A comprehensive review of the MSC facies, their origins, and effects on seismic imaging in the offshore Sirt Basin, Libya

S. A. Bowman

CGGVeritas, Crompton Way, Manor Royal Estate, Crawley, West Sussex, RH10 9QN
(steven.bowman@cggveritas.com)

Abstract

Interpretation of 2D long offset multi-client seismic data acquired by CGGVeritas in 2004-5 has allowed the distribution and composition of the Messinian Salinity Crisis (MSC) facies to be mapped across the offshore Sirt Basin, Libya. The results reveal that only the Lower and Upper Evaporites are present within the marginal offshore Sirt Basin with the Middle Halite unit confined to the deeper basin corresponding to the present day Ionian Abyssal Plain. The Upper Evaporites, ‘Lago Mare’, are characterised by a period of fluctuating sea-level and strong water salinity changes controlled by astronomical precession. They consist of inter-bedded evaporites and clastics with a total of seven precessional cycles recognised, each associated with erosional sub-aerial channels interpreted to have been created by the Eosahabi rivers sourced from the flooding of Neogene Lake Chad. The Lower Evaporites display a high relief, irregular topography which strongly controls the distribution of the overlying Lago Mare facies. They have an overall chaotic high amplitude response with very little internal structure and are interpreted to represent mass transport complex deposits of the Re-sedimented Lower Gypsum unit. There is a strong correlation between the distribution and composition of the MSC facies and the quality of seismic imaging.
Introduction

There have been very few studies focusing on the Messinian Salinity Crisis (MSC) in the offshore Sirt Basin, Libya, largely due to a lack of good quality seismic data and sparse well penetrations. However, this has recently changed following the lifting of UN trade sanctions and the return of several western oil companies to Libya. In 2004-5 CGGVeritas acquired 38,000 km of 2D long offset multi-client seismic data across the whole of offshore Libya in support of the upcoming EPSA IV licensing rounds (Figure 1).

Figure 1 Seismic database offshore Libya, re-processed lines shown in red.

Understanding the distribution and composition of the MSC facies is crucial for seismic acquisition and processing. The MSC facies can vary significantly both vertically and laterally with the Messinian evaporites representing a significant velocity inversion in the shallow subsurface above the main Eocene and Cretaceous target intervals. The MSC facies also represent a significant barrier to the penetration of seismic energy due to a combination of their high impedance contrasts, often chaotic internal structure, and scattering due to erosional surfaces.

Theory

The MSC can be subdivided into three units, the “Messinian trilogy”, comprising of the Lower Evaporites, Halite, and Upper Evaporites (Decima and Wezel, 1971). The Lower Evaporites were deposited at the onset of the MSC, dated at 5.96 Ma based on astronomic tuning (Krijgsman et al., 1999). They were deposited in relatively shallow waters whilst the Mediterranean was still a deep water basin and are composed of gypsum inter-bedded with thin euxinic shales (CIESM, 2008). They can be sub-divided into two distinct stratigraphic units, Primary Lower Gypsum (PLG) and Re-sedimented Lower Gypsum (RLG). The PLG was deposited in situ in marginal settings whilst the RLG deposits were deposited during large-scale mass-wasting processes (Roveri et al., 2008).

Deposition of the Halite unit occurred at approximately 5.59 Ma (Krijgsman et al., 1999) following the isolation of the Mediterranean from the Atlantic which lead to a substantial fall in sea level estimated at approximately 1,500 m (Ryan, 1976). The presence of halite is therefore confined to the deeper basins whilst the continental shelves and marginal basins were sub-aerially exposed and subjected to significant erosion forming the Messinian erosional surface (MES) (Roveri et al., 2008).

The Upper Evaporites, known as ‘Lago Mare’, were deposited at approximately 5.50 Ma (Krijgsman, 1999) and conformably overlie the Halite unit in deep basinial areas and onlap the MES in shelfal areas and marginal basins (CIESM, 2008). They are characterised by a period of fluctuating sea-level
and strong water salinity changes with a gradual return to marine conditions (Orszag-Sperber, 2006) once again controlled by astronomical precession (Krijgsman, 1999). They were deposited in shallow marine and brackish to lacustrine waters and consist of conformable cyclic alterations of sandstones, conglomerates, marls, and gypsum deposited in a dominantly non-marine environment (CIESM, 2008). Sub-aerial channels have been reported within the Lago Mare facies in the offshore Sirt Basin where they are deeply incised and up to 4 km in width. (Sabato Ceraldi et al., 2010).

**Observations**

The Upper Messinian Lago Mare facies cover an area of approximately 45,000 km² with a maximum thickness of around 550 m. They are clearly imaged and instantly recognisable on CGGVeritas’s seismic data due to their inter-bedded nature, with alternating high and low amplitudes, and the presence of several major channels (Figure 2A). High amplitude reflectors are thought to correspond to the deposition of evaporites, gypsum or anhydrite, whereas low amplitude reflectors correspond to periods of low energy clastic deposition in a fluvial or lacustrine setting. This alternating sequence is repeated several times with each evaporite inter-bed regionally correlatable even on 2D seismic data with line spacings of 10 – 15 km.

![Re-processed seismic section showing the typical cyclic and channelised nature of the Lago Mare facies observed in the offshore Sirt Basin. B) Schematic interpretation.](image)

Six regionally extensive evaporite inter-beds have been mapped sub-dividing the Lago Mare facies into seven distinct units (Figure 2B). Each unit consists of a thick clastic sequence up to 80 m thick overlain by a thin evaporite layer up to 20 m thick. Each unit is associated with erosional, seismically transparent, clastic filled channels. Units 1–4 are characterised by relatively minor channels with a maximum width of 4 km and maximum thickness of 130 m. Units 5–7 are characterised by major channels with a maximum width of 7.5 km and maximum thickness of 350 m capable of eroding down to the base of the earlier Lago Mare facies. The major channels are regionally correlatable and can be traced back to a single channel pathway sourced from the present day southern Gulf of Sirt.

The distribution of the Lago Mare facies is controlled by the underlying topography of the Lower Evaporites and Oligo-Miocene clastics as well as older structural lineaments. The Halite Unit is absent within the marginal Sirt Basin occurring only in the deeper part of the basin beyond the Cyrenaica Ridge corresponding to the present day Ionian Abyssal Plain. Recent studies have drawn attention to the importance of gravitational collapse and slumping within Oligo-Miocene deposits in
the offshore Sirt Basin (Sabato Ceraldi et al., 2010). The high relief, irregular topography of the Oligo-Miocene deposits cannot be correlated to the structure of the underlying section implying that it is depositional in origin and/or located above a detachment surface. The majority of the structural high’s within the basin centre which affect the distribution of the Lago Mare facies are interpreted to represent MTC’s, consisting of large slide blocks, slumps, and debris flows.

Conclusions

Each unit within the Lago Mare facies is interpreted to represent a precessional cycle, and given that the average periodicity for precession during the Neogene is 21.7 kyr (Krijgsman et al., 1999) this implies that the Lago Mare facies within the offshore Sirt Basin had a duration of less than 152 kyr with the onset of deposition at approximately 5.48 Ma. Evaporite deposition would have occurred during precession maxima during relatively dry periods when evaporation exceeded precipitation (Krijgsman et al., 1999). This would have resulted in the drying out of the marginal Sirt Basin and a lowering of the base level leading to channel incision. During precession minima and relatively wet periods high freshwater runoff (Krijgsman et al., 1999) would have at least partially refilled the marginal Sirt Basin creating a brackish or lacustrine environment with deposition of channel sands, silts, and clays sourced primarily from the Eosahabi rivers.

There is currently no active drainage system within the southern Gulf of Sirt which raises the question; What is the origin of the major channel systems? Barr and Walker (1973) mapped a large fossil drainage system onshore, which they named the Sahabi channel, located north of Gialo, which they assigned a probable Upper Miocene age. Its characteristics and age correlate well with the major channel systems within the Lago Mare facies and it is proposed that they are part of the same drainage system. Landsat 4/5 TM satellite imagery has been used to map the geomorphology of north eastern Chad and southern Libya and the results define a pathway between the southern Gulf of Sirt and Neogene Lake Chad (Griffin, 2006). This implies a total length of approximately 2,000 km for the Upper Messinian Eosahabi rivers which were sourced from flooding of Neogene Lake Chad.

Slumping and gravitational collapse began during the Oligocene, prior to the MSC, involving deltaic clastics. Multiple detachment surfaces can be observed indicating that the slumping and gravitational collapse of Oligo-Miocene sediments was an ongoing process. There is a strong negative impedance reflector below the Upper Miocene age. Its characteristics and age correlate well with the major channel systems within the Lago Mare facies and it is proposed that they are part of the same drainage system. Landsat 4/5 TM satellite imagery has been used to map the geomorphology of north eastern Chad and southern Libya and the results define a pathway between the southern Gulf of Sirt and Neogene Lake Chad (Griffin, 2006). This implies a total length of approximately 2,000 km for the Upper Messinian Eosahabi rivers which were sourced from flooding of Neogene Lake Chad.

The quality of seismic imaging within the offshore Sirt Basin is extremely variable ranging from good to very poor. The MSC deposits have long been understood to be the cause for the poor imaging quality. However, the MSC deposits are widely distributed and in places the imaging quality below them is good indicating that there is no simple correlation between imaging quality and the presence of MSC deposits. A MSC facies map (Figure 3) has been created describing the different depositional and erosional environments active during the MSC, with a total of eight environments recognised.

The areas with the worst seismic imaging correspond to the karstified shelf margins, RLG, and the Halite unit. The karstified shelf margins attenuate the higher frequencies causing a ‘ringing’ effect in the data due to multiple energy. The RLG typically has a chaotic internal structure consisting of mixed clastics and PLG with rapid facies and thickness changes (Roveri et al., 2008) and as such represents a significant barrier to the penetration of seismic energy. Imaging below the Halite unit is poor due to its thickness, up to 1 km, and its high interval velocity creating a major velocity inversion in the shallow subsurface. The areas with the best seismic imaging correspond to the eroded shelf slope, Lago Mare facies, and marginal Lago Mare/Sabkha. Along the eroded shelf slopes the MSC deposits are absent meaning that there is no major barrier to the penetration of seismic energy. The imaging quality below the clastic-dominated Lago Mare facies and Marginal Lago Mare/Sabkha is generally good due to the reduced thickness or absence of the underlying RLG.
Re-processing of the original seismic data produced significant improvements but was still strongly constrained by the MSC facies. The distribution and composition of the MSC facies should be considered when designing the acquisition parameters for future seismic surveys. The original seismic data was far superior to any previous 2D seismic data acquired due in large part to the use of a long-offset 8 km streamer which should be a pre-requisite for imaging below the MSC facies. Higher frequencies are diffracted and attenuated by the MSC facies and as such it is vitally important to achieve good penetration of lower frequencies. This could be achieved using a combination of a larger source array, MAZ or WAZ shooting configurations, increased streamer depth, or recording a fuller range of frequencies. CGGVeritas’s new BroadSeis solution is ideally suited to imaging below the MSC facies. It uses a unique variable depth streamer acquisition technique and proprietary de-ghosting and imaging technology to record over 5 octaves of signal bandwidth. This technique can record signal down to 2.5Hz providing better penetration of seismic energy and deep imaging.

References


