Reconstructing Mediterranean-Atlantic exchange during the Miocene (MEDGATE)

The research aim of MEDGATE is to reconstruct the geometry and flow pattern of the Mediterranean Gateways before, during and after the Messinian Salinity Crisis and to evaluate the impact on both the Mediterranean and global environmental change.

Marine gateways play a critical role in the exchange of water, heat, salt and nutrients between oceans and seas and hence impact regional and global climate. Today, Mediterranean-Atlantic exchange through the Gibraltar Strait dominates the mass and energy budgets of the Mediterranean Sea [*Bethoux*, 1979; *Bryden and Stommel*, 1984] and is a major influence on North Atlantic circulation [*Iorga and Lozier*, 1999; *Ozgokmen et al.*, 2001]. However, the current single marine corridor at Gibraltar is a relatively recent phenomenon having been initiated 5.3 million years ago [e.g. *Garcia-Castellanos et al.*, 2009] and was preceded by several different configurations linking the Mediterranean and the Atlantic through gateways in southern Spain and northern Morocco (Fig. 1).

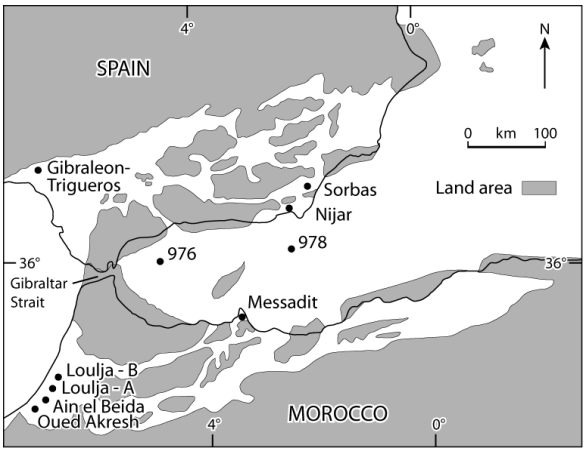

Figure 1 Map of the pre-Gibraltar Atlantic-Mediterranean gateways 5-10 million years ago [Santisteban and Taberner, 1983] and the location of the astronomically tuned sections to be used in this study.

Changes in gateway geometry can significantly alter the pattern of ocean circulation and hence heat transport and climate [e.g. Panama Strait and Drake Passage, *Lunt et al.*, 2008; *Omta and Dijkstra*, 2003; *von der Heydt and Dijkstra*, 2005]. The advantage of studying ancient gateways that have since closed rather than their modern counterparts is that the ancient gateway sediments record the full process of closure. However, most fossil gateways exposed on land owe their current location to tectonic compression and uplift. This necessarily results in erosion of the sediments and dislocation of the original gateway.

The Mediterranean-Atlantic gateways that pre-date Gibraltar largely escape this problem because, although incipient collision has closed the gateways, closure was a relatively recent occurrence and has not, so far, resulted in substantial erosional and tectonic dismemberment. In addition, the Neogene deposits of the Mediterranean have been intensely studied resulting in excellent age constraints [e.g. *Krijgsman et al.*, 1999a]. As a result, this region is an ideal focus for 2-3 year research projects to reconstruct the timing and processes of gateway closure. This information will provide insight into the functioning of extant gateways, gateways that are believed to exert important control on the present-day climate system.

Where ocean gateways link to marginal marine basins, the impact of changes to the pattern and volume of exchange on the depositional environment of that basin can be profound. Even subtle changes to the hydrologic budget can alter the temperature, salinity and circulation of the marginal basin and hence transform its entire depositional environment [e.g. *Bethoux and Pierre*, 1999; *Cramp and O'Sullivan*,

1999]. More substantial changes to the hydrologic system are achieved mainly through tectonic processes acting on the gateway itself. These result in significant alterations to the sedimentary architecture and may generate targets for oil and gas exploration. The progressive closure of the Mediterranean-Atlantic gateways in the Messinian (7-5 Myr ago) caused one of the most dramatic paleoceanograpic events in Earth's history; the Messinian Salinity Crisis [MSC, *K Hsü et al.*, 1973; *Ryan*, 2009]. This event is a superb example of an extreme response to gateway restriction. Sediments deposited in the Mediterranean during the MSC reflect huge fluctuations in salinity [e.g. *K J Hsü et al.*, 1977]. Although the MSC has been the subject of intense study since the 1970s, many key questions concerning the controls on its onset, progression and termination remain unanswered mainly because the evolution of its Atlantic gateways is so poorly constrained. By targeting these gateway sediments MEDGATE aims not only to reconstruct the evolution of Mediterranean exchange and explore its impact on both the Mediterranean and global environmental conditions, but also to develop new techniques for reconstructing gateway evolution that will be applicable to older and less well preserved gateway successions.

The Mediterranean-Atlantic gateways

In pre-MSC times, two marine gateway systems existed connecting the Mediterranean to the Atlantic: the Iberian Portal through southern Spain and the Riffian Corridor through northern Morocco [Fig. 1, e.g. *Benson and Rakic-El Bied*, 1991]. Most of the Messinian gateway sediments that are now exposed on land have been intensively studied, but the exact closure ages are still subject to significant uncertainty [*Benson and Rakic-El Bied*, 1991; *Husing et al.*, 2010; *Krijgsman et al.*, 1999b; *Martin and Braga*, 1994; *Martin et al.*, 2001; *van Assen et al.*, 2006] largely because the area which first blocks the marine connection is, by default, the highest area and hence subject to the most extensive erosion. Previous studies, however, suggest that gateway closure occurred up to a million years before the onset of the MSC [*Benson and Rakic-El Bied*, 1991; *Kouwenhoven et al.*, 1999; *Martin et al.*, 2001]. This result is problematic since the deposition of thick evaporite deposits during the MSC requires the existence of at least one gateway to supply sufficient salty water to the Mediterranean, although modelling studies suggest that only a very narrow (~1 km) and shallow (~10m) connection is necessary [*Meijer and Krijgsman*, 2005]. Re-examining and reducing the uncertainty in the age of gateway closure and identifying its location and geometry is therefore critical for constraining the process-response chain linking gateway evolution and the development of the MSC succession.

MEDGATE's multidisciplinary approach

MEDGATE provides a unique opportunity to train researchers in interdisciplinary research and to tackle an important and enduring research problem with significance for our understanding of Mediterranean and global-scale environmental change.

MEDGATE is a unique opportunity to obtain new, multidisciplinary constraints on Mediterranean-Atlantic gateway evolution. All elements of the research require the incorporation of existing datasets drawn from both academia and industry and their integration with new analytical results generated using state-of-the-art methodologies.

1. Timing: a precise date for gateway closure will be achieved using novel isotopic and organic geochemical water mass tracers combined with ecological information derived from fossils and facies and palaeocurrent analysis. The sedimentary sequences preserved at either end of the marine corridors (Fig. 1) will be

targeted for this analysis because these uninterrupted successions are astronomically tuned with a resolution of <20kyr. The resulting record will document the presence or absence of both Mediterranean Outflow Water (MOW) at the western end, and Atlantic water at the eastern end through time, thus constraining precisely when the connections were severed and exchange ceased.

2. Exchange: this record will also allow us to test the various hypotheses that describe different exchange scenarios for the MSC period. Some of these hypotheses advocate two-way flow through each corridor while others consider that all Atlantic water entering the Mediterranean was siphoned through Morocco at the same time as MOW was funnelled through the Betic portal [*Benson and Rakic-El Bied*, 1991; *Martin et al.*, 2001] and the investigation of the impact of exchange via precise correlation with MSC sedimentary events in the Mediterranean.

3. Palaeogeography: timing information can be integrated with the results of high-resolution field survey data and the analysis of both onshore and offshore subsurface (core, well-log and seismic) datasets. Both the offshore western extensions of the Riffian Corridor (the Rharb Basin), and the Betic Portal (Guadalquivir –Cadiz Basin) can be studied through the investigation of the seismic profiles and boreholes that have been generated as a result of hydrocarbon exploration in the area. Partnership with the oil company Repsol and ONHYM delivers these data and additional data has been contributed by the oil company Gas Natural. The aim is to identify the precise location and geometry of the gateways involved throughout the onshore and off-shore Betic-Riffian region.

4. Impact assessment: The final important aspect to MEDGATE's multidisciplinary approach is the integration of all relevant information from these disparate data sources with of state-of-the-art mathematical modelling. MEDGATE will utilise a range of modelling tools that allow us to focus both on the impact of exchange on the Mediterranean (e.g. box-models and Mediterranean-scale ocean circulation models) and on the impact of Mediterranean Outflow on thermohaline circulation in the North Atlantic and global climate (e.g. climate General Circulation Models).

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