Our understanding of the evolution of the Earth has dramatically improved over the past 100 years. It began with the idea of continental drift - the realisation the land we stand on is not fixed, slowly moving through geological time - creating the broken jigsaw of continents that we see on a map. This idea evolved into the theory of plate tectonics, which explains that the forces driving the plate motion come from the convective cooling of the Earth: cold and heavy oceanic floor subducts and sinks into the mantle, while hot and light material from deep in the Earth rises to form new ocean floor at mid-ocean ridges.

When these driving forces combine to pull on a continent, a process called continental rifting can occur. Essentially the continent is ripped apart in two pieces over millions of years, and eventually a new ocean is formed between them. This process is vitally important on many different spatial and temporal scales: creating new ocean basins can influence climate by changing ocean currents; life within the ocean relies on continental shelves providing relatively warm and shallow marine environments; and for our modern lives, almost all oil reserves are found on the edges of continental plates, known as passive margins.

These passive margins evolve under the complex interaction between the stretching, thinning and eventually breakup of the crust and mantle; and surface processes that control the flux of sediments at the Earth's surface through rain and river networks eroding and transporting material from the land, and dump it all into these rift zones as they form.

Our project has explored how this interaction influences the evolution of passive margins. We used two numerical modelling codes, Underworld and Badlands, to simulate the tectonic and surface processes through time. These codes were run on supercomputers to allow us to test different scenarios. For example we have found that under a wet climate, where erosion is very strong and sediments are easily transported, the tectonic force required to break the continent is reduced by a significant fraction, changing the rate of rifting, the style of stretching of the passive margin, and where sediments are captured and stored.

This project also helped pioneer the use of large-scale three-dimensional numerical models to explore tectonic problems. In the past, the computing power available was not sufficient to be able simulate these processes in three-dimensions at a useful resolution, and so most numerical research in tectonics was done through two-dimensional cross-sections. Since surface processes are inherently three-dimensional, we developed a framework for the Underworld code to leverage the new computing hardware that has been developed, and produce these large experiments rapidly.

The project was able to explore in details how passive margins form in complex plate systems. The Woodlark Basin in PNG is an example of continental rifting occurring right now. Due to a strong plate rotation, the continental crust is slowly being stretched at the western end, while in the east rifting and oceanization is already completed. We used our three dimensional framework to simulate this situation, and revealed that the upwelling mantle in the area that has already rifting imparts a strong force onto the surrounding passive margins and un-thinned crust. This force may explain why we sometimes see compressional structures and earthquakes in passive margins, despite being formed by stretching and pulling.

6 Million Years of Continental Rifting Close to an Euler Pole