2D and 3D Modeling of the Stratigraphic Sequences at the Adriatic and Rhone Continental Margins

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LONG-TERM GOALS

My goal within the EuroSTRATAFORM program is to understand the creation of the preserved stratigraphic record on continental shelves and slopes as the product of physical processes acting with spatial and temporal heterogeneities. I have been using numerical models to provide insight into the formation and preservation of stratigraphic sequences at margins. My goal has been to obtain a quantitative understanding of the interactions of environmental parameters and their influence on stratal architecture and facies distribution. I wish to be able decipher the stratigraphy on margins to read the geologic record of the past and predict future stratigraphy.

OBJECTIVES

EuroSTRATAFORM is an opportunity to extend stratigraphic model applicability to new margins and to expand the capabilities of our products. The Rhône and Adriatic margins are similar to the earlier field areas in that they are mid-latitude clastic margins, but the stratigraphy is highly affected by the 3D geometry of the basins. The forcing provided by these boundary conditions provide a challenge, but are also necessary for modeling realistic systems. My aim is to quantitatively determine the system response of margins to different forcing functions sufficiently to be able to both predict stratigraphy and invert observed sequence architecture for geologic history.

APPROACH

I have used numerical models as a tool to provide insight into the formation and preservation of stratigraphic sequences at continental margins. To study these margins I will apply a multi-pronged approach. Together with Italian and French colleagues, I have been modifying and apply our existing 2D stratigraphic models to serial sections of the two EuroSTRATAFORM margins. This will test the portability of the models. It will also aid in evaluating the relative along- and across-strike transport and tectonics, and their influences on sequence architecture. John Swenson, with assistance from Chris Paola, Juan Fedele, myself and others have jointly developed a 3-D sequence stratigraphic model. Together, we will extend our time-averaged, moving-boundary model for continental-margin sedimentation with its coupling of multiple transport regimes from 2-D to 3-D. The advantage of this modeling approach is that it allows for a systematic exploration of the margin's response to variations in sea level, sediment supply, tectonic subsidence, and wave climate over longer timescales. I am providing flexural component and parameterizations for the field areas. I will also make use of 3D flexural modeling and backstripping being done for a separate project on the Gulf of Lion to recover

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estimates of tectonic subsidence and/or initial morphologies of paleosurfaces that are necessary for the forward modeling.

WORK COMPLETED

The 2D model developed during STRATAFORM (Steckler, 1999; Steckler et al., 2001) has been modified in order to apply it to the Adriatic field area. The primary changes have been to include along-strike transport of offshore sediments and improvements in variations of the sediment flux with sea level. Additional changes were added this year to improve the flexibility of modifying the sediment input, sea level control and tectonics have been added to more easily complete the modeling of multiple profiles. The 2D modeling is focusing on the Gargano Peninsula region where a succession of four depositional sequences (e.g., Fig. 1) mainly composed of regressive deposits have been mapped by Ridente and Trincardi (2002). Together, we have chosen a series of 10 seismic profiles along the Gargano structure for modeling (Fig. 1). We started with one of the northernmost profiles, which is relatively unaffected by the tectonics of the peninsula and are in the process of sequentially modeling the lines towards the south.

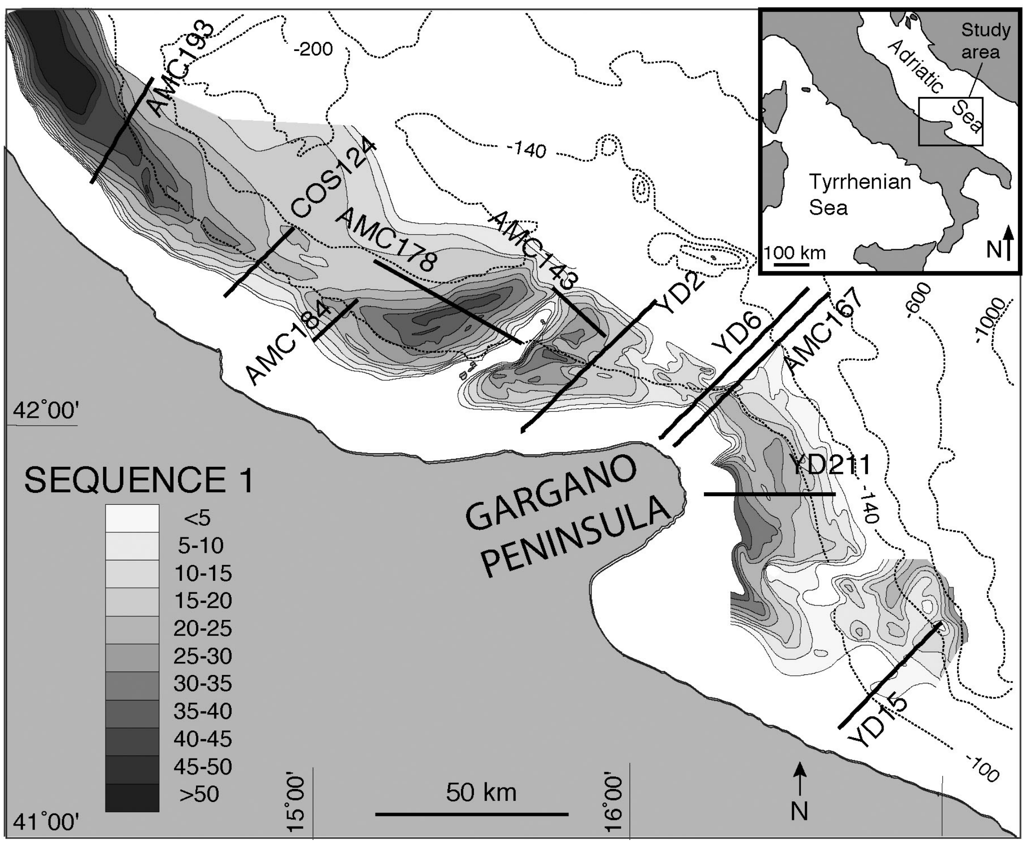

Figure 1. Map of the Gargano Peninsula region with bathymetric contours. The thickness of Sequence 1 is indicated by shades of gray. Heavy lines indicate the positions of the 10 seismic profiles selected for modeling. An inset map shows the position of the Gargano Peninsula region along the Adriatic coast of Italy.

Led by John Swenson, a 3D stratigraphic model has been developed (Swenson, 2003; Swenson et al., 2003). I am working on completing a 3D variable rigidity flexure module (Graindorge et al., 2004) to be incorporated into the code. The model has been adapted to perform simplified simulations of the Adriatic Sea using parameterizations that I provided.

A new parameterization of fluvial dynamics, which includes channel belt and overbank deposition, has been developed by Juan Fedele and Chris Paola of the University of Minnesota. This provides an improved estimation of the sand/mud ration and thus the mean grain size for non-marine strata. This model has been incorporated into the multigrain-size version of SEQUENCE.

RESULTS

A model was developed that reproduces the main features of the sequences north of the Gargano Peninsula using line COS124 (Fig. 2; Steckler et al., accepted). This model is being used as a basis for modeling the sections farther south that have been affected by the tectonics around the Gargano Peninsula. In the profiles, sequences are composed primarily of regressive deposits separated by regional unconformities (Ridente and Trincardi, 2002). The geometry of the units is such that the regressive clinoforms flatten out at their seaward termination into relatively planar strata (Fig. 2). Attempts to simulate the sequences were frustrated by the lack of thinning of the sequences seaward of the clinoform rollovers. Instead, the clinoforms flatten in the latter stages of each sequence. This contrasts with the development of clinoforms and a depositional shelf break that is characteristic result of most conceptual and numerical models of sequences. We therefore modified the sequence model to account for the dramatic changes in sediment pathways that happen with sea level fluctuations in the shallow northern Adriatic Sea. During times with high sea level, such as the present, sediment from the Po and smaller Apennine Rivers are transported southwards along the coast by marine coastal currents and storms (Cattaneo et al., 2003). At times of low sea level, fluvial transport of an enlarged Po River, in which the Apennine Rivers are captured as tributaries, discharges directly into the MAD basin. This produces a reciprocal sediment supply pattern where the coastal supply at high sea level produces prograding clinoforms, but their supply cuts off as the exposure of the northern shelf at low sea level switches supply to the fluvial system, which discharges into the 260-m deep MAD. In the model, the clinoforms flatten as nearshore sediment supply decreases and is replaced by the deposition in the MAD during sea level low stands. The inclusion of these changes in sediment supply along the profile as a function of sea level enabled us to obtain a good fit to the overall stratigraphic architecture.

The northernmost profile, AMC193, the youngest sequence does not display the flattening of the clinoforms seen farther south. It has a foreset angle of 1.5°, triple that of older sequences. We interpret this increase as due to additional sediment added to the system during lowstand because of the progradation southwards of the shallow Adriatic shelf. Thus the lower sequences can be modeled similar to COS124, with a cutoff in coastal sediment supply with sea level fall, but the most recent requires the large sediments supply of the lowstand Po system.

Additional sediment pathway effects during sea level cycles affect the sections farther south due to the presence of structural highs such as the Tremiti Ridge. Beyond the Mid-Adriatic deep, the basinal source of sediments is cut off by the Gargano-Biokova high. South of the Gargano, progradation towards the deeper southern Adriatic basin increases the slope of the clinoforms, while subsidence increases sediment thickness. Another consequence of the sediment rate changes was that the decreasing flux during sea level falls aids erosion of the previous transgressive deposits. Finally, the model required uplift increasing towards land similar to estimates reported in the literature (e.g., Mastronuzzi and Sansò, 2002; Ferrante and Oldow, 2005, in press). All of these factors contribute to the variability of the stratigraphy between sections that are being accounted for by the numerical model. I have also assisted John Swenson in creating a three-dimensional model of the Adriatic Sea. In the model, current sweep the sediments along the Italian coast during highstand but the shoreline crosses the Adriatic perpendicularly during lowstand

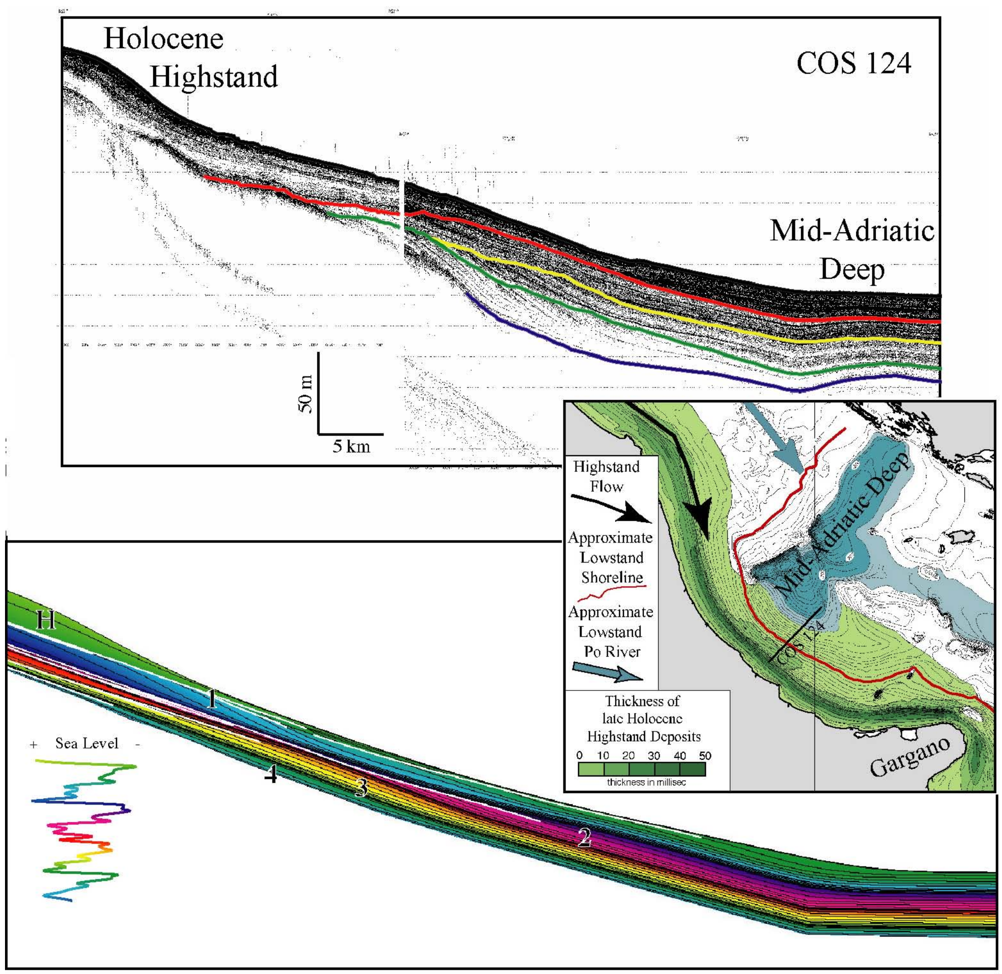

Figure 2. The top shows a seismic section from the central Adriatic, located on map in center right. Horizontal scale is in kilometers, vertical in meters. The sequence boundaries separating the four depositional units representing the last four 100 Ky sea level cycles are marked by colored lines. Below is a simulation of the section at the same scale. It is colored acording the the age of the deposits (indicated on sea level curve in lower left). Unconformities are shown as white lines. The stratigraphy is composed of four regressive sequences, labeled 1-4, capped by Holocene transgressive deposits labeled H. The model fits the main features of the section and the geometry of the strata, namely the flattening of the clinoforms into parallel bedded strata at the seawards end of the profile. A critical part of matching the depositional patterns is reciprocal sedimentation pattern caused by the sediment source switching from the coastal system to the MAD.

A problem with models of fluvial deposition has been integrating the different dynamics of channels and floodplains for a spatially-averaged cross-section. The new model of fluvial deposition predicts the avulsion frequency of channel belts. In river systems, preserved channel belts are primarily sand, while the overbank deposits are primarily muddy. Avulsions shift the channel belt, cutting into previously deposited overbank deposits with the result that the higher the avulsion frequency, the greater the average percentage of sand that preserved in the resulting strata. The avulsion frequency, among other things, depends upon the relative mean deposition rates in the channel and overbank regions, the inventory of sand and mud in the fluvial system, subsidence rates, and sea level change. The numerical stratigraphic model can readily track all of these factors and calculate their variation both downstream and through time. An additional result is an estimate of the channel density in the preserved strata. Figure 3 shows an example of the fluvial section of a model run. The most prominent feature is the prediction of a sandy basal above the sequence boundary, a feature common in outcrop and coreholes. In addition, subtler variations in grain size with fining down dip and at maximum sea level rise are predicted, again features consistent with field observation indicating the promise of this new model. This year corrections to the model were made to improve its reliability and accuracy.

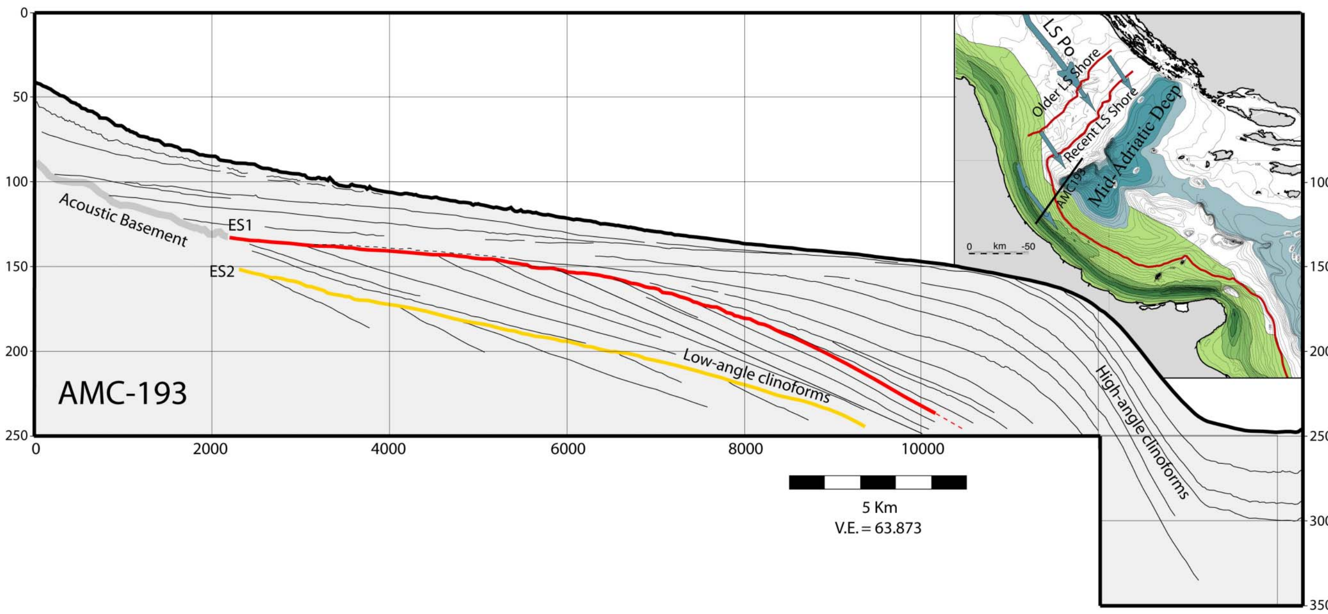

Figure 2. Line drawing of Chirp seismic line AMC-193 in the Adriatic Sea offshore from Pescara. Horizontal scale is in kilometers, vertical in meters. Red and Yellow surfaces are sequence boundaries corresponding to lowstands of last two 100ka glacial cycles. Strata below them are are composed of low-angle (~0.5°) regressive clinoforms similar to sediment package on other profiles farther south. The strata above the last lowstand increases in dip to ~1.5° under the influence of the encroaching Adriatic shelf. The Inset map shows that sediment carried by the Lowstand (LS) Po river system prograded the shallow northern shelf of the Adriatic towards the profile, increasing the sediment suppply and the clinoform dip.

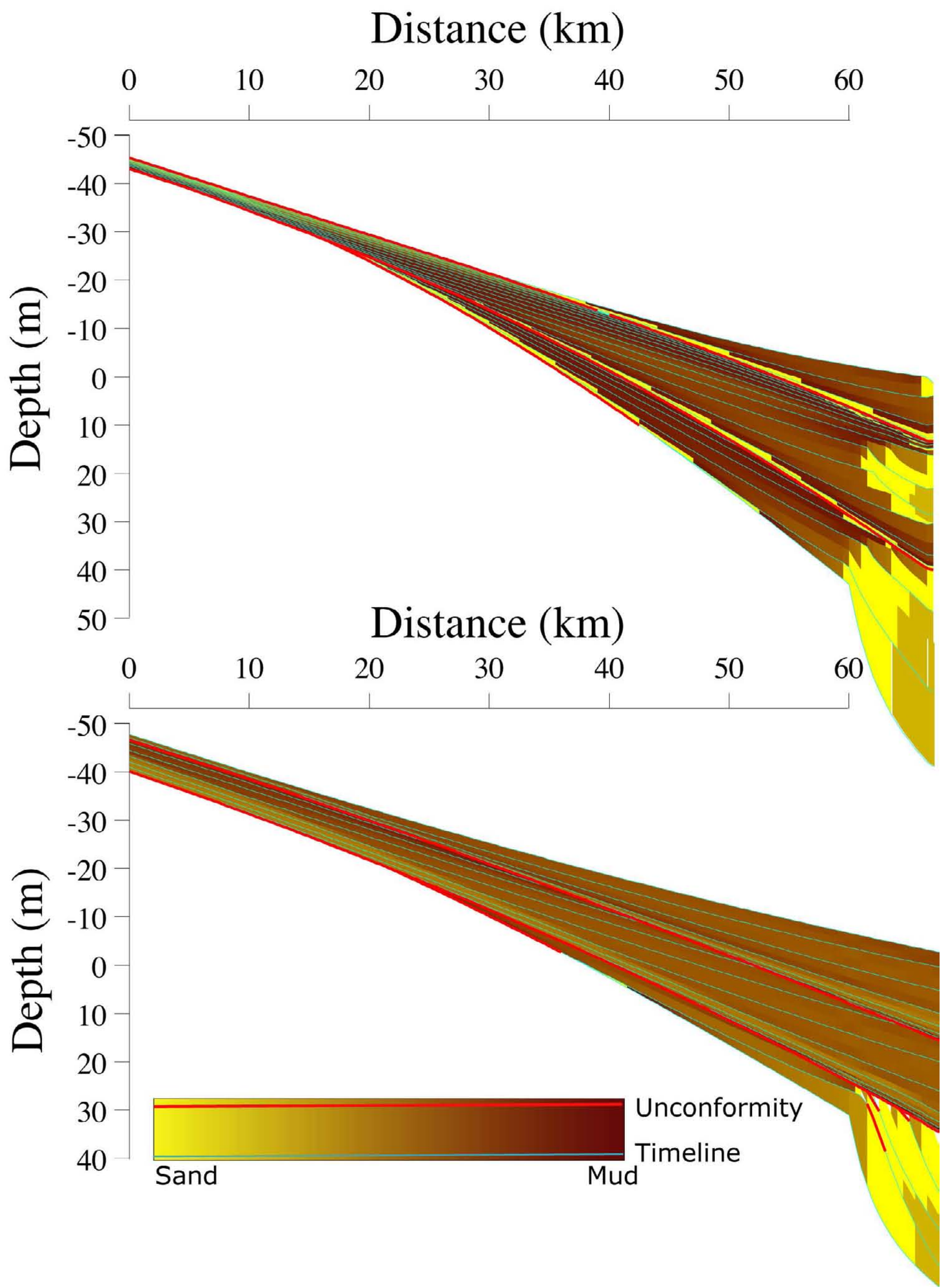

Figure 3. Two cross-section of coastal plains from numerical model colored to show lithology. Horizontal scale is in kilometers, vertical in meters. The sections show timelines in blue and unconformities in red. The two sections are from almost identical models with the difference being that in the bottom model 95% sediment was suppied from land on the left-hand side of the model. In the top model, only 25% was from land and the rest from the coastal jet. Thus the total sediment supply to the model is the same, but the sedument supply to the coastal plain is quite different. The top model develops a coarse transgressive lag absent in the bottom model, although the bottom model is sandier above the sequence boundary. The top model is muddier overall but with larger variations in mean grain size.

IMPACT/APPLICATIONS

Sediment supply is commonly assumed to increase during sea level falls, when a larger area is subareally exposed, and decrease during sea level rises, as surface area is flooded and sediments trapped in estuaries. Along the Adriatic coast, we find the opposite effect occurs due changes in sediment pathways associated with sea level fluctuations. Furthermore, the modeling the sections shows the sediment pathways change with time as a result of deposition and tectonics. The primary sediment supply pattern found along the Gargano Peninsula, with alternating transport patterns for different sea levels, may be common along margins other partially-filled foreland basins. At foreland basins, such as the Tigris-Euphrates-Persian Gulf system, sediment transport often has a large along-strike component. It may also occur at margins where rivers discharge directly into canyon systems during lowstands such as both the Rhone and Eel River margins. The new fluvial model holds the promise of better prediction of lithology and channel parameters in non-marine strata such as those that underlie many continental shelves.

RELATED PROJECTS

I have been funded by NSF to undertake a 3D backstripping reconstruction of the Gulf of Lions continental margin (Steckler et al., 2003). During the Messinian Salinity Crisis (5.96-5.32 Ma), the Mediterranean was cut off from the world ocean and desiccated. As a result the Gulf of Lions continental was heavily eroded and the margin morphology reduced to a heavily incised seaward dipping ramp (Guennoc et al., 2000). Following the flooding at the end of the Messinian, the margin rebuilt to its present shelf-break morphology. The 60-100 km of progradation during the Plio-Pleistocene provides a stratigraphic record of the establishment and regrowth of the margin (Lofi et al., 2003, in press; Steckler et al., 2004). The 2D reconstructions completed can provide reconstructions of the morphology of the margin for time slices of interest to EuroSTRATAFORM and other efforts (Rabineau, 2004), as will the 3D reconstructions when done. The project also involves Greg Mountain and Bill Ryan at Lamont, and Serge Berné of IFREMER Marina Rabineau of IUEM, David Graindorge of the University of Brest and Christian Gorini of USTL from France. A new variable-rigidity 3D flexure code has nearly been completed for this project (Graindorge et al., 2004). It will be adapted for use in the 3D stratigraphic model.

Umberto Fracassi of the Istituto Nazionale di Geofisica e Vulcanologia (INGV) studies the tectonics of southern Italy, including the Gargano Peninsula. He finds that Apulia is being deformed by right-lateral strike-slip motion along E-W faults (Fracassi et al., 2004). The seismic data of Fabio Trincardi and Dominico Ridente that I am using has primarily been analyzed for stratigraphic research, but also contains a record of the tectonic deformation offshore. We are now starting to develop a collaboration to add more tectonic analysis to the seismic data around the Gargano.

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