Formation of Okains Bay sea caves – original features and development: Eastern Banks Peninsula

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ABSTRACT

Structural, stratigraphic studies provide insight into the formation and geomorphology of marine erosional features. Seven sea caves of volcanic composition have been identified in the Okains Bay area. This pilot study focuses on the origin of the sea caves in terms of development processes affected by the volcanic features of the caves and by the sea level height of the Last Interglacial. The presence of joints and lava flow layers and igneous intrusions within the caves that are susceptible to erosion suggest that initial weak zones caused by these structures significantly contributed to formation processes and current morphology. Other proposed contributing factors to sea cave morphology are wave refraction energy and shore platform morphology.

INTRODUCTION

Volcanic material varies both lithologically and stratigraphically, and impacts the morphology of the natural landscape. Banks Peninsula is located in mid Canterbury and comprises the remnants of two shield volcanoes, Lyttelton and Akaroa (Bal, 1997). Volcanic activity initiated c. 15 m.y. ago and continued for c. 10 m.y. through to 5.8 m.y. ago. Today, both volcanoes are inactive (Bal, 1997). Ongoing fluvial and marine erosion has contributed to formation of harbors Lyttelton and Akaroa, as well as the numerous bays along the Banks Peninsula coastline (Lawrie, 1993).

Many researchers question Banks Peninsula and its tectonic history, and have been studying the peninsula since the early 1900s. Relatively recent research suggests that Banks Peninsula has been tectonically stable for the past 125,000 years.

Early research began with R. Speight (1930) who stated that the platforms suggest uplift of the peninsula by 3.6-4.5 m, while peat beds and intertidal molluscs at a depth of 183 m below modern day sea level suggest an overall progressive “lowering of the land.” In 1985, S.D. Weaver et al. noted a lack of raised beaches on Banks Peninsula, and suggested the peninsula has a history of subsidence, not uplift. J. Gibb (1986) stated that Banks Peninsula was subsiding based on the lack of interglacial benches near Banks Peninsula, and offered a subsidence rate of 0.1 ± 0.03 m/ka. Lawrie (1993) observed interglacial shore platforms 6-8 m above sea level on Banks Peninsula, and concluded that the peninsula has been stable during the late Quaternary. Brown and Weeber (1994) proposed that the northern margin of Banks Peninsula was subsiding, while the southern margin has been stable. Bal (1997) reaffirmed Lawrie's conclusion using coastal erosion features such as sea caves to show that Banks Peninsula did not undergo differential subsidence in the past 120,000 years.

Today, no definite evidence has thus been offered for either the submergence or stability of Banks Peninsula, while the possibility of uplift has yet to be seriously considered by any researcher. Currently, earthquakes in the Canterbury area are trending towards the east and Banks Peninsula. Therefore, alleged tectonic stability of the peninsula is no longer applicable. An example of this can be seen with Port Hills, which uplifted as much 400 mm, and the nearby estuary, which subsided 200mm.

One of the more recent studies done by Bal (1997) used coastal erosion features such as sea caves to show that Banks Peninsula did not undergo differential subsidence in the past 120,000 years. Bal's study focused on Cave Rock, a sea stack located in Sumner, which contains a network of sea caves that have been described in some detail (Bal, 1997). Sea caves are prominent features on the Banks Peninsula coast. Sea caves, or coastal caves are caves that develop from the interaction of marine and terrestrial processes along coastlines. A coastal cave can form through the process of marine erosion excavating a cavity within coastal rock. Sea caves occur in the weakest areas of rock, such as joints, faults, soft strata, breccias, and internal lava flow structures (Pirazzoli, 2007).

Sea caves similar to the ones at Sumner can be found at Okains Bay (see Fig. 1). Okains Bay is located on the northeastern coast of Banks Peninsula, South Island, New Zealand (43°42'S, 173°04'E). Walls of layered basaltic lava flows bound either side of the 0.9 km long Okains Bay beach (Stephenson and Shulmeister, 1999). Within the walls are seven sea caves that have been carved out. Three caves, referred to as Lagoon Caves or LC, are located along the northwestern lagoon edge of the Okains Bay Reserve, one cave, referred to as the Dike Cave or DC, sits within the base of an exposed sea cliff on the western edge of the bay, and three caves, referred to as Beach Caves or BC, are located just inland of the east-southeastern edge of the Okains Bay Beach (see Fig. 2). The depths and heights of each cave are on the 10s of meters scale or less, indicating that these caves are neither connected nor part of a larger pseudo-karst cave system, such as can be demonstrated with sea caves associated with lava tubes. Each cave has its own associated shore platform covered in sand from Pegasus Bay (Dingwall, 1974).

The entrance to Okains Bay and to the beach is oriented to the northeast. Therefore, only northeasterly winds can generate waves that will directly enter the bay (Stephenson and Shulmeister, 1999). Today, low energy waves with heights of and less than 0.3 m dominate the wave environment, and only few waves with heights of higher than 1.0 m have been noted (Stephenson and Shulmeister, 1999). Despite the current dominance of low energy waves, a significant wave energy level created the coastal erosional features of Okains Bay and all of Banks Peninsula.

The origin of the Okains Bay sea caves has not been previously examined. Their origin in terms of development processes affected by the volcanic features of the caves and by the sea level height of the Last Interglacial may help to resolve the question of tectonic stability, subsidence or uplift in the banks Peninsula area.

METHODS

Field work was done at Okains Bay on February 11 and February 25, 2012. Observations and sketches of volcanic and erosional structures at seven sea caves were recorded. Photographs and photo mosaics were also used for observations and preliminary interpretations. The heights of key features were surveyed relative to ground level, as there were no proximal benchmarks that could be used. Key erosional features focused on include the cave arch maximal and minimal heights, pillars, fractures, and benches. Other key features observed were adjacent shore platforms, surrounding lava flows, high and low tide heights, textural differences in l ava flow layers, and any intrusive bodies such as dikes. Literature reviews focused on the textural differences in flows were used to interpret the formation processes of the caves. Approximate relative and absolute ages of the caves were calculated using published progradations rates of Okains Bay (Stephenson and Schulmeister, 1999).

The field sketches and photographs collected in the field were used to create individual cave cross-sections as representations of the structures that form the cave. These help us to understand and interpret the processes needed to shape these structures.

RESULTS

DC1 lies within the Okains Bay sea cliffs is the only cave at Okains Bay that sits at present-day sea level and is actively undergoing constant marine erosion. The cave opening follows the orientation of the dike, with the western most edge of the cave aligned with the dike’s western edge. The cavity laterally extends approximately 5 to 6 m, and occurs primarily in the dike and the 5 m thick columnar jointed pahoehoe lava flow layer that begins at sea level. The height of the cavity is also approximately 5 m and ends at the contact between the pahoehoe lava and the overlaying breccia layer that is thinnest over the cave mouth.

The LC1 cave mouth extends vertically ~3 to 4 m up through vertically jointed rock and stops within a brecciated layer. Jointed lava layers bound either side of the cavity, which is approximately 5 to 6 m wide. The geometry of the cave opening is triangular, with the eastern side of the cave mouth following a conventional cave arch from the cave ceiling to the floor, while the western side extends laterally into a slope and does not mimic the eastern side. The cave ceiling is horizontal and subparallel to the exterior lava flow layers.

LC2, just north of LC1, has a small cavity that is 4 m in height and 4-5 m in width. The height of the cave mouth extends vertically up to columnar jointed lava with an onion-skin weathered exterior. Like the previous lagoon cave, this cave displays an asymmetrical cavity, with the eastern side having a regular cave arch, and the western side eroding to a more vertical plane. See Fig. 3 for a complete cross-section.

LC3 is located in the main entrance of the bay, and actively undergoes marine erosion with the exception of low tide. The cave mouth is about 2.5 m high and 3 m wide. This cave is made primarily of scoria, with overlying layers of breccia and columnar jointed pahoehoe lava.

The cavities of the beach caves differ from the lagoon caves in shape and size. The eastern sides of the cavities slope at shallow 25 to 35° angles. The western sides of the cavities are at steeper 50 to 60 ° angles.

The maximum height and width of BC1 are 6 m and 10 m respectively. The ceiling of the cave mouth is the approximate contact plane between the overlying lava and the brecciated layers carved out underneath. This is the oldest cave, with an age over 672 B.P. (Fig. 4). BC2 has a 7 to 8 m high and 8 to 9 m wide cave mouth that cuts through thick lava flow layers. The ceiling of the cave mouth is brecciated, while the western wall has a platy texture. BC3 is 7 to 8 m high and over 10 m wide. It has a ceiling that parallels the angle and dip of the lava flow layers. The ceiling has levels of solid lava and patches of the contact between soft, brecciated material and underlying solid lava. Within the cave is second cavity, with a mouth 1.5 m high and 3 m wide.

Only the lagoon caves have visible shore platforms. See Fig. 5 for shore platform cross sections. The beach caves and the dike cave do not have an apparent shore platform.

Shore platforms along the lagoon are currently active platforms, and as a result they are not horizontal. They are covered in fine sands, but some platy volcanic material is exposed at the surface. The platforms range from 1 to 4 m in elevation.

DISCUSSION

The alignment of the cave mouth suggests that the formation of the cavity was influenced by the properties of the igneous intrusion. The cavity interior follows the length of the dike, indicating that the dike was the point of weakness on which marine erosion processes focused. Marine erosion not only cut into the dike, but the adjacent columnar jointed pahoehoe layer. This suggests columnar joints also provide areas of weakness that promote the formation of sea caves.

The lagoon and beach caves exhibit similarities in cavity erosion. Both brecciated layers and layers with jointing enable sea cave occurrence. Joints create permeable space where water can infiltrate and erode the surrounding rock. Brecciated and scoria layers create the same space between clasts and within the rock matrix. The contact planes between these layers appear to be ideal sea caves ceilings, as seen in caves LC2, BC1, BC2 and BC3. This is likely because the change in strength from the breccia to overlying pahoehoe lava to inhibits marine erosion processes. In LC1, the cavity ceiling cuts through mostly pahoehoe layers and also cuts into overlying breccia. This indicates that the breccia is weaker than the pahoehoe, and the water energy needed to erode pahoehoe will also erode breccia, but not vice versa as seen with the previously mentioned caves.

LC1 and LC2 have similar shore platforms, experience similar wave refraction, (Fig. 4) and exhibit comparable cave morphologies in size and geometry. LC3 has a slightly different shore platform morphology, but still exhibits a smaller amount of marine erosion like LC1 and LC2.

The energy behind wave refraction plays an integral role in the erosion of shore platforms, while the location and elevation of shore platforms affect the extent of marine erosion that occurs on the cliffs behind the platforms. The lagoon cave cavities are overall shorter and smaller in volume than the beach caves. Based on the differences between the lagoon caves and the beach caves, it is possible that shore platforms have a direct effect on sea cave morphology. At high sea level, a significant shore platform could possibly impede wave height, as wave energy rapidly dissipates across shore platforms (Trenhaile, 1987). Over time, this proposed phenomenon would reduce the amount of marine erosion, making any notches in sea cliffs behind the platforms less volumetric than exposed sea cliffs without a shore platform, such as the dike cave.

Caves LC1-3 and BC1-3 are all located at elevations higher than Mean Sea Level (MSL). Based on the elevation of the caves and shore platforms, and the distance of the Beach Caves from sea level at high tide, is unlikely that present-day sea level coastal processes contributed to the major morphological features of the caves that are 2 to 5 m above MSL. During the Last Interglacial, sea levels were at 6 m above present-day MSL. Following previous assumptions of the tectonic stability of Banks Peninsula, it appears that the coastal features described here can be attributed to the high sea level of 120,000 years ago or earlier. However, the recent chain of earthquakes demands a future revisit to previous suggestions from Weaver (1985) and Brown and Weeber (1994) about Banks Peninsula's tectonic instability, as today we see uplift and subsidence in the region. Further studies could be done to focus primarily on geomorphologic indicators of tectonic subsidence or uplift after the Okains Bay sea caves, and apply them to both previous and present-day ideas on Banks Peninsula's tectonic instability.

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Figure 1. Aerial map of Okains Bay study area with sea cave locations marked. Legend: DC = dike cave, LC = lagoon cave, BC = beach cave.

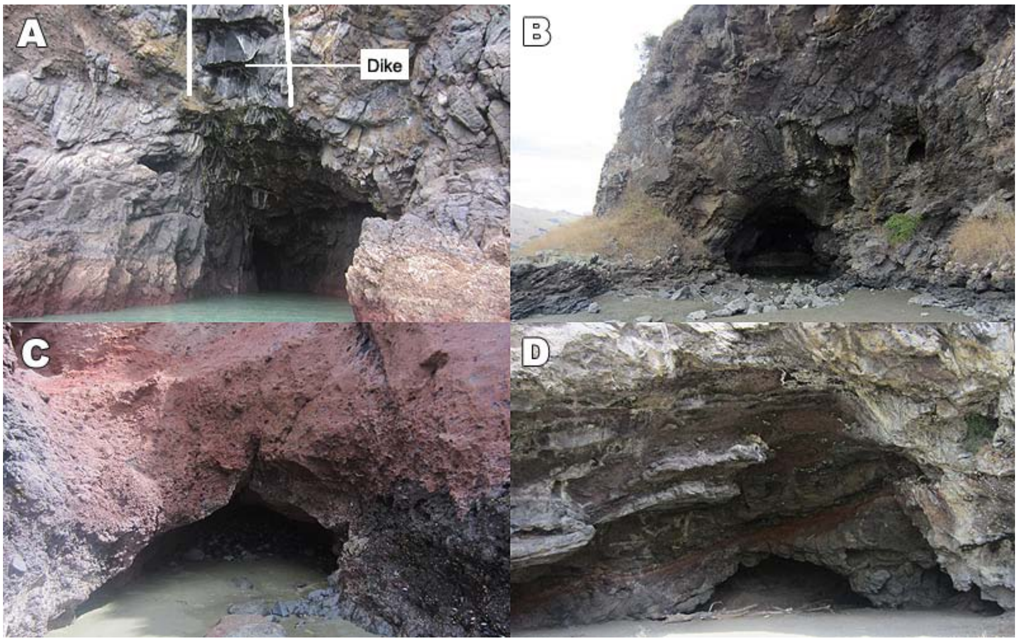

Figure 2. Photo mosaic of various cave types at Okains Bay. A.) The dike cave. Photo taken facing southwest 22 minutes before low tide. B.) LC2. Photo taken facing southwest-west at low tide. C.) LC3, a scoria sea cave. Photo taken facing southwest-west at low tide. D.) BC3. Photo taken facing southeast.

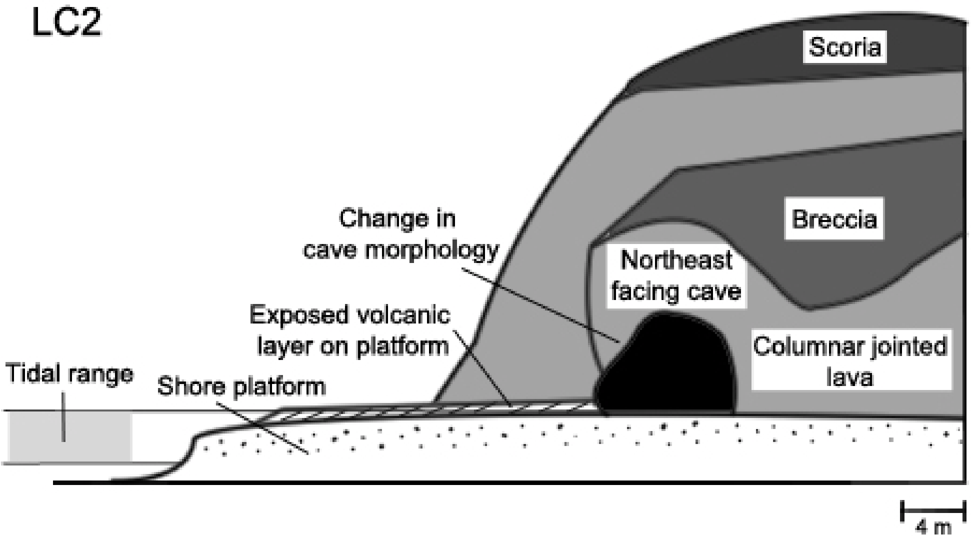

Figure 3. Schematic cross section of Lagoon Cave 2, highlighting key morphological features.

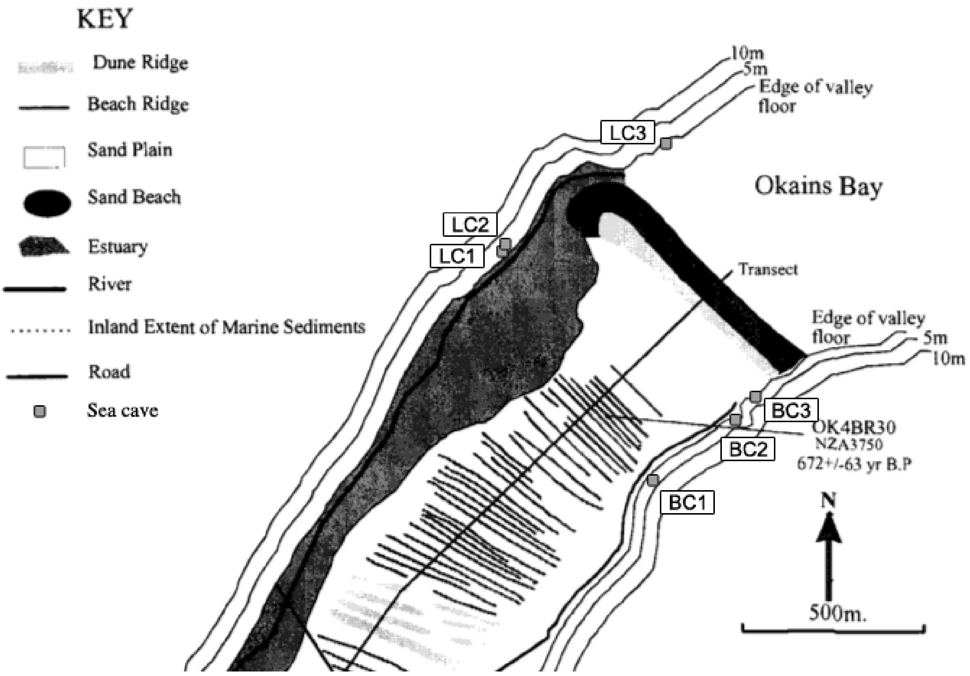

Figure 4. Geomorphological map of Okains Bay with sea cave locations at approximate elevations. Foredune ridge OK3BR30 indicates approximate age of BC1. Figure modified from Stephenson and Schulmeister, 1999. Foredune ridge dating from Stephenson and Schulmeister, 1999 study.

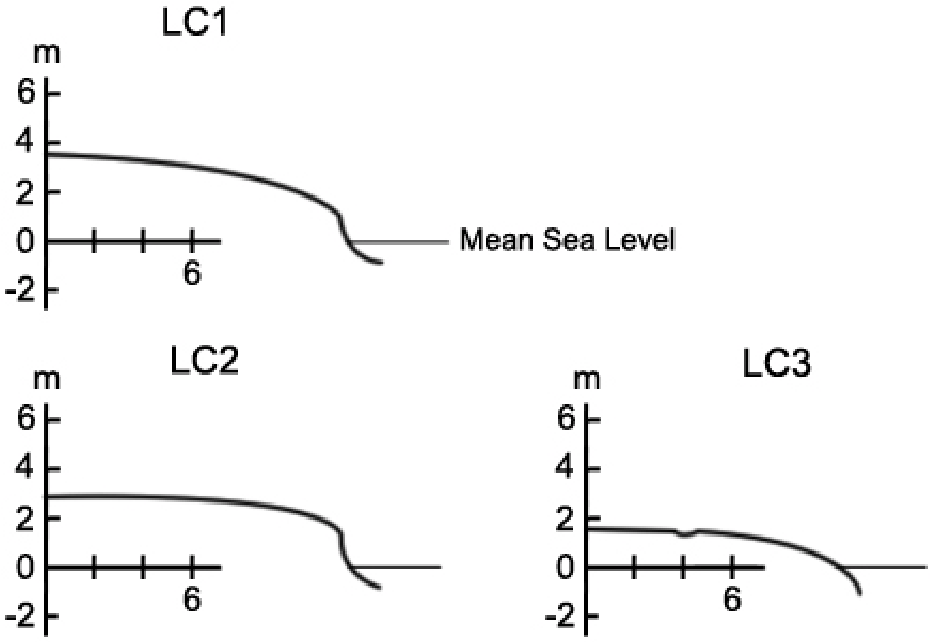

Figure 5. Platform cross sections of lagoon caves.