# Astrobiochronology of Late Neogene deposits near the Strait of Gibraltar (SW Spain). Implications for the tectonic control of the Messinian Salinity Crisis.

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## INTRODUCTION

The Messinian Salinity Crisis was the result of total isolation or strong restriction in the Atlantic-Mediterranean water exchange during the Late Messinian. This isolation could be driven by global sea level changes or tectonic processes affecting the Atlantic-Mediterranean gateways. Tuning of rythmic sedimentary records and/or oxygen isotope records to astronomical solutions allowed in the last decades to establish a reliable time framework for the late Neogene, including the Messinian (Hilgen and Langereis, 1993; Hilgen *et al*., 1995, 2000; Hilgen and Krijgsman, 1999; Krijgsman *et al*., 1999a,b; Lourens *et al*., 1996; 2004; Sierro *et al*., 2001). This allowed for the first time the cycle to cycle correlation of Mediterranean and open ocean sections with a resolution higher than a precession cycle (Hodell *et al*., 2001; Vidal *et al*., 2002; Krijgsman *et al*., 2004; Van der Laan *et al*., 2005, 2006; Tiedemann *et al*., 2006). Although some global events can be related to particular events in the Mediterranean, these studies suggest that there is no significant drop in global sea level at around the onset of evaporite deposition in the Mediterranean, neither a major sea level rise near the Pliocene inundation. This strongly argues in favour of tectonic changes along the Gateways as the main cause for the Mediterranean isolation during the Messinian and the early Pliocene flooding.

The Guadalquivir-Gulf of Cadiz basin in Southern Spain is a foreland basin that was originated north of the Betic orogen during the Miocene and Pliocene, north of the Strait of Gibraltar. This basin was always open to the Atlantic and during the Middle to late Miocene it was one of the main gateways that connected the Atlantic and Mediterranean.

Fig. 1. Map of south Spain, showing the Guadalquivir basin and the location of boreholes and seismic line mentioned in the text.

The main objective of this work is to explore the Guadalquivir basin and the Gulf of Cadiz to obtain continuous sediment records for the interval of the Messinian Salinity Crisis on the Atlantic side of the Iberian peninsula so as to analyse the possible paleoenvironmental, tectonic or paleoclimatic changes in a region which was only a few kms away from the Mediterranean coasts during this time period.

## CLOSURE OF THE NORTH BETIC ATLANTIC-MEDITERRANEAN GATEWAY

During the middle Miocene the North Betic Gateway was a deep forebasin extending from the Atlantic margin in the Gulf of Cadiz to the Mediterranean Sea. It was a foreland basin that was originated between the Betic orogen to the South and the Iberian Foreland to the North. Marine deposits throughout the basin evidence a deep water connection between the Atlantic and Mediterranean at that time (Geel *et al*., 1992). However, rapid emergence of the Prebetics during the Tortonian blocked this connection to the East, which left a relatively narrow Atlantic Mediterranean connection through the Guadix basin to the southeast (Soria *et al*., 1999; Betzler *et al*., 2006). Marine deposits of Middle to Late Tortonian age are present in the eastern part of the Guadalquivir basin that extend towards the Guadix basin (Sierro *et al*., 1996; Soria *et al*., 1999; Betzler *et al*., 2006) and the Mediterranean. Near the Tortonian-Messinian boundary, however, a change from marine to continental deposits marks the end of the Atlantic-Mediterranean connection through the Guadix basin (Soria *et al*., 1999; Betzler *et al*., 2006). This cannot be tested in the eastern Guadalquivir basin because deposits of this age were probably eroded (Sierro *et al*., 1996).

Since its eastern closure, the Guadalquivir basin was progressivelly filled with sediments that prograded from west to east. Emplacement of huge olistostromic masses from the south (Martínez del Olmo, 1984; Suárez *et al*., 1989; Martínez del Olmo *et al*., 1996; Riaza and Martínez del Olmo, 1996; Sierro *et al*., 1996) rapidly filled up the Gualquivir basin, causing a significant shallowing and narrowing of the Betic Gateway. This event occurred in the western part of the basin near the Tortonian-Messinian boundary (Sierro *et al*., 1996).

The last Atlantic-Mediterranean connection through the North Betic corridor seems to occur through the Guadalhorce Gateway that connects the Alboran Sea, the Guadalquivir basin and the Atlantic margin (Martin *et al*., 2001). Records of sediments formed under active bottom Mediterranean outflow currents were formed until 6.3 myr (Martin *et al*., 2001), well before the onset of the Messinian evaporates. This seems to be the date of final closure of the North Betic Gateway.

## ORIGIN OF THE MESSINIAN SUBMARINE CANYON OF THE GUADALQUIVIR BASIN

Infilling sediments of the Guadalquivir-Gulf of Cadiz basin mainly consist of hemipelagic homogeneous clays that were deposited from the Late Serravallian to the Quaternary, recording normal marine conditions (Martínez del Olmo, 1984; Suárez *et al*., 1989; Martínez del Olmo *et al*., 1996; Riaza and Martínez del Olmo, 1996; Sierro *et al*., 1996). Biostratigraphic studies allowed us to identify planktonic foraminifer events of regional significance that were later calibrated to the Astronomical Polarity Time Scale (APTS) (Sierro *et al*., 1993; 1996; 2001). Some events, such as the sinistral to dextral coiling change in *Neogloboquadrina acostaensis* and the First abundant occurrence of *Globorotalia margaritae* predate the onset of the Messinian evaporites in the Mediterranean (Sierro *et al*., 1996), but no significant event was recognized at the Miocene-Pliocene boundary. In fact, the time interval of the Messinian Salinity Crisis can only be constrained between the First abundant occurrence of *Globorotalia margaritae*, which is approximately synchronous with the base of the evaporites and the First occurrence of *Globorotalia puncticulata* that occurred well into the Pliocene (Ledesma, 2000).

Numerous boreholes were drilled for gas exploration over the last 50 years, especially in the western part of the basin and offshore in the Gulf of Cadiz. Tuning of sonic and gamma-ray logs to the 65ºN summer insolation record has allowed to accurately correlate Atlantic and Mediterranean records during the Pliocene (Sierro *et al*., 2000). The use of biostratigraphic events together with the cyclical analysis of the well logs and the seismic profiles allowed us to precisely reconstruct the geometry of the sedimentary filling (Ledesma, 2000).

During the Messinian a significant tectonic elevation, especially in the eastern and southern margins of the basin, caused a profound incision that can be easily recognized in the seismic profiles (Martínez del Olmo *et al*., 1996). This canyon is narrow and deeply erosive in the central part of the basin and relatively flat and conformable towards the west (Martinez del Olmo *et al*., 1996). Filling of this canyon led to rapid SE to NW progradation accompanied by deposition of turbidite lobes that develop along the axial part of the basin in front of the slope (Martínez del Olmo *et al*., 1996; Ledesma, 2000). Although we still have not dated it with precision, this event was contemporaneous with the evaporite deposition in the Mediterranean. We suggest that this tectonic uplift recorded in the Guadalquivir basin could be the expression of a more general tectonic elevation occurring in the Strait of Gibraltar area and, in consequence, responsible for the progressive restriction of the Atlantic-Mediterranean water exchange. Alternatively, part of this tectonic uplift and canyon incision in the Guadalquivir basin could be originated by the Messinian isostatic rebound caused by water removal from the Mediterranean after dessication because this basin is not far away from the Mediterranean coast.

## THE MIOCENE-PLIOCENE BOUNDARY IN THE GUADALQUIVIR-GULF OF CADIZ BASIN

Near the Miocene-Pliocene boundary turbidite deposition in the basin ceased and was replaced by hemipelagic sediments both in the Gulf of Cadiz and the Guadalquivir basin (Ledesma, 2000). Throughout the basin an important change in the sedimentary filling occurred. Uplift during the Late Messinian changed to subsidence all along the basin, especially in the southern margin towards the Strait of Gibraltar. As a result, the dominant northwestward progradation during the Late Messinian changed to a general southwestward progradation during the Early Pliocene, indicating subsidence was high in the southern part (Ledesma, 2000). This change is especially evident in seismic profiles from the Gulf of Cadiz (Figure 2).

The lack of a reliable stratigraphic framework prevented to accurately date this tectonic event in the past, however, tuning of cyclical changes in physical properties to astronomical solutions indicates that subsidence was synchronous with the reopening of the Atlantic-Mediterranean connection, marking the end of the Messinian Salinity Crisis.

Correlation between sonic and gamma-ray logs from the Gulf of Cadiz and sedimentary cycles from Capo Rossello sections in Italy is very straightforward from insolation cycle 502 to insolation

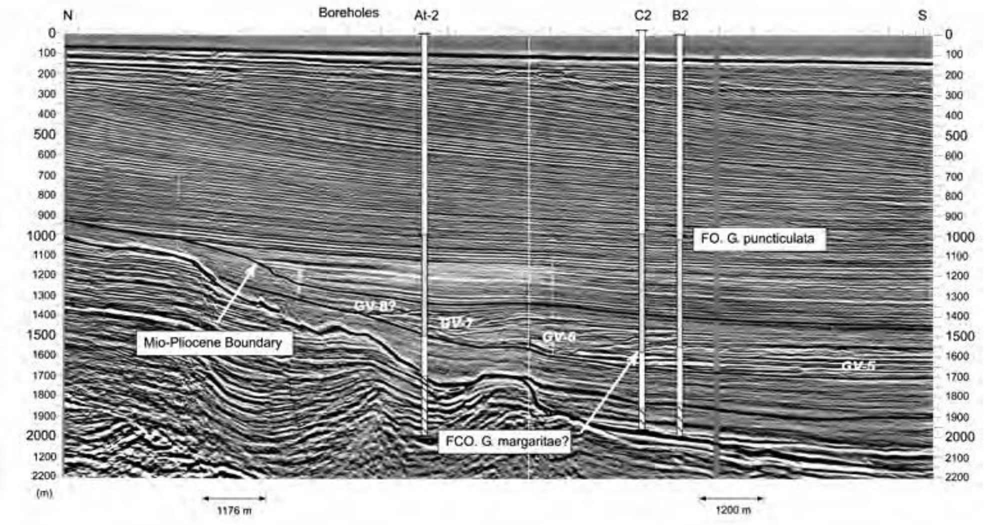

Fig. 2. Seismic line showing the Late Neogene sedimentary filling in the Gulf of Cadiz and the location of three boreholes drilled for gas exploration. Modified from Ledesma 2000 . Various turbidite bodies (Gv 6 to Gv8?) were deposited during the Late Messinian between the First abundant occurrence of *G. margaritae* and the Miocene-Pliocene boundary. At the Miocene-Pliocene boundary a major change in sedimentation from turbidite to hemipelagic deposition took place. Log astrobiochronology (Sierro *et al.,* 2000) allowed to precisely locate the Miocene-Pliocene boundary (see Figure 3). Location of the seismic profile is shown in Figure 1.

cycle 250 a (astronomical cycles as defined by Lourens *et al*., 1996). The change from turbidite to hemipelagic sedimentation in the Gulf of Cadiz seems to be the result of an important relative sea level rise in the Guadalquivir basin probably caused by the initiation of tectonic subsidence. This important sedimentary change was recorded in various holes a few meters below insolation cycle 502 which can be correlated with cycle 5 in Capo Rossello and consequently very close to the Miocene-Pliocene boundary (Figure 3).

In outcrops from the northwestern margin of the Guadalquivir basin a glauconite-rich layer can be traced for more than 100 km between Sevilla and Huelva. Apart from glauconite grains, this layer is characterized by abundant biogenic and authigenic grains, in particular foraminifer and mollusk shells as well as shark teeth and other bones. It was interpreted as a condensed deposit that was probably originated during this relative sea level rise at the Miocene-Pliocene boundary, although the lack of accurate datings does not allow to fully confirm this hypothesis (Sierro *et al*., 1996).

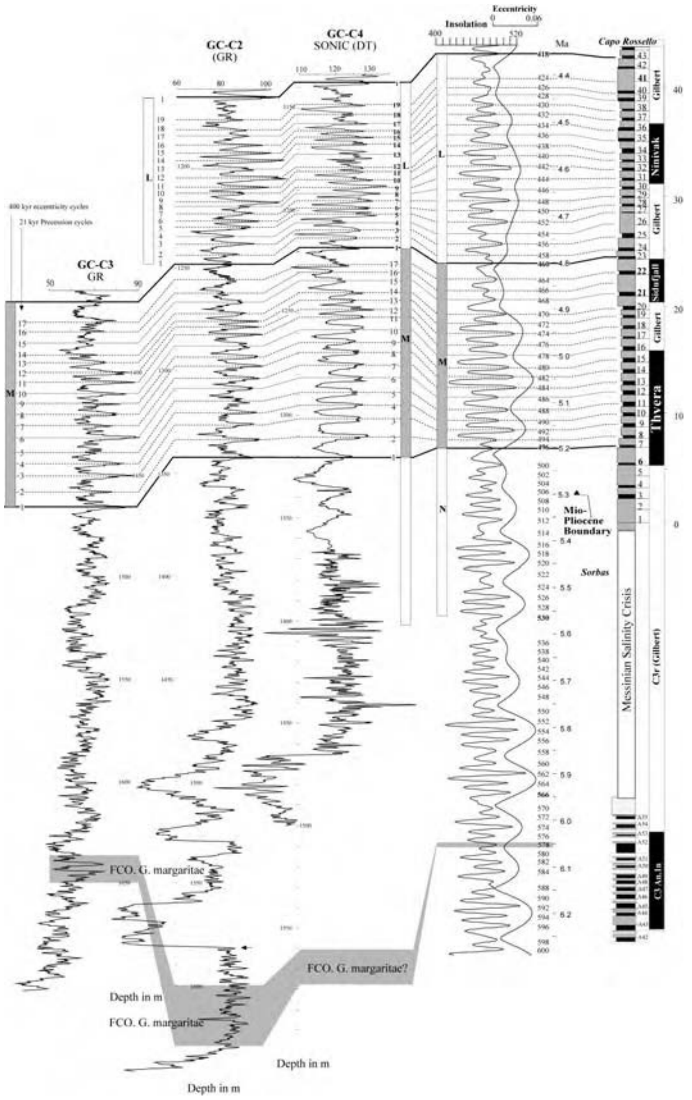

Fig. 3. Gamma ray (GR) and sonic (DT) logs for boreholes GC-C2, GC-C3 and GC-C4 drilled in the Gulf of Cadiz. Modified from Ledesma, 2000. Analysis of cycle patterns allowed the astrochronological correlation of these logs with the 65ºN summer insolation record (Laskar *et al.,* 1990) and Capo Rossello section (after Hilgen, 1991; Langereis and Hilgen, 1991; Lourens *et al.,* 1996) in the Mediterranean (see Sierro *et al.,* 2000; Ledesma, 2000). For reference, rythmic sections from the Sorbas basin are shown (Sierro *et al.,* 2001; Krijgsman *et al.,* 2001). Astronomical cycles are clearly recorded in the logs from nearly the base of the Pliocene. The Miocene-Pliocene transition is marked by a change in physical properties as recorded in the logs. Letters L, M, N mark the 400 kyr cycles as recognized in Sierro *et al.,* 2000 and in Ledesma, 2000).