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Unlocking hydrocarbon potential in East Java's mud volcanoes: insights from Central and North East Java

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ABSTRACT : This study investigated mud volcanoes in Central Java and North East Java, part of the East Java Basin, focusing on their potential as part of the petroleum system play. These mud volcanoes, distinct from conventional volcanoes, emit low-temperature mud containing hydrocarbons. Fieldwork involved morphological observations and the collection of rock and mud samples for comprehensive analysis, both in the field and in laboratories. The results showed that the source rock quality in the area ranged from moderate to good, indicating promising hydrocarbon potential. Moreover, the analysis indicated that gas was the predominant product, with some instances of oil and gas coexistence. The research also categorized the source rock's kerogen type, predominantly identifying Kerogen-III (gas-producing) and, in some cases, Kerogen-IV (dry gas or inert). The maturity of source rocks implied that gas was the primary product, with varying degrees of maturity observed. These findings provide valuable insights into the hydrocarbon potential within these mud volcanoes, contributing to a deeper understanding of the East Java Basin's geological and resource prospects.

KEYWORDS – Mud Volcanoes, Central Java, North East Java,Hydrocarbon

I. INTRODUCTION

A mud volcano is a unique geological feature created by the accumulation of material expelled from underground due to surface pressure. This process is typically associated with mud diapirism, where mud and other sediments are forced upwards, breaching the surface [1]. Several authors, such as [2], [3], [4], and [5], have extensively documented mud volcanoes in Central and East Java. The current study focuses on an area in East Java with six distinct mud volcano eruption points, providing a valuable setting for exploring these intriguing formations. The phenomenon of mud volcanoes raises numerous questions about the underlying mechanisms that drive their formation and the role they might play in hydrocarbon generation. One ongoing debate revolves around the subsystems that govern the creation of mud volcanoes and their potential to produce hydrocarbons. The East Java mud volcano research area contains significant amounts of gas and water, suggesting a complex interaction between geological forces and chemical processes. This opens new avenues for research into the link between mud volcanoes and geochemical hydrocarbons, offering potential insights into natural resource exploration and geological dynamics.

II. GEOLOGY OF THE RESEARCH AREA

The East Java Basin is formed from an east-west trending half-graben active in The Paleogene and then reactivated in the compression process during the Early Miocene to the present. As an extensional basin that experiences inversion, it produces weak folded rock layers with normal faults or faults cutting the anticline inversion peaks [7]. The main structural patterns that control the Meratus structure pattern (East-West) and the Sakala (East-West) direction structure are met.

The research area is in the Rembang zone, part of the northern East Java Basin (Figure 1). The Rembang zone is a large anticlinorium stretching from Semarang to Madura and Kangean, resulting from late Tertiary tectonics [8]. It comprises shallow marine sediments from the Eocene to Pliocene, including clastic and carbonate rocks [9]. The zone is characterized by principal fault-controlled elevations trending northeast-southwest [10] with sedimentary layers showing no volcanic deposits.

The research area in North East Java is included in the Rembang Zone. Stratigraphy in both study areas can be referred to (Figure 2), which summarises East Java regional stratigraphy from previous researchers. The oldest Ngimbang Formation features shales, marls, coal, and limestones from the Middle Eocene to Early Oligocene. The Kujung Formation follows, containing clays and marls with reef limestone insertions, dating from the Late Oligocene to Early Miocene. Subsequent formations—Prupuh, Tuban, Tawun, Ngrayong, Bulu, Wonocolo, Ledok, Mundu, Kalibeng, Selorejo, Lidah, and Paciran—exhibit a variety of sedimentary characteristics and contain rich fossil records that help date and describe the environmental context. These formations cover a range

of ages from Early Miocene to Late Pliocene, with deposition environments ranging from shallow to deep marine settings.

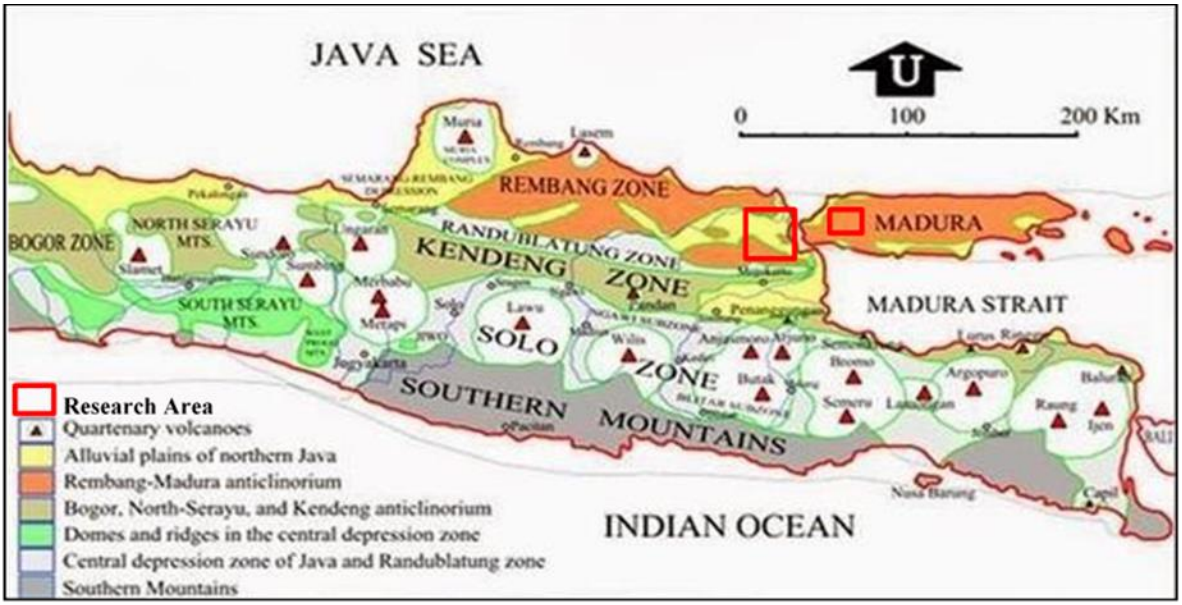

Figure 1. Physiography of the Kendeng Zone and Rembang Zone research areas [10]

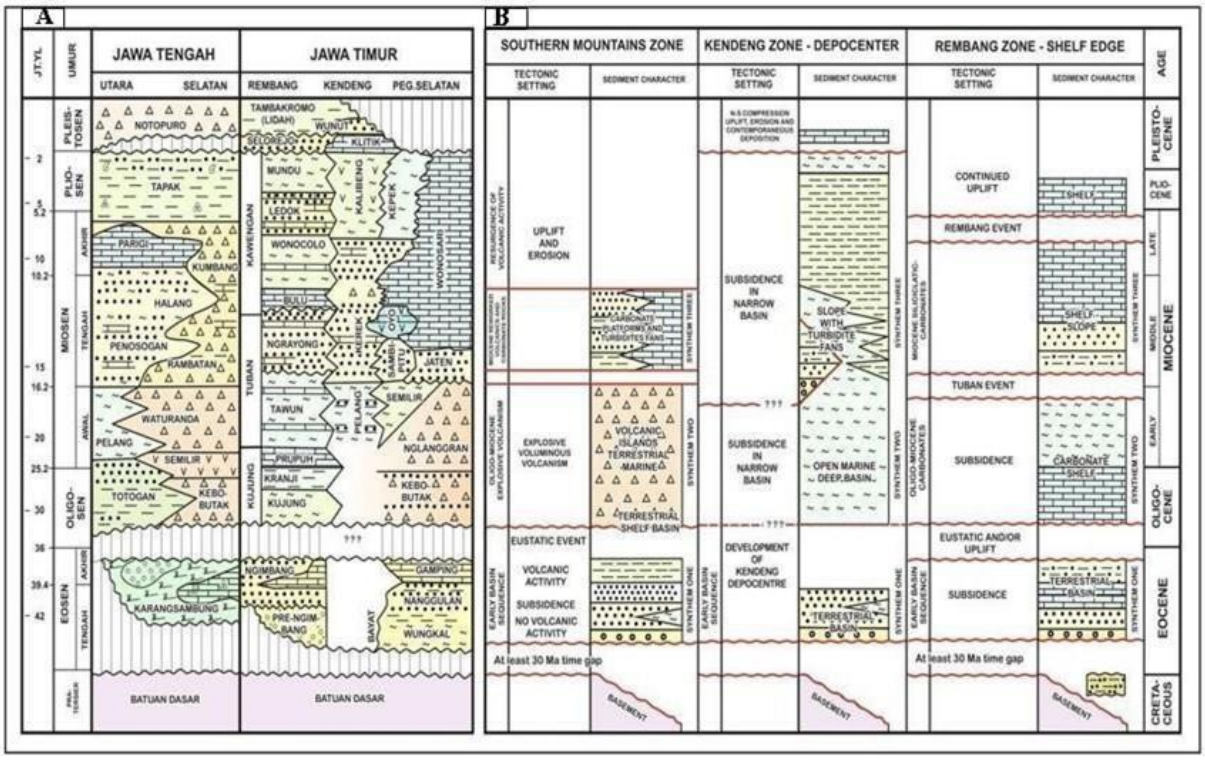

Figure 2. Regional Stratigraphy in North East Java Basin. (A) [8], [9] and (B) [10]

III. DATA AND METHODS

The data is from literature studies, field data, and laboratory data (mud, rocks, and water). The research methods were carried out quantitatively, including data collection and analysis.

Method of collecting data : Methods such as literature studies, field data collection, and laboratory data are used to determine the conditions and characteristics of the mud volcano on the surface and subsurface. These data will represent the geological model conditions and mud volcano models of the study area.

Method of Analysis Data : The researcher classifies and categorises the mud volcano model based on surface characteristics and the model based on subsurface data used as a reference. A previous study mentioned that water geochemical analysis is performed to identify the properties of water and trace the origin of the released water material. Additionally, mud geochemical analysis is conducted within the hydrocarbon context to ascertain the existence of source rock. The study also involves analysing the physical properties of sludge using the drilling mud approach and examining the activity of mud volcanoes in the designated research area.

IV. RESULTS AND DISCUSSION

Geochemical analysis of mud was conducted on seven samples taken from various morphologies and characteristics of mud volcanoes within the Sidoarjo and Madura mud volcano complexes. The geochemical tests focused on the Total Organic Carbon (TOC) values and Rock-Eval Pyrolysis. This analysis aimed to determine the potential presence of source rocks in the mud volcano complexes in the Sidoarjo and Madura regions (Table 1). The elements examined in the mud geochemistry included Total Organic Carbon (TOC) and Rock-Eval Pyrolysis values, which provide insights into the source rock's characteristics.

Table 1. Summary of TOC analysis results on Mud Volcano in the research are

No	ID Sample	TOC (%)	S1	S2	S3	PY	Tmax (°C)	PI	PC	HI	OI	Age	Source Rock Type [11]
			mg/g										
1	MD-06	1.15	0.25	1.93	1.01	2.18	435	0.11	0.18	167	87	Eocene	Potential
2	MD-04	0.62	0.1	0.56	1.41	0.66	431	0.15	0.05	90	226	Eocene	Potential
3	GN-01	1.29	0.96	2.4	1.33	3.36	312	0.29	0.28	187	103	Eocene	Potential
4	KL-01	0.57	0.06	0.25	1.7	0.31	396	0.19	0.03	44	296	Eocene	-
5	MD-01	0.69	0.09	0.52	1.3	0.61	431	0.15	0.05	75	188	Eocene	Potential
6	TB-02	0.68	0.09	0.3	1.23	0.39	318	0.23	0.03	44	182	Eocene	-
7	WG-01	0.51	0.05	0.27	1.55	0.32	418	0.16	0.03	53	307	Eocene	-

In the research area, the analysis involved cross-plotting the TOC values against S2 (Figure 3, Part A). This analysis indicated the source rock's capacity, which ranged from moderate to good, based on the classification system established by [11]. Furthermore, when cross-plotting TOC against The Hydrogen Index (HI) (Figure 3, Part B), the source rocks were predominantly associated with gas production, with some instances yielding limited quantities of oil and gas. This classification was also based on Waples' system Moreover, another cross-plot analysis involved the TOC values against S2 (Figure 3, Part C). This analysis aimed to determine the type of kerogen present in the source rocks. The results showed that the source rocks in the research area were primarily associated with Kerogen-III, known for gas production. While some exhibited characteristics of Kerogen-IV, indicative of dry gas or inert substances. This classification was also based on Waples' categorization. Mud volcano complexes in the Sidoarjo and Madura regions, aiding in the understanding of the source rock characteristics and their readiness for hydrocarbon extraction gas. The distribution of these samples is illustrated in Figure 4.

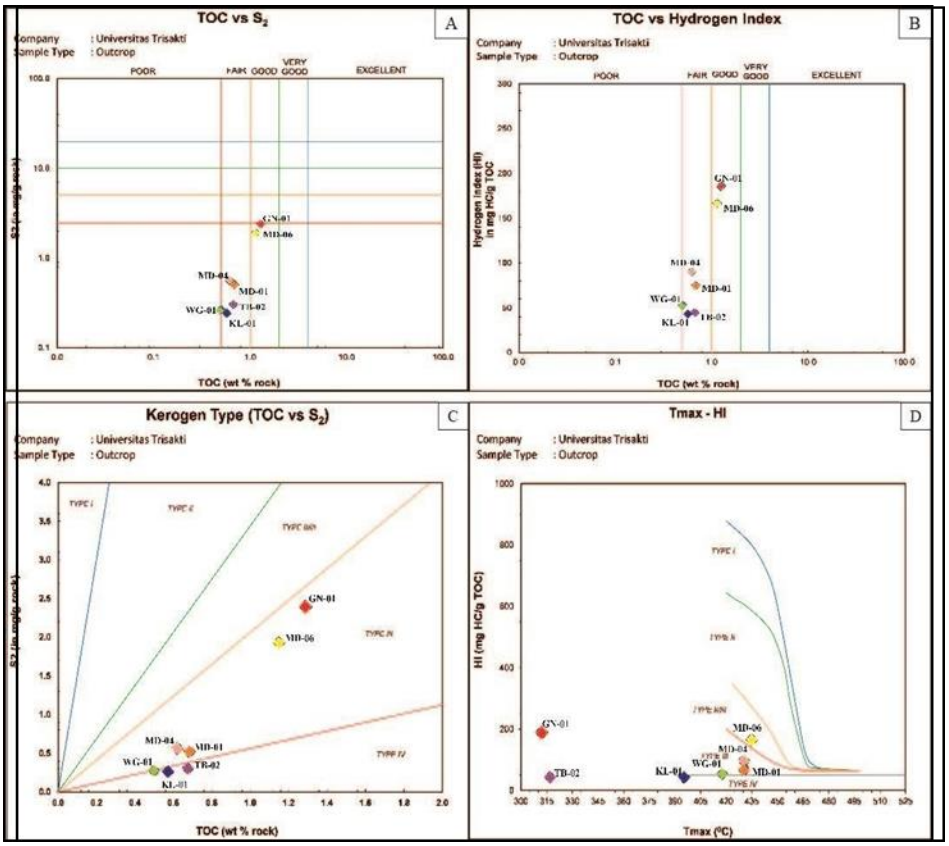

Figure 3. (A) TOC vs S2 graph. (B) Toc vs HI (Hydrogen Index) graph. (C) Graph of kerogen type determination via TOC vs S2. (D) Graph of Determining Kerogen Type via Tmax vs HI (Hydrogen Index)

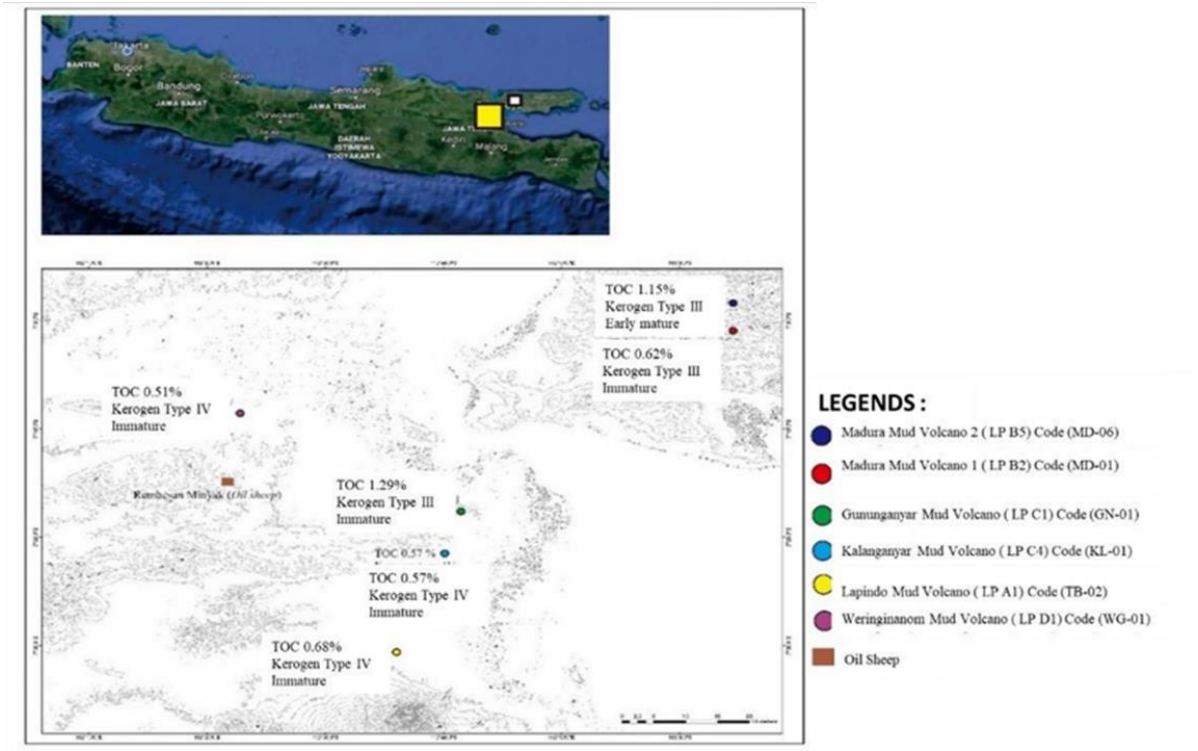

Figure 4. Mud volcano distribution map and geochemical analysis of mud volcanoes

V. CONCLUSION

In conclusion, this research provides valuable insights into the potential of hydrocarbon resources within the mud volcano complexes of the Sidoarjo and Madura regions in Central and North East Java, East Java Basin. Geochemical analyses of mud samples from these areas have highlighted critical aspects of the source rock characteristics and their suitability for hydrocarbon exploration. The study results indicated that the source rocks in the research area exhibit a range of qualities, from moderate to good, as determined through cross-plot analyses of Total Organic Carbon (TOC) against S2 and TOC against the Hydrogen Index (HI). These findings suggest the presence of source rocks capable of hosting hydrocarbon reservoirs, making these mud volcano complexes promising targets for further exploration. Furthermore, the dominant gas production in the source rocks, with some instances yielding oil and gas, underscores the potential for hydrocarbon extraction. The geochemical analyses also revealed that the source rocks are predominantly associated with Kerogen-III, known for gas production, and some exhibited characteristics of Kerogen-IV, indicating the presence of dry gas or inert substances. This information is crucial for understanding the composition of the hydrocarbons present and the subsequent exploration and extraction processes. The maturity evaluation of source rocks, conducted through cross-plotting T-max values against HI, revealed that the source rocks primarily produced gas, with varying degrees of maturity, ranging from immature to early maturity. The source rock suggests that the hydrocarbons are at various stages of readiness for extraction.

Overall, the findings from this research contribute significantly to our understanding of the geological and geochemical aspects of these mud volcano complexes in the East Java Basin. The results provide a foundation for future exploration and exploitation efforts, offering the potential for valuable hydrocarbon resources in these unique geological formations. Lastly, the source rock's maturity was evaluated by cross-plotting T-max values against HI (Figure 3, Part D). This analysis aimed to determine the level of source rock maturation. The results revealed that the source rocks in the research area primarily produced gas with varying degrees of maturity, from immature to early maturity, following the classification established by [12]. These geochemical analyses provide valuable insights into the hydrocarbon potential of the mud.

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