Seismic Geomorphology and Stratigraphy of the Provence Shelf since the Messinian Salinity Crisis (SE France)*

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Abstract

Outcrops in Provence have been exhaustively studied, however few studies focused on the marine geology and the possible offshore continuity of onshore structures. It is a complex geological domain situated between the Alpine arc and the continental margin of the Liguro-Provençal back-arc basin, which was also influenced by the high amplitude Neogene eustatic changes, especially during the Messinian Salinity Crisis (MSC).

The salinity crisis in the Mediterranean basin during the Messinian is considered as one of the most spectacular events on the marine environment since the beginning of the Neogene. During the Messinian, the reduced inflow of Atlantic Ocean water through the Betic and Rifian corridors combined to a high evaporation rate provoked a dramatic Mediterranean base level drop of at least 1,500m (Benson et al., 1991; Krijgsman et al., 1999; Jolivet et al., 2008).

Introduction

In South of France, most of the studies related to the MES and Plio-Quaternary deposits focused on the southwestern and central part of the Gulf of Lion margin (synthesis in Séranne, 1999 and Guennoc et al., 2000), and the Ligurian margin (Sage et al. 2011). The published maps of the MES on the Gulf of Lion margin (Gennesseaux and Lefebvre, 1980; Guennoc et al., 2000) evidence a buried Messinian drainage network comprising two main valley systems, the Rhône valley system to the northeast, and the Languedoc-Roussillon valley system to the southwest. Offshore Marseilles, bathymetric maps evidence deep canyons incising a narrow shelf break, the Cassidaigne and Planier Canyons, which do not extend to the present-day coastline. In addition, the impact of the Messinian eustatic event on the coastal hydrologic systems was never investigated in this area.

Geological Setting

Offshore Marseilles, the continental shelf morphology is narrow and relatively flat from the coast to the shelf-break, which is incised by deep canyons, the Cassidaigne and Planier Canyons, which do not extend to the present-day coastline. The Cassidaigne canyon is the largest one and consists of an up to 1,500 m deep and 20 km long incision, located 8 km south from the coast. It is oriented NNE-SSW in its upper part and direction move toward NW-SE in its lower part. Its abrupt edges are asymmetric and mainly controlled by the nature of the rocks subcropping on the margin during its formation.

Data and Method

To improve our knowledge on this key domain within the context of the characterization of coastal karst system, it is critical to integrate data from onshore geology and offshore seismics. A major asset of this study has been the acquisition since 2007 of high-resolution offshore seismic lines and shallow coring. The dataset used in this study includes marine seismic reflection 2D profiles, rock samples extracted from seabed and coastal outcrop data. Marine seismic data were acquired during 4 surveys using the R/V TETHYS II ship (Figure 1): MAST5913 (2007-2009), MARSOLIG (2008), CASSEIS (2009) and CASSEIS II (2011). The seismic grid covers more than 1800 km2 with a total survey length of 2740 km, a mean profile spacing of 1 km. Seismic profiles consists of 255 high resolution (HR) and very high resolution (VHR) sections with a recording length ranging from 0.2s to 2s Two-Way-Travel-Time (TWTT). In addition, older industrial and academic seismic surveys were integrated in this study: GL80 (TOTAL), RM84 (TOTAL), MARION (IFREMER), Me-Sea (IFREMER) and Carry (EOSYS). Paper seismic profiles from Leenhardt (1969) were used for geological interpretations but not integrated in the digital dataset. The present study integrates seabed rock sample descriptions published by Froget (1967, 1972, and 1974) and newly acquired samples collected with the CNEXO-VILLE ROCK CORER (BRGM) during the CASSEIS (2009) cruise.

Results

Based on the integration of a wide marine seismic database, sea-bottom cores and onland field studies, the present study aims at:

1) Providing a new geological map of the offshore Provence Continental margin
2) Providing a detailed map of the MES on the offshore Provence margin,
3) Assessing the role of the pre-Messinian structural framework on the Messinian canyon development,
4) Reconstructing the Messinian and Pliocene drainage network,
5) Estimating the role of the Messinian karstification on the present-day marine physiography.

A variety of seven seismo-facies has been interpreted in terms of stratigraphic and structural characteristics, sedimentary and diagenetic heterogeneities of the formations and rock properties measured on outcrop samples.

The lack of offshore wells in the studied area did not allow direct calibration of the seismic strata. The vicinity of coastal outcrops allowed a significant degree of stratigraphical and structural calibration of seismic data in complement to seabed rock sample analysis. The chrono-stratigraphic interpretation of the seismic unconformities and units are based on 1) the interpretation of seismic facies in terms of lithology and small-scale (meter to decameter-scale) heterogeneity distribution, 2) the comparison between the seismic stratigraphic patterns evidenced from profiles offshore and the regional stratigraphic architecture onshore and 3) dating of seabed rock samples located on seismic profiles.. Ages for seabed rock samples were obtained using benthic foraminiferal biostratigraphy or, when relevant microfossils were lacking, by lithologic and faciologic analogies with onshore regional outcrops.

Seismic interpretation of the whole dataset and core data allows a geological map of the Provence continental shelf to be realized. Main geological onshore structures prolong towards the continental shelf. In the Eastern Area, Hercynian basement, which outcrops at the Sicié Cape, prolongs westwards. It is limited on the North by the Bandol Canyon and structures its South flank. To the West, Hercynian basement is incised by the Cassidaigne Canyon and seems to prolong on the continental slope. Offshore Bandol, the slice thrusts prolongs to the Southwest. They structure the Northeast part of the Cassidaigne Canyon and are deeply incised by the Bandol Canyon, forming its Northern flank. Bandol canyon develops at the limit between Hercynian basement and Mesozoic Slice thrusts. In the Central Area, Mesozoic strata of the Beausset and Calanques units prolongs toward South and West and are transgressed by

Tertiary sediments which amply dominate the Western Area. The western head of Cassidaigne Canyon develops into the soft Aptian marls, displaying a bad-land erosive structure on this part of the canyon, whereas the eastern part is partially filled by the Plio-Quaternary deposits coming from the Bandol Canyon. Calanques faults systems continuity is evidenced from onshore to offshore with a NW-SE direction. This fault systems structure the area between the coastline and the head of the Cassidaigne canyon in horsts and grabens, with vertical offsets of hundreds of meters.

The depth map of the base Plio-Quaternary, in the East part of the Gulf of Lion, from the Nerthe massif to the Cap Sicié, build from seismic interpretation of the whole dataset shows various morphologies.

Close to the coast, the Provençal Margin MES morphology is flat, slowly dipping (0.8 to 1.2%) towards the offshore. The depths of the MES vary between 50 to 250 m, when it reaches 1000 m in the Gulf of Lion Messinian drainage network of the continental plate (Mistral exploratory well; Lofi et al., 2003), indicating that the Messinian topography is not affected by the typical fluvial erosive processes.

To the south of Cassis, the MES is deeply incised by the Cassidaigne canyon displaying a different morphology during the Messinian. The originality of the Messinian Cassidaigne Canyon is that an incised and sedimentary filled valley is connected to its head on its eastern margin. This valley-like incision, (which called “Bandol Canyon”) is 20 km long with a depth increasing from 150 to 700 m westwards, resulting in 2.75 % slope towards the present day Cassidaigne canyon. An additional, less extensive, incision with an E-W direction is present close to the coast on the North side of the Bandol Canyon. Its depth varies from 350 m to 550 m. During the Pliocene, it was totally filled with progradant to aggradant marine sedimentation. Cassidaigne canyon, which is deeper and still erosive downstream, is only partially filled by turbiditic deposits coming from the Bandol Canyon.

Conclusion

This shelf cartography allows a better understanding of the geometry of Bandol and Cassidaigne Canyons. Strong lithologic and structural controls permit incision to be realized on a place affected by strong tectonics between geological units characterized by different rock hardness. Such results imply new considerations for the tectonic, stratigraphic and hydrographic framework of the Provence area.

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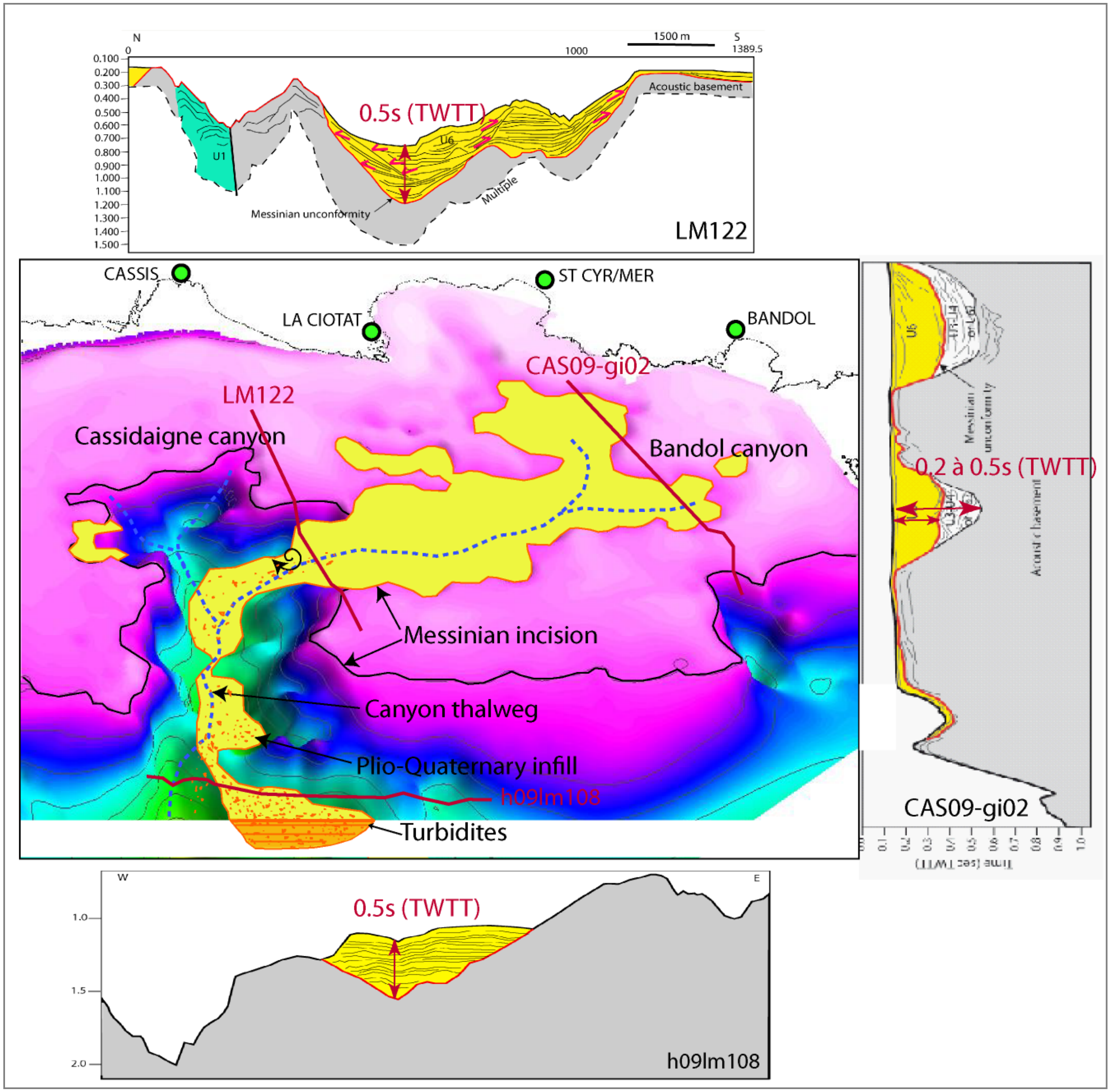

Figure 1. 3D view of Pliocene-Quaternary canyon fill in the Bandol and Cassidaigne canyons and line drawing of seismic profiles (CASSEIS cruise).