Asthenospheric flow and plate tectonics in the Antarctic

New geophysical research has provided evidence to support a 46-year-old theory about the effects of the split in the Earth's tectonic plates which separated South America and Antarctica. In studies carried out by Manuel Catalán for the Spanish Royal Naval Observatory and Yasmina M. Martos, for NASA Goddard Space Flight Center (GSFC) and the University of Maryland (UMD) in the USA, technological advances have provided data which help to better understand convection flows in the Earth's mantle through its outermost expression 'asthenospheric currents', which are a possible driving mechanism for plate tectonic processes helping to understand why continents drift.

The 800-km wide body of water known as Drake Passage lies between the tip of South America and the Antarctica. Connecting the Atlantic, Pacific and Southern Ocean, this remote region is where powerful currents collide, giving the Drake Passage its reputation as one of the roughest sea passages in the world.

Until the opening of the Panama Canal, the Drake Passage was an important but testing trade route, which, as the name suggests, was first discovered by 16th century sailors. Half a millennium later, it is the site of new discoveries by geophysicists who are using advanced technologies and plate tectonics' theory to study the evolution of the Earth.

Drake Passage was formed when an opening developed along the junction of the South American and Antarctic tectonic plates. This allowed the oceans to flow in and separated South America from Antarctica. The opening is believed to have taken place at a critical moment in history, around 40 million years ago, when the greenhouse warmth of the Eocene Epoch gave way to the icy conditions of the Oligocene.

The Alvarez Hypothesis

The American geologist Walter Alvarez is best known for his theory that an asteroid impact was responsible for the mass extinction of dinosaurs. Prompted by another interest in finding geological evidence for why the Earth's tectonic plates move, Alvarez's research and the ideas he developed about convection within the Earth's mantle still intrigue scientists today.

Alvarez proposed that if upper mantle return flow existed, the flow would be conditioned by continental masses, depending on whether they separate or join. His ideas assumed the existence of 'asthenospheric currents' or upper mantle outflow from the Pacific to the Atlantic through three oceanic gateways, including Drake Passage and the neighbouring Scotia Sea.

Asthenospheric Flow

Alvarez's hypothesis is the starting point of research currently being carried out by geophysicists Manuel Catalán of the Spanish Royal Naval Observatory, and Yasmina M. Martos of NASA GSFC, and the University of Maryland, USA. Using advanced technologies and plate tectonic theory, they are interested in what Drake Passage, or rather the Earth below its seabed, can tell us about asthenospheric flow and its effects on the surface and above.

Lying immediately below the Earth's solid outer shell or 'lithosphere', the 'asthenosphere' extends approximately from 100 to 300 km below its surface. The asthenosphere is the layer most involved in the movement of the tectonic plates, which 'glide' above it, thanks to the convective currents that rise through it from the deep mantle.

Asthenospheric currents suppose an injection of heat that affects geophysical features sensitive to temperature. Crustal magnetic properties provide a view of the Earth's crust and provide information regarding plate tectonic history. Additionally, magnetic anomalies provide information about the thermal structure of the Earth's lithosphere, where the temperature is high, magnetic anomaly amplitudes weaken.

BARRIERS IN THE SCOTIA SEA

Catalán and Martin's early research published in 2014 looked at barriers to outflow between the Pacific and Atlantic. It also set out to determine the main features of the lithosphere below the Scotia Sea to the east of Drake Passage, based on the compilation and analysis of global satellite and gravity data.

In particular, for the first time they identified significant variation in the depth of the lithosphere below the Scotia Sea, with the western area having a thinner lithosphere. They interpreted this as a consequence of asthenospheric current flows and argued that the thinned lithosphere of the newly born Scotia Sea facilitated mantle flows between the Pacific and Atlantic, supporting Alvarez's hypothesis.

Geothermal Structure

In 2019, Catalán and Martos published research (Martos et al., 2019), which studied the geothermal structure of the lithosphere of the Scotia Sea and the relationships of the Pacific and Atlantic upper mantle. Using magnetic anomalies to build a thermal model to create a geothermal heat flux map of the ocean floor, they also used multichannel seismic and satellites depth measurement or 'batmetry' data to determine thermal subsidence.

Their study detected the presence of two high geothermal heat flow branches, one to the south of South America and the other to the north of the Antarctic Peninsula. As proposed in Alvarez's hypothesis, the results further corroborated the existence of a mantle outflow that pored into the Atlantic from the Pacific. The data also showed that the seafloor under the West Scotia Sea reaches thermal equilibrium more quickly than other oceans do and behaves like old oceanic crust does in larger oceans. Catalán and Martos attributed the anomalous thermal evolution detected to both high geothermal heat flow branches, which acted as an out-of-the-ordinary heat source causing this anomalous thermal state and evolution.

Atlantic Asthenospheric Flow

In 2019, Catalán and Martos also published research (Catalán et al., 2019) into asthenospheric currents further north in the Earth's mantle below the Atlantic Ocean, between the Gulf of Cadiz and Canary Archipelago. This area links an active volcanic environment - the Canary Archipelago - and an area where two tectonic plates meet - the Eurasia and Africa plates.

Here Catalán and Martos's objectives were to analyse and integrate different geophysical techniques and data, including geothermal heat flow, total magnetic field and crustal's magnetic properties to provide information about the thermal state and evolution of the Earth's surface.
Behind the Research

Dr Manuel Catalán
E: mcatalan@roa.es
W: http://www.roa.es
T: +34 956 599285

Dr Yasmina M. Martos
E: yasmina.martos@nasa.gov
W: https://science.nasa.gov/sed/bio/yasmina.martos

Research Objectives

The geophysical research of Manuel Catalán and Yasmina M. Martos explores the convection flows of the Earth’s upper mantle and provides insights into plate tectonics movement.

References


Personal Response

The opening of the Drake Passage, so related with your research, seems to have occurred at a time of significant climate change and it led to the establishment of the Antarctic Circumpolar Current. Its connection with the current climate from a scientific point of view is utterly clear, in a sense a simple takeaway from your research that may help our understanding of the world’s current climate crisis?

We must think that our planet behaves as a stable thermodynamic system where the Equator and Poles act as hot and cold sources respectively, and the ocean currents affect the balance of heat among them. Altering this distribution of mass can modify this process and its evolution.

The current problem you are asking us about is measured on a much shorter timescale, of hundreds of years and it is related to other factors. In this sense, the reasons and effects of the current and short time changes are not part of the framework of our studies.

Your research is for the most part located in one of the world’s most remote and extreme geographical areas. What do you find most challenging when working in such conditions?

Probably the greatest challenge in these expeditions is not related to getting the scientific instrumentation to work properly, or to get good quality data. All of this is taken for granted as the scientific team is made up of professionals. The greatest challenge when the work is carried out under extreme weather conditions, and in a reduced space, either in a ship or in a small station, is to keep a good atmosphere and harmony among the team members. Frictions and tensions are not only undesirable, but they can also affect the scientific performance of the expedition itself.

The thinned lithosphere of the newly born Scotia Sea facilitated mantle flows between the Pacific and Atlantic.

Catalán and Martos propose that asthenospheric flow from the Scotia Sea (upper panel) had a major impact in the evolution of the crustal magnetic properties of the Powell Basin (bottom panel). A dashed square (upper panel) delimits the Powell Basin.

The opening of the Drake Passage, so related with your research, seems to have occurred at a time of significant climate change and it led to the establishment of the Antarctic Circumpolar Current. Its connection with the current climate from a scientific point of view is utterly clear, in a sense a simple takeaway from your research that may help our understanding of the world’s current climate crisis?

We must think that our planet behaves as a stable thermodynamic system where the Equator and Poles act as hot and cold sources respectively, and the ocean currents affect the balance of heat among them. Altering this distribution of mass can modify this process and its evolution.

The current problem you are asking us about is measured on a much shorter timescale, of hundreds of years and it is related to other factors. In this sense, the reasons and effects of the current and short time changes are not part of the framework of our studies.

Your research is for the most part located in one of the world’s most remote and extreme geographical areas. What do you find most challenging when working in such conditions?

Probably the greatest challenge in these expeditions is not related to getting the scientific instrumentation to work properly, or to get good quality data. All of this is taken for granted as the scientific team is made up of professionals. The greatest challenge when the work is carried out under extreme weather conditions, and in a reduced space, either in a ship or in a small station, is to keep a good atmosphere and harmony among the team members. Frictions and tensions are not only undesirable, but they can also affect the scientific performance of the expedition itself.