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The sea level rose fast, but Sarawak was rising faster

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Abstract: Since the end of the last glacial period, around 15550 years ago, melting ice caused the sea level to rise on average by about 110 m, or 7 mm/year. Data collected at the Tusan Cliff section indicate that during the same time span, the Borneo coastline south of Miri was elevated by 132 m. The average rate of uplift of the coastline was estimated to be in the order of 8.5 mm/year, which exceeded the average rate of sea level rise by 1.5 mm. As a result, a prominent cliff section is now exposed. The uplift may be continuing today but may be outpaced in the future by a much faster sea-level rise.

Keywords: Sea level rise, Borneo, uplift, Pleistocene, Holocene

OBJECTIVE AND METHODOLOGY

The objective of this paper is to review the C-14 age record of the coastal terraces at the Tusan Cliff location (Sarawak; Kessler & Jong, 2011; 2014), south of Miri, in the light of improved global sea level data and the availability of better field geology data. Additional photographic material is added to document the cliff section, which is in a setting characterized by very strong coastal erosion. The Tusan Cliff is seen as a particularly reliable data point (among several others), endowed with well-stratified outcrop sections, and without fluvial incisions.

RISING SEA LEVEL, RISING LAND, CLIFFED COAST

Sea level

The context of global sea level rise and tectonic uplift on the northern Sarawak coast resembles a horse race, in which two stallions are galloping side by side and neck to neck, and with an open outcome.

Abundant sea level measurements around the world (Figure 1a) have indicated that sea level has risen by more than 110 m since the last Ice Age ended, when large ice caps melted. At the onset of deglaciation about 19,000 years ago, a brief, at most 500-year long, glacio-eustatic event may have contributed as much as 10 m to the sea level rise at an average rate of about 20 mm/year. During the remaining part of the early Holocene, the rate of sea level rise varied from about 6.0–9.9 mm/year to as high as 30–60 mm/year during brief periods of accelerated sea level rise (Blanchon, 2011; Cronin, 2012). The above range of 6.0-9.9 mm/year is well in line with the estimated yearly 7 mm measured in Tusan. The sea level rise led to a submergence of coast lines all around the world, and the continued sea level is threatening low-lying lands and coastal cities.

Uplift, wave action and age determination

As everywhere else, the sea level is rising along strip of coastline between Kpg. Bakam and Pantai Bungai in Sarawak. The mentioned coastline south of Miri has the characteristics of a cliffed coast (Figure 2, and Kessler & Jong, 2011; 2014). The cliff originated at the end of the last Ice Age, when the platform, the High Terrace (Figure 3), was at sea-level and the coastline laid some 200 m -10 km further land landwards. The (paleo)coastline can be mapped only in places, due to the widespread land clearance for oil palm plantation and other infrastructure projects. Due to the steep seaward dip of the cliff-forming formations, the cliff is highly unstable as the waves and longshore currents scour its base. Wave-cut notches (Figure 2, 4) will eventually cause the collapse of the rock above, as it happened at the “Drinking Horse” location (Kessler & Jong, 2020, and Figure 5).

The elevation of the cliff varies along the coast. There is a scatter of C-14 values from the coaly sands of the High Terrace (Kessler & Jong, 2011; 2014 and Table 1), which suggests minor vertical movements since the end of the Pleistocene. The age dates of the coaly clasts suggests that individual segments of the High Terrace, with their mangrove swamp facies developed at slightly different times. The Tusan section was selected as a suitable location to compare the sea-levels with uplift as it provides a good stratigraphic outcrop section at the cliff, and the elevation of the High Terrace is at a constant elevation of approximately 22 m relative to the immediate surroundings.

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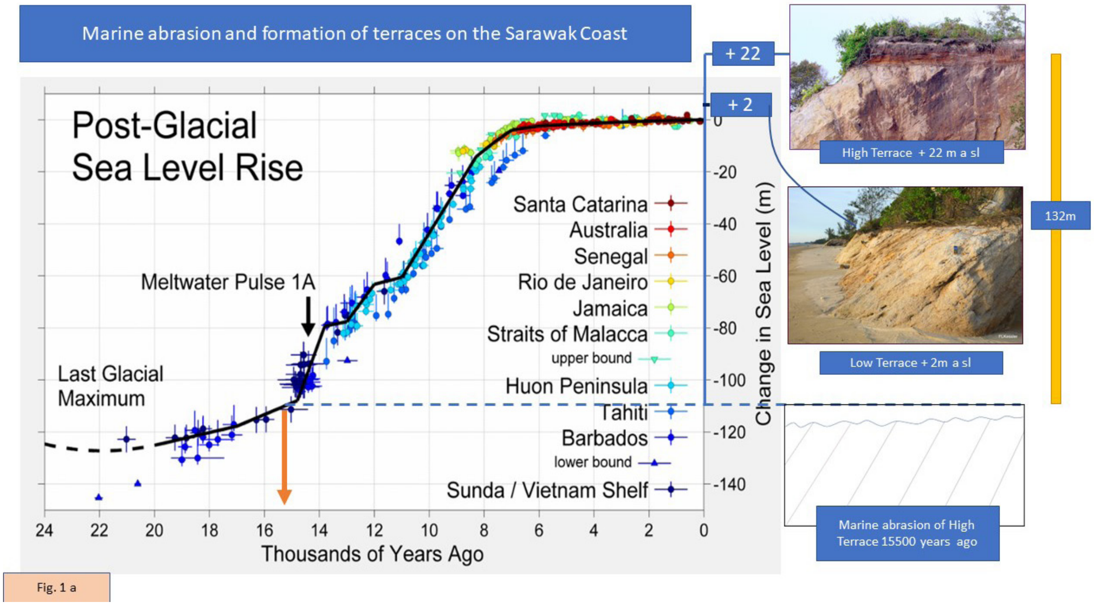

Figure 1a: A comparison of sea level rise and coastal uplift data. This figure shows sea level rise the end of the last glacial episode based on data from Fleming *et al*. (2012), and Milne *et al*. (2005). These papers collected data from various reports and adjusted them for subsequent vertical geologic motions, primarily those associated with post-glacial continental and hydro-isostatic rebound. Fleming *et al.* (2012) refers to deformations caused by the weight of continental ice sheets pressing down on the land. The latter (Milne *et al*. 2005) refers to uplift in coastal areas resulting from the increased weight of water associated with rising sea levels. Because of this and associated uplift, many islands, especially in the Pacific, experienced higher local sea levels in the mid-Holocene than they do today. The coastal uplift information of the Sarawak coast near Miri is based on extended field work by the author, during the period 2004-2022. The C-14 measurements are from Kessler & Jong, 2011 and 2014.

Figure 1b: View of the cliffed coast between Tusan cliffs (center) and Pantai Bungai. The orange line indicates the approximative position of a paleo-coastline 15550 years ago in the early Holocene. The yellow line indicates the contemporaneous outer boundary of the shoreface.

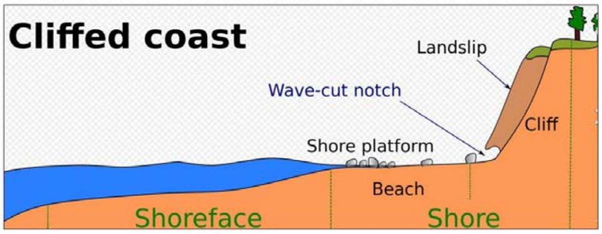

Figure 2: Schematic aspect of a cliffed coast. From Whitthow, John (1984). Dictionary of Physical Geography. London: Penguin, 1984. pg. 97. ISBN 0-14-051094-X.

Figure 3: Picture of the High Terrace on top of the Tusan Cliff, about 22 m above sea level. The Tukau Formation dips at 50° and is cut by a marine abrasion surface, overlain by sands with coaly material/ grains. These carbonaceous materials gave a C-14 age date of 15550 ± 80 years (Kessler & Jong, 2014).

Figure 4: Scoured cliff front of the Tusan Cliff area. The ever deeper grinding sea washes out wave-cut notches. These will destabilize the cliff front until it collapses, layer by layer.

Figure 5: Close-up on a High Terrace outcrop with coaly sands in the Tusan area, above a marked unconformity surface. Picture was taken 2022 at the access road to the now collapsed “Drinking Horse” rock. The uppermost part of the sequence is formed by white, bleached sands. The brown-colored sediments below contain charcoal clasts, charred remnants of roots of mangrove trees, and reworked quartz pebbles originating from the eroded Tukau Fm. beneath. The sands are level-bedded.

Table 1: C-14 age dating of charcoal clasts in sediments of the High Terrace (Kessler & Jong, 2014). The Tusan Cliff is seen as a particularly reliable data point, endowed with well-stratified outcrop sections, and without fluvial incisions.

Sample Index	Northing	Easting	Altitude (m)	Above formation, dip, dip direction	Thickness	Area	C-14 Age (years BP)
1	04° 13.596″	113° 55.149″	18	20° NW, Tukau	>1 m	Sewa Yaya	24,150±170
2	04° 19.757″	113° 59.931″	23	5° NW, Tukau	>1 m	Taman Tunku	25,580±190
3	04° 15.174″	113° 55.758″	14	13° NW, Tukau	>2 m	Bakam Sandpit	18,880±140
4	04° 21.996″	113° 58.160″	38	30° NW, Tukau	>1.5 m	Miri Jalan Tanjung	24,140±170
5	04° 21.107″	113° 59.801″	30	Probably Tukau	>2 m	Riam	28,570±230
6	04° 09.140″	113° 51.169″	23	80° NW, Lambir	2-3 m	Coastal road	8,880±50
7	04° 02.153″	113° 53.555″	17	70° NW, Lambir	2-3 m	Coastal road	16,360±80
8	04° 07.403″	113° 49.289″	22	50° NW, Lambir	1-2 m	Tusan Cliff	15,550±80
9	04° 15.293″	113° 56.955″	21	25° NW, Tukau	1-2 m	Sungai Rait Valley	11,230±60
10	04° 11.376″	113° 52.708″	16	45° NW, Tukau	> 4 m	Beraya Boathouse	8,170±50

Another wave-cut platform, called the Low Terrace (Figures 6 and 7) occurs at only some 2 m above the present sea level and is almost completely destroyed by marine erosion. The Low Terrace remains undated by the C-14 method.

Today, we note the presence of a contemporaneous marine abrasion platform, which reaches some 1-2 km into the sea (Figure 1b). The steeply dipping cliff section is formed by sandy and clayey deposits of Tukau and Lambir formations. The coastline is constantly pounded by waves and scoured by long-shore currents.

The coaly sands of the High Terrace are located 22 m above sea level in Tusan (Figure 3), and were age-dated by the C-14 method (Kessler & Jong, 2014), and

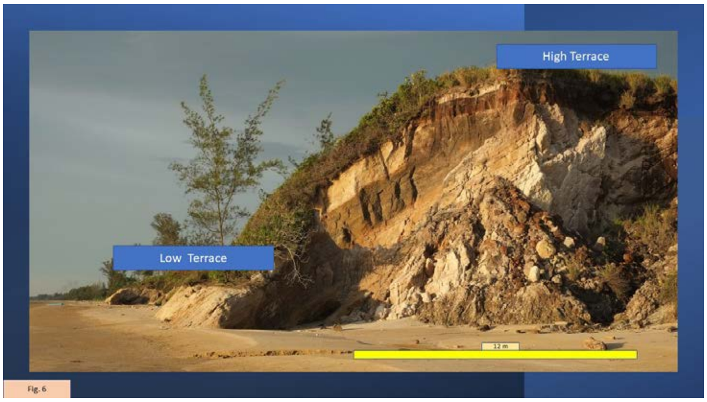

Figure 6: Between Tusan and Beraya Beach, a view of High Terrace and Low Terrace. The High Terrace has started to collapse.

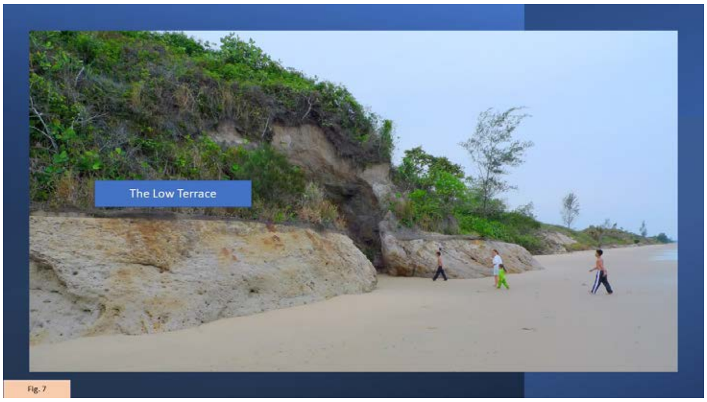

Figure 7: Between the Tusan Cliff section and Kpg. Beraya one can observe remnants of a lower wave-cut platform, 2 m above sea level, which is called the Low Terrace. The sediments above the abrasion platform have not been age-dated yet.

yielded an age of 15550 +/- 80 years. These (char-) coaly sands (Figure 5) are overlying a marked unconformity, which may be inferred to be somewhat older than the dated sediments.

Uplift

Accordingly, it is inferred that the High Terrace rose 132 m since the end of the last Ice Age, in a time span of merely 15550 years. This suggests a rise of 8.5 mm/year. The cause of the uplift remains unknown. The Low Terrace may have formed during a pause in the uplift.

A glance into the future

If tectonic uplift had prevailed over a period of rising sea level, its rise appears to have accelerated during the last hundred years and may have started to outpace the slower rising cliffed coast of Northern Sarawak. What will the future hold for the Tusan Cliff? It will continue to be scoured and damaged by waves and longshore currents. A front of wave-cut notches would gradually grind deeper, until the rock formation above it eroded cliff front collapses. This process would continue, and the cliff front would further recede.

WHICH ARE THE FORCES THAT CAUSED BORNEO TO RISE? A DISCUSSION

Large parts of Borneo Island have undergone a history of uplift and erosion (Kessler & Jong, 2016). A few factors may have contributed to the uplift. These are:

(i) Endogenic factors such as tectonic compression leading to faulting and folding. There is evidence of faulting and thrusting in the Pliocene and Pleistocene.

(ii) Uplift of mountainous regions in the hinterlands. Vast amounts of sediment were eroded and shed into the SCS; on the island, the load on crust and mantle was diminished. The reduced weight on the island may have caused an elastic rebound (see explanation Figure 1a). On the other hand, the sea-covered crust of the SCS was loaded by additional sediment and water, and may have subsided further consequently.

(iii) Diapiric upwelling of mobile clay from the Setap Formation. As shown in Kessler & Jong (2011), diapiric upwelling has occurred in the greater Miri area. The elevation of the High Terrace is not equal level in the entire area of studies and may indeed point to a relatively mobile substratum, which allowed the High Terrace abrasion platform and the coastal mangrove swamps to develop on the paleo-coastline earlier or later.

CONCLUSION

Since the end of the last glaciation, some 15550 years ago, melting ice caused the sea level to rise by some 110 m, or 7 mm/year. During the same time span, the Borneo coastline south of Miri rose by 132 m, and the uplift of the coastline was in the order of 8.5 mm/ year. A prominent cliff section with an abrasion platform on top, called the High Terrace is now exposed at Tusan. The rate of tectonic uplift, averaged over 15550 years, exceeded the average sea level rise by 1.5 mm/ year. The reasons for the uplift that outpaced the rising sea level are not well understood.

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DECLARATION OF COMPETING INTEREST

The author declare that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The author have no conflicts of interest to declare that are relevant to the content of this article.

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