Short Note: Sedimentology of Bali Touristic Locations - Tanah Lot and Uluwatu

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Introduction

Tanah Lot and Uluwatu are famous touristic sites in the southern part of Bali (Figure 1), and part of the Sunda Volcanic Arc. Most visitors come to these places to enjoy the scenery and visit the temple. The uniquity of these sites, however, is the result of the specific local geological setting in which they are located.

The Tanah Lot temple was built on top of Quarternary volcanic clastic deposits, and was separated from the main island because of erosional processes. Uluwatu which is well known for the temple was built on a Miocene limestone cliff (Figure 2). Due to the excellent exposure of the geology, both localities allow for studying the sedimentary history which has resulted in these remarkable sites.

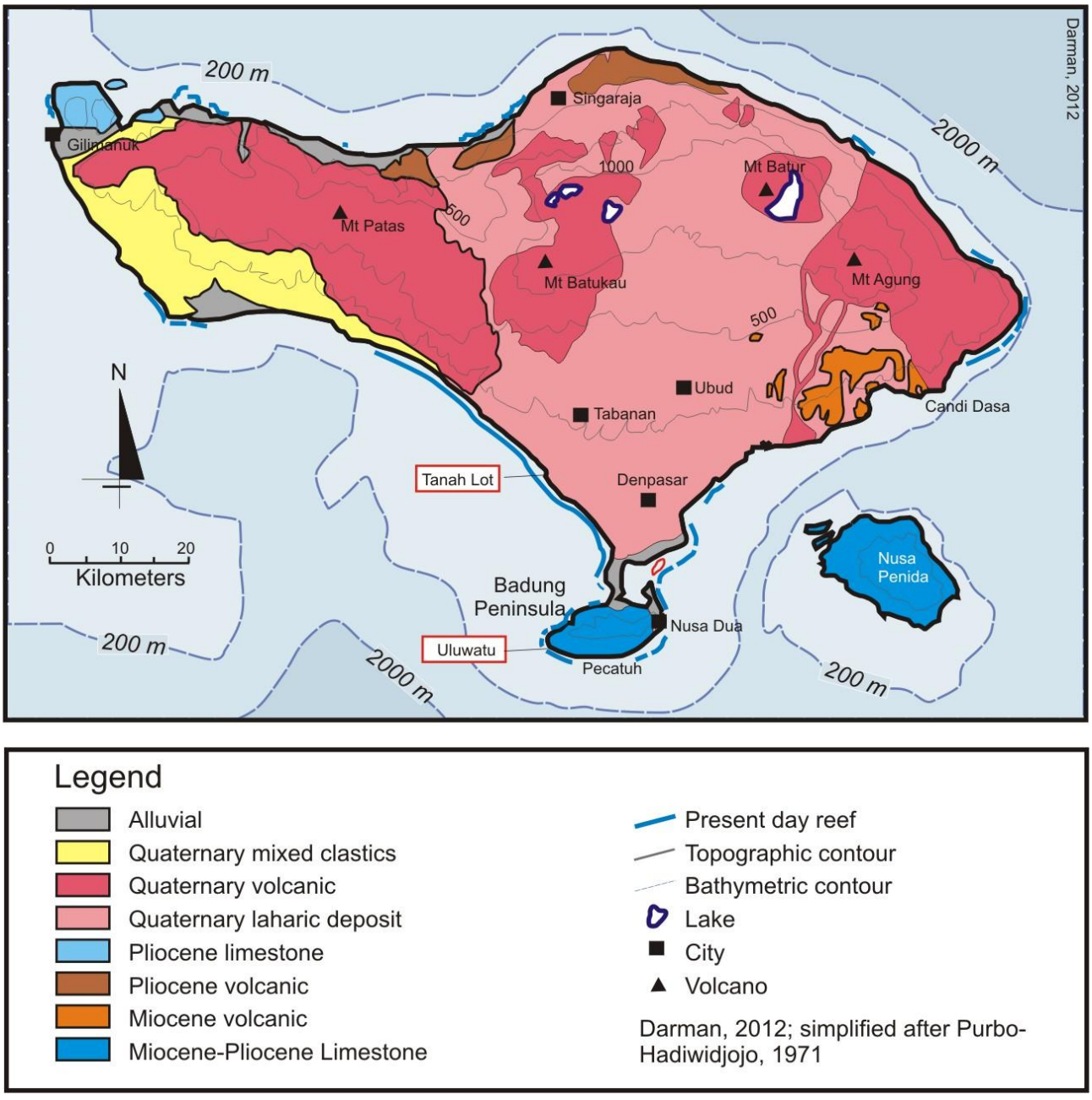


Figure 1. *Simplified geological map of Bali, after Purbo-Hadiwidjojo (1971)*

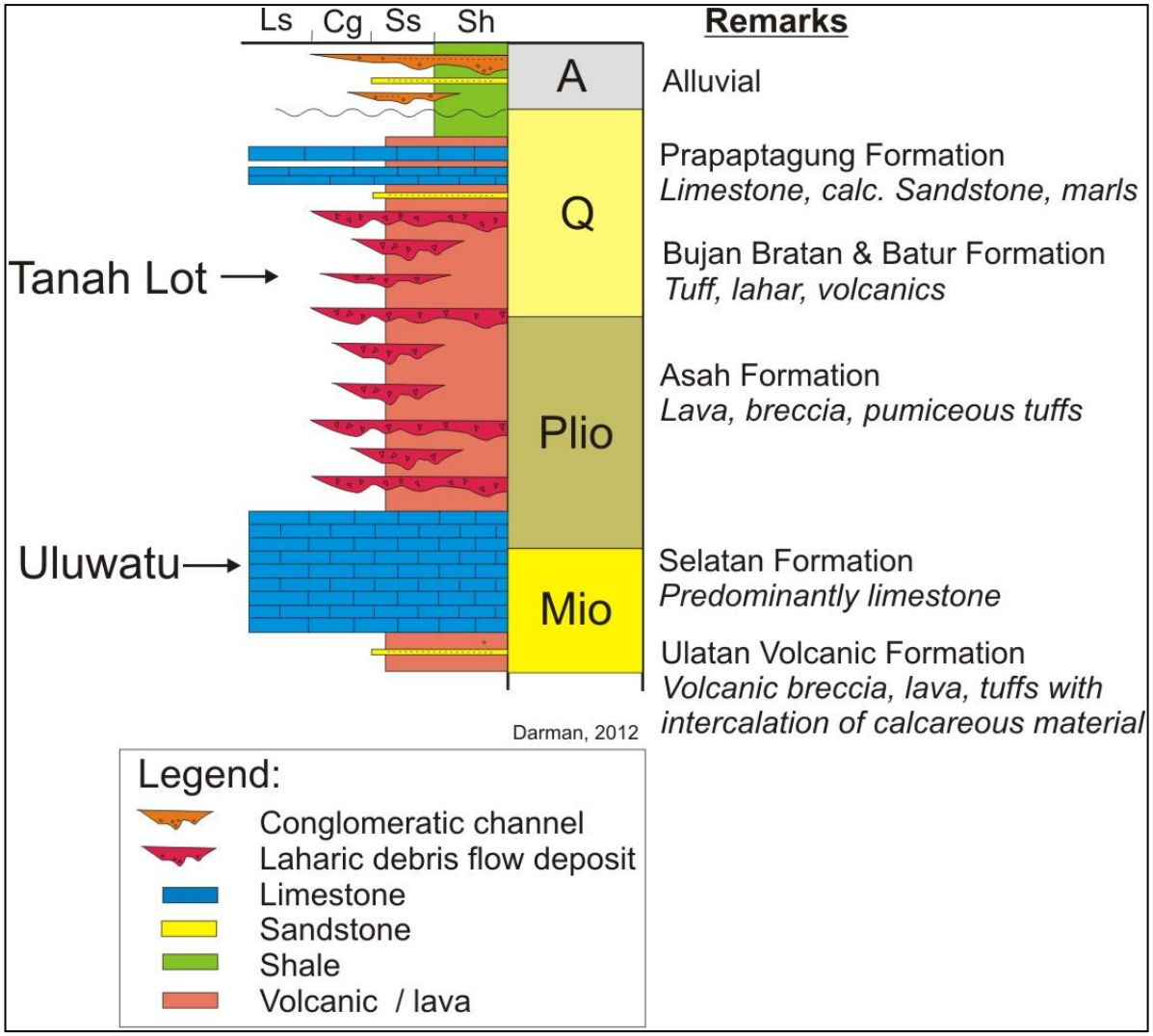


Figure 2. *Proposed simplified stratigraphy of Bali Island based on Purbo-Hadiwidjojo (1971) map showing relative stratigraphic position of Tanah Lot and Uluwatu sites*

This article discusses the stratigraphy and sedimentological features seen on these two locations. Despite the excellent exposure, both locations have received very little attention and only few studies have been reported. Both sites but especially the Uluwatu cliff, provides an excellent lateral exposure, allowing to discuss the depositional in a spatial framework. The outcrops in both locations show close relationship between volcanic activity and carbonate deposition

Regional Geology

The island of Bali is part of the Sunda volcanic arc which is curving from the West to the South of Indonesia. The Western part of the arc is dominated by large islands of Sumatra and Java, and is commonly called the Greater Sunda arc. Towards the East, the arc is characterized by smaller volcanic islands known as the Lesser Sunda Islands. Bali Island is located in the far West of the Lesser Sunda Islands. Most islands in this arc were generated cored by active volcanoes.

The island of Bali is one of those islands which are cored by quaternary volcanic and lahar deposits. Active volcanoes are located at the centre of the island, e.g. Mt. Batur and Mt. Agung (Figure 1). Pliocene carbonate systems and Pliocene volcanics are located in the North of the island. Older units, such as the Miocene limestone deposits and Miocene volcanics, are located in the South side of the island.

Tanah Lot

The Tanah Lot temple is located in the West of Denpasar. The temple was built on relatively flat beds, exposed on the South coast of Bali (Figure 3). Purbo-Hadiwidjojo (1971) mapped this area as a part of the Bujan-Brata and Batur Formation which is dominated by tuff and lahar deposits. The cliffs show layered sandstone beds with breccia lenses with thickness ranging from 0.2 to 1 metre. The sandstone beds exhibit significant lateral grain size and thickness variation. Many beds are in fact discontinuous (Figure 4A).

The breccia lenses are isolated sedimentary bodies characterized by sub-angular coarse gravel, poorly sorted, with sand matrix (b unit in Figure 4B). Lateral variation in grainsize, ranging between coarse gravel and sand, is visible predominantly at the base of the breccia lenses. At several locations, breccia pebbles show high-angle cross bedding as seen in unit "a" in Figure 4C. This unit has an



Figure 3. *The temple in Tanah Lot, built on top of sub-horizontal beds, mainly composed of volcaniclastic sandstones with breccia lenses in places. Due to erosional processes, it became an island during high tide*

erosional base above unit "b" and "d". Unit "c" has been cut out by unit "b". The sand beds in Tanah Lot are composed of medium to coarse volcanic sand grains and moderately sorted. The grains are dark grey in color. Some horizontal sand beds were cut by gravel beds, which indicate erosional processes (Fig. 4D). Based on field observations, the grains, both minerals and lithoclasts, in these beds are of predominatly volcanic origin. Several coral fragments are present in this unit. Figure 4E shows a coral fragment, about 14 cm in diameter, within the breccia unit.

The breccia lenses are interpreted as a laharic debris flow deposit in a very proximal setting. The grain size in the breccia units indicated a high energy environment of deposition. The Tanah Lot outcrop section mainly composed of poorly sorted and generally angular to sub-angular grains, which indicate short distance migration. The coral fragments in Tanah Lot section suggests that this lahar was probably deposited nearby the coast line.

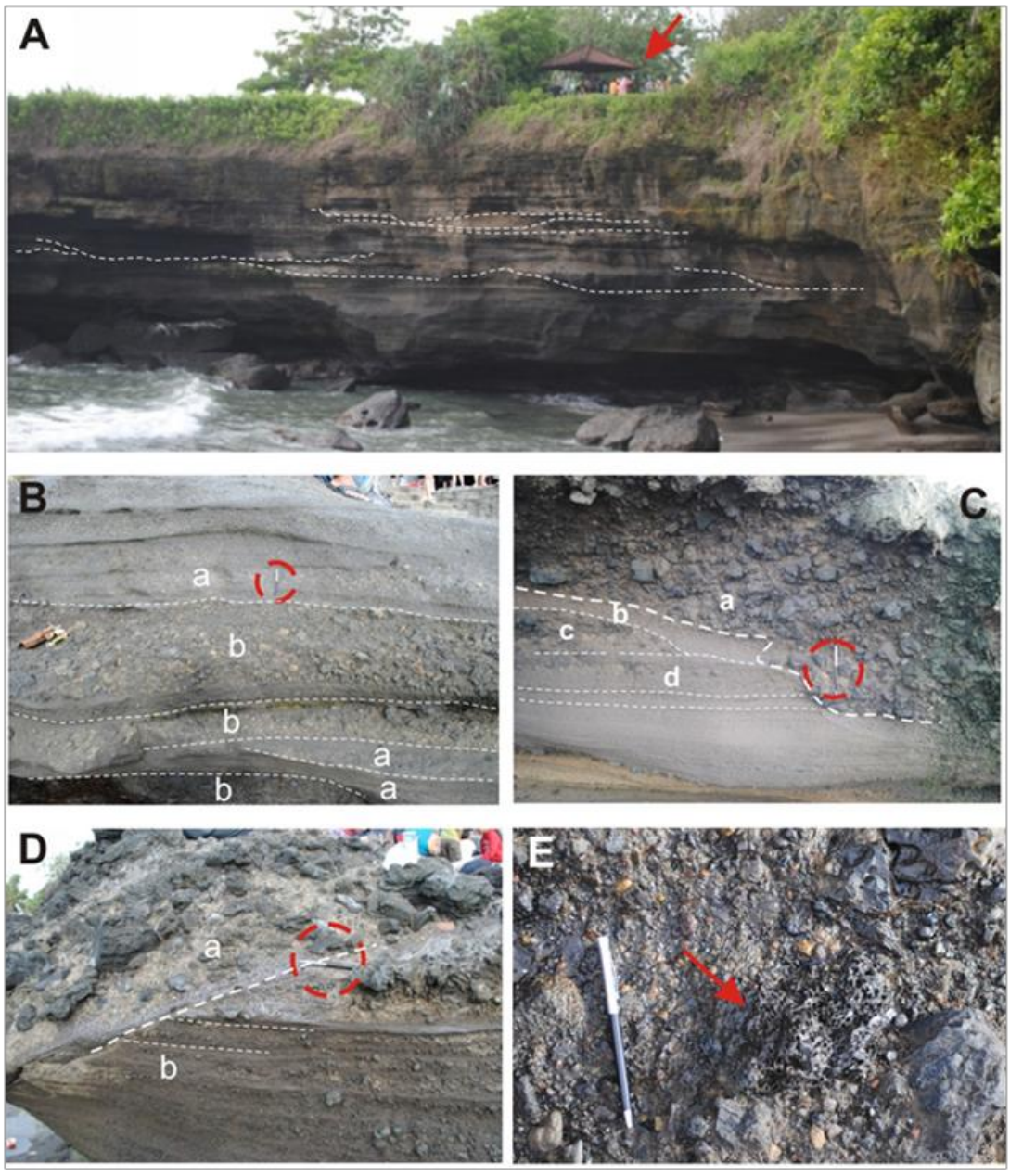


Figure 4. *Outcrop pictures from Tanah Lot location.* ***A)*** *An outcrop section shows the sand body discontinuity;* ***B)*** *A detail picture of the rock layers with sandstone beds (a) and breccia (b);* ***C)*** *Erosional base of the breccia (a) which cut through sandstone beds (b and d). The (c) bed was eroded by (b) bed;* ***D)*** *A high angle erosional surface where (a) breccia cut deeply into (b) unit, which composed mainly of sands with large volcanic fragments at the lower part and change to breccia in the upper part;* ***E)*** *Coral fragment (pointed by red arrow) within the poorly sorted breccia unit, indicate the process was very close to the sea. Note a pen as scale in red dashed circle*

Uluwatu

The limestone outcrops exposed at the Uluwatu location and generally in the Southern part of Bali and Nusa Penida Island are Miocene-Pliocene in age, and referred to as Selatan Formation (Purbo-Hadiwidjojo, 1971). The limestone cliffs are up to 200 m high. In the South of Bali Island, the limestone outcrops are located in the Western and Southern part of Badung Peninsula (Figure 1 and 5).

The cliff height decreases from South to the Northwest and East of the peninsula. The limestone beds characterized by their lighter grey shade are clearly visible on the cliff. In the sequence of these enormous exposures the lower half of evenly stratified limestones are shallowing upward into a reef facies (Boekschoten et al, 2000).

The cliff section in the Uluwatu area is about 70 m high (Boekschoten et al, 2000). The limestone beds are relatively flat and fairly continuous. (Figure 6A & B). Figure 6A shows an outcrop profile in the Pecatuh Beach, south of Badung Peninsula. The lower section (unit "c" in Figure 7A) is composed of coral rudstones, characterized by abundant coral fragments which are up to 10s of cm in diameter (Figure 7B). Bedding is poorly visible and rudstones have formed a hard outcrop which is relatively resistant to wave erosion.

Above the unit "c", limestone beds of unit "b" are show stratification. The beds are composed of finer grained limestone with smaller coral fragments. The boundary between "c" and "b" unit is sharp (see Figure 7C). Volcanic fragments which are up to a couple of centimeters in diameters are common in the Selatan Formation (Figure 7D).This implies volcanic activity at times of carbonate growth and deposition.

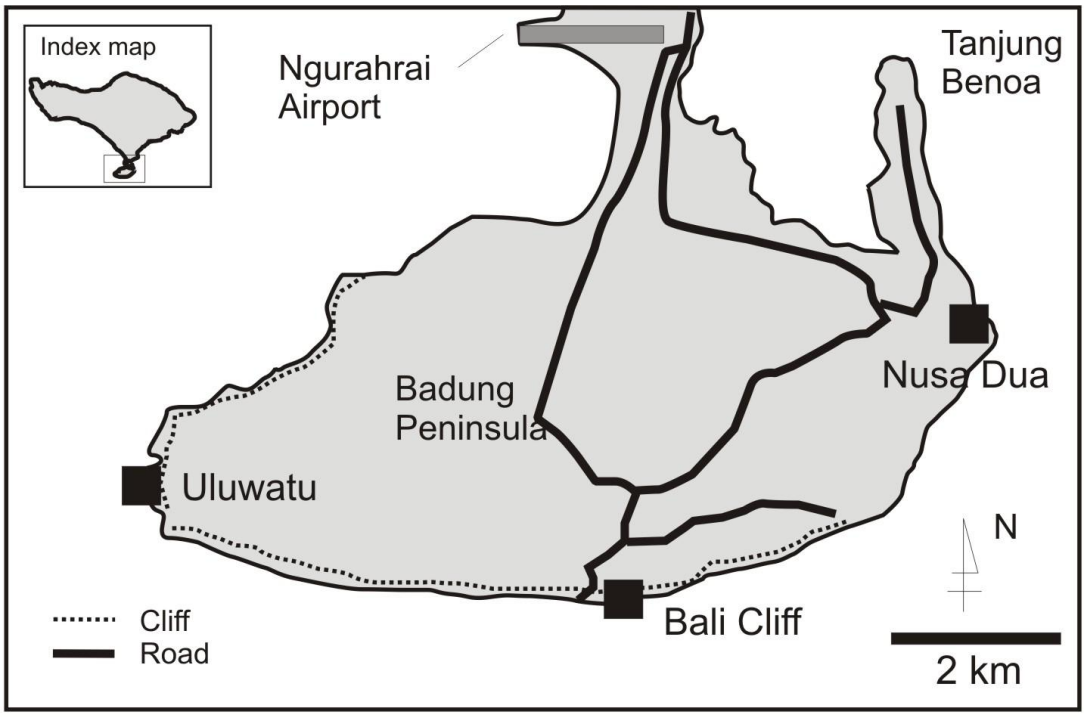


Figure 5. *A map of Badung Peninsula in the south of Bali, showing the limestone cliff distribution in the west and south part*



Figure 6. A) *Aerial photo of Uluwatu cliff with the temple (pointed by arrow) as a scale. Some part of the cliff can reached more than 90 meters;* ***B)*** *A cliff picture from the side showing the lateral extension of the relatively flat beds*

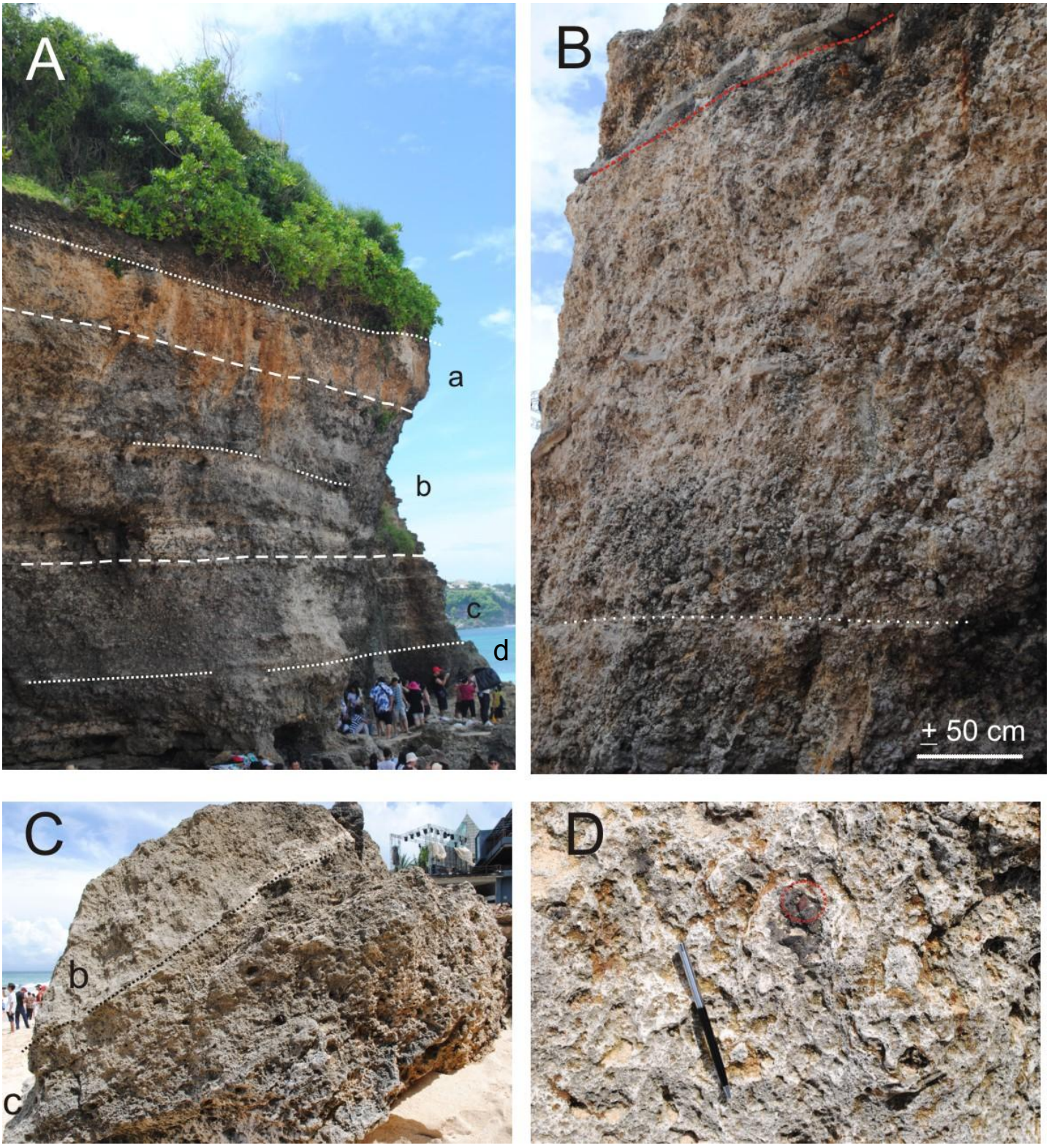


Figure 7. A) *Selatan Limestone Formation in Pecatuh Beach. The cliff profile may indicate the rock hardness. The 'c-d' sequence is relatively hard, with abundant of large coral fragments with poor beds on the left and well bedded unit on the right with smaller fragments. The sequence above it is relatively softer (especially around 'b' horizon) with much finer limestone fragments. Above 'a' horizon the beds are heavily mixed with soil;.* ***B)*** *A detail picture close to 'd' horizon in Figure 7A, showing the large fragments of corals which is commonly called as Rudstone;* ***C)*** *A boulder large coral fragments at the bottom part (bottom right) and well layered limestone in the upper section (upper left);* ***D)*** *A volcanic rock fragment (red circle) within the limestone bed.*

Conclusion

In the Lesser Sunda Islands, volcanic activity and carbonate deposition took place simultaneously and very close to each other. These two depositional systems shaped Bali Island, and appear both in present day and in the rock records. Uluwatu and Tanah Lot outcrops are good example for these depositional systems. In these sites, limestone fragments are found in volcanic deposits and vice versa. It is therefore concluded that although volcanic eruptions may disturb the growth of a carbonate system, it is not a continuous process. The volcanic activity, therefore, won't kill the carbonates.

Recommendation

Both Uluwatu and Tanah Lot outcrops are excellent exposures for detailed studies of the relationship between volcanic activities and limestone depositional processes in Bali. The lateral variation of the long cliff in the southern part of Bali may also worth to be investigated in further detail. Unfortunately there were not many geological research and studies on these outcrops. These issues may come as projects which could be done by Indonesian universities.

Acknowledgement

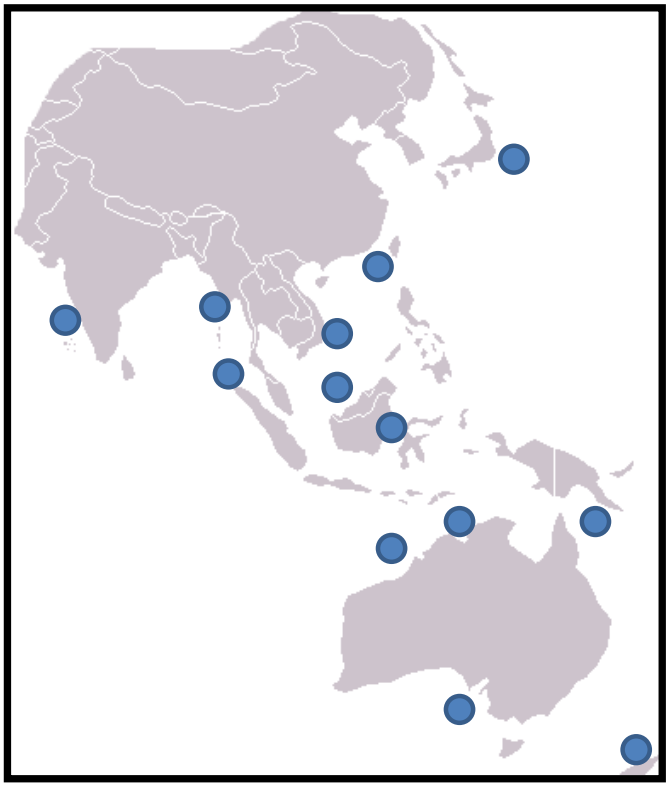
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References

Boekschoten, G. J., Best, M. B, and Putra, K. S., Balinese reefs in historical context, in Proceedings 9th International Coral Reef Symposium, Bali, Indonesia 23-27 October 2000.

Purbo-Hadiwidjojo. 1971, Geological map of Bali, Geological Survey Indonesia.





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