Figure 1: The southern Heron reef edge exposed during low tide looking at Heron Island on the horizon to the east on an unusually calm day, photo by Dr Luke Nothdurft, Heron Reef, GBR.

INVESTIGATING PROCESSES SURROUNDING CORAL REEF STABILISATION USING AUTOMATED MINERALOGY

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THIS RESEARCH PROJECT IS BEING CONDUCTED by Lisa Kearney, a PhD candidate from the School of Earth & Atmospheric Sciences at Queensland University of Technology (QUT), working with Dr. Luke Nothdurft and Dr. Crystal Cooper at QUTs Central Analytical Research Facility (CARF).

The project investigates the formation of limestone rock through natural cementation in modern coral reefs. These are the processes responsible for reef formation and stabilisation. This research uses samples of marine carbonate material collected from Heron Reef, within the southern Great Barrier Reef, Australia. The project commenced in 2017, with the Tescan TIMA arriving in 2020.

The TESCAN TIMA is an automated mineralogy solution, typically used by mine sites and geoscientists. In this article, we explore a non-conventional application that has wide-ranging importance across the world's corals reefs.

WHY IS IT IMPORTANT TO KNOW ABOUT THE HOLOCENE MARINE CARBONATE REEF ROCK AND THEIR MINERAL CONTENT?

Coral reefs are the most biodiverse ecosystems of the ocean. The Great Barrier Reef is the largest reef complex, spanning 2,300 km along the northeastern coast of Australia. It is composed of many individual reefs, which in turn are home to a vast array of organisms. These individual reefs exhibit a wide and complex range

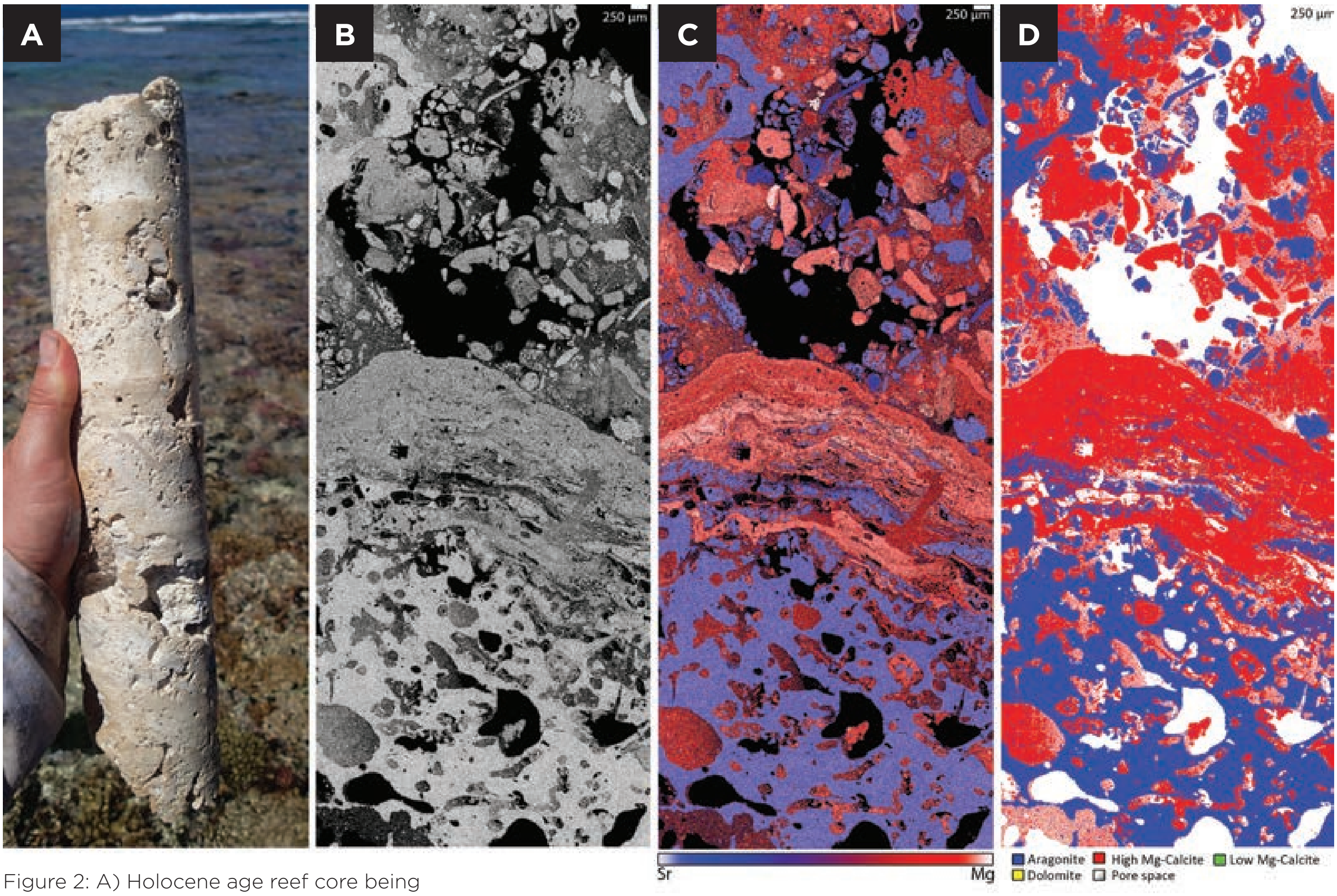

Figure 2: A) Holocene age reef core being collected on Heron Reef, GBR, by Dr Luke Nothdurft. B) BSE map of Heron Reef Reefrock sample, C) Elemental composite map showing Sr and Mg variation; D) Primary phases map generated using the TIMA software.

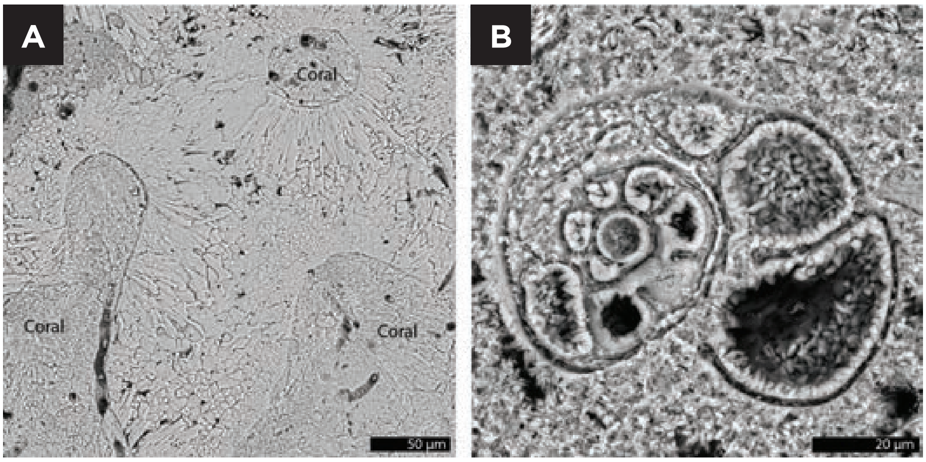

Figure 3: A) Fossilised coral skeleton and natural aragonite cements are some of the common components that form limestone and preserve well in the fossil record; B) Foraminifer test in high-magnesium calcite cement matrix.

of reef morphologies from the macroscale down to the microscale making them ideal to compare to fossil and modern reefs.

Corals themselves are made up of colonies of individual polyps, which are made up of soft parts that do not preserve very well in the fossil record, but their skeletons do. As each individual polyp grows, it leaves behind deposits of calcium carbonate to make the skeleton (see figures 2 and 3). This calcium carbonate is what limestone is made of and, over time and under favourable conditions, corals contribute to forming thick limestone build-ups, which in turn act as substrate for new organisms to grow on.

Corals alone cannot make a coral reef. Marine geologists describe coral reefs as being a rigid, wave resistant skeletal structure whose framework is comprised of hard corals and many other components, including other skeletons such as algae, sediment grains and 'cements'. The binding and gluing of the many components is what stabilises the reef framework. Marine cements are natural minerals that precipitate into voids providing the crucial glue that cements the skeletons, shells, and sand together. These cements can be abiotic precipitates or facilitated by biological processes such as microbial organisms living within the pores.

The chemistry of fossilised reef communities (skeletal remains of algae, animals, and natural cements) can reflect the conditions of the ambient seawater in which they grew and be used to inform us about past environmental conditions, such as water chemistry and sea level. There is a lot that we don't understand about the drivers and timing around cement formation and the overall lithification of reefs and is focus of this research.

WHAT IS CORAL REEF CEMENTATION AND STABILISATION?

Modern marine reef carbonates are typically composed of calcium carbonates, $CaCO_3$; the primary phases being aragonite, and high and low magnesium calcite (HMC and LMC respectively), but other mineral phases may be present (e.g., dolomite, brucite, silica).

These carbonate cements are typically present as crusts (~1 cm thick) or as pore lining (nano-micro) crystals within or on the skeleton components and grains. Cement textures are produced via mineralogical and chemical changes in a process called diagenesis, which can be diagnostic of the environment in which they formed.

These various textures are typically segregated and can occur both intra- and inter-skeletally (i.e., outside or inside the skeleton). Compared to the million-year time scales of typical geological rock formation, the complex range of textures observed in reef environments can form in days to weeks following deposition, especially when aided by biological processes such as microbial biofilms and other microbes that bore into the limestone.

When removed from the marine environment and exposed to freshwater by longer term geological processes or large sea level changes they can be altered to another mineral phase (i.e., from original skeletal aragonite into calcite). These diagenetic changes can be found in fossil reefs throughout geological time dating back as far as the first life on Earth.

WHAT ARE THE AIMS OF YOUR RESEARCH PROJECT?

The overall project aims to analyse the processes of diagenesis in a modern marine environment by looking into the past. We do this is by analysing rock cores retrieved from the subsurface of the reef, and that limestone material allows us the travel back in time over several thousand years. We want to know what happens from the earliest deposition of reef materials, through to the formation of the final cemented reefrock (limestone). The current study focuses on answering what is gluing the reef together, or literally, what is cementing the reef. Samples have been selected showing the early stages of lithification. These sections contain grains and/or fossil skeletons of the reef community that are loosely

held in place within reef cavities (figure 2A). These sections provide a unique opportunity to investigate early diagenetic products.

Diagenetic alteration to reefal components, especially in coral skeletons, affects the reliability of the geochemical data that is used for palaeoenvironmental and isotopic dating. For example, cements can form several thousand years after the original coral skeleton, so if a section that is sampled contains natural cement, the data is likely to reflect the conditions the cement formed in rather than conditions that the original skeleton grew in. This variation is a poorly understood aspect of reef formation but could have an important baring on the interpretation of geochemical data for the purposes of isotopic dating and, in turn, our understanding of past climates.

IS YOUR RESEARCH RELEVANT TO OTHER CORAL REEFS ELSEWHERE IN THE WORLD?

Yes. This research is relevant to all tropical reef carbonates, especially reefs with similar geomorphology (platform reefs). The technique can be applied to any reef material and is currently being used to investigate ancient reef carbonates.

CORAL AND OTHER REEF BUILDERS ARE A BIOLOGICAL MATERIAL. HOW HAS THE TIMA, DESIGNED FOR MINERALOGICAL MATERIALS BEEN SUITABLE TOOL FOR YOUR RESEARCH?

Corals, and most carbonate materials, are formed through biological processes, but the end material/part that is preserved is the fossilised skeleton. This skeleton is composed of a metastable calcium carbonate mineral, aragonite, orthorhombic $CaCO_3$. Skeletal aragonite contains minor amounts of strontium (Sr), as it is a biologically relevant mineral that can be used to chemically differentiate it from calcite, rhombohedral $CaCO_3$. Subtle variations in strontium and magnesium content can be used to distinguish carbonate mineral phases (e.g. aragonite, calcite, low and high Magnesium calcite, and dolomite).

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WHY IS IT IMPORTANT TO BE ABLE TO LOOK AT CORALS ON A MICRO-LEVEL?

Scanning electron microscopy is a non-destructive method that provides microtextural and elemental information. Texture can be used as a distinguishing feature for many cements and skeletal parts of the samples. The research question currently being addressed looks at the cements between grains in the samples, much of which is micritic. Being able to view the samples at various length scales is key for their accurate identification.

IF YOU HAD NOT HAD ACCESS TO THE TIMA, WHAT WOULD YOU HAVE USED?

Previously, I was using the TESCAN MIRA3 system as it has low vacuum and large field of view imaging capabilities. The MIRA3 provided high-resolution large-area maps, which can be used to gain valuable microtextural and elemental information. The previous workflow involved the acquisition of large area back scattered electron (BSE) maps, which were used to select regions of interest for subsequent image acquisition and elemental analysis by energy dispersive x-ray spectroscopy (EDS). These were used for the identification of minerals/materials during point analysis, which is a time consuming and error prone method where a thin section of rock is placed on a petrographic light microscope with a stage that moves over a predefined grid. Each phase that falls under each point is identified and counted to get a gaussian distribution of data.

COMPARED TO USING MIRA3, HOW HAS THE TIMA BEEN BENEFICIAL TO YOUR RESEARCH?

The TIMA allows for relatively non-destructive, automated and detailed mapping of carbonate minerals at high-resolution. The multiple EDS detectors easily allows for the rapid collection of high quality spectral data and the identification of subtle phase distinctions within the carbonate mineral groups.

Collection of detailed microtextural BSE, elemental, and phase (mineralogy) information from the TIMA streamlines understanding the carbonate quantification process. The automation of data collection is a major benefit. Numerous datasets can be acquired for multiple samples in a time-effective manner.

The unique software capabilities allow for the processing of spectra, where a mineral phase library can be built upon sample spectra and reference materials or online standards.