Breaking up is hard to do

Active fault lines are relatively easy to locate on land. Beneath the sea is a different matter, but seismologists ignore these at their peril, says **Rebecca Bell**.

The Gulf of Corinth in central Greece is a thin, 35-kilometre-wide tear in the Earth's crust from Patras on the Mediterranean coast in the west to Corinth in the east. This innocent looking seaway harbours a dark secret: it is one of the most dynamically and quickly stretching areas of continental crust on Earth. Here at the National Oceanography Centre, Southampton, we want to know how Greece is breaking apart and we want to locate the large fractures which may generate earthquakes in the future.

The Earth's continents fit together like pieces of a huge planetary-sized jigsaw puzzle. Since the 1960s and the acceptance of the theory of plate tectonics we've known that continents such as South America and Africa were once connected and shared common geology and wildlife. The previously-joined edges of these continents are now what we call passive and separated by thousands of kilometres of ocean; they are unlikely to experience significant earthquake activity.

So what happens when a continent decides the time is right to split? Does the ripping apart, or rifting, happen smoothly rather like undoing a zip, or does the breaking occur in discrete sections? Does it tear at a continuous rate or can it change through time? The answers are important not only to Earth scientists interested in how continents move and how new oceans form, but also to everyone living (or holidaying) in such rift zones. Any geological clues as to what happened during the start and early stages of South America and Africa's tearing lie buried beneath many kilometres of sediments that settled when rifting ended.

Fortunately, we know of a few places in the world that, at this very moment, are under strain and in the early stages of breaking up. These places are perfect snapshots of what happens when a continent starts to separate.

The whole Aegean region is tectonically challenging. The African plate, which dips beneath Europe, is responsible for a string of volcanic islands like the popular holiday destination of Santorini; meanwhile Turkey is shifting westward into Greece along the North Anatolian Fault, while Greece drifts south-west. However, northern Greece lags behind the south, so slowly the country is ripping itself apart, hence the Gulf of Corinth.

When tectonic forces stretch continents stress builds up along fault lines. Eventually an earthquake will strike. In 373BC, ancient writings report that the city of Helike on the shore of the Gulf of Corinth disappeared into the water overnight. In 1981, three earthquakes, all greater than magnitude six on the Richter Scale, hit in less than two weeks. While it is interesting to study the Gulf of Corinth as an example of a young separating continent, it is also important to identify the location of active faults and identify areas of Greece most at risk.

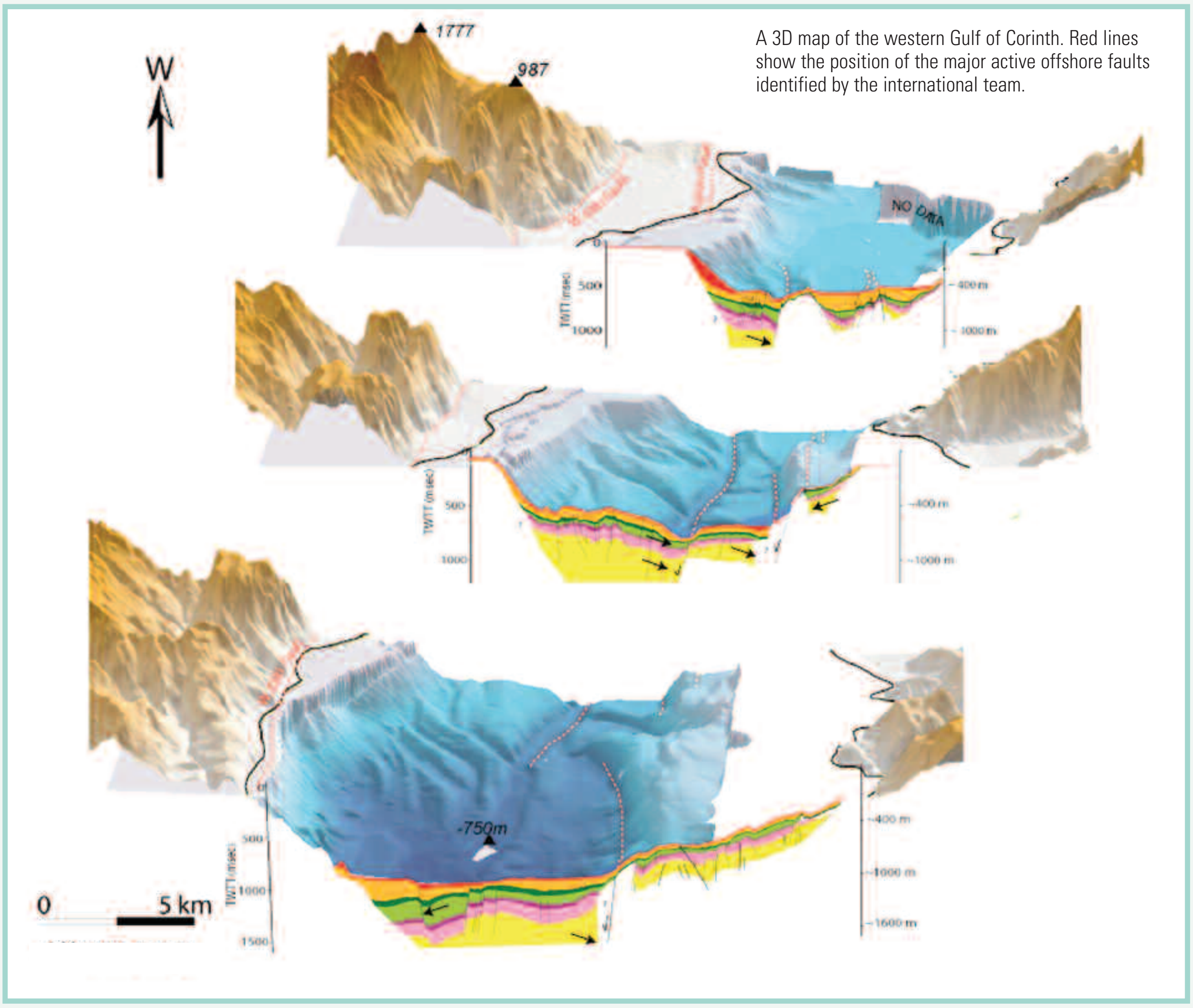
We needed a slice through the Gulf of Corinth.

On land, geologists can locate active faults quite easily. In areas that are stretching, like the Gulf of Corinth, they form steep cliffs or scarps in the landscape. Under water is another matter. Without geophysical surveys or earthquake monitoring we would be unaware of them.

In 2003, we joined scientists from the universities of Leeds and Patras* aboard the research ship MV *Vassilios* to look for faults that have ruptured the seabed and which could potentially fail in a future earthquake. We scanned the seafloor to build up a 3D image of the topography using a technique known as multibeam bathymetry which illuminates the seabed with sound and records how long it takes for it to return. This produced some stunning high-resolution images 500 metres below sea level. But ideally we needed a slice through the rock beneath the Gulf of Corinth. This would allow us to locate large, potential earthquake-generating cracks. We did this using a technique often employed by the oil industry known as seismic reflection. An instrument below the ship generates sound waves that pass through the seafloor and rebound when they hit various types of sediment or hard rock with different

The team used the Greek research ship MV *Vassilios* to map the seafloor.

**The city of Patras lies at the western end of the Gulf of Corinth.*



A 3D map of the western Gulf of Corinth. Red lines show the position of the major active offshore faults identified by the international team.

sound-carrying properties. We took some top quality images below the surface down to around 1.5km. They confirmed the presence of four major previously undocumented faults. The size of these fault lines means they are potentially capable of producing earthquakes with a magnitude of between six and seven on the Richter Scale.

During an earthquake a slab of the Earth's surface slips along a fault line and produces a step in the landscape. Sediments eroded from higher ground slide down to fill in these steps recording the history of earthquake activity and fault slip. The seismic reflection data showed us that sediments in the western-central gulf thickened and tilted towards the newly discovered offshore faults before 400,000 years ago. Prior to this date these faults generated the largest vertical displacements. From this we can deduce that these offshore faults were the most active. Since then the situation has changed. According to sediment patterns in more central parts of the gulf, onshore faults on the south coast now dominate. In the most western part of the gulf, offshore faults still have structural control and are the most active faults in the area.

In 373BC, the city of Helike disappeared into the water overnight.

Our analysis shows that the style of faulting that controls rifting in the Gulf of Corinth varies within short 20km segments and has done so over the gulf's two-million-year history. This study contributes to a growing understanding that rift systems are often segmented: the orientation and character of faults that are dominant at a particular time can change along a rift – they are not necessarily simple systems that act in the same way along their length. To help seismic hazard mitigation and eventually earthquake prediction we must recognise that the orientation of the important earthquake-inducing faults can change along the rift. Such changes in the character of faulting has also been seen in the East African Rift system. So, to truly appreciate earthquake hazards, seismologists must consider both onshore and offshore data together with an analysis of fault evolution along the rift and through time.

Finally, what does the geological future hold for the Gulf of Corinth itself? Could it ever stretch to become a fully fledged ocean? Greece's advance towards the African continent means this is extremely unlikely. When the southern tip of Greece and Africa eventually and inevitably collide the gulf will find itself in a completely different compressional tectonic setting. So, after the break-up, we may see a make-up. ■

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