Subaqueous Emplacement of Rheoignimbrite at Bald Head, within the Myall Trough, South Eastern end of Tamworth Belt, New South Wales East Coast.

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Abstract.
The main focus of this document is to highlight the presence of a previously undocumented subaqueously emplaced rheoignimbrite that displays abundant oblique folds, curvilinear folds, detached thrust folds and associated structures that crop out in the headland at Bald Head within the Myall Trough, on the lower Mid North Coast of New South Wales.

Introduction.

The Amateur Geological Society of the Hunter Valley implemented an introductory field study at Bald Head in April 2023, making several observations regarding the geology in this area. The field study was conducted by people with professional knowledge but constrained by access to modern technology, preventing a full assessment of geological information. Gathering data regarding the geology and associated structures from publicly available sources regarding this area proved somewhat fruitless. There is mention of the geology from some workers, but only in passing, which is surprising considering the conspicuous nature of the geology at Bald Head.

The AGSHV hopes that this document will generate interest and form the basis for further investigations into the geology at Bald Head by scholarly individuals or groups.

This report describes a previously unidentified 6 to 8 m thick band of rheoignimbrite associated with the emplacement of high-grade, super-heated pyroclastic materials in a marine environment. The ignimbrite displays an abundance of chaotic structures that include oblique folds, possible sheathfolds, and detached thrust folds, which formed in the course of, or subsequent to emplacement within the influence of tractional, near-shore currents, surface currents, tides and waves. Field observations gathered at Bald Head, located at the northern end of Celitto Beach, (Sandbar) lower Mid North Coast of New South Wales (*Figure 1, 2 & 3)*, suggest a volcanic event deposited pyroclastic material directly onto the sea floor during the Mid to Late Carboniferous period, 331 Ma to 299 Ma in shallow marine shelf environment (GSNSW-Seamless Geology of NSW). The location of the source vent is not evident. But likely to be a subaerial eruption associated with the onshore Violet Hill Volcanics to the southwest.

Most rheoignimbrites documented in Australia are related to volcanic activity during the Proterozoic era. The rheomorphism of ignimbrite is widely reported in Australian geological literature but is poorly understood. There is mention of subaqueously emplaced rheoignimbrite in the Pussy Cat Group rhyolites in the west Musgrave Province, Central Australia (Medlin et al., 2015), along with a brief mention from the region within the Lachlan Orogen, Southeastern Australia, where subaerial pyroclastic flow deposits have been interpreted as an ignimbrite that has been subjected to rheomorphism by gravitationally induced downslope flow, causing the folding of the foliation (Fergusson et al., 2019). In the Northern Territory, rhyolite in the Peculiar Complex is interpreted as subaerial rheomorphic ignimbrite or long lava flow Australian Stratigraphy Unit Database ASUD (2004). All of these sites are related to orogenic or subduction events associated with the formation of the Australian continent. Other well-documented examples are overseas and include the Green Tuff Ignimbrite Pantelleria, Italy (Scarani. et al., 2023); Snake River Plain, USA, associated with the Yellowstone hotspot track and the southern projection of the west Snake River rift (Knott. et al., 2016); the Somers ignimbrite and related volcanics, Mt Somers, mid-Canterbury, New Zealand (Smith. 1994); and the Pitts Head Tuff Formation of the Ordovician (Caradoc) age in North Wales (Kokela and Königer 2000), which has several similarities to the outcrop at Bald Head.

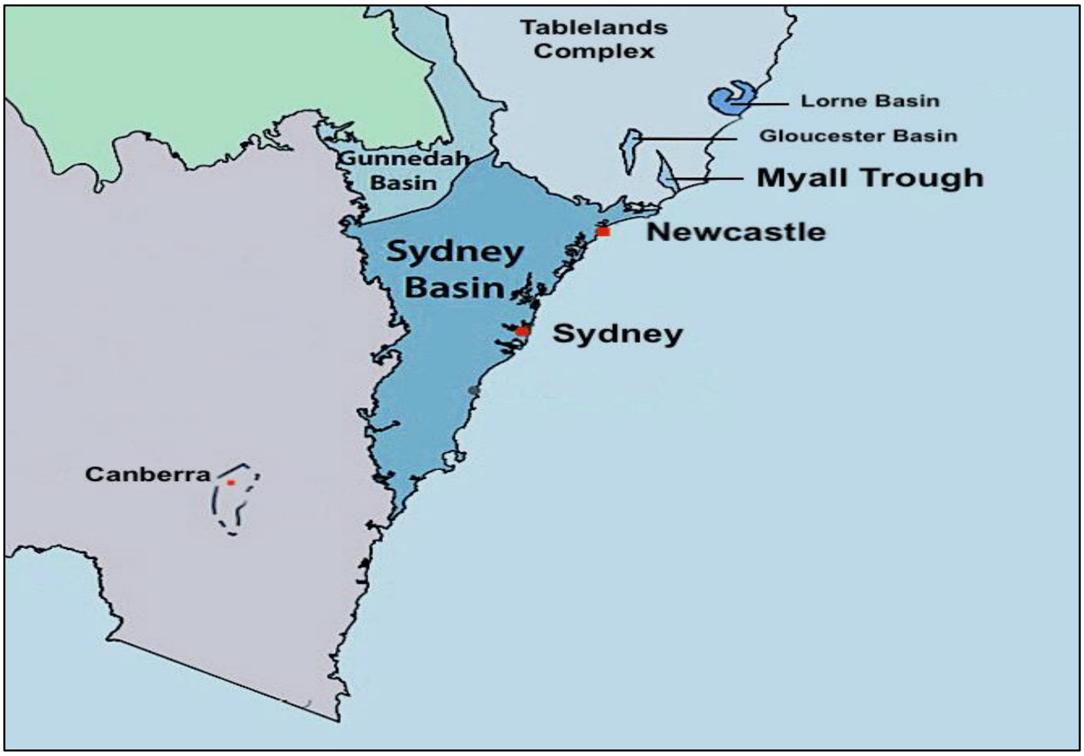

Figure 1. Map of NSW showing the location of the Myall Trough.

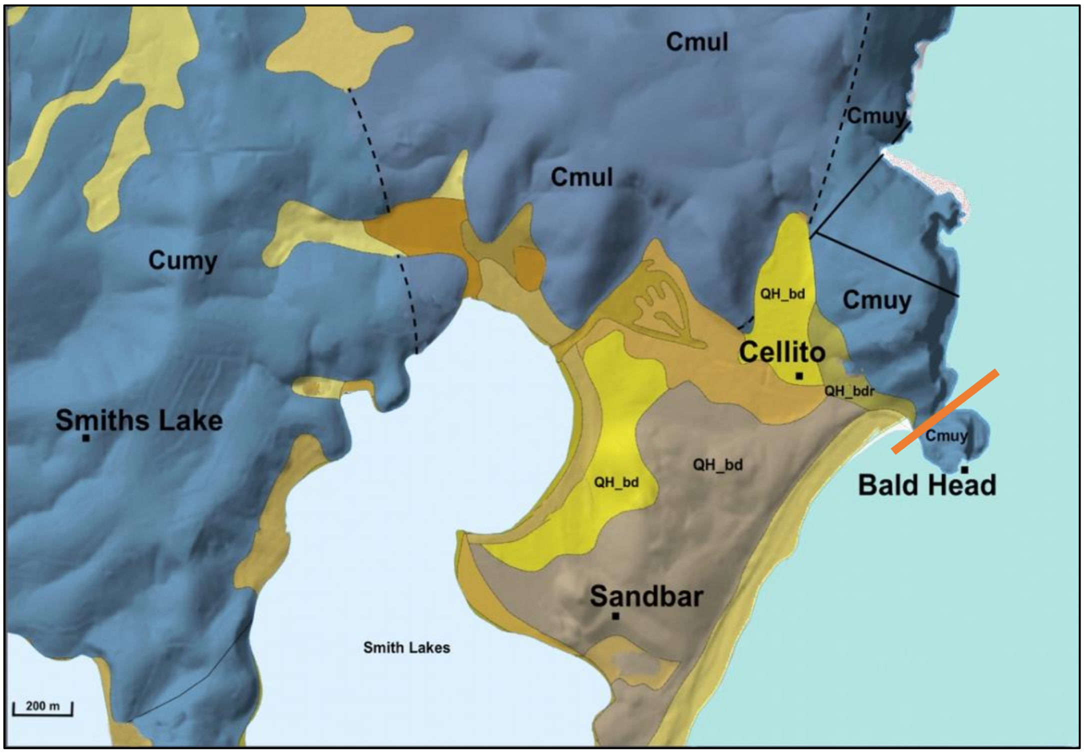

Figure 2. Geological map (MinView) of the Bald Head area, within the Myall Trough. Cmul - Koolanock Sandstone; Brown to grey interbedded bioturbated siltstone, cream rhyolite flows, upward fining conglomerates, carbonaceous siltstone and minor coal seams. Cmuy - Yagon Siltstone; fossiliferous dark siltstone. Minor interbeds of sandstone and fossiliferous sandstone. QH_bd; QH_bdr; Holocene coastal marine deposits.

Rhyolite dyke, infilling fault. *Fault.* *Sequence boundary.*

Rheoignimbrite.

Definition.

Wolff and Wright (1981, p. 13) state, Rheomorphism [rheoignimbrite], or secondary mass flowage, can occur in welded tuffs or ignimbrite of air-fall derived origin. The presence of a linear fabric is taken as the diagnostic criterion for the recognition of the process. It is believed deposition on a slope is an essential condition for rheomorphism after compaction and welding. Internal structures produced during rheomorphic flow can be studied by the methods of structural geology and show similar dispositions to comparable features in sedimentary slump sheets. It has been shown that secondary flowage can occur in welded tuffs emplaced on gentle slopes, provided that the apparent viscosity of the magma is sufficiently low. Compositional factors favour the development of rheomorphism in densely welded tuffs of peralkaline type.

Key Features.

Branney, et al., (2004, p. 486), state, rheomorphic ignimbrites [rheoignimbrite] represent a peculiarly awesome and destructive volcanic event; they can inundate entire landscapes with searing-hot glass in minutes. Rheomorphism is the ductile deformation of hot, welded pyroclastic material during and just after deposition. Since its first descriptions in the 1960s, rheomorphic ignimbrites have been increasingly recognised as a widespread volcanic phenomenon, with volumes exceeding 100s of km^3. They form a significant component of volcanism in diverse volcanic settings, including intracontinental volcanic provinces and continental arcs.

Diagnostic features.

Ignimbrites undergoing rheomorphism develop a variety of ductile deformational structures, including folded and attenuated pumices, vesicles, and welding fabrics. These features develop within the viscous welded mass whilst still hot and degassing. Some rheoignimbrites can develop flow banding and/or upper and marginal autobreccias similar to viscous lavas. However, based on preserved pyroclastic features, most rheoignimbrites can be readily distinguished from lavas (Branney et al., 2003, p. 485).

Depositional concepts.

Pyroclastic density currents are one of the most dangerous occurrences caused by volcanic eruptions consisting of hot mixtures of ash, gas, and rocks that travel rapidly and propagate around the volcanoes, which is impossible to monitor. Because of this, the emplacement of the ignimbrites is open to interpretation. There are at least two theories (Branney et al., 2004, p. 485) for the origins of rheomorphism. Some workers say the major factor of deposition is when the air-fall-derived-ash flow is cool enough to undergo viscous flow. Others suggest it occurs post-deposition but before the tuff has cooled past the brittle-ductile transition point when gravity can pull it downhill. According to Andrews and Branney (2005, p. 3), Wolff and Wright (1981) “propose that deformation welding and rheomorphism begin only after the pyroclastic density current has ceased transport and deposition”. The deformational processes are thought to be caused by similar mechanisms as seen in comparable features such as sedimentary slump sheets, which are well understood.

Terrestrial Eruption with Deposition of Pyroclastic Flow in a Marine Environment.

The Pitts Head Tuff.

The deposition of pyroclastic material at Bald Head appears to be analogous to the Pitts Head Tuff in North Wales, where pyroclastic material was emplaced onto the sea floor, as described by Kokelaar and Königer, (2000). At Pitts Head, a subaerial volcano sent a pyroclastic flow downslope into a subaqueous environment, filling a downfaulted half-graben. Pitts Head Tuff is exposed along a syncline in a half-graben with the volcanic source on the adjacent horst block. Originally the half-graben was under the sea while the horst block was onshore (Kockelaar and Königer, 2000). Their work is a comprehensive investigation of surface exposures of about 5 km^2 at the northern end of the approximately 6 km long outcrop. Their research included core drilling and petrological analysis.

The Pitts Head Tuff records a subaerial, large-volume eruption and associated pyroclastic current that flowed into the sea. The current 15 km from the source was steadily sustained, with high mass flux and high particle concentration towards its base, and it entered the sea without substantial mixing with water and thus without large-scale hydro-explosivity without general cooling. It continued to aggrade ignimbrite at >580°C for at least 3-4 km from the original shoreline in water initially ≥50 m deep. Entirely subaqueous, hot-state, progressive aggradation, welding of the ignimbrite occurred where the water could not be wholly displaced by the current, although eventually, the deposit moved the shoreline >4 km

Figure 3. Aerial view of Bald Head Peninsular at the northern end of Cellito Beach. A - Rheoignimbrite; Aa - Presumed older ignimbrite flows; B – Yagon Siltstone; C – Rhyolite dyke. (See Figure 9 for details). [Photo, Barrington Coast. Mid Coast Council].

Figure 4. Looking north, the section between Bald Head Headland and the mainland shows. A - Cliff face with skeletonised rheoignimbrite; B - Vesicles and two of three pressure domes associated with deposition over wet seafloor; C - Rhyolite dyke.

seawards. Saturated sea-floor sediments buried by the ignimbrite was heated and locally fluidised by steam, with several square kilometres of hot ignimbrite with variable thicknesses of sedimentary substrate detached and sagged downslope. Directions of sliding and the order of piling-up of slide sheets are shown by hot-state (rheomorphic) deformation fabrics and the geometric relations of detachment surfaces (Kokelaar and Königer, 2000, p. 517).

Similarities Between Myall Trough and Pitts Head.

Bald Head lies on the eastern edge of the Myall Trough (*Figure 1 & 2*), which formed as an elongated trough within the eastern end of the Myall Block between the magmatic arc to the west and a convergent plate to the east. This is thought to be the result of basin subsidence, driven by the transposed strike-slip vector of oblique convergence (Skilbeck and Cawood, 1994). Sediments and pyroclastic material from the terrestrial magmatic arc were considered to be the main contributors to the Trough. The Trough is a sequence of sediments exceeding 2 km in thickness (Geeve et al., 2002). The sequence contains five depositional systems in which environments range from non-marine to deep marine, representing the deepest water environments in the east. Sediments within the Trough were derived from a south-westerly dacitic to a rhyolitic magmatic arc, including the Nerong Volcanics (338-340 Ma, Jessop, et al., 2018) and the Violet Hill Volcanics (331-299 Ma. ASUD). Overall, the sequence is younger towards the west (Skilbeck 1986), consequently, the rocks at Bald Head represent deeper/older turbidite facies. Subsequently, a complex development of folding, faulting and jointing has resulted in significant inclination of beds. Therefore, the location of the source vent for the ignimbrite at Bald Head is not immediately apparent.

Geology of Bald Head.

The structural and depositional history of Bald Head is contemporaneous with the development of the Myall Trough. More specifically, the area of interest is within a 6 to 8 m thick band of welded ignimbrite exposed in a vertical section of the cliff face 0.63 km in length, where at its northern extremity, it is truncated by a thrust fault at sea level *(Figure 6).* At the southern end, it passes below sea level.

Directly underlying the ignimbrite are coherent layers of medium to thick intercalated siltstone, mudstone and minor beds of sandstone and tuff of the Yagon Siltstone (*Figures 5, 7 & B - Figure 9*). The rheoignimbrite is overlain by horizontally, thinly bedded Yagon Siltstone sediments infilling the troughs on the upper surface of the ignimbrite (*Figures 7 & 8*). Australian Stratigraphy Unit Database (AUSD.) records these beds as Yagon Siltstone, Violet Hill Volcanic Member. GSNSW -Seamless Geology of NSW describes them as Carboniferous in age between Serpukhovian 331 Ma base at the base to Gzhelian 299 Ma top, Mid to Upper Carboniferous, deposited in an outer shelf shallow marine environment.

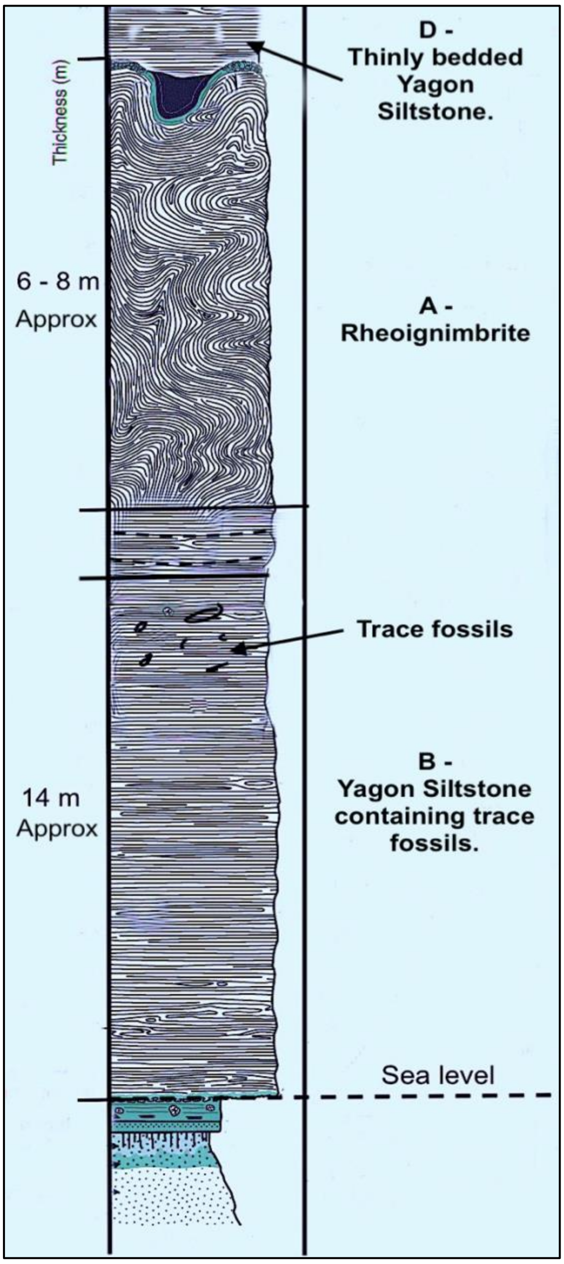

Figure 5. Schematic diagram shows Yagon Siltstone at the base directly below rheoignimbrite overlaid by thinly bedded siltstone infilling the troughs.

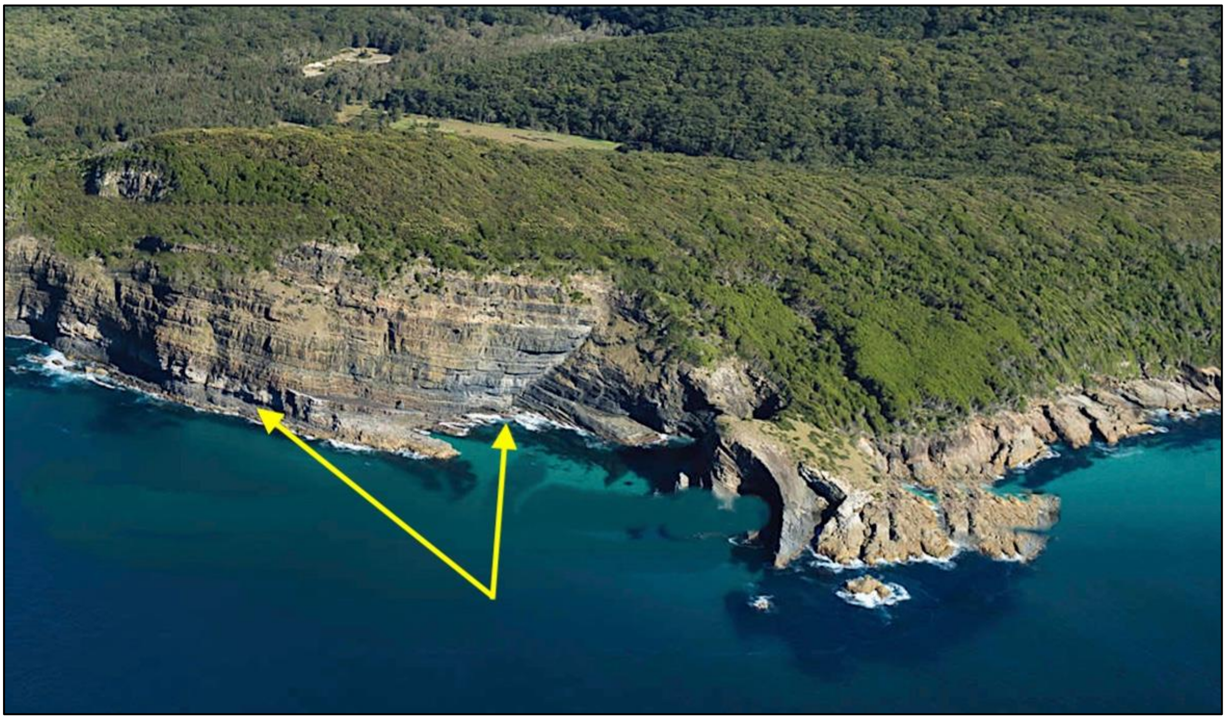

Figure 6. West-southwest view of the white band of rheoignimbrite at the base of the cliff face where it is truncated by a thrust fault at sea level (yellow arrows). (Note complete change in orientation of bedding).

The Bald Head peninsula is dissected by a northeast-southwest trending fault that was either contemporaneously or subsequently infilled with magmatic material forming a rhyolite dyke (*Figures 3 & 4).* The area between the headland and the mainland has eroded into a col, exposing the centrally located dyke with a vertical cliff face on the mainland side, and dipping to the west on the western side of the headland (Figure 4). The 6 to 8 m thick band of ignimbrite exposed in a vertical section of the cliff shows evidence of being deposited onto the seafloor as a pyroclastic density current, displaying violent deformation of the upper two-thirds of the ignimbrite from rheomorphism, such as crude overfolding and disrupted contorted bedding. It is therefore identified as a rheoignimbrite. Weathering has removed softer material within the ignimbrite, effectively leaving it in a skeletonised state, and accentuating the visibility of the folds and deformities within the ignimbrite (*Figures 7, 8 & A - Figure 9)*.

The suite of rocks at Bald Head is recorded by the Australian Stratigraphic Data Base as the Yagon Siltstone and its Violet Hill Member. This suite comprises beds, principally of siltstone, fine sandstone and ignimbrite, lying stratigraphically between the Booti Booti Sandstone and Koolanock Sandstone. Skilbeck (1986) describes the presence of a sequence of intercalated tuffs, indicating that volcanism in the source area was contemporaneous with sedimentation in the Trough.

Yagon Siltstone was deposited in a marginal marine to outer shelf environment. This is evident from the presence of *ichnofossils* (trace fossils) in the form of animal burrows and cavities of various shapes and sizes within the Yagon Siltstone (E – Figure 9 & Figures 10 A & B). There are good examples of infilled rectilinear and crescent-shaped burrows that are partially unroofed and devoid of fill, with some of the walls of the unfilled burrows showing still intact wall linings. Interestingly, some of the abovementioned burrows show relatively smooth walls, with rare subtle indentations (Figure 10 B). This indicates the unidentified marine creatures responsible for forming the burrows may have had a nodular exoskeleton, that largely inhabited near-shore environments. In effect, the lining has the advantage of acting as a scaffold, supporting the weight of the sediment above the animal stopping the burrow from collapsing. Apart from the trace fossils, there are the remains of a small tree trunk, 1.45 metres in length, with the root collar still intact. Noticeably, the tree trunk has experienced the effects of carbonisation from either fire or severe heat (*Figure 10 C)*.

Figure 7. Skeletonized rheoignimbrite lying above the Yagon Siltstone (dark Grey) weathered to lighter colours by the removal of softer material accentuating the visibility of the folds and deformities within the rheoignimbrite (see stratigraphy column, Figure 5).

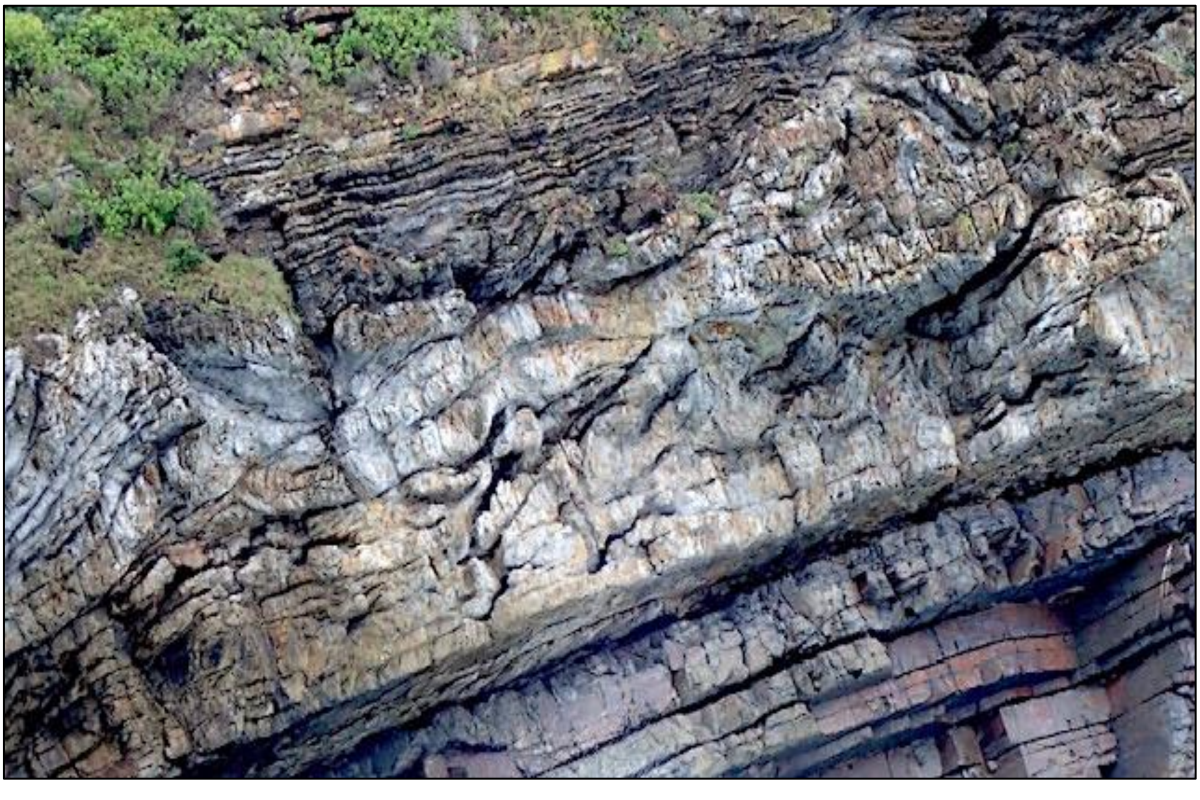

Figure 8. Enlargement of Figure 7, shows a complex arrangement of fold geometry and thinly bedded siltstone overlaying ignimbrite infilling the troughs, with a hint of subsequent transform dislocation creep.

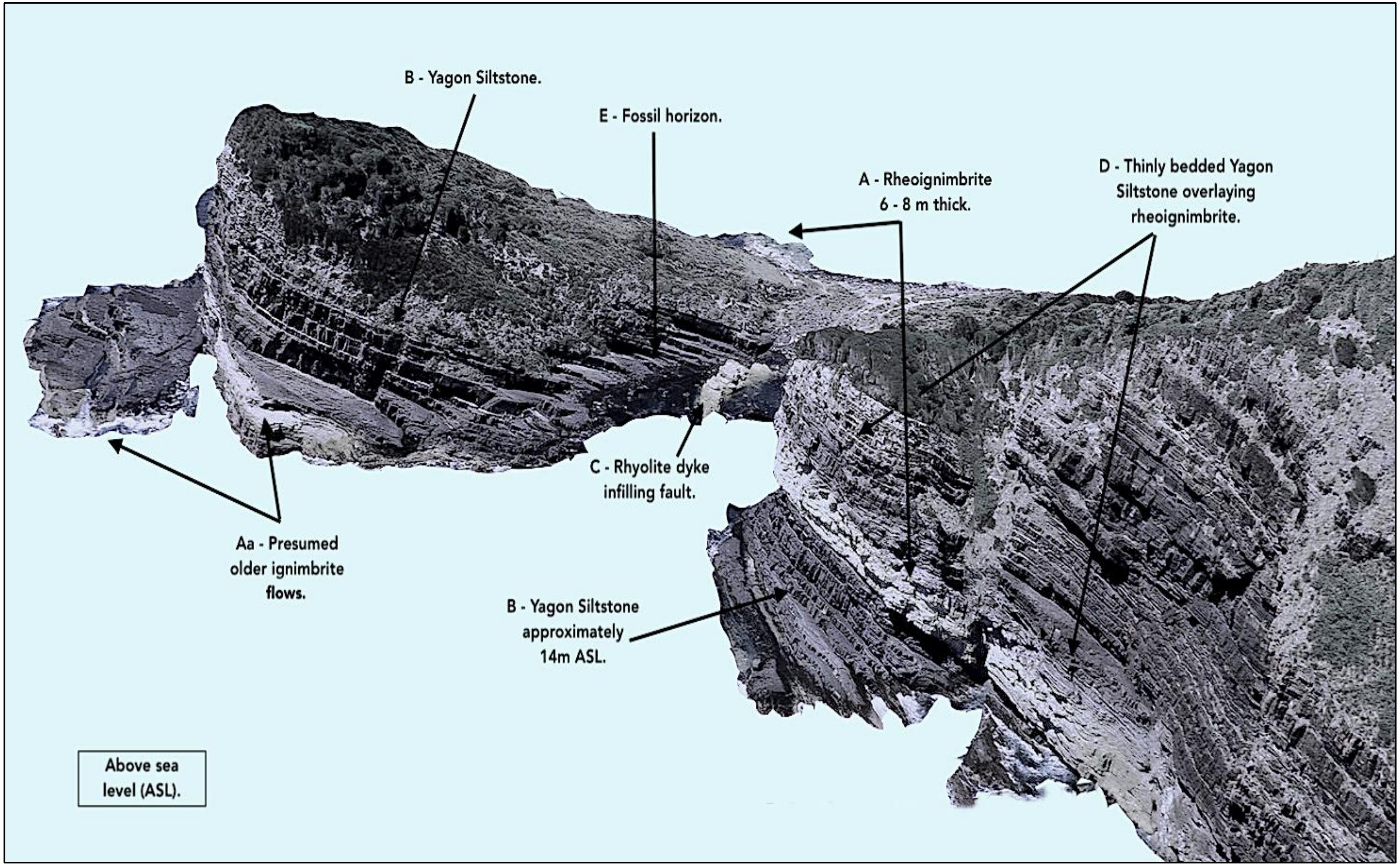

Figure 9. Cut-out image with captions describing the location of structural elements within the headland and the cliff face at Bald Head.

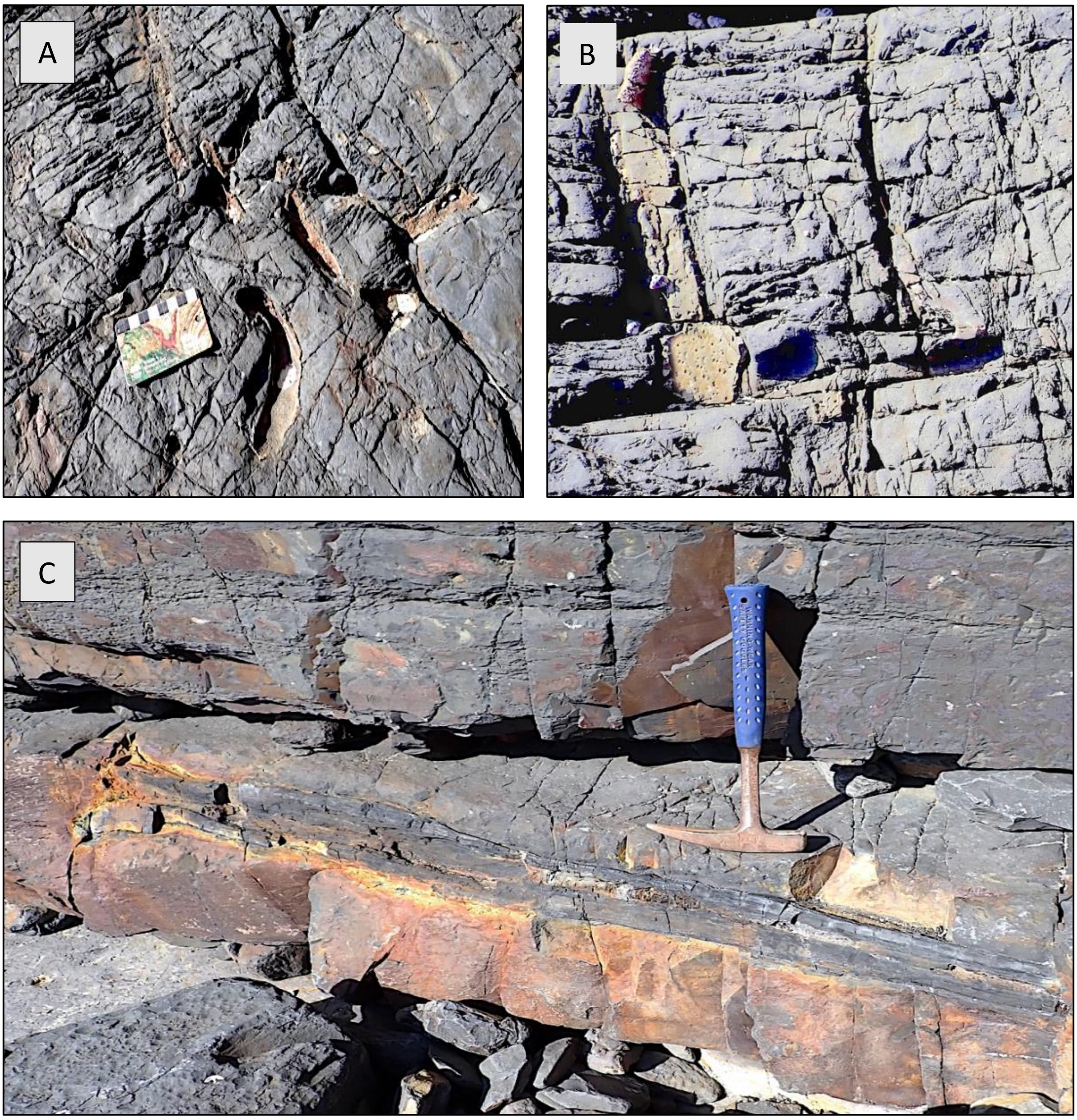

Figure 10. A - Rectilinear and crescent-shaped lined burrows preserved in the Yagon Siltstone devoid of fill (scale in cm); B - Curious indentations in the wall linings of the burrow (photo enlarged, burrow 10 cm in length); C - Small fossilised 1.45 m tree with intact root collar showing carbonisation from either fire or severe heat.

Emplacement Models of Rheomorphic Ignimbrite at Bald Head.

Rheoignimbrite flows exposed within the cliff at Bald Head suggest the emplacement of pyroclastic material was across a pre-eruptive terrestrial and marine environment from a violent volcanic eruption, that blasted an eruption column high into the air before collapsing to feed a ground surge depositing ash on the sea floor beyond the bounds of where tephra and volcanic clasts can travel. There have in the past been two main models to consider where the emplacement of air-fall-derived ash flows can be deposited onto the sea floor. However, new research has shown other phenomena may explain the deposition of ignimbrite onto a saturated sea floor.

Firstly, theoretical models by Sparks et al., (1980) suggest debris flow emplacement of some types of pyroclastic flow can flow into and maintain their integrity underwater. Subaqueous flows can be emplaced at high temperatures, where dense flows can enter the sea and be deposited on the sea floor, still hot enough to interact with the seafloor, the flow is sub-aqueously welded into ignimbrite. However, beyond the theoretical models, there is no evidence to suggest that welding in wholly subaqueous environments is common. Further, Cas & Wright (1991, p. 371) ask, "Is the [flow] boundary a stable boundary layer, allowing little or no mixing and ingestion of water due to the formation of a film or carapace of steam due to film boiling"?

Secondly, Legros and Druitt (2000) state, that there is a region in which the [pyroclastic] flow displaces the sea, irrespective of whether the flow is lighter or denser than water. Provided that the eruption is sustained for some time, the [pyroclastic] flow can deposit hot ignimbrite on the seabed. Once the eruption ceases, the sea will return to cover the ignimbrite.

Thirdly, seafloor uplift. Vanorio and Kanitpanyacharoen (2015, p. 1) state, "Uplifts in the Campi Flegrei caldera reach values unsurpassed anywhere in the world (~2 m). Beginning in 1982, the ground beneath Pozzuoli began rising at an alarming rate. Within two years, the uplift exceeded 2m [six feet], an amount unprecedented anywhere in the world. The rising sea bottom rendered the Bay of Pozzuoli too shallow for large craft to navigate.

Ground swelling associated with volcanoes occurring near calderas such as Yellowstone or Long Valley in the United States is well known, but never to the degree where it could displace a large body of water (Vanorio 2015). However, recent geological events at the port city of Pozzuoli in Italy are 3 to 6 times larger than those observed at Yellow Stone or Long Valley. This new information provides new insights into the mechanism of emplacement of pyroclastic deposits on the sea floor. Recent events in Pozzuoli, where the subsurface geology properties are similar, may be present at other calderas past and present around the world.

Other recorded events associated with coastal uplift are the M 7.8 Hawke's Bay New Zealand of 1931. The earthquake was felt throughout most of New Zealand and caused extensive damage at Napier, Hastings, and throughout Hawke's Bay. Surface deformation accompanying the earthquake resulted in a >90 km long, 17 km wide asymmetric dome trending northeast and extending from southwest of Hastings to northeast of the Mohaka River mouth. A maximum uplift of 2.7 m occurred near the mouth of the Aropaoanui River (Hull. 1990, p 309).

More recently as a result of the 2016 M 7.8 Kaikoura, New Zealand earthquake, it is reported there was a displacement of up to 10 m of horizontal slip and up to 7-8 m's of vertical displacement (Cubrinovsky and Bray. 2017, p 2-3). Sawi and Manga (2018, p.1). state, Volcanic Explosivity Index (VEI) values ≥2 are preceded within days by nearby major earthquakes (magnitude M 8 or larger) about 4 times more often than expected, suggesting that large earthquakes can trigger eruptions. They later expanded their definition of a triggered eruption to include the possibility of M 6 or greater earthquakes within 5 days and 800 km of a VEI 2 or greater eruption.

Consequently, there are numerous mechanisms by which hot ignimbrite can be emplaced on the seafloor: (1) by dense laminar flows that travel under the sea without significant mixing; (2) by flows (laminar or turbulent) that push back the sea from the shoreline and deposit ignimbrite on the seabed. The ability to push back the sea is a function of discharge rate, flow density, and seafloor bathymetry; (3) ground swelling where uplift of the sea floor can rise 2 or more metres displacing the shoreline and (4) Tectonic activity causing uplift resulting from earthquakes, as seen in New Zealand. Despite this fact, the statistical record of seismically triggered eruptions shows they are a relatively rare occurrence (Seropian et. al., 2021).

Often the focus of some workers concentrated on the ability of pyroclastic flows to shift the sea margin (*Figure 11*). This is referred to as shoreline displacement. Legros and Druitt (1999) State, we assume that the pyroclastic flow spreads radially and sustained over a long period. This model is only applicable to sustained eruptions in which there is enough time for the hot pyroclastic flows to flush the seawater out of the displacement zone. We also assume that the flow behaves as a homogeneous, turbulent fluid. Their experiments show the distance of displacement was not reduced. Their equations show pyroclastic flows of about 10 km^3 or more are capable of pushing back the sea at least a couple of kilometres and possibly more in shallow water, enabling hot ignimbrite to be laid down on the seafloor at depths corresponding to a few tens of metres.

Therefore, shoreline displacement is a feasible mechanism for the emplacement of welded ignimbrite in a marginal marine setting. Whether some of the events mentioned above can happen

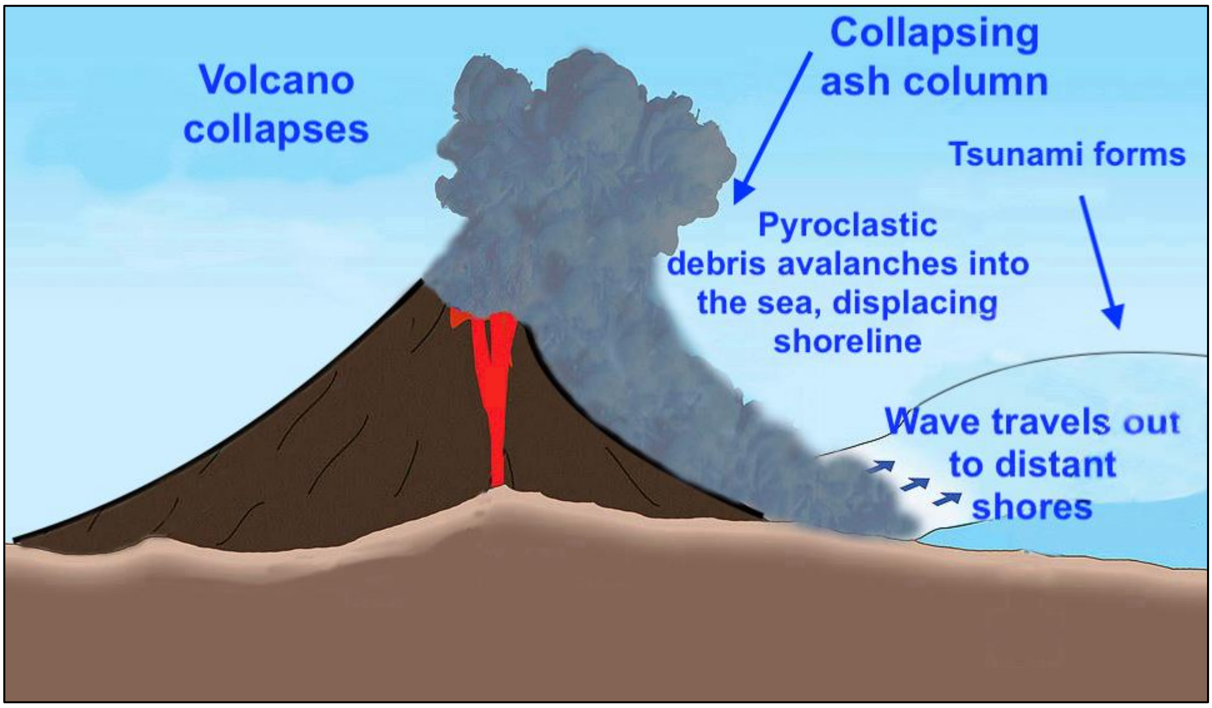

Figure 11. Schematic drawing depicting collapsing eruption (ash) column and shoreline displacement.

in conjunction with or separately during a volcanic event, shoreline displacement from coastal uplift from ground swelling or tectonic activity, whether episodic or permanent, the consequences of coastal growth initiating the draining of water away from the coastline exposing the sea bed should be included in the discussion.

Rheomorphism at Bald Head.

Field observations indicate baseline uniform, relatively undeformed sheeted linear flows, with the upper sections of the rheoignimbrite displaying abundant non-coaxial, oblique folds, curvilinear folds, detached thrust folds, possible sheath-folds and associated structures that formed whilst the flow was still in a plastic state. The ignimbrite rests directly over conformably inclined shallow marine sediments overlaying the ignimbrite are horizontally thinly bedded sediments infilling the troughs and hollows of the rheoignimbrite (*see Figures 7 & 8*).

Figures. 13 A, B and C, show the rheoignimbrite contains numerous joints that were initially interpreted as shrinkage joints from rapid cooling, but which are more probably tension joints related to the downslope slippage of the ignimbrite and pressure doming of the plastic mass during the rheomorphic processes. Other observations suggest that water contained in the saturated seafloor sediments beneath the ignimbrite and entrained within the pyroclastic flow vapourised into steam (gas streaming), instigating the formation of gas bubbles within and below the pyroclastic material.

Thin-section microscopy shows the tuff at Bald Head, is a very fine tuff with lots of fine quartz fragments and stringers of organic matter. Needs more work though.

Gas streaming occurs when highly pressurised steam generated by super-heated ash escapes through joints to form gas bubbles (vesicles). The presence of vesicles indicates volatile contents, which would be expected within a hot ignimbrite consolidated in or on the water-saturated substrate. The vesicles occur as bubble trains, extending parallel to an elongated domed structure (rootless vent) (*Figure 12),* indicating the upward migration of volatiles. However, the ellipsoidal shape of some cavities, sigmoidal faults and the wavy structures in the lower part of the deposit (*Figures 13 – A & B)* suggest that the ignimbrite has been sheared (*pers. comm.* A. Freundt), possibly from subsequent deformation associated with downslope slippage related to rheomorphism. As the ignimbrite cooled, it depressurised, freezing the bubbles within the matrix, allowing secondary mineral assemblages to form on the walls of the joints and vesicles. Percolating hot fluids contributed to the adherence of unwelded ash and secondary clay mineral assemblages on the walls of the joints and cavities (*Figures 13 A & B*).

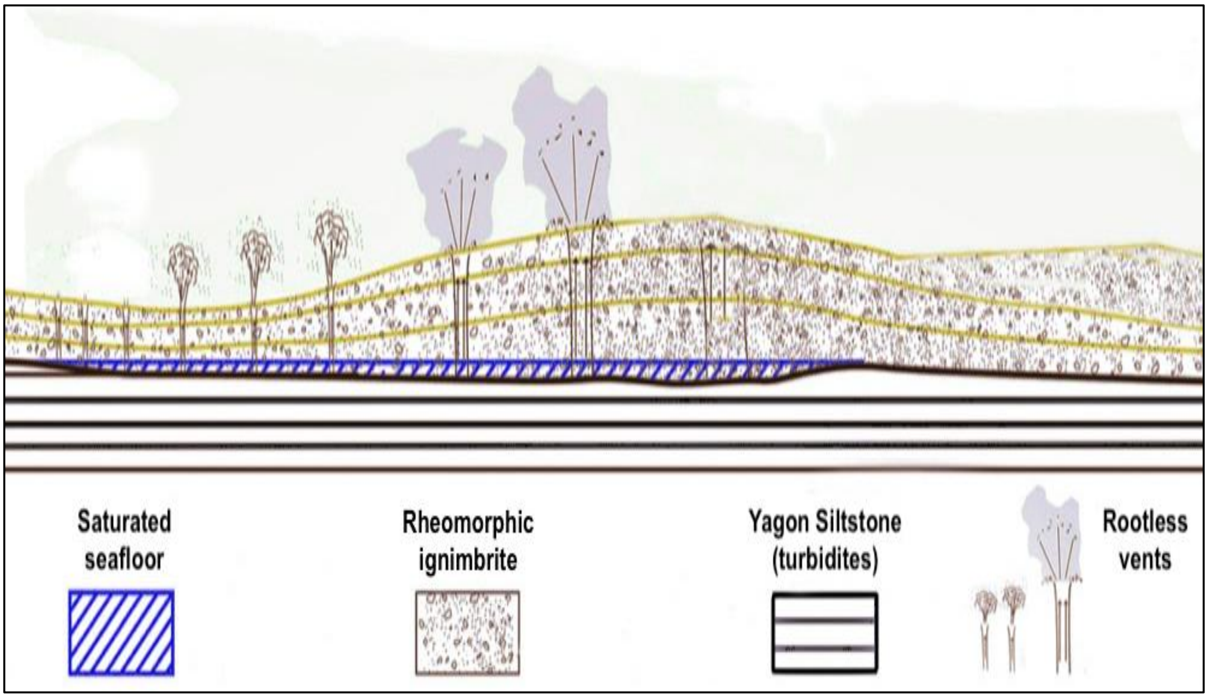

Figure 5. Schematic sketch depicting the development of rootless vents resulting from trapped packets of steam, generated by the interaction of hot ignimbrite and the underlying saturated sediments.

Examples of such gaseous vents are seen as raised domes, one of which measures 3 m x 2 m (*Figure 13 C)*. Three such rootless vents were found. All three domes are elongated, which indicates the flow direction of the ignimbrite. In this sense, rootless vents are vent-like structures of the conical form. Rootless vents form when trapped packets of steam generated by the interaction of hot ignimbrite and the underlying wet sediments rise through the unconsolidated ash to eventually break through to the surface as a phreatic eruption, leaving small craters or ash mounds (see Figure 13 B, for micro crater) these pseudo steam volcanos intermittently release gas (burping, much like boiling porridge on a stove, where after the release of gas, the conduit and surface closes back over). This process continues until the ignimbrite has cooled.

In addition to the above observations, preliminary investigations of the siltstone bedding plains within the headland showed evidence of what is probably lapilli-size scoria (*Figure 14 A*). The identification of tephra within the Yagon Siltstone suggests that the pyroclastic material was fallout from a volcanic eruption. Despite not having evidence of a source vent, the presence of scoria ejecta indicates proximity to a volcanic vent. This correlates with Rosenbaum (2012), who reported, that clasts of volcanic rocks (e.g., scoria) are found within the fine-grained clastic rocks, indicating proximity to the volcanic source. Whether the scoria is associated with this eruptive event or previous events is inconclusive; more work is necessary to confirm or rule this out.

However, confusing the situation, within the Yagon Siltstone is the presence of weathered-out and intact iron-rich concretions. The concretions have a range of shapes and sizes, from cannonball to ovoid shapes ranging from 20 mm up to 450 mm in diameter (*Figure 14).* Skilbeck (1986) noted the presence of pyritic concretions in his thesis. Some concretions where the cores have been exposed to the elements have had the nucleus weathered out, creating a void in the centre, leaving the concretion's outer shell intact.

The continued effects of weathering from the harsh marine conditions have left the surface of the concretions shell pitted, which may lead to the misidentification of the pits as vesicles, normally associated with volcanic clasts. A close inspection of the pitted surface shows that the pits are the result of salt-induced weathering (tafoni) and are not vesicles. This indicates the concretions are porous with the salt expanding on drying. Figure 14 A, clearly demonstrates this, showing the pitted surface with some of the concretions encrusted with salt that occurs during the warmer months of the year.

More broadly, it should be pointed out, that within the headland on the northeast face at sea level within the Yagon Siltstone, there is a second and probably a third thick band of ignimbrite

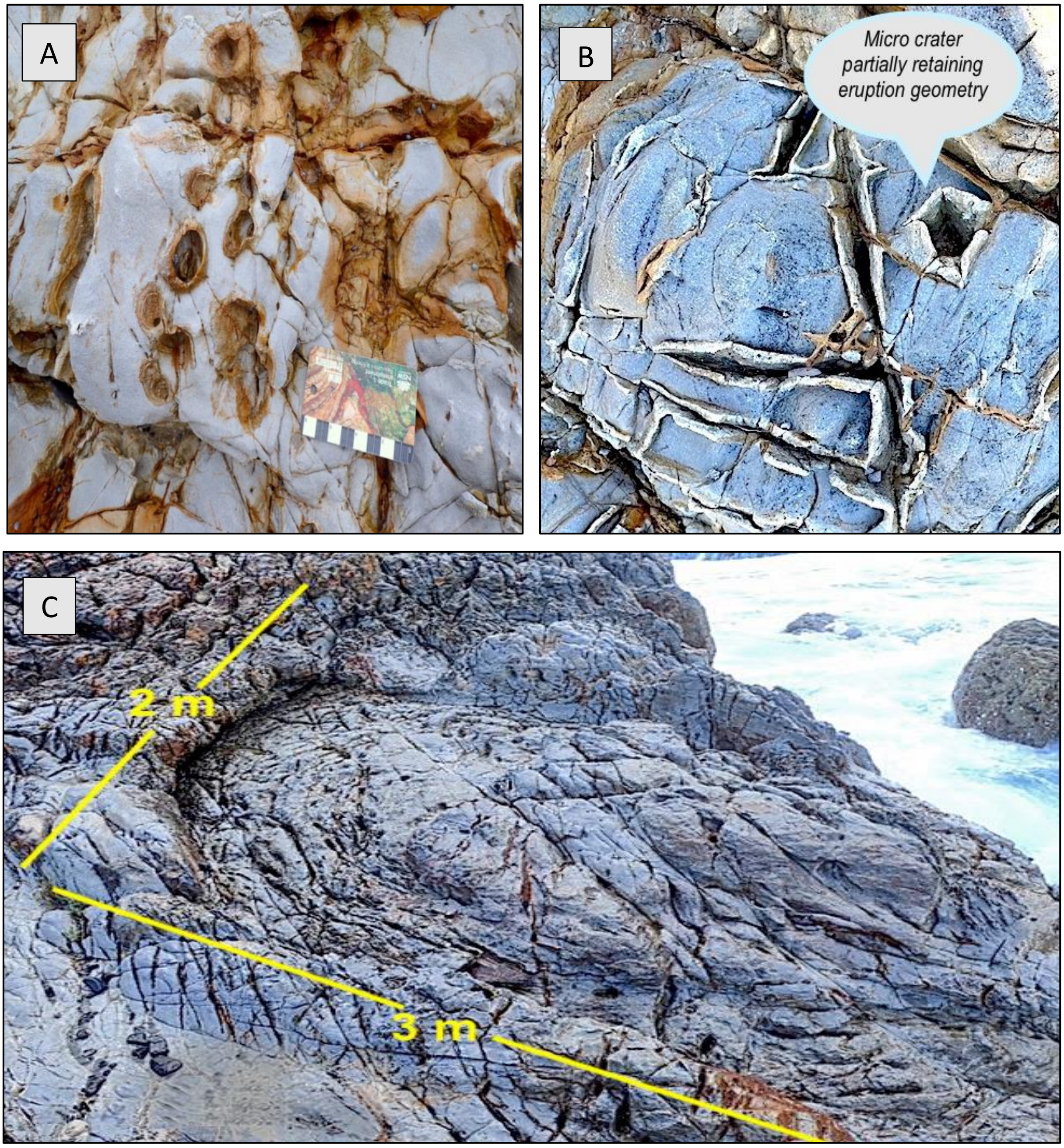

Figure 13. A - Ellipsoid, contorted vesicles showing iron-stained ash and secondary mineralization (scale in cm); B - Secondary mineralization adhering to walls of deformed joints and vesicles (enlarged, micro crater 2cm DIA. Photo by B. England); C - One of three rarely seen pressure domes, generated by the interaction of hot ignimbrite and the underlying saturated sediments.

(*Figures 3 & Aa - 9)*, with thin bands of ignimbrite scattered throughout the overlying sequence of siltstone and mudstone. Drone images show the upper thick band of ignimbrite displays rheomorphism, this has not been verified because of the difficulty of accessing the rock platform.

Concluding Remarks.
The term, subaqueous emplacement of ignimbrite, is controversial and often greeted with scepticism. Nonetheless, field observations at Bald Head suggest pyroclastic density currents were emplaced onto the seafloor. Overall, without in-depth field studies and the gathering of samples for chemical petrological and dating analyses the events of the emplacement and rheomorphism of ignimbrites may never be fully understood.

Hopefully, the information within this report will encourage comprehensive studies from others interested in the volcanism of the Eastern Myall Block. The challenge for groups or individuals conducting detailed investigations is to overcome the rugged nature of the coastal morphology in

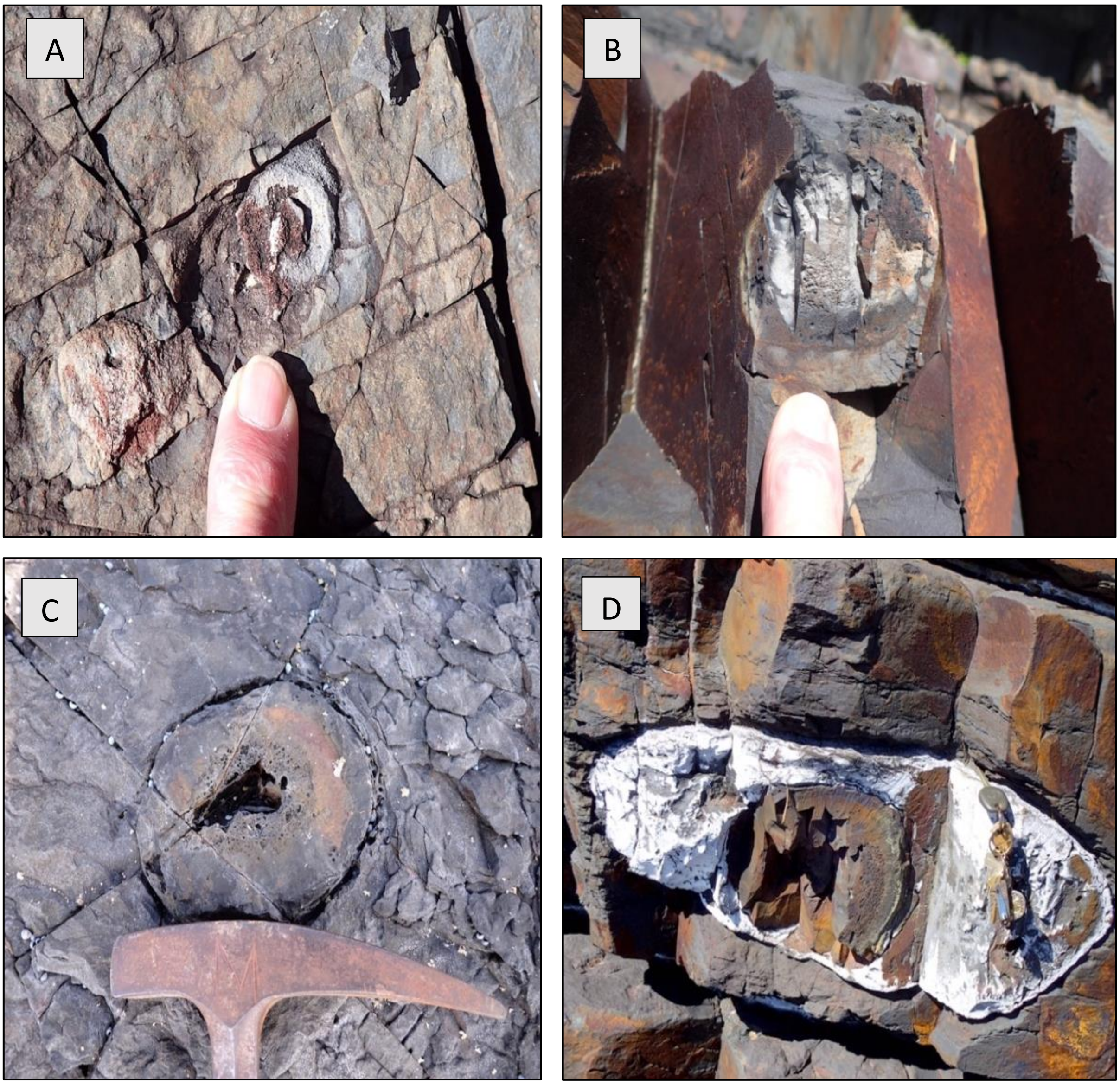

Figure 14. Compares a volcanic clast, against an assortment of concretions. A - Shows a 22 mm scoriaraceous clast, whereas, B, C & D are concretions. B - Shows a 40 mm concretion with a pitted inner surface and flattened base; C - shows a 10 cm cannonball concretion with a pitted inner shell and weathered-out nucleolus; D - shows a 30 cm salt-encrusted, ovoid concretion with the 11 cm inner core pitted with weathered-out nucleolus (the key protruding from the crevice is 3 cm long).

this area, which will not make the task easy. Such studies may offer new insights into volcanism in this locality. Interested groups would need access to petrological sectioning for analysis, digital mapping tools and equipment for gathering rock samples from difficult places. The importance of Violet Hill volcanism with its lava-like ignimbrites, is perhaps not fully appreciated. A thorough investigation would add much to the knowledge of the Violet Hill Volcanics and may shed some new light on the neighbouring Nerong and the slightly younger (Permian) Alum Mountain Volcanics.

This report has concentrated on the emplacement of subaqueous rheomorphic ignimbrites, which in this location has gone unnoticed. Also, to give a sense of location by reporting the presence of trace fossils belonging to marine organisms of an unknown genus and the fossilised remains of a small tree. The presence of organic matter within the ignimbrite, satisfies the criteria set by Cas and Wright (1991) in their paper on Subaqueous pyroclastic flows and ignimbrite: an assessment, which is a concise assessment of identifying true pyroclastic flow deposits. This report does not cover the brittle structural deformation, which is also evident. There are many examples of brittle deformation within the cliff face associated with compressive stress regimes consisting of thrust faulting and transpressive shearing from strike-slip movement, along with later periods of an extensional regime in the form of rifting, (Figures 3, 6 and 15A & B), which goes well beyond the scope of this report.

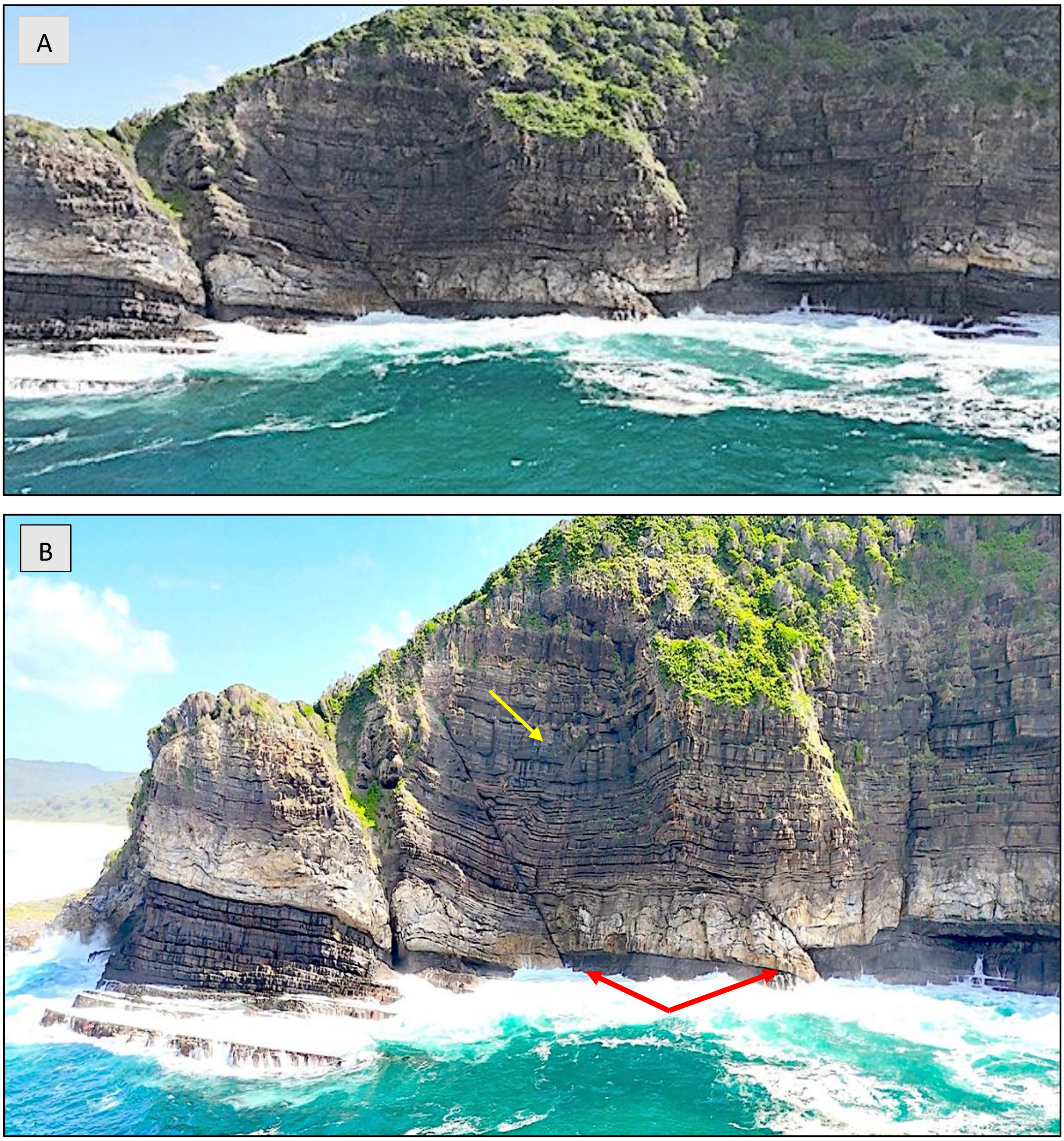

Figure 15 A, Drone photo shows a thrust fault zone. 15 B. Shows high angle thrust fault (left red arrow) and associated incipient antithetic backthrust (yellow arrow) and low angle thrust fault (right red arrow within the cliff face related to periods of a compressive stress regime (Drone photos P. Gilmore, 2024).

From the outset, the purpose of writing this report was to document the previously unreported emplacement and events leading to the ductile deformational processes of rheoignimbrite at Bald Head. There remain many uncertainties relating to the Violet Hill Volcanics, and if this document provokes further research, then we have surpassed the goals we first set out to achieve. Curiously, there are no published or publicly available structural appraisals for the geology of Bald Head. Considering the conspicuous nature and characteristics of rheomorphic ignimbrite and geology exposed within the cliff face and headland at Bald Head, along with the accessibility and popularity of the area, it is surprising that the Bald Head Peninsular has not received more attention.

Cas and Wright (1991. p, 371) state, "that if pyroclastic flows maintain their integrity and flow into the sea, then their deposits should be preserved in the associated basinal successions offshore, and the rock record should abound with them, which it apparently does not". So here is an opportunity to add to that meagre list.

Acknowledgements.
Documenting this report regarding the subaqueous emplacement and subsequent rheomorphism of ignimbrite at Bald Head has been challenging but, at the same time, very rewarding. Complications arose from the lack of data in the public domain regarding the Violet Hills Volcanics and the geology of Bald Head. Therefore, I would like to gratefully thank Brian England for his company and insights on the many field trips to gather information and to verify or dismiss anomalies that arose during the research, and for his patience in answering endless questions and the generosity he showed in volunteering time proofreading and editing this report. Also, Winston Pratt for comments on the early draft of this paper and his ongoing constructive suggestions regarding the layout of this report; along with Phil Gilmore for his assistance in facilitating the preparation of thin section slides for analysis and for supplying drone images and video of the Bald Head headland and escarpment. Robin Offler for reviewing this report, and finally, Peter Mitchell for his encouragement and insightful comments that greatly strengthened this report.

Terminology.

Aggradation: is the deposition process in which a depositional area fills with vertical stacking of sediment in deep water (Science Direct).

Cored bombs: are bombs that have rinds of lava enclosing a core of previously consolidated lava. The core consists of accessory fragments of an earlier eruption, accidental fragments of country rock or, in rare cases, bits of lava formed earlier during the same eruption (Volcanic Bomb, Geology Science).

High-grade ignimbrite: refers to the intensity of welding exhibited by ignimbrite sheets (Walker, 1983; Branney and Kokelaar,1992.

Lava-Like: A purely descriptive term referring to a lithofacies that resembles lava. It may be massive or flow-banded. This term can be used for parts of extremely high-grade ignimbrites, where pyroclasts are inferred to have coalesced. (Andrews & Branney 2005).

Pyroclastic density currents: are perhaps the most hazardous events to local areas during volcanic eruptions. These hot, ground-hugging flows of ash and debris can travel at speeds of hundreds of metres per second, reaching many tens to hundreds of kilometres from the source. (British Geological Survey).

Pyroclastic flow: A dense, fast flow of solidified lava pieces, volcanic ash, and hot gasses (National Geographics).

Rheoignimbrite (rheomorphic ignimbrite): an ignimbrite displaying ductile deformation processes due to secondary flowage when hot pyroclastic current decelerates and gradually deflates.

Rheomorphism: is the process of at least partial mobilization involving the addition and removal of diffusing elements such that a rock becomes mechanically mobile (Woolley. 1989).

Scoria Bomb: are vesiculated bombs that may or may not enclose consolidated lava or accidental fragments (Cas and Wright 1987).

Subaerial: are features and events occurring or formed on or near the Earth's land surface, exposed to Earth's atmosphere (Science Direct).

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