e., from inner neritic (0 – 20 m) to middle - outer neritic (20 – 200 m).

ACKNOWLEDGEMENTS

We are extremely grateful to the Head of Geological Engineering Study Program, also thanking the Dean of Faculty of Earth Sciences and Technology, Institut Teknologi Bandung (ITB), for the valuable opportunity given to conduct this study. The field research was funded by Paleontology Laboratory, Geological Engineering Study Program, Faculty of Earth Sciences and Technology, Institut Teknologi Bandung (ITB). We are most grateful to the following people for their help for the improvement of this paper in fieldwork laboratory analysis and providing literatures: Yahdi Zaim, Mika Rizki Puspaningrum, Nadila Novandaru, Wahyu Dwijo Santoso, Nurcahyo Indro Basuki, Ellya, Khoiril Anwar Maryunani, Nur Rochim, and M. Rifky Ghifari.

REFERENCES

Adisaputra, M. K., Hendrizan, M., and Kholiq, A., 2010. *Katalog Foraminifera Perairan Indonesia*. Kementerian Energi dan Sumber Daya Mineral, Puslitbang Geologi Kelautan, Bandung, 198p.

Ambarjaya, B. S., 2006. *Tsunami Sang Gelombang Pembunuh (The Tsunami of the Killer Waves)*, CV Karya Mandiri Pratama, Jakarta, 68p.

Aswan, Zaim, Y., Rizal, Y., Sukanta, I. Y., Anugrah, S. D., Hascaryo, A. T., Gunawan, I., Yatimantoro, T., Weniza, Hidayanti, and Hawati, P., 2017. Age Determination of Paleotsunami Sediments around Lombok Island, Indonesia and Identification of Their Possible Tsunamigenic Earthquakes. *Earthquake Science*, 30(2):107-113.

Cuven, S., Paris, R., Falvard, S., Miot-Noirault, E., Benbakkar, M., Schneider, J., and Billy, I., 2013. High-resolution Analysis of a Tsunami Deposit: Case-study from the 1775 Lisbon Tsunami in Southwestern Spain. *Marine Geology*, 337:98-111.

Dahanayake, K., and Kulasena, N., 2008. Geological Evidence for Paleo-Tsunamis in Sri Lanka. *Science of Tsunami Hazards*, 27(2):54-61.

De Martini, P. M., Barbano, M. S., Pantosti, D., Smedile, A., and Pirotta, C., 2012. Geological Evidence for Paleotsunamis along Eastern Sicily (Italy): An Overview. *Natural Hazards and Earth System Science,* 12(8):2569-2580.

Hawkes, A. D., Bird, M., Cowie, S., Grundy-Warr, C., Horton, B. P., Hwai, A. T. S., Law, L., Macgregor, C., Nott, J., Ong, J. E., Rigg, J., Robinson, R., Tan-Mullins, M., Sa, T. T., Yasin, Z., and Aik, L. W., 2007. Sediments Deposited by the 2004 Indian Ocean Tsunami along the Malaysia-Thailand Peninsula. *Marine Geology*, 242(1-3):169-190.

Jackson, K. L., 2008. *Paleotsunami History Recorded in Holocene Coastal Lagoon Sediments, Southeastern Sri Lanka* [Unpublished MSc thesis]. University of Miami, Miami.

Lespez, L., Lescure, S., Saulnier-Copard, S., Glais, A., Berger, J., Lavigne, F., Pearson, C., Virmoux, C., Clka, S. M., and Pomadere, M., 2021. Discovery of a Tsunami Deposit from the Bronze Age Santorini Eruption at Malia (Crete): Impact, Chronology, Extension. *Nature Portfolio*, 11:1-14.

Løvholt, F., Kűhn, D., Bungum, H., Harbitz, C. B., and Glimsdal, S., 2012. Historical Tsunamis and Present Tsunami Hazard in Eastern Indonesia and the Southern Philippines. *Journal of Geophysical Research*, 117:1-19.

Naruse, H., Arai, K., Matsumoto, D., Takahashi, H., Yamashita, S., Tanaka, G., and Murayama, M., 2012. Sedimentary Features Observed in the Tsunami Deposits at Rikuzentakata City. *Sedimentary Geology*, 282:199-215.

Nentwig, V., Bahlburg, H., Górecka, E., Huber, B., Bellanova, P., Witkowski, A., and Encinas, A., 2018. Multiproxy Analysis of Tsunami Deposits – The Tirúa Example, Central Chile. *Geosphere*, 14(3):1067-1086.

Pilarczyk, J. E., Sawai, Y., Matsumoto, D., Namegaya, Y., Nishida, N., Ikehara, K., Fujiwara, O., Gouramanis, C., Dura, T., and Horton, B. P., 2020. Constraining Sediment Provenance for Tsunami Deposit Using Distributions of Grain Size and Foraminifera from the Kujukuri Coastline and Shelf, Japan. *Sedimentology*, 67:1373-1392.

Rhodes, B., Tuttle, M., Horton, B., Doner, L., Kelsey, H., Nelson, A., and Cisternas, M., 2006. Paleotsunami Research. *EOS*, 87(21):205-209.

Rizal, Y., Aswan, Zaim, J., Puspaningrum, M. R., Santoso, W. D., and Rochim, N., 2019. Late Miocene to Pliocene Tsunami Deposits in Tegal Buleud, South Sukabumi, West Java, Indonesia. *Modern Applied Science*, 13(12):80-92.

Scicchitano, G., Costa, B., Di Stefano, A., Longhitano, S. G., and Monaco, C., 2010. Tsunami and Storm Deposits Preserved within a Ria-type Rocky Coastal Setting (Siracuse, SE Sicily). *Zeitschrift für Geomorphologie*, 54(3):51-77.

Tipsword, H. L., Setzer, H. M., and Smith, F. L. Jr., 1966. Interpretation of Depositional Environment in Gulf Coast Petroleum Exploration from Paleoecology and Related Stratigraphy. *Transaction Gulf Coast Association of Geological Societies*, 16:119-129.

Visher, G. S., 1969. Grain Size Distributions and Depositional Processes. *Journal of Sedimentary Petrology*, 39(3):1074-1106.

Yawsangratt, S., Szczuciński, W., Chaimance, N., Chatprasert, S., Majewski, W., and Lorenc, S., 2012. Evidence of Probable Paleotsunami Deposits on Kho Khao Island, Phang Nga Province, Thailand. *Natural Hazards*, 63:151-163.

Yudhicara, Zaim, Y., Rizal, Y., Aswan, Triyono, R., Setiyono, U., and Hartanto, D., 2013. Characteristics of Paleotsunami Sediments: A Case Study in Cilacap and Pangandaran, Jawa, Indonesia. *Indonesian Journal of Geology*, 8(4):163-175.

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

Yan Rizal, Aswan, Reynaldy Fifariz, and Adityan Mulia

Geological Engineering Study Program, Faculty of Earth Sciences and Technology, Institut Teknologi Bandung (ITB), Jl. Ganesha 10 Bandung, Indonesia (40132).

Corresponding author: yan@gl.itb.ac.id

(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 terhadap19 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 allochtonous, 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 108.12517710º - 108.17064020º E and 6.800410490º - 6.845316900º 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).

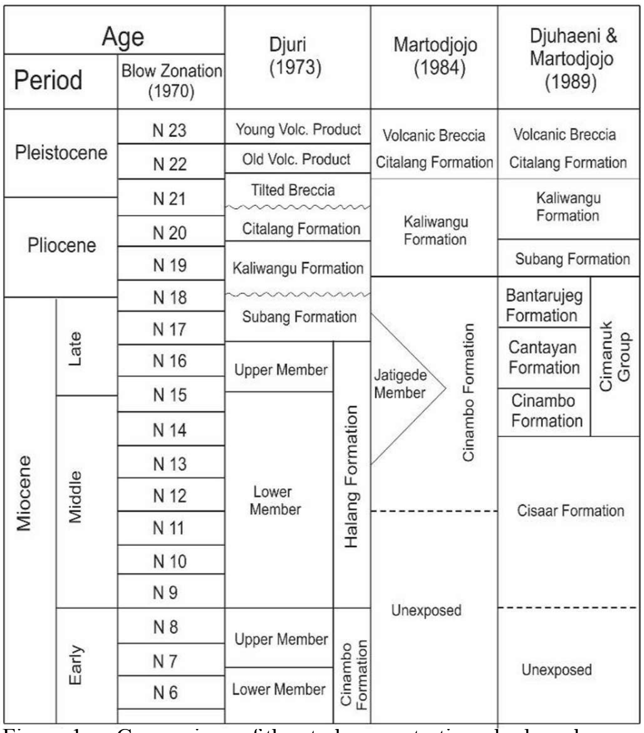


Figure 1. Comparison of the study area stratigraphy based on previous studies (translated from Nova et al, 2018)

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

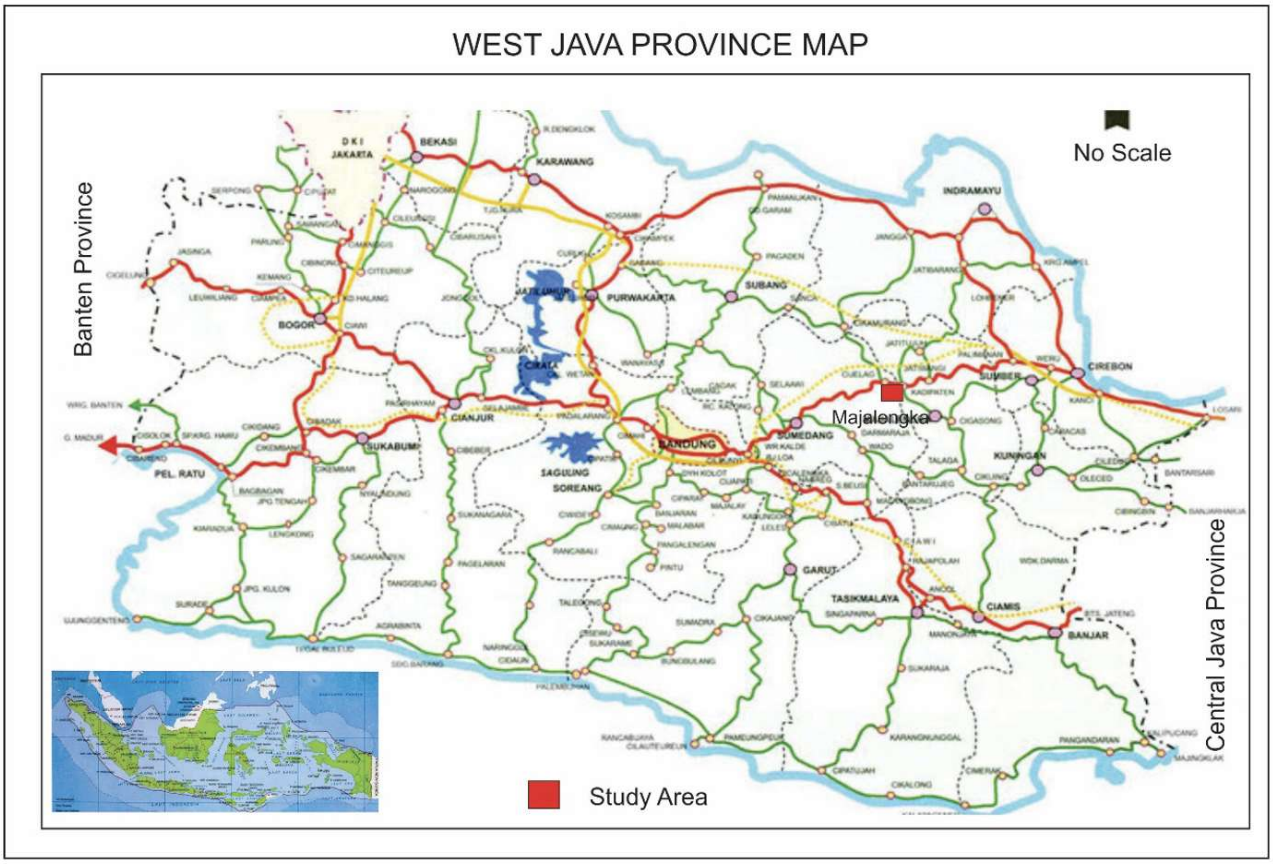


Figure 2. Location map of the study area (108.12517710º - 108.17064020º E and 6.800410490º - 6.845316900º S)

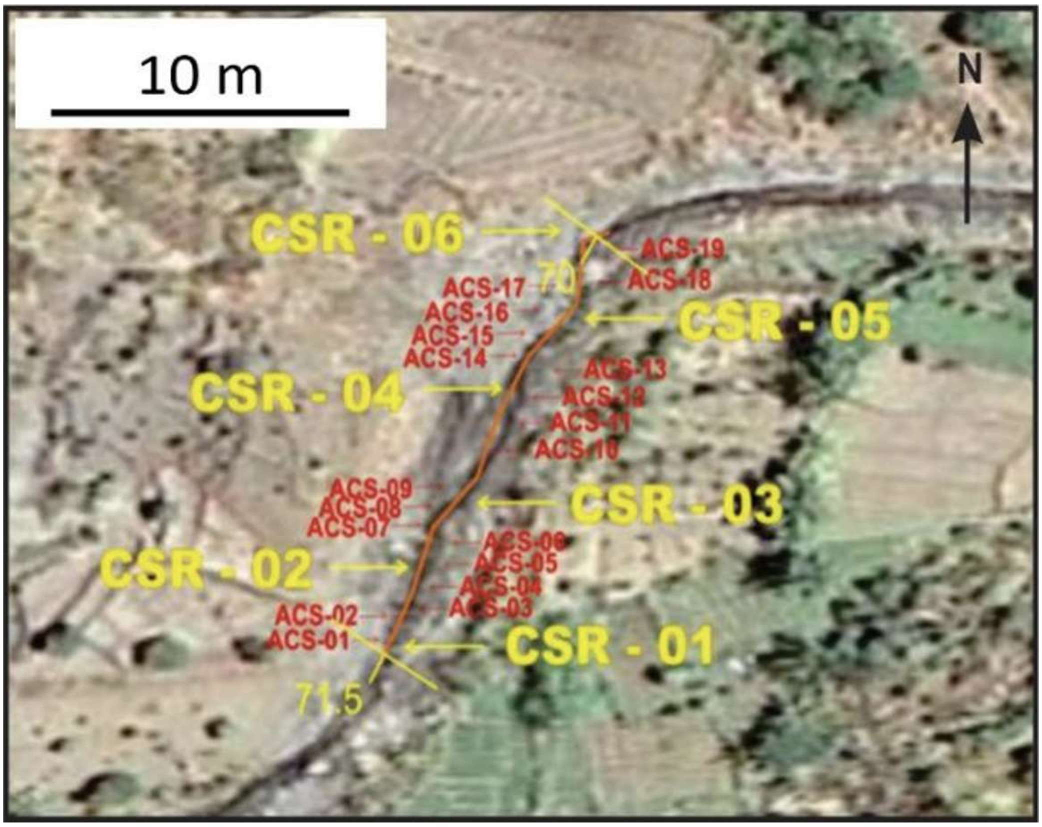


Figure 3. location of traverse line, observation site (yellow color), sampling location and sample number (red color) in Cisaar River

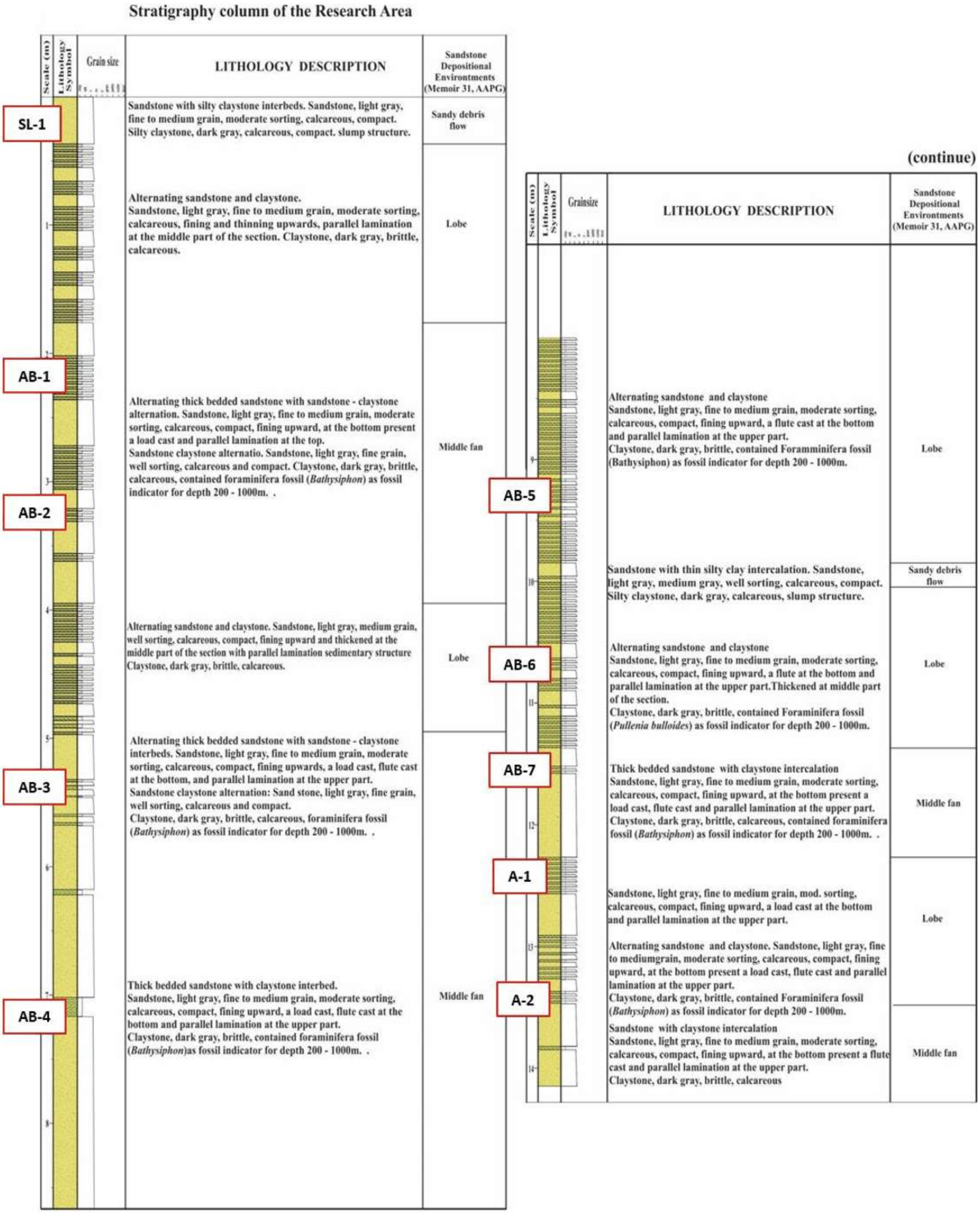


Figure 4. Detailed description of the stratigraphic section in the study area. Sandstone depositional environments interpretation based on Howell and Nomark in Scholle and Spearing (1982). Microfossils sampling locations for. Table 1 shown inside red box.

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

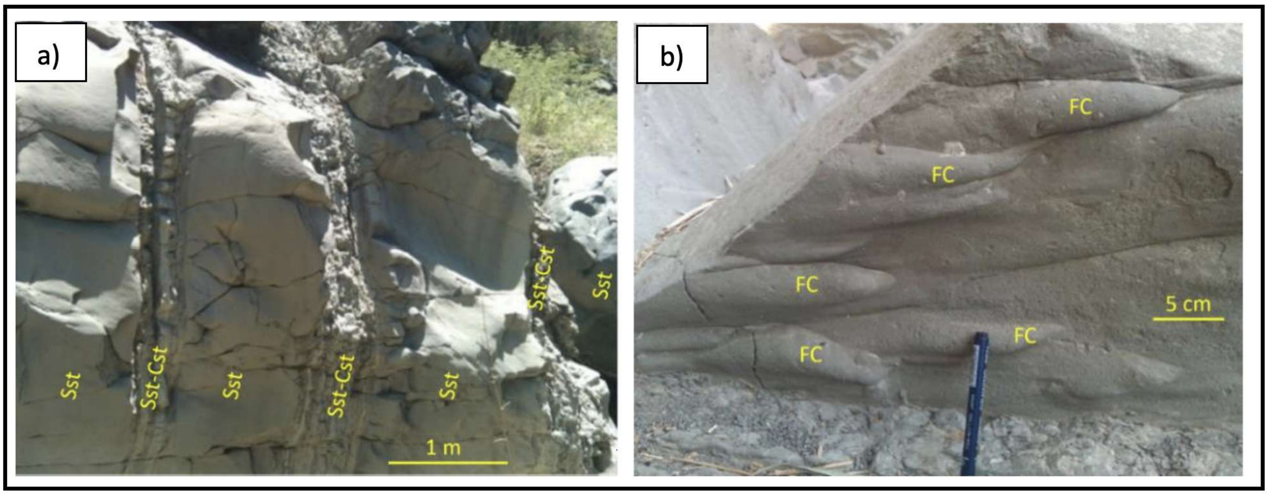


Figure 5. a) Sandstone (Sst) and interbedded claystone (Cst) and sandstone layers at CSR-01 location.b) Flute casts (FC) on the base of a sandstone layer at CSR-01 location.

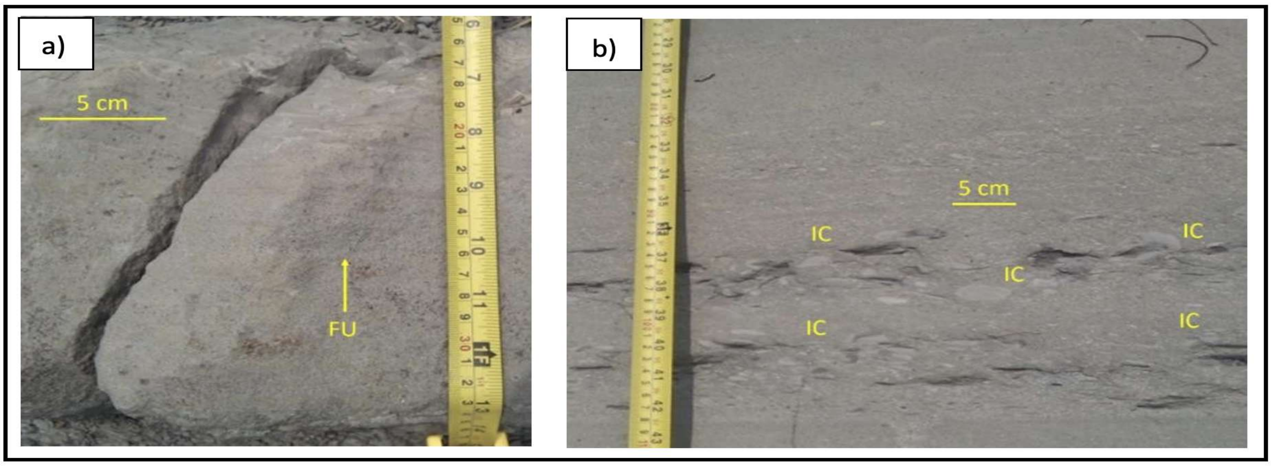


Figure 6. a) Fining upward (FU) succession within sandstones resulted from gravity-driven processes deposition. Photo was taken at the lower part of a sandstone layer at CSR-02 location. b) Mud drape pseudo layers overlain by parallel lamination at CSR-02 location.

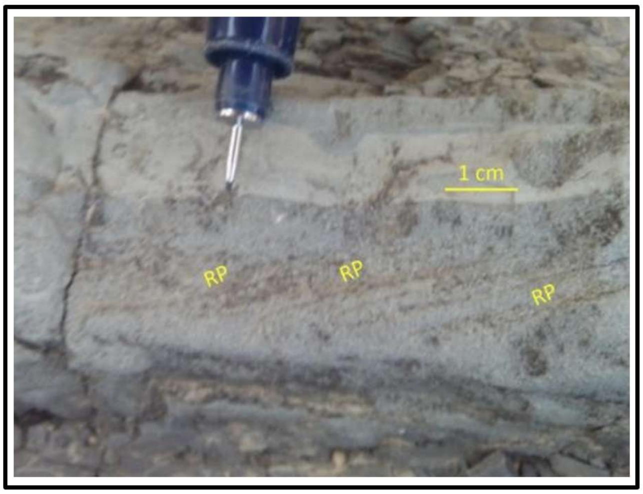


Figure 7. Ripple (RP) marks on a sandstone layer at CSR-05 location.

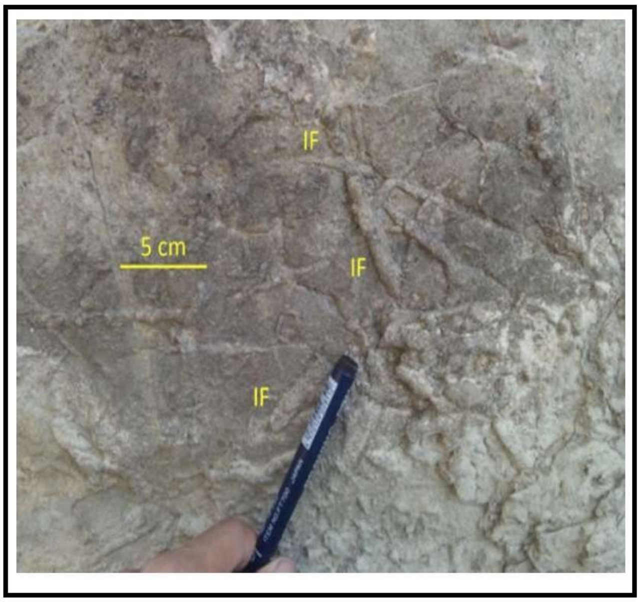


Figure 8. Ichnofossils (IF) at the bottom of the sandstone layer at CSR-02 location.

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 anastamotic (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, Sabelleria, 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. Uliarense*, 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

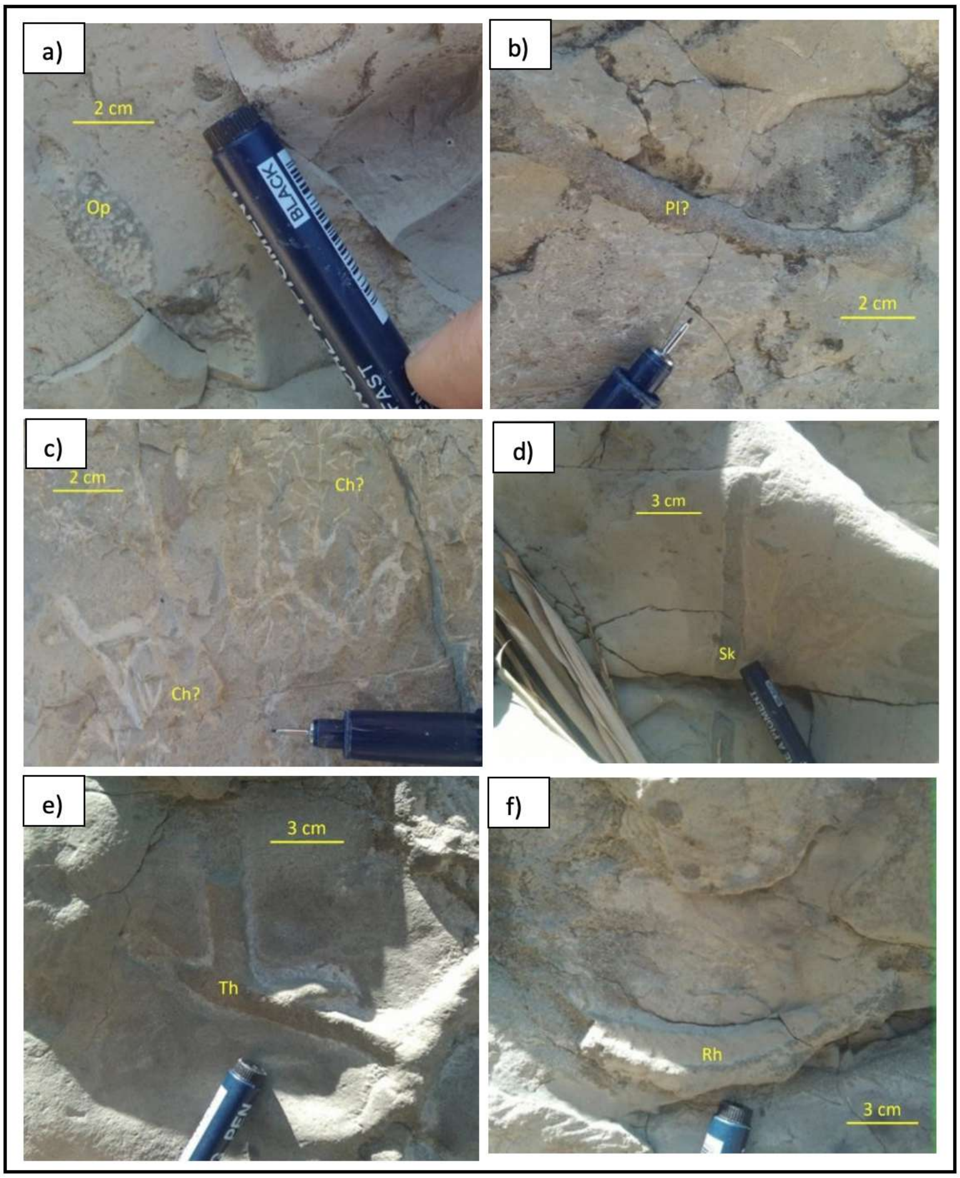


Figure 9. a) *Ophiomorpha* (Op) on sandstone layer at CSR-05 location. b) *Planolites* (Pl) in a sandstone layer at CSR-03 location. c) *Chondrites* (Ch) on a sandstone layer at CSR-06 location. d) *Skolithos* (Sk) on a sandstone layer CSR-04 location. e) *Thalassinoides* (Th) on a sandstone layer at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

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

Sample Position	Fossil Name																												Depth				
	Planktonic									Benthic																							
	Globigerina bulloides	Globigerinoides ruber	Globigerinoides sacculifer	Orbulina universa	Globorotalia continuosa	Globigerinella siphonifera	Globigerina selli	Globorotalia menardii	Foraminifera fragments	Pararotalia sp.	Rotalia canui	Pullenia bulloides	Marsipella elongata	Bathysiphon filiformis	Botellina labyrinthica	Cassidulina obtusa	Arenoturrispirillina Sp	Oolina emaciata	Rotorbis auberii	Tubinella funalis	Dentalina filiformis	Protobotellina cylindrica	Textularia sp. 3	Loeblichopsis cylindricus	Nodulina dentaliniformis	Dentalina ittai	Pyrgo murrhyna	Siphogenerina striata	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					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).

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 microfosssil 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.

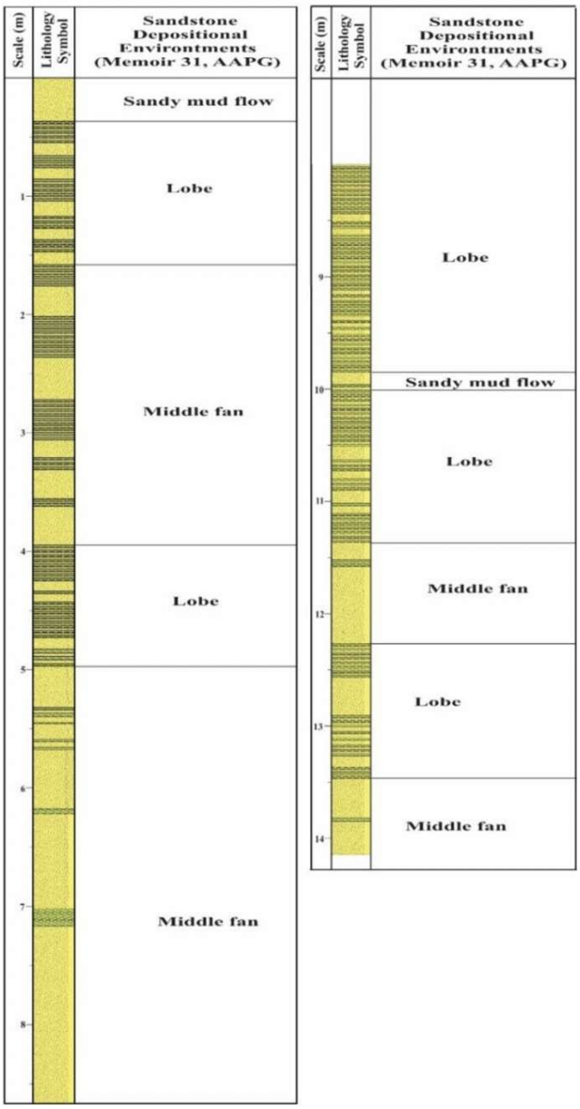


Figure 10. The Cisaar Formation sandstones in the study area and their depositional environments based on Howell and Nomark in Scholle and Spearing (1982).

Figure 12. Slump structures at CSR-06 location.

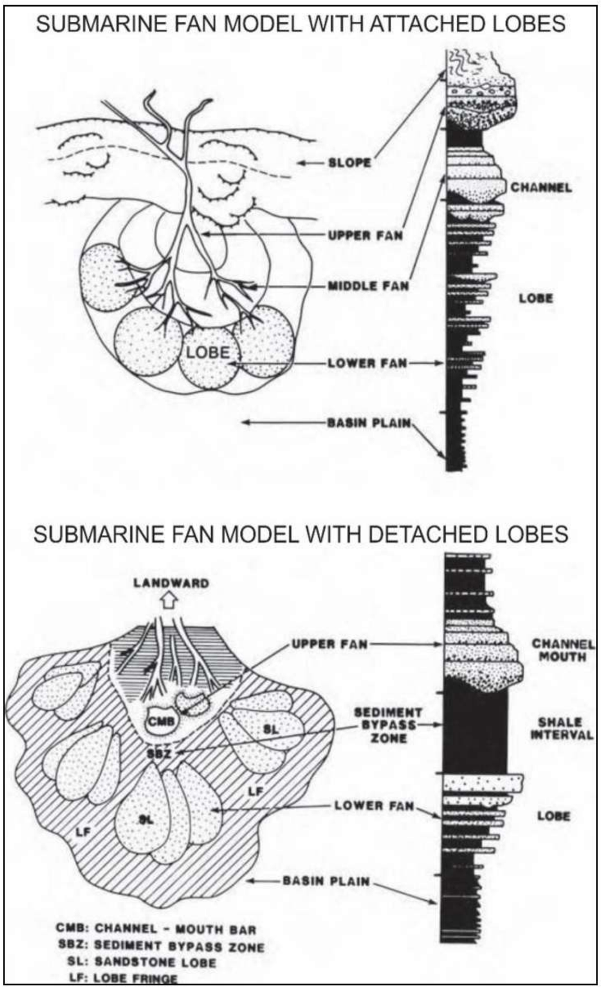


Figure 11. Depositional model of submarine fans (Shanmugam, 2006).

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

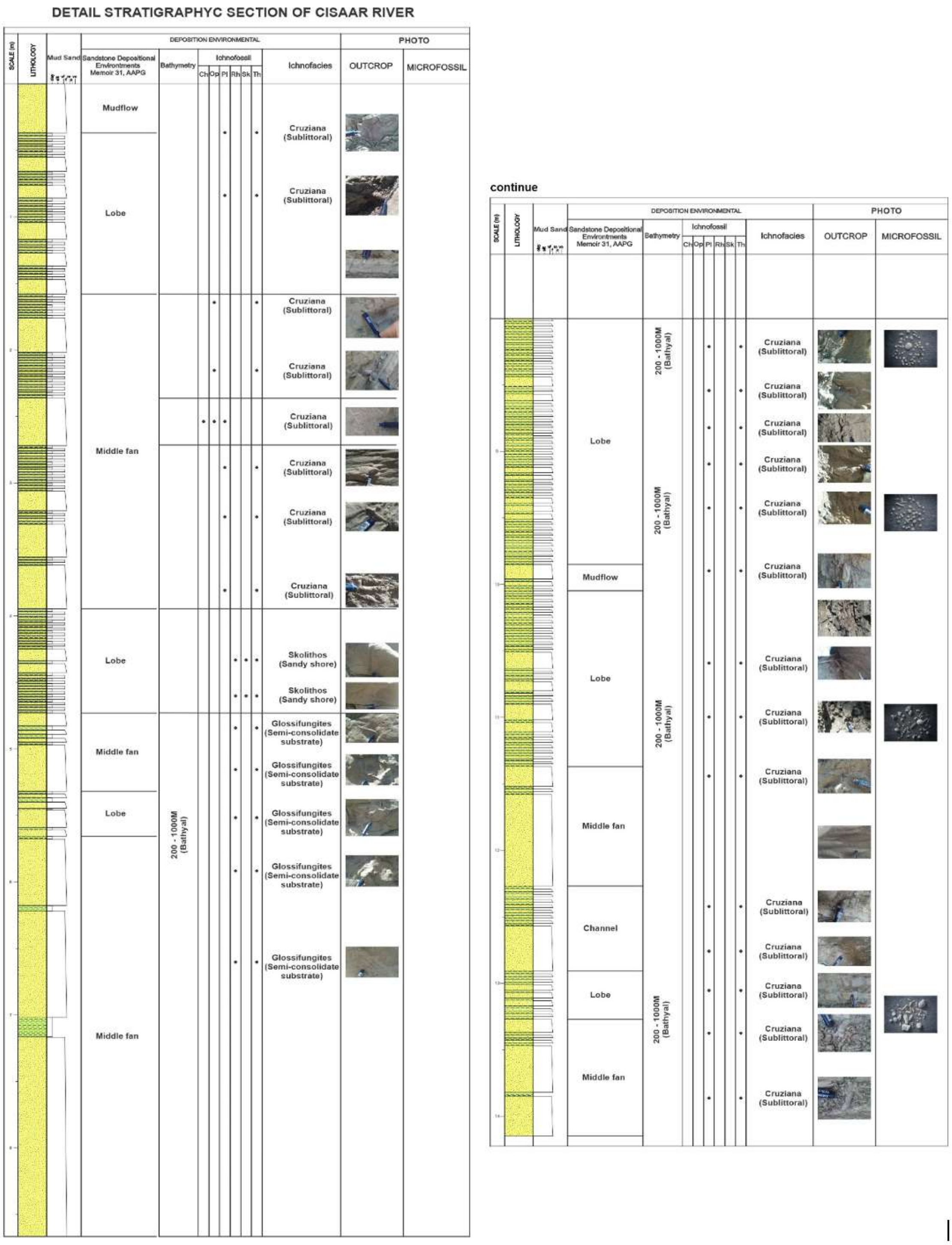


Figure 13. Detailed description of the whole stratigraphic section with photographs of ichnofossils, outcrops, and microfossils.

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).

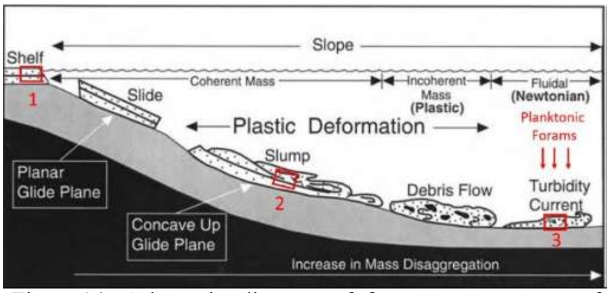


Figure 14. Schematic diagram of four common types of processes that transport sediment to the deep-water environment and are affected by gravity (Shanmugam et al., 1994).

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, *Lamlellibrachia luymesi* inhabit 500-800 m water depth, while *Lamlellibrachia 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 *Lamlellibrachia satsuma* can only survive a maximum of up to 100 m water depth, conversely, *Lamlellibrachia luymesi* 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 ichnofosil 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 consollidated 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.

REFERENCES

Blow, W. H., 1969, Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy, *in Proceedings of the First International Conference Planktonic Microfossils 1967*: Ej Brill, p. 199-242.

Bouma, A. H., 1962, *Sedimentology of Some Flysch Deposits, A Graphic a pproach to Facies Interpretation.* Amsterdam (Elsevier), v. 168, p. 168.

Byers, C. W. (1982). Geological significance of marine biogenic sedimentary structures. In P. L. McCall & M. J. S. Tevesz (Eds.), *Animal-sediment relation: The biogenic alteration of sediments* (Vol. 2, pp. 221–256). Springer Science+Business Media New York.

Djuhaeni, and S. Martodjojo, 1989, *Stratigrafi Daerah Majalengka dan hubungannya dengan tatanama satuan lithostratigrafi di Cekungan Bogor: Geologi Indonesia*, PPPG-Bandung, p. 227–252.

Djuri, H. M. D., 1973, *Peta Geologi Lembar Arjawinangun*, Jawa Skala 1: 1000.000: Direktorat Geologi Bandung.Ekdale, A. A. (1988). Pitfalls of paleobathymetric interpretations based on trace fossil assemblages. *PALAIOS, 3*(5), 464–472.

Fernández & Pazos, 2012, Ichnology of Marginal Marine Facies of the Agrio Formation (Lower Cretaceous, Neuquén Basin, Argentina) at its Type Locality, *Ameghiniana,* 49(4): 505-524. DOI:10.5710/AMGH.23.7.2012.439

Follmi, K. B., and Grimm, K. A., 1990, Doomed pioneers: gravity-flow deposition and bioturbation in marine oxygen-deficient environments, *Geology*, 18(11): p. 1069–1072, doi: 10.1130/0091-7613(1990)018<1069: DPGFDA>2.3.CO;2.

Frey, R. W., 1971, *Trace fossils: a field guide to selected localities in Pennsylvanian, Permian, cretaceous, and tertiary rocks of Texas and related papers: School of Geoscience, Louisiana State University*.

Frey, R. W., J. D. Howard, and W. A. Pryor, 1978, *Ophiomorpha*: its morphologic, taxonomic, and environmental significance. *Palaeogeography, Palaeoclimatology, Palaeoecology*,23: 199–229.

Frey, R. W., and S. G. Pemberton, 1985, Biogenic structures in outcrops and cores. I. Approaches to ichnology, *Bulletin of Canadian Petroleum Geology*, 33(1): 72–115.

Frey, R. W., S. G. Pemberton, and T. D. A. Saunders, 1990, Ichnofacies and bathymetry: a passive relationship. *Journal of Paleontology*, 64(1): 155–158, doi: 10.1017/s0022336000042372.

Fürsich, F. T., 1974, Ichnogenus *Rhizocorallium*, *Paläontologische Zeitschrift*, 48(1–2): 16–28, doi: 10.1007/BF02986987.

Grimm, K.A., and Follmi,K. B, 1994, Doomed Pioneers: Allochtonous Crustacean Tracemakers in Anaerobic Basinal Strata, Ologo-Miocene San Gregorio Formation, Baja California Sur,Mexico, *Palaios*, 9: 313-334.

Kelling, G., and E. K. Walton, 1957, Load-cast Structures: Their Relationship to Upper-Surface Structures and their Mode of Formation, *Geological Magazine*, 94(6): 481–490, doi: 10.1017/S0016756800070175.

Knaust, 2013, The ichnogenus *Rhizocorallium*: Classification, trace makers, palaeoenvironments and evolution, *Earth-Science Reviews*, 126: 1 – 47, Elsevier BV, doi: 10.1016/ j.earscirev.2013.04.007

Lowe, D. R., 1982, Sediment gravity flows: II.

Depositional models with special reference to the deposits of high-density turbidity currents, *Journal of Sedimentary Petrology*, 52(1): 279–297, doi: 10.1306/212f7f31-2b24-11d7-8648000102c1865d.

Mángano, M. G., Buatois, L. A., West, R. R., Maples, C. G, 2002, Ichnology of a Pennsylvanian Equatorial Tidal Flat- The Stull Shale Member at Waverly, Eastern Kansas, *Bulletin of Kansas Geological Survey,* 245: 1-133.

Martodjojo, S., 1984, Evolusi Cekungan Bogor: Jawa Barat, D*isertasi Doktor ITB*, unpublished.

Miura, T., J. Tsukahara, and J. Hashimoto, 1997, *Lamellibrachia satsuma*, a new species of Vestimentiferan worms (Annelida: Pogonophora) from a shallow hydrothermal vent in Kagoshima Bay, Japan, *Proceedings of the Biological Society of Washington*, 110(3): 447–456.

Nielsen, J. K., Hansen, K. S., Simonsen, L., 1996, Sedimentology and ichnology of the Robbedale Formation (Lower Cretaceous), Bornholm, Denmark, *Bulletin of the Geological Society of Denmark,* 43:115-131.

Nova. M. Z, Abdurrokhim, Firmansyah, Y., 2018, *Studi Litofasies dan Lingkungan Pengendapan, Formasi Halang pada Lintasan sungai Ciwaru,Majalengka , Jawabarat. Padjadjaran Geoscience Journal*, Vol. 2 no. 2.

Pemberton, S. G., 1992, *Applications of ichnology to petroleum exploration: Applications of ichnology to petroleum exploration*, doi:10.2110/cor.92.17.

Pemberton, S. G., Frey, R. W., 1982, Trace fossil nomenclature and the Planolites-Palaeophycus dilemma, *Journal of Paleontology,* v.56, no. 4, p. 843 – 881.Posamentier, H.W. and Walker, R.G., 2006, Deep-water Turbidite and Submarine Fans, *SEPM (Society for Sedimentary Geology)*, 84:399-520.

Scholle, P. A., and D. Spearing, 1982, Sandstone Depositional Environments: *AAPG Memoir 31*: AAPG.

Seilacher, A., 1967, Bathymetry of trace fossils, *Marine Geology*, 5(5–6): 413–428, doi: 10.1016/0025-3227(67)90051-5.

Shanmugam, G., 2006, *Deep-water processes and facies models: Implications for sandstone petroleum reservoirs*, Elsevier.

Shanmugam, G., 1996, High-density turbidity currents: Are they sandy debris flows? *Journal of Sedimentary Research*, 66(1): 2–10, doi: 10.1306/ D426828E-2B26-11D7-8648000102C1865D.

Shanmugam, G., L. R. Lehtonen, T. Straume, S. E. Syvertsen, R. J. Hodgkinson, and M. Skibeli, 1994, Slump and debris-flow dominated upper slope facies in the Cretaceous of the Norwegian and Northern North Seas (61–67 N): implications for sand distribution, *AAPG Bulletin*, 78(6): 910–937.

Thompson, F. C. 2003. Nomenclature and Classification, Principles of. Pp. 798-807. In Resh, V. H. & Carde, R. T. (Eds.), 2003, Encyclopedia of Insects, xxx + 1266 pp. Academic Press, San Diego

Vinn, O., Wilson, M. A., 2013, An event bed with abundant Skolithos burrows from the late Pridoli (Silurian) of Saaremaa (Estonia), *Carnets de Géologie*, 13(2):83-87, doi: 10.4267/2042/49316

Yanin, B. T., Baraboshkin, E. Y., 2013, *Thalassinoides* burrows (decapoda dwelling structures) in Lower Cretaceous sections of southwestern and central Crimea, *Stratigraphy and Geological Correlation,* 21(3):280-290._________Doi: 10.1134/ S086959381303009X.

STATISTICAL PARAMETERS ANALYSIS OF SEDIMENT GRAIN SIZE FROM RAYA RIVER BENGKAYANG REGENCY, WEST BORNEO

ANALISIS PARAMETER STATISTIK UKURAN BUTIR SEDIMEN DARI SUNGAI RAYA KABUPATEN BENGKAYANG, KALIMANTAN BARAT

Muhardi[1], Yusuf Arief Nurrahman[2], Risko[2], Muliadi[1], Kanti Rahayu[1], Heni Susiati[3]

1 Department of Geophysics, Faculty of Mathematics and Natural Sciences, Tanjungpura University, Pontianak, Indonesia

2 Department of Marine Science, Faculty of Mathematics and Natural Sciences, Tanjungpura University, Pontianak, Indonesia

3 National Atomic Energy Agency, Indonesia

Corresponding author: muhardi@physics.untan.ac.id

(Received 05 September 2021; in revised from 07 September 2021; accepted 06 February 2022)

DOI: 10.32693/bomg.36.2.2021.726

ABSTRACT : The study of the statistical analysis parameters of grain size in the waters of Sungai Raya was carried out in order to understand the characteristic of the sediment in the river and coastal areas. The grain size analysis was conducted by sieving method, afterwards, the statistical parameters including the average grain size, sorting, skewness, and kurtosis, were also analyzed. Sediment samples were acquired from six stations with each station consisting of three sampling points representing river west bank, river midstream, river east bank, and the coastal area consisting of five stations. The results of the sediment analyses showed that the average grain size in the river ranges from 1.23 to 2.77 mm, and on the beach area is between 1,52 - 2,59 mm, classified as fine sand, medium sand, very fine sand, and coarse sand with predominant fine sand in all stations. The results of the statistical parameter analysis of the grain size of the bottom sediment in the waters of Sungai Raya exhibit the average diameter value ranging from 1.23 to 2.77 mm, classified as fine sand to medium sand. This value indicates that the type of sediment in this location is dominated by silt with grain sizes ranging from < 0.05 - 0.002 mm. The sorting value ranges from 0.14 to 1.59 mm, categorized into moderately sorted, moderately well-sorted, very well sorted, and poorly sorted classes. The average value of skewness is 2.17 with the classification of the bed load being very fine. The kurtosis value ranges from 0.72 to 1.67 indicating the classification in these waters is platycuric, mesokurtic, leptokurtic, and very leptokurtic. These findings concluded that in the study area there is a variation in the angularity of the sediment grains due to the different hydrodynamic processes.

Keywords: Sediment, grain size, statistical parameters, Raya River waters

ABSTRAK: *Kajian tentang analisis parameter statistik ukuran butir di perairan Sungai Raya dilakukan untuk memahami karakteristik sedimen di bagian sungai dan daerah perairan pantai. Analisis ukuran butir dilakukan dengan metode pengayakan, kemudian dilakukan pula analisis parameter statistik yaitu rata-rata ukuran butir, sortasi, skewness dan kurtosis. Sampel sedimen di sungai diperoleh dari enam stasiun dengan masing-masing stasiun terdiri dari tiga titik pengambilan sampel dan bagian pantai terdiri dari lima stasiun. Hasil analisis parameter statisik ukuran butir sedimen dasar di bagian sungai diperoleh nilai diameter rata-rata berkisar antara 1.23 - 2.77 mm dan area pantai 1.52 - 2.59 mm dengan klasifikasi pasir halus hingga pasir sedang. Nilai tersebut menunjukkan bahwa jenis sedimen di lokasi ini didominasi oleh lanau dengan ukuran butir berkisar antara <0.05 - 0.002 mm. Nilai sortasi seluruh sampel sedimen diperoleh nilai berkisar antara 0.14 - 1.17 mm dengan empat jenis klasifikasi yaitu terpilah sedang, terpilah cukup baik, terpilah sangat baik, dan terpilah buruk. Untuk nilai skewness nilai rata-rata sebesar 2.17 mm dengan klasifikasi sedimen dasar condong sangat halus dan nilai kurtosis diperoleh berkisar antara 0.72 - 1.67 mm yang menunjukkan klasifikasi di perairan ini adalah tumpul, cukup tumpul, runcing dan sangat* *runcing. Hasil ini menunjukan bahwa di lokasi ini terjadi variasi keruncingan butiran sedimen yang disebabkan adanya proses hidrodinamika.*

Kata kunci: Sedimen, ukuran butir, parameter statistik, perairan Sungai Raya

INTRODUCTION

Rivers are very dynamic waters due to their flows which transport sediment to the estuary. Sediment and nutrient run-off cause siltation in the waters, thus decreasing the transport capacity of the rivers, leading to the flood hazard (Soemarwoto, 1978). The process of sediment deposition can be estimated through the distribution of sediment grain size (Nugroho and Basit, 2014; Purnawan et al., 2015). Grain size is the most basic aspect of sedimentary particles that affects sedimentation, transport, and deposition processes (Blott and Pye*,* 2001; Gemilang et al., 2018). One of the methods used to explore sediment transport pathways is by using the granulometric method. Grain size observation is determined by grain size analysis (methods: sieve, pipette, particle size analyzer by laser or settling, etc.). From the analysis, we could evaluate the average grain size, sorting, skewness and kurtosis. These values are used to interpret the distribution, transport, and deposition mechanisms of sediment in waters (Korwa et al*.,* 2013; Nugroho and Basit, 2014).

The grain size distribution in rivers is influenced by several hydrological factors, one of which is current velocity, particularly for suspended sediment (Purnawan et al., 2012). Slow current speeds are only able to transport sediments with smaller particle sizes and stronger current speeds will be able to carry coarser sediment particle sizes. Finer sediments are usually found further from river mouths and shores, while coarser sediments are generally found in coastal areas (Mukminin, 2008; Tanto et al*.,* 2017). The large potential for sedimentation is influenced by the reduced current velocity and wide river conditions (Lestari et al., 2017; Brookes, 1994; Li et al., 2007). Coarse sediments such as gravel and sand will settle faster in high turbulent areas as opposed to fine grain sediments such as mud (Darlan, 1996; Nugroho and Basit, 2014).

This research was conducted in the waters of Raya River Bengkayang Regency, West Kalimantan. The problem is that there is siltation in the downstream part of the river so it interferes with access to and from fishing boats. Moreover, considering this area is designated for Nuclear Power Plant (PLTN) by the government, it is imperative to understand the characteristics of the bottom sediments to provide initial information. Therefore, this study was conducted to determine the grain size of the sediments based on statistical parameters in the waters of the Raya River, in order to understand the characteristics of the sediment in the river and in the coastal area.

MATERIALS AND METHODS

Time and Study Area

This study was conducted in March 2021 in Raya River, Bengkayang Regency, West Kalimantan (Figure 1). Field activities involved hydrologic parameter measurements including river current velocity, water depth and sediment sampling. Sediment sampling was carried out by using an Ekman Grab sampler. We collected 3 samples from each station of sta. 1-6 in the river area, and only one sample was taken from stations 7 – 11 in the coastal area, thus in total there are 23 samples for this grain size analysis.

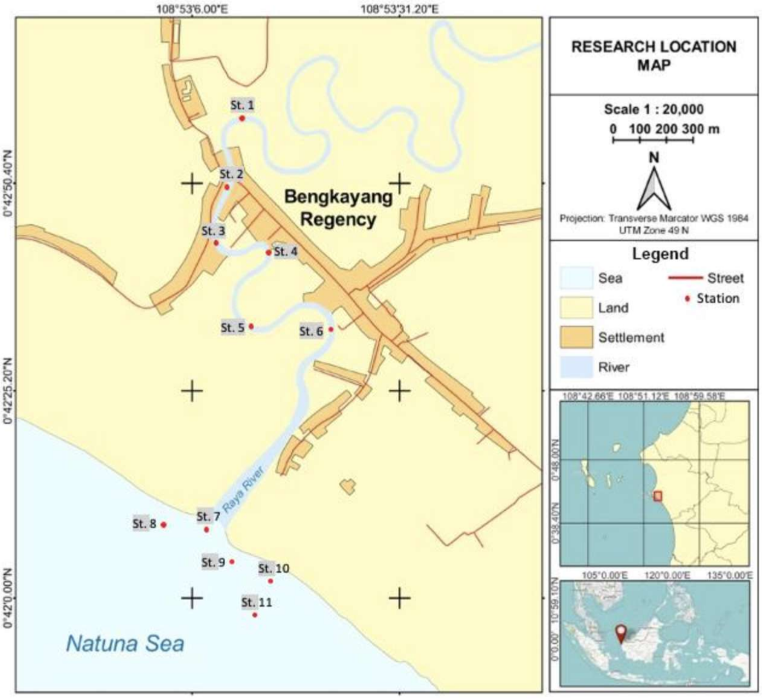


Figure 1. Location of sediment sampling along Raya river and coastal areas

Data analysis

Statistical parameters analysis of sediment grain size is generally characterized by four parameters, namely mean, sorting, skewness, and kurtosis. The grain size indicates the amount of energy derived from the flow of water or wind acting in the area (Folk and Ward, 1957; Friedman, 1967; Purnawan et al. 2015). Separation of grain size is carried out by sieve method using the following sieve sizes: 0.85; 0.425; 0.25; 0.18; 0.125; and 0.075 mm. Determination of the sediment type is based on the classification of Shepard Triangle Diagram (Dyer, 1986). Statistical parameters analysis of sediment in the form of mean size, sorting, skewness and kurtosis using Wentworth classification (1922).

The sediment grain size is presented in phi (φ) scale that is defined by (Folk and Ward, 1957) as:

$$\varphi = -\log_2 d \quad (1)$$

Where φ and d are grain size and grain diameter (mm), respectively.

The average grain size is the average grain size value and can be calculated using the equation:

$$M_z = \frac{\varphi_{16}+\varphi_{50}+\varphi_{84}}{3} \quad (2)$$

Determination of sorting will be better using a mathematical approach by finding the value of the standard deviation determined by the equation:

$$\sigma_i = \frac{\emptyset_{84}-\emptyset_{16}}{4} + \frac{\emptyset_{95}-\emptyset_{5}}{6,6} \quad (3)$$

Determination of skewness is based on the standard deviation value. If in a grain size distribution there is an excess of coarse particles, then the shrinkage is negative and vice versa and if the grain size distribution is excessive, the fine particle size distribution is positive, which can be calculated using the equation (Folk, 1974):

$$SK_t = \frac{\emptyset_{84}+\emptyset_{16}-2\emptyset_{50}}{2(\emptyset_{84}-\emptyset_{16})} + \frac{\emptyset_{95}+\emptyset_{5}+2\emptyset_{50}}{2(\emptyset_{95}-\emptyset_{5})} \quad (4)$$

Kurtosis is calculated by the equation of Folk and Ward (1957):

$$K_G = \frac{(\emptyset_{95}-\emptyset_{5})}{2,44(\emptyset_{75}-\emptyset_{25})} \quad (5)$$

RESULTS

The statistical parameters of particle size that are commonly used are mean grain size, sorting (OT), skewness (SKI), and kurtosis (KG). This research was conducted in 2 study areas, each representing a part of the river and coastal waters. The results of the overall sediment grain size classification are presented in Table 1.

Based on the calculation of statistical parameters of the bottom sediment grain size in the river area, the average diameter value ranges from 1.23 to 2.77 mm, and in the coastal area it ranges from 1.52 to 2.59 mm, classified as fine sand to medium sand. The sorting value of all basic sediment samples at each station ranges from 0.14 - 1.59 mm, as a result, the research area is divided into 4 classification, are moderately sorted, moderately well sorted, very well sorted, and poorly sorted. The higher sorting value in the river was found at Stations 3, 4, and 6 with an average value of 1.04 mm, 1.17 mm, and 1.15 mm. In the coastal area, the sediment is relatively categorized into a poorly sorted group. The average value indicates that the classification is poorly disaggregated.

According to Ingmanson and Wallace (1989), the poorly sorted classification is due to the particle size that accumulated randomly. Many fishing boats are anchored at Stations 3, 4, and 5 may modify and block the current flows, lead to the occurrence of unstable currents. In addition, the morphology of the river bottom topography also affects the classification of the sorting value. Rifardi (2012) stated that poor sorting is influenced by current velocity that is inhomogenous most of the time, so the

Table 1. Grain Size Parameter and Classification

ST	Mean size (mm)	Classification	OT	Classification	SKI	Classification	KG	Classification
1a	2,46	fine sand	0,89	moderately sorted	1,59	very fine skewed	1,67	very leptokurtic
1b	2,86	fine sand	0,64	moderately well sorted	2,71	very fine skewed	0,92	mesokurtic
1c	2,98	fine sand	0,71	moderately sorted	1,89	very fine skewed	1,34	leptokurtic
2a	2,77	fine sand	0,14	very well sorted	2,56	very fine skewed	0,86	platycuric
2b	1,83	medium sand	1,59	poorly sorted	0,63	very fine skewed	0,9	mesokurtic
2c	3,28	very fine sand	0,35	very well sorted	2,39	very fine skewed	1,01	mesokurtic
3a	3,12	very fine sand	0,57	moderately well sorted	2,84	very fine skewed	1,49	leptokurtic
3b	2,22	fine sand	1,37	poorly sorted	0,77	very fine skewed	0,72	platycuric
3c	2,57	fine sand	1,18	poorly sorted	1,02	very fine skewed	0,97	mesokurtic
4a	2,4	fine sand	1,26	poorly sorted	0,96	very fine skewed	0,74	platycuric
4b	1,39	medium sand	1,37	poorly sorted	0,7	very fine skewed	0,85	platycuric
4c	1,33	medium sand	0,86	moderately sorted	1,18	very fine skewed	1,08	mesokurtic
5a	2,62	fine sand	0,98	moderately sorted	1,37	very fine skewed	0,96	mesokurtic
5b	0,97	coarse sand	0,99	moderately sorted	0,67	very fine skewed	1,33	leptokurtic
5c	0,09	coarse sand	0,99	moderately sorted	0,37	very fine skewed	1,29	leptokurtic
6a	2,01	fine sand	1,29	poorly sorted	0,76	very fine skewed	0,94	mesokurtic
6b	2,87	fine sand	0,8	moderately sorted	1,55	very fine skewed	1,47	leptokurtic
6c	2,2	fine sand	1,35	poorly sorted	2,09	very fine skewed	1,08	mesokurtic
7	2,59	fine sand	1,02	poorly sorted	1,22	very fine skewed	1,14	leptokurtic
8	2,70	fine sand	0,77	moderately sorted	2,04	very fine skewed	0,95	mesokurtic
9	2,38	fine sand	1,14	poorly sorted	0,94	very fine skewed	1,35	leptokurtic
10	2,55	fine sand	1,19	poorly sorted	0,94	very fine skewed	1,64	very leptokurtic
11	1,52	medium sand	1,10	poorly sorted	0,85	very fine skewed	0,95	mesokurtic

accumulated sediment grains would be relatively various. The shape of the riverbeds at each station is as shown in Figure 2.

The value of skewness in the river area is diverse, ranging from 0.30 to 2.84 mm (2.17 mm on average). Based on the average value of the skewness, the sediments are defined to be very fine. In the coastal area, the skewness value is 0.95 – 1.64 with the same classification, which is very smooth. While the kurtosis values ranged from 0.72 to 1.67 mm, can be categorized as platycuric, mesokurtic, leptokurtic and very leptokurtic.

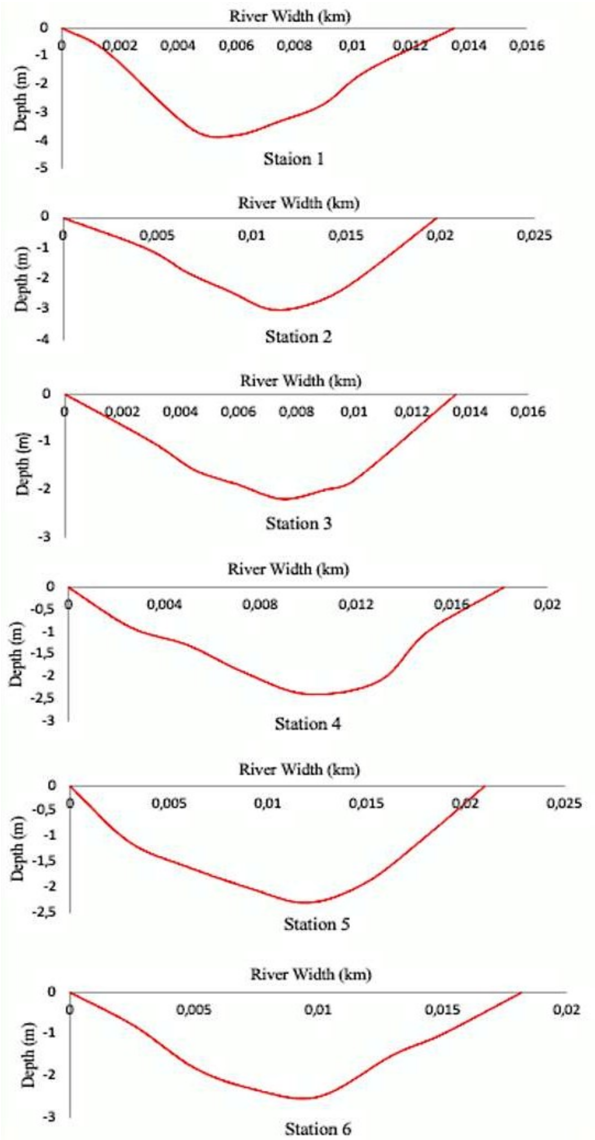


Figure 2. Cross-section of the river shapes in the water of Raya River Bengkayang Regency West Borneo

DISCUSSION

Sediment Characteristics

Based on the results of statistical parameter analysis in the river and coastal sections, the classification of both areas indicates relatively similar findings. The coherent result can be observed from the correlation between the kurtosis and skewness value of both areas (Figure 3). The average kurtosis and skewness values in the river are 1.09 and 1.4, respectively. Meanwhile, on the coast, the average kurtosis and skewness values are 1.20 and 1.21. These results indicate that the values of kurtosis and skewness in both areas are within similar group, which is very fine skew and leptokurtic. Aritonang et al. (2014) argued that positive value of skewness generally indicate fine-sized substrate (silt to mud). Surbakti (2010) also mentioned that the skewness in the estuary is in the average range of symmetrical, smooth, to very fine. According to Purnawan et al (2015), the very high kurtosis value is produced by the distribution pattern, which is dominated by medium and fine sand fractions. Boggs (2009) also explained, the peak's high degree is parallel with the observed sorting conditions, where all stations are quite well sorted.

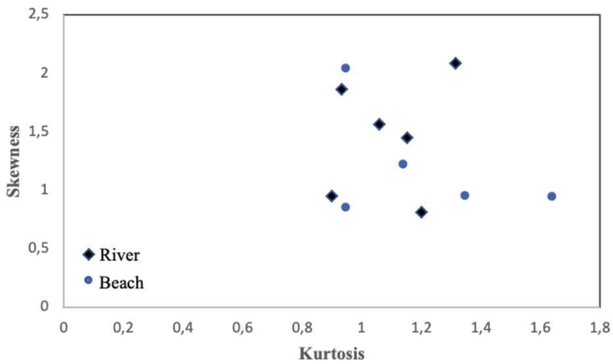


Figure 3. The scatter of graphic kurtosis Vs skewness in the river and beach area display a close correlation between both areas

The grain size values obtained ranged from <0.05 mm – 0.002 mm, indicating that the overall sediment type was dominated by silt. Sediment grain size in general is strongly influenced by the current speed in the waters (Thruman in Arifin, 2008). Fine grain sizes dominate slow currents and strong currents are dominated by coarser ones. According to Djurdjani (1998) in Sukuryadi (2015), the weak/slow current is defined for current speed <0.4 m/s. The average of current speed measurement in the river of our study is 0.33 m/s, while in the coastal most part is 0.37 m/s in average, considered as a weak current, resulting in relatively fine grain size of sediment as we have discussed above.

CONCLUSION

Based on statistical parameter analysis of sediment grain size, the average diameter of sediment in the river area ranged from 1.23 to 2.77 mm, and within the beach area, the grain size value was 1.52 to 2.59 mm, that can be classified into fine sand, medium sand, very fine sand, and coarse sand. However, the average value of the grain size is 2.22, which indicates that fine sand is dominant. Sorting values in the river and coastal waters ranged from 0.14 - 1.59 and 0.77 - 1.19, respectively, defined as moderately sorted, moderately well-sorted, very well sorted, and poorly sorted. Overall, the average of sorting value is 0.96, signifies moderately sorted. This classification indicates that the sorting process is not good indicated by the more diverse distribution of sediment grain sizes. The skewness of both in the river and in the coast can be categorized as very fine skewed, confirmed from relatively low skewness value, which are is between 0.37 to 2.56 mm, and between 0.85 to 2.04 mm respectively. These results indicate that the density or grain size of the sediment is more distributed to the finer grain size. The value of kurtosis in rivers ranges from 0.89 to 1.31 mm, classified as platycuric, mesokurtic, leptokurtic, and very leptokurtic. While in coastal areas it ranges from 0.95 to 1.64, classified as leptokurtic and very leptokurtic.

ACKNOWLEDGEMENTS

The author would like to thank the Center for the Study of Nuclear Energy Systems, the Indonesian National Nuclear Energy Agency (BATAN) through the RISTEK BRIN LPDP funding, which has provided funding to complete this research.

REFERENCES

Arifin, B., 2008. *Karakteristik Sedimen ditinjau dari Aktifitas Anthropogenik di Perairan Dumai* (Skripsi Sarjana). Universitas Riau, Riau.

Aritonang, A.E., Subakti, H., dan Purwiyanto, A.I.S., 2014. Laju Pengendapan Sedimen di Pulau Anakan Muara Sungai Banyuasin Provinsi Sumatera Selatan. *Maspari Journal*, 8(1): 7-14.

Blott, S.J., Pye, K., 2001. Gradistat : A grain size distribution and statistics package for the analysis of unconsolidated sediments. *Earth Surface Processes and Landforms,* 26(11): 1237–1248.

Boggs, S. Jr., 2009. *Petrology of Sedimentary Rocks*. 2th ed, Cambridge University Press, Cambridge, 600p.

Brookes, A., 1994. River channel change. In Calow, P., and Petts, G.E (eds), *The river handbook: hydrological and ecological principles*, volume 2. Oxford, Blackwell Scientific, 55-75p.

Darlan, Y., 1996. *Geomorfologi Wilayah Pesisir*. Aplikasi untuk penelitian wilayah pantai, Pusat Pengembangan Geologi Kelautan, Bandung, 96p.

Dyer, K.R. 1986. *Coastal and estuarine sediment dynamics*. John Wiley dan Sons Ltd, New York, 342p.

Folk, R.L., Ward, W.C., 1957. Brazos river bay: a study in the significance of grain size parameters. *Journal Sediment Petrol*, 27: 3-26.

Folk, R.L. 1974. *Petrology of Sedimentary Rocks*. Hemphill Publishing Company Austin, Texas, USA, 179h.

Friedman, G.M., 1967. Dynamic Processes and Statistical Parameters Compared For Size Frequency Distribution of Beach and River Sand. *Journal of Sedimentary Research,* 37(2): 327 – 354.

Gemilang, W.A., Wisha, U.J., Rahmawan, G.A., dan Dhiauddin, 2018. Karakteristik Sebaran Sedimen Pantai Utara Jawa Studi Kasus: Kecamatan Brebes Jawa Tengah. *Jurnal Kelautan Nasional*, 13(2): 65-74.

Ingmanson, D. E., Wallace, W. J., 1989. *Introduction to Oceanography*. 4th ed, Belmont, California, 54p.

Korwa, J.I.S., Opa, E.T., dan Djamaludin, R., 2013. Karakteristik Sedimen Litoral di Pantai Sindulang Satu. *Jurnal Pesisir dan Laut Tropis*, 1(1): 48–54.

Lestari, A. D., Pramadita, S., Simatupang, J. M. T. 2017. Sedimentasi di Sungai Kapuas Kecil, Pontianak Provinsi Kalimantan Barat. *Seminar Nasional Sains dan Teknologi.* TS-007: 1-7.

Li, Luqian., Lu, Xixi., Chen, Z., 2007. River channel changes during the last 50 years in the middle Yangtze River, the Jianli reach. *Geomorphology*, 85(3): 185-196.

Mukminin, A., 2008. *Proses Sedimentasi di perairan pantai Dompak Kecamatan Bukit Bestari Provinsi Kepulauan Riau* (Skripsi Sarjana). Universitas Riau, Riau.

Nugroho, S.H., dan Basit, A. 2014. Sebaran Sedimen Berdasarkan Analisis Ukuran Butir di Teluk Weda, Maluku Utara. *Jurnal Ilmu dan Teknologi Kelautan Tropis*, 6(1): 229-240.

Purnawan, S., Setiawan, I., dan Warmantin, 2012. Studi sebaran sedimen berdasarkan ukuran butir di perairan Kuala Gigieng, Kabupaten Aceh Besar, Provinsi Aceh. *Depik*, 1(1): 31-36p.

Purnawan, S., Haridhi, H. A., Setiawan, I, dan Marwantim, 2015. Parameter statistik ukuran butiran pada sedimen berpasir di Muara Kuala Gigieng, Kabupaten Aceh Besar. *Jurnal Ilmu dan Teknologi Kelautan Tropis*, 7 (1): 15–21.

Rifardi. 2012. *Geologi Sedimen Modern.* Universitas Riau Press, Pekan Baru, 167h.

Surbakti, H. 2010. Pemodelan Sebaran Sedimen Tersuspensi dan Pola Arus di Pesisir Banyuasin, Sumatera Selatan. *Jurnal Segara*. 2(2): 42-48.

Soemarwoto, O., 1978. *Aspek Ekologi dalam Pengelolaan Daerah Aliran Sungai*. Yayasan Penerbit PUTL, Majalah Nomor: 3/XV/1978.

Sukuryadi., 2015. Analisis Arus dan Gelombang Perairan Batu Belande Gili Asahan Desa Batu Putih Kecamatan Sekotong Lombok Barat, *Jurnal Paedagoria*, 12(2): 1-10.

Tanto, T.A, Putra, A., Kusumah, G., Farhan, A.R., Pronowo, W.S., Husrin, S, Ilham, 2017. Pendugaan Laju Sedimentasi di Perairan Teluk Benoa - Bali Berdasarkan Citra Satelit. *Jurnal Kelautan Nasional*, 12(3): 101-107.

Wentworth, C.K., 1922. A scale of grade and class terms for clastic sediments. *Journal of Geology*. 30, 377-392.

MARINE GEOLOGICAL INSTITUTE

RESEARCH AND DEVELOPMENT AGENCIES FOR ENERGY AND MINERAL RESOURCES
MINISTRY OF ENERGY AND MINERAL RESOURCES

Jl. Dr. Junjunan No. 236, Bandung - 40174. Indonesia
http://www.mgi.esdm.go.id, Email : ejournal.p3gl@gmail.com

ISSN 1410 - 6175
9 771410 617003