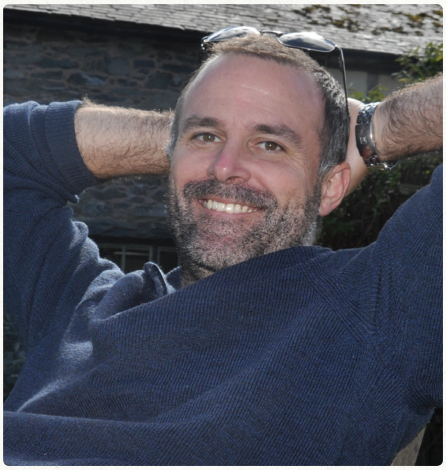
Investigating plate tectonics

Tectonic geologist **Professor Alan Collins** offers a unique glimpse into his collaborative research and how it has uncovered exciting insights into palaeogeography



How did you first become involved in palaeogeography? What do you find most fascinating about this area of research?

Palaeogeography is the mapping of our planet over the billions of years in which it has been in existence – it is the ideal combination of science, history and geography. I have always loved maps and been interested in the world. Mapping the globe over its 4.65 billion year history is a natural extension of this to me. The fascination comes from being able to picture past worlds. The process of gaining this picture involves mental gymnastics, from trying to understand the intricacies of isotopic fractionation in the deep Earth one minute to moving around past continents the next. I find it absorbing and regularly surprising.

As a tectonic geologist, what skills do you bring to the science of plate tectonics?

A tectonic geologist needs to be a jack of all trades. They need to have a working understanding of many Earth science fields and be able to apply them to rocks in a 4D structural and temporal framework. I have always been interested in many aspects of geology. During my undergraduate and postgraduate studies, I leaned more towards structural geology, which is the study of the geometry and shape of rocks to work out the strength and orientation of past forces that acted in a region. These skills can provide a sort of structural 'stratigraphy', or a relative temporal map, of changing magnitudes and orientations of forces. As a postdoctoral researcher I learnt a lot about geochronology – that is, the dating of geological materials. These geochronological techniques are essential in providing the time dimension to plate tectonics; they provide us with the framework for when plate tectonic processes happened in different places and can also provide rates for these changes.

What are the main obstacles associated with the study of ancient oceanic plates? How may these be overcome?

After the oceanic lithosphere turns 80 million years old, it becomes denser than the underlying asthenosphere and this negative buoyancy eventually causes it to subduct deep into the Earth. This is why we don't have any *in situ* oceanic crust preserved from the Neoproterozoic era. This obviously inhibits the study of the ancient oceanic plates, meaning we need to find proxies for the places and times when these oceanic plates were subducted. We can do this by looking for the remains of the subduction zones and their products in geological records, such as volcanic arcs. However, volcanic arcs are not highly preserved either – and we often end up looking for their remains in sedimentary basins that are formed by the erosion of the mountain chains that once contained the arc. From the combined range of ages for the volcanic arc's presence and its geochemical signature we can reconstruct the time of existence and tectonic geography of the destructive oceanic plate margin.

With particular reference to tectonic geography, how do you envisage the world to look in the next 50-100 million years?

Australia is rapidly moving north towards Indonesia and East Asia – it is likely to sideswipe Asia in the next 50 million years – and Africa is slowly rotating into Europe. Asia, Europe, Australia and Africa seem to be forming the nucleus of a new supercontinent. The question is, what will happen to the Americas – will they continue moving west with respect to Africa and eventually collide with Asia and Australia or will the subduction zones in the Scotia Sea and the Caribbean 'unzip' and join to form a 'strip of fire' from east Canada along the east coast of the Americas to the Antarctic Peninsula? Whatever the result, it seems that a new supercontinent will form that has been aptly called Amasia (America and Asia) by some researchers.

How important is collaboration in your research?

Collaboration is not just important, it is absolutely essential. The multiple data sources needed to make realistic contributions to ancient tectonic geography require close collaborations with experts in palaeomagnetism, geochronology, structural geology, sedimentology and geochemistry, to name but a few. In addition, these data need to be collected from many parts of the world and collaboration with excellent geologists from many countries is essential to advance this work.

Exploring tectonic geography

A multidisciplinary group of researchers and students based in the Discipline of Geology and Geophysics at the **University of Adelaide**, is researching one of the most compelling periods of the Earth's geological history

WITH AN ESTIMATED 4.65 billion-year history, the Earth has undergone many dramatic changes. One of the most fascinating periods of its past is the Neoproterozoic era, which occurred between 1,000 and 541 million years ago. It was during this time that life evolved into complex multicellular organisms that preceded the first hard-shelled animals which mark the beginning of the succeeding Phanerozoic era. The Neoproterozoic also saw intense plate tectonic activity with the progressive construction of continental amalgams such as Gondwana, which included most of the landmasses in today's Southern Hemisphere. Several large-scale glacial events are also believed to have occurred during this period, with ice sheets extending to the tropics.

Crucially, it is impossible to understand the processes that occurred in the Neoproterozoic era without understanding the tectonic geography of the world during this time. Theories as to why the world became so cold in this period relate to the placement of the continents and oceans; for example, continents are brighter than oceans and reflect more of the Sun's radiation, therefore it could be concluded that the majority of the continents were located in tropical regions. Similarly, as reactive rocks remove carbon dioxide from the atmosphere and reduce the greenhouse effect, it would be logical to assume that more reactive rocks were once exposed on the Earth's surface. This exposure occurs as a consequence of numerous volcanic eruptions or continental collisions. Finally, mapping evolutionary dynamics is dependent on the geography of the time, meaning that the location of ancient continents and oceans must be explained before the roles of biota vicariance and geodispersal can be determined.

AN INGENIOUS GEOLOGIST

Professor Alan Collins, a tectonic geologist and researcher at the University of Adelaide, Australia, has dedicated his research to analysing the roots of ancient mountain chains – studying mineralogical rock changes in order to discover when the ancient continents collided. The nature of Collins' research is highly collaborative, working closely with a range of students and researchers at the University, as well as a number of prominent scientists from across the world.

Over the past 15 years, Collins' has focused on discovering ancient continents. One of his major breakthroughs to date occurred in Madagascar where his team's extensive analysis of grains of sand – relics of the ancient collision of India and Africa – revealed the existence of an earlier continent: "Central Madagascar is composed of old Archaean rocks, dating back about 2,550 million years," Collins divulges. "My team recognised that these ancient continental crustal rocks were bound, to both the east and west, by metamorphosed Neoproterozoic sedimentary and volcanic rocks, the protoliths of which formed in an oceanic environment. Importantly, if central Madagascar was surrounded by oceans to the east and west in the Neoproterozoic, then it must have been a separate continent."

Detailed analyses of the age distribution of zircon sand grains in Neoproterozoic and older metamorphosed sedimentary rocks led to the hypothesis that this continent – which they named 'Azania' – had been roughly the size of the Middle East and lay off the coast of East Africa before being smashed up and destroyed in collisions with Africa and India. Today, just a few relics of this continent can be found in Madagascar, Arabia, East Africa and Southern India.

GRANITE MOUNTAINOUS CORE OF AZANIA, CENTRAL MADAGASCAR

CONFRONTING CHALLENGES

There are many challenges associated with tectonic geography. Indeed, current geographic models of the Neoproterozoic world are not particularly accurate and it is only in the past 20 years that more advanced and readily available dating techniques have been developed. While important datasets have already been collected, there is an urgent need to continue collecting vital information – unfortunately, often from politically unstable or physically remote regions.

One key issue is that almost 90 per cent of the Earth's geographic history is based on continental crust alone as no oceanic crust – which comprises two-thirds of the planet – exists from the Neoproterozoic era. Because oceanic crust subducts, it is not preserved over geological time, meaning that the continents themselves are the main resource for developing a palaeomagnetic record that maps the latitude of continents at different times in geological history. In order to uncover what happened in the oceans during this time, researchers must locate ancient volcanic arcs. This enables them to pinpoint the locations where oceanic plates were subducted, subsequently allowing the tectonic geography jigsaw to be pieced together. At present, Collins is collaborating with a diverse group of international colleagues and students in Eastern Africa, Arabia, Brazil, Madagascar and India in an effort to fit these pieces together for Gondwana.

KEY DEVELOPMENTS

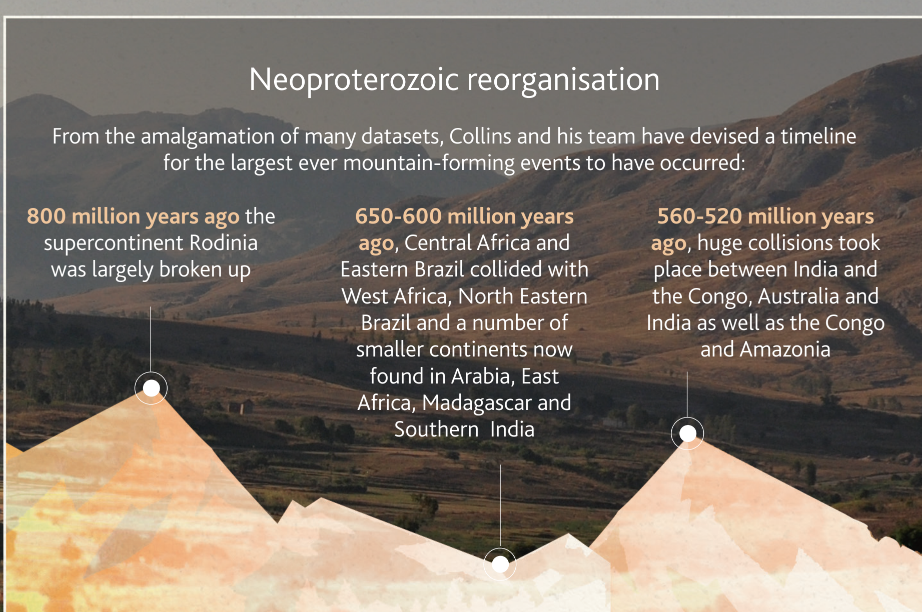
In spite of the challenges, there have been considerable advances in the theories and models for Neoproterozoic geography over the last 10 years. Interestingly, geologists' understanding of the Neoproterozoic world has changed dramatically. Originally it was thought that one or two major continents dominated the Earth. However, it is now believed that many smaller continents existed before breaking apart from the Rodinia supercontinent and partially reforming as Gondwana towards the end of the era.

Important strides have also been made with the development of more advanced microprobe techniques, improved ways of imaging the internal structures of minerals and a greater number of laboratories that are able to perform complex analyses. Because there are very few fossils from the Neoproterozoic era – and even fewer dating from before this time – researchers often rely on radiometric dating techniques for rocks from this period.

For example, the dating of zircon – a relatively common and extremely robust mineral – has opened up new insights into the geological past: "Zircon commonly contains a few hundred parts per million of uranium (U) in its crystal structure, and importantly can't really accommodate lead, the daughter product of the natural radioactive isotopes of U (^{235}U and ^{238}U)," explains Collins. "So if you can measure the U isotopic content of the minerals and the lead isotopes, then you get an age for the mineral." Importantly, dating a 600-million-year-old zircon has a margin of error of only a few million years. This means that many major tectonic events, such as continental collisions, rifting and island arcs, can be dated with extremely high levels of precision.

IMPACT OF TECTONICS

Collins is clear that his long-term goal is to build a plausible model for the Earth's tectonic geography during the Neoproterozoic era. Excitingly, such a model would not only represent an advance in geology; it would also inform other disciplines, furthering understanding of biogeography, the palaeography of ancient petroleum systems and the impact of tectonics on extreme climate fluctuations.



INTELLIGENCE

THE ORIGIN OF GONDWANA AND TECTONIC PALAEOGEOGRAPHY

OBJECTIVES

To understand the tectonics and palaeogeography of the Neoproterozoic world; use isotopic proxies to unravel the evolution of Australian Gondwana; and provide geological data to assist in understanding the palaeogeographic controls on the Neoproterozoic Earth System including climate variations, sea-water chemistry and bioprovinciality of the Ediacaran world and Cambrian Explosion.

KEY COLLABORATORS

Associate Professor Chris Clark; **Dr Sergei Pisarevsky**; **Dr Diana Plavsa**, Curtin University, Australia • **Professor Théodore Razakamanana**, Toliara University, Madagascar • **Professor M Santosh**, Chinese University of Geosciences, Beijing, China • **Professor Ricardo Trindade**; **Associate Professor Marly Babinski**, Universidade de São Paulo, Brazil • **Professor John Foden**; **Dr Stijn Glorie**; **Dr Ben McGee**; **Donnelly Archibald**; **Morgan Blades**, University of Adelaide, Australia • **Tadesse Aleumu**, Geological Survey, Ethiopia • **Dr Girma Woldetinsae**, Ministry of Mines, Ethiopia • **Professor Salah Al Khirbash**, Sultan Qaboos University, Oman • **Khalid Kadi**, Geological Survey, Saudi Arabia

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PROFESSOR ALAN COLLINS completed his PhD in 1997 at the University of Edinburgh, UK, on the tectonics of southwest Turkey. Collins then began work on the Ediacaran-Cambrian amalgamation of Gondwana at Leicester University, UK, before continuing his research at the Tectonics Special Research Centre in Curtin University and the University of Western Australia. In 2005, Collins became a Senior Lecturer at the University of Adelaide and was promoted to Associate Professor in 2009 and Professor in 2014. He was Academic Group Leader of Geology and Geophysics in the School of Earth and Environmental Science (2010-12) when he won an Australian Research Council Future Fellowship. He is now Director of TRaX.

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