GEOTOURISM

Geology of Labuan Bajo Area, East Nusa Tenggara: A short geological note as a supplement to Komodo National Park

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ABSTRACT

Labuan Bajo is a captivating destination in the Lesser Sunda Islands, Eastern Indonesia. The location is renowned for its unique landscape–where volcanic remnants dramatically meet the ocean. The Komodo Dragon is the most famous animal living in the area. While the region's geological history undoubtedly encompasses a series of complex events, its regional geology has received little of the attention it deserves. This paper explores the geology of Labuan Bajo: the diverse rock formations, which consist of volcanic and carbonate sediments.

The oldest rock encountered in the area is the Miocene volcanic rocks. Quaternary volcanics, which is the youngest unit, dominated the area. Columnar joints occur in some areas, indicating lava activities. Mio-Pliocene carbonates are common in the area. A cave system developed in the carbonate unit and the erosion processes develop unique shapes.

***Keywords**: Labuan Bajo, East Nusa Tenggara, Lesser Sunda Islands*

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INTRODUCTION

Labuan Bajo draws divers and nature lovers worldwide to its paradisiacal setting. It is known for its unique and beautiful landscape. Underwater, the mesmerizing ballet of the manta ray, circling gracefully, provides a remarkable spectacle. Ashore, the iconic Komodo dragon commands attention with its immense size, deliberate, heavy movements, and the ever-present darting of its forked tongue.

The tourism-driven economy of Labuan Bajo and Komodo National Park (West Manggarai, Flores, East Nusa Tenggara) often overshadows the region's geology. Little is exposed about *Batu Cermin* (Mirror Cave), a remarkable formation that is located hidden uphill. This paper addresses this by exploring Labuan Bajo's

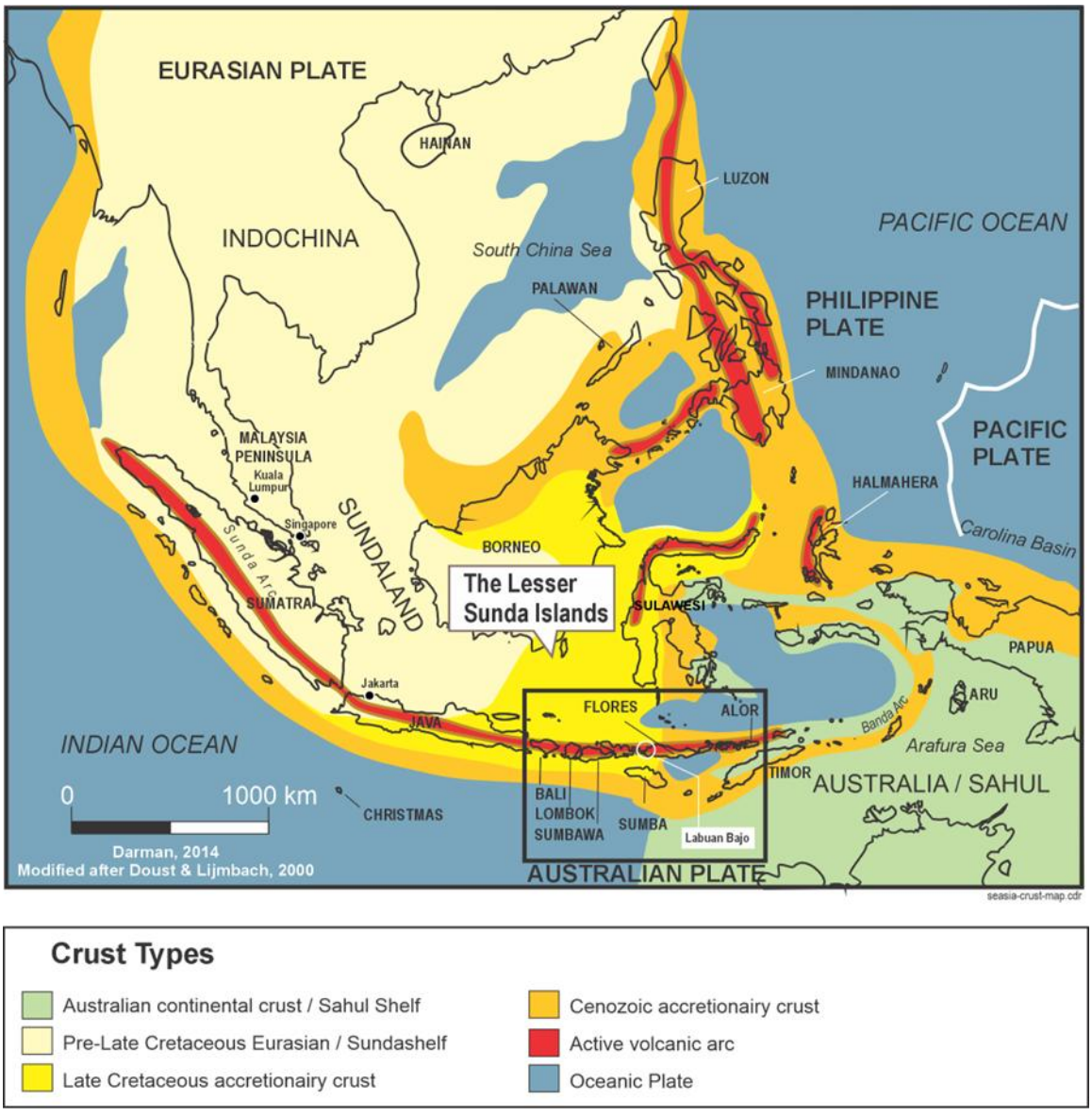


Figure 1: *Regional tectonic setting of Indonesi and the location of the Lesser Sunda Islands (from Darman, 2012)*

diverse rock formations, which range from Early Miocene volcanic and carbonate rocks to recent sediments, exemplified by Pink Beach.

Geologically, Labuan Bajo is part of the Lesser Sunda Islands. This small section of the greater archipelago is identified by a chain of young volcanic islands (Figure 1, Darman & Sidi, 2000). This collection of smaller islands encompasses major islands such as Bali, Lombok, Sumbawa, Flores, Sumba, and Timor wherein the two latter islands do not have volcanic origins (Minarwan, 2012). Timor Island serves as a bridge between the Lesser Sunda Islands and the Banda Arc. The volcanic activity that shaped many of these islands significantly contributes to the region's unique geological and ecological diversity.

PREVIOUS STUDIES

This paper acknowledges the pioneering work of Theodorus Lambertus Verhoeven (Figure 2) in initiating geological investigations within the Nusa Tenggara region. His work in the documentation of the "Batu Cermin" limestone cave has been relevant to this study. Verhoeven discovered this remarkable cave in 1951. The cave derives its name from the phenomenon of sunlight penetrating the cave and reflecting off the walls, creating a mirror-like effect. This recognition extends beyond scholarly circles, as a street in Labuan Bajo is named after Verhoeven–a lasting testament to his dedication to geological exploration.

Father Verhoeven, a Dutch Catholic Missionary with the Societas Verbi Divini (SVD), arrived in Indonesia in 1948. Initially, the SVD called Verhoeven to teach at Matalako Seminary–where he later spent 18 years in Flores, beginning in the 1950s. While living in Flores, Verhoeven dedicated a significant portion of his time to archaeological investigations (van Gorsel, 2022). He visited caves where remains of ancient living might have settled.

Verhoeven's contributions to paleontological research in Flores include the following list: (1) the excavation of the first Pleistocene giant rats at Liang Toge, (2) the discovery of the first Stegodon jaw from Ola Bula in January 1957, and (3) the unearthing of another Stegodon fossil at Meta Menge. In 1964, he extended beyond Flores and worked on a Stegodon molar and fragments of a giant tortoise east of Atambua. Furthermore, his research encompassed the broader Indonesian archipelago, as evidenced by his discovery of an Eocene hippopotamus-like skull fragment and upper molar in West Timor (van Gorsel, 2022).

Based on his extensive fieldwork, Verhoeven concluded that *Homo erectus* had crossed the Wallace Line into Eastern Indonesia approximately 750,000 years ago. This groundbreaking insight, however, gained significant attention only after his death, coinciding with the subsequent discoveries of "island fauna" mammals and *Homo floresiensis* in other parts of the region. In recognition of his pioneering contributions to paleontology in Indonesia, the giant tree rat species from Liang Toge was aptly named *Papagomys theodorverhoeveni* in his honor (van Gorsel, 2022).





Figure 2:

(A) Father T.L. Verhoeven at an excavation at Mata Menge in the Soa Basin in 1963, where he found stone tools associated with Stegodon fossils (Photo by Verhoeven, 1968, in Morwood et al., 2009; documented by van Gorsel, 2022).

(B) A street named after Verhoeven in Labuan Bajo area. He is well-respected by the local people.

REGIONAL GEOLOGY

Geoscientists examine the geology of the Lesser Sunda Islands within the context of the larger and more intricate Banda Arc system (Minarwan, 2012). This region in eastern Indonesia represents a complex geological setting where the Indo-Australian, Eurasian, and Pacific Plates converge and collide. Notably, the subduction of the Indo-Australian Plate beneath the Banda Plate drives the formation of a prominent volcanic arc (Minarwan, 2012; Fig. 1).

This dynamic interaction in subduction, collision, and intense volcanic activity shaped the arc's unique landscape of volcanic islands, deep-sea trenches, and frequent earthquakes (Minarwan, 2012). Arc volcanism occurred in the Lesser Sunda Islands for much of the Cenozoic, except in the Late Oligocene (Charlton, 2000 in Minarwan, 2012). Calc-alkalic magma generated the volcanics in the inner Banda Arc; intercalated with volcanogenic sediments and carbonates (Hamilton, 1979; in Minarwan, 2012).

STRATIGRAPHY

The geological evolution of the inner arc region within the Nusa Tenggara Islands commenced in the Early Miocene with the formation of a basin (Figure 3). This period witnessed substantial marine volcanic activity: the deposition of andesitic-basaltic breccia—which represents the oldest exposed rocks in the region. These volcanic rocks provide evidence of a marine depositional environment. Initial sedimentation within this evolving basin comprised clastic sediments, including tuffaceous sandstone and limestone. This suggested a depositional environment with water depths ranging from approximately 20 to 100 meters, as indicated by the work of Darman and Sidi (2000).

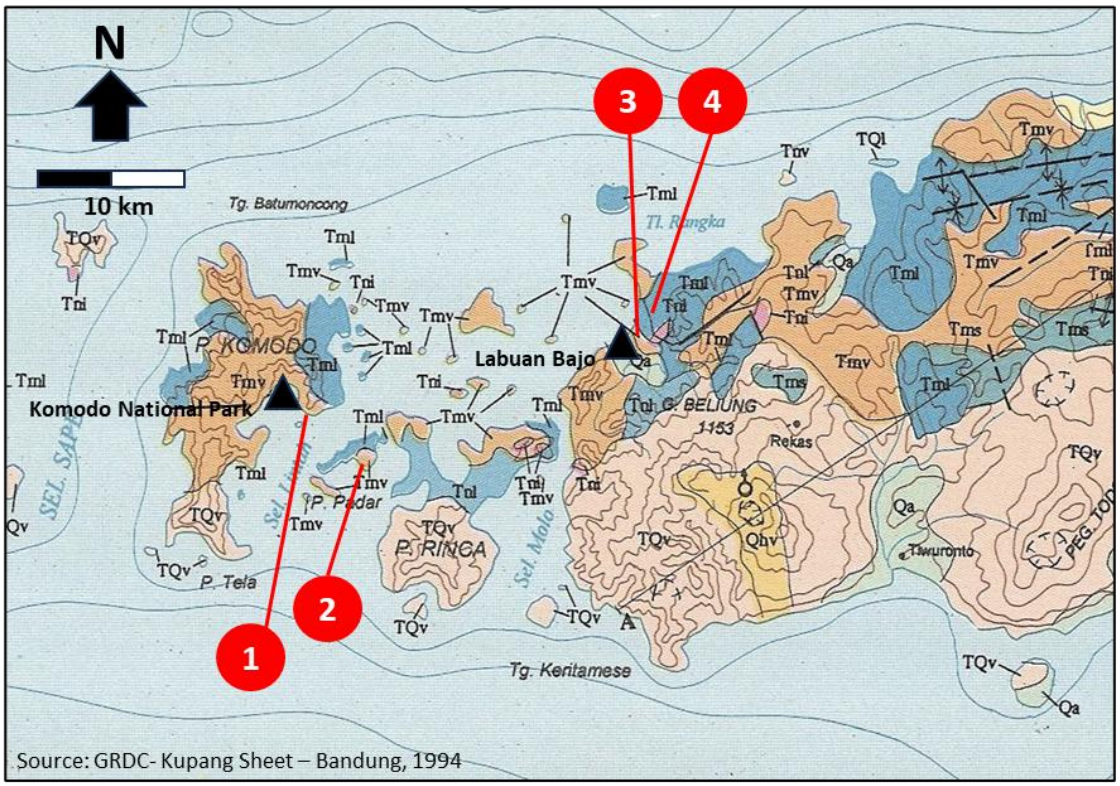
GEOLOGICAL SITES FOR TOURIST DESTINATIONS

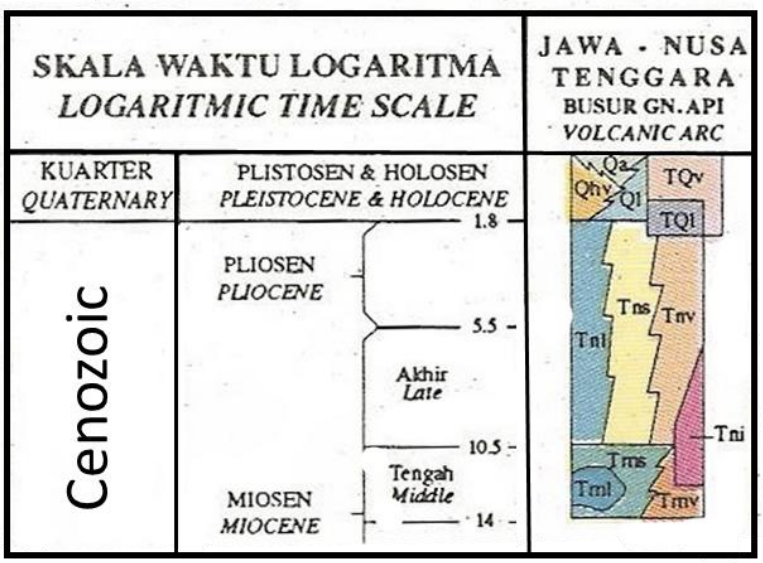
Holocene Pink Sand

The unique pink hue of the sand originates from the presence of finely crushed red coral mixed with white sand (Figure 4). This captivating combination creates the signature color that gives the beach its name. The sand itself is incredibly soft, consisting of fine to very fine grains and an almost powdery texture, thus making it a delight to walk on. Moreover, when looking further off-shore, another stunning geological phenomenon of columnar join is visible. The common boat stop to observe this sand is in Pink Beach, Komodo National Park (Location 1, Figure 3).

Middle Miocene Padar Island

From the summit of Padar Island (Location 2, Figure 3), breathtaking panoramic views unfold. The island's dramatic landscape is a sight to behold (Figure 5); a testament to its volcanic origins. The diverse array of volcanic rock formations provides compelling evidence of past volcanic activity, including weathered volcanic breccia and impressive columnar joints. Geological studies suggest that the formation of Padar and the surrounding islands spans from the Early-Middle Miocene to the





Note:

1. Pink Beach
2. Pulau Padar
3. Ayana Hotel
4. Batu Cermin

Figure 3: *Geological map of the Komodo National Park and Labuan Bajo vicinity and the stratigraphic column of the area (after Simandjuntak et al., 1994)*

present day (Darman and Sidi, 2000; Simandjuntak et al., 1994).

Trekking up and down the cliff typically takes about half an hour each way, including a few brief stops along the trail. Four designated areas for the break lay on the ascent, offering opportunities to catch your breath and admire the surrounding rock formations. While most of the steps are well-maintained and spacious, some sections may present a challenge. Handrails stretch out on steeper inclines.



Figure 4: *Scenery of the Pink Beach and weathered columnar joints (white arrow), indicated by vertical column features (see arrow). Inset: several corals found in this location. The dark red corals on the right is Octocorallia, which contribute the reddish colour to the beach. Together with other whitish colour skeleton and coral, they generate pink sands.*



Figure 5: *A scenery of Padar Island with volcanic materials such as fractured breccia.*

Middle Miocene Columnar Joint Across Ayana Hotel Labuan Bajo and Pink Beach

The columnar jointing provides a remarkable geological feature of volcanic descent (Figures 4 & 6). This impressive formation rises approximately 10 meters high and extends laterally for about 50 meters. Its color ranges from light to dark brown. Columnar jointing is present in other locations, however, the site of the Ayana Hotel (Location 3, Figure 3) offers the most convenient access for visitors, allowing for easy parking and a brief stop for observation.

At Pink Beach, the columnar joint extends offshore. The distance is near and is best accessed by a small boat. However, visitors can still appreciate the impressive volcanic outcrop from the shoreline. The mesmerizing blend of pink sand and the ocean's various shades of blue enhance the stunning scenery. Onshore, the beach is strewn with dark-colored volcanic rocks, providing a testament to the erosive forces that have shaped the landscape.

Neogene Carbonate Batu Cermin Cave of Labuan Bajo

Batu Cermin carbonate outcrop hangs prominently, has cliff-like exposure, reaches a height of approximately 75 meters, and is situated within a 19-hectare bamboo forest (Figure 7). The



Figure 6: *Columnar jointing outcrop across the Ayana Hotel, on the road side, about 7m height.*



Figure 7: *Several photos taken at the Batu Cermin (mirror rock) cave. a) The entrance to the cave. b) Stalactites hanging from the cave roof. c) Narrow path within the cave. d) Layered limestone with coreals, algae and shell fragments.*



Figure 8: *Batu Payung (umbrella rock) is located in the same complex as Batu Cermin. This outcrop has a shape like a mushroom or an umbrella. It is a bedded limestone with coreal and algae fragments. The beds are ½ to 1 ½ m thick. The total height is about 5 m.*

dominant lithology is limestone – with a light to dark grey-brown coloration. The limestone's character is by relatively well-developed, flat bedding, indicative of deposition in a shallow marine environment during the top Miocene (approximately 5 million years ago).

Batu Cermin Cave is a 20-minute drive from Labuan Bajo's port. The paved road, though winding, comfortably accommodates two lanes of traffic. Upon arrival at the parking lot, visitors purchase tickets before proceeding to the cave entrance. A short, five-minute walk was taken to get to the cave, and guides were accompanying visitors throughout the exploration.

By using a torch, the tour uncovered an abundance of marine fossils, ancient coral, and the marks of algae that clung to the surfaces of the limestone. The cave itself has several smaller caverns, allowing an in-depth exploration of the various stalagmites and stalactites forming unique shapes. In several spots, light penetrating dissappered at all, and walking was hard, especially when passing a very low wall.

Neogene Carbonate Batu Payung of Labuan Bajo

Batu Payung (Umbrella Rock; Figure 8), rises a short distance (hundreds of meters) from the Batu Cermin, likely shares a similar geological origin and age. This limestone formation provides compelling evidence of its subaquatic past. Its distinctive shape reflects the erosive forces of water over millennia. Further supporting its underwater origins are the abundance of marine fossils, including ancient coral remnants at the base of the formation, as well as the unique algae which clings to the middle portion of the limestone.

CONCLUSION

Despite many tourism objects, geological objects are usually under-exposed in Labuan Bajo. This is a missed opportunity, as the region boasts stunning limestone formations, volcanic landscapes, and unique geological features that could attract a niche marketof adventure travelers and nature enthusiasts. Labuan Bajo can enhance its tourism appeal by developing more accessible trails, providing informative signage, and offering guided geological tours. Labuan Bajo showcases the unique natural wonders of the region.

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