Drilling objectives for the Corinth Rift Interdisciplinary Laboratory (western Greece)

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Abstract

The recent age (slightly more than 1 My) of the Corinth Rift in western central Greece, and its rapid extension rate has been linked by some to changes in velocity of the Hellenic slab roll back, while others relate it to the progression of the North Anatolian fault, or possibly to both. Further, some others relate the uplift rate observed on the southern shore with crustal response to fast erosion.

The intense seismic activity observed in the western section of the rift has been interpreted by some as the occurrence of a decollement zone while some others consider this activity to be connected with deep fluid migration. Similarly, the creeping activity of some faults is still uncertain and its consequences for earthquake mitigation is a source of debate.

Further, because of the fast sedimentation rate, the rift is an ideal site for investigating the stability of soft sediments under dynamic loads, but also to sample continuously recent climate changes through their sedimentary signature.

Some of the ongoing debate raised by these various results could be efficiently solved by drilling projects meant either to core critical zones , to provide continuous logs of needed physical data (in particular temperature), or to install permanent equipment for monitoring fluid fluxes and creep.

The object of this white paper is to propose to organize a joint ICDP-IODP workshop to evaluate the present state of knowledge in the various disciplines and to define a coordinated course of action for this unique interdisciplinary in situ laboratory.

1. **Introduction : The Corinth Rift**

The Corinth Rift, in western central Greece, is one of the fastest continental rift in the world (e.g. McKenzie, 1978; Le Pichon et al., 1995) and one of the most seismic regions in Europe with more than four earthquakes with magnitude larger than 6 during the last thirty years. The Rift is about 110 km long, oriented in the N110°W direction and separates Peloponnesus from continental Greece. This structure is the site of up to 1.5 cm.y^{-1} north south extension in its western section (e.g., Clarke et al., 1998; Avallone et al., 2004) and uplifts of the southern shore that reaches 1 mm.y^{-1} in its south-eastern section (Armijo et al., 1996). Its depth reaches 800 m below sea level for distances longer than 40 km in its eastern section while it is only 60 m deep at its western Rio-Antirio extremity . It is slightly older than 1 My and the fast sedimentation rate that has been active over the years oscillates from lacustrine to marine depending on the fluctuation of the sea level (Perissoratis et al; 2000). Frequent slope failures have been documented in these soft sediments (Lykoussis et al., 2008).

The Rift has been the site of extensive investigations over the last twenty years, and more especially for the last ten years. We address here after some of the recent results that have been obtained and new questions that have been raised. They fall in different working groups' interest and drilling activity in this area, both onshore and offshore, would benefit a broad community. A workshop addressing these various facets is necessary for coordinating efforts undertaken by the various concerned communities.

2. A laboratory for better understanding rift-margin development (WG2.5)

The compilation of GPS data over the Anatolian plate (McClusky et al.,2000) demonstrates an acceleration of extension from east to west, with no clear plate boundary in the so called Central Hellenic Shear Zone (CHSZ) that extends between the western termination of the North Anatolian Fault and the Hellenic subduction zone.

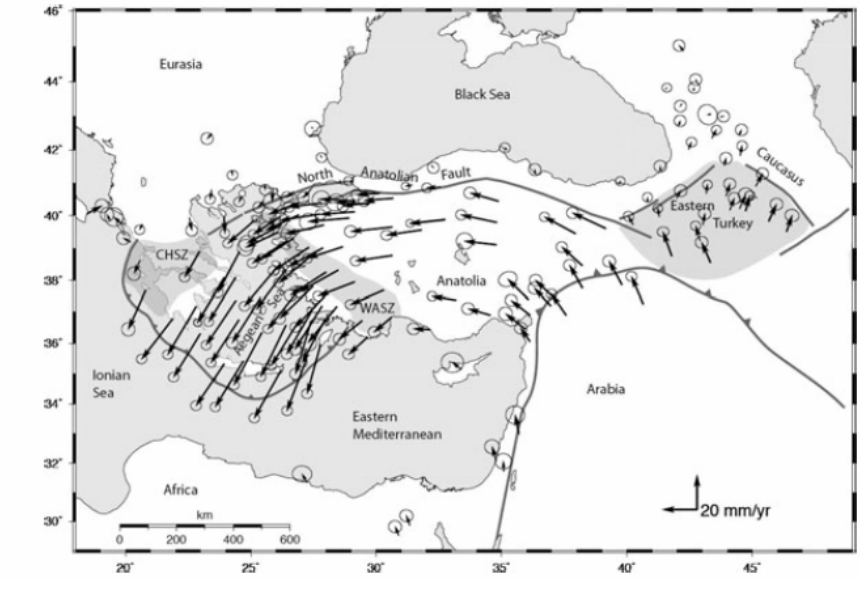

Fig. 1 : GPS velocities of the Aegean region and Turkey with respect to Eurasia (from McClusky et al., 2000, as cited by Suckale et al., 2009). The Hatched zone marked CHSZ to the west refers to the Central Hellenic Shear Zone that includes the Corinth Rift Zone.

Within The Central Helenic Shear Zone, deformation localizes strongly within the Gulf of Corinth (Clarke et al., 1998; Avalonne et al.2004) where a set of offshore and onshore faults accommodate most of the observed deformation (Bell et al., 2009).

Recent work by Suckale et al. (2009) has characterized well the geometry of the subducting slab below the Corinth Rift and has confirmed the proposition by Royden (1993) on the influence of the slab "Roll Back" on regional tectonics. It also documented very efficiently the tearing of the slab in its western domain with its relation to the Kefalonia Transform Fault, west of the Ionian islands. Additional effects from the North Anatolian Fault extension (Armijo et al., 1996) and from erosion effects (Westaway, 2006) have also been proposed to explain observed uplift rates.

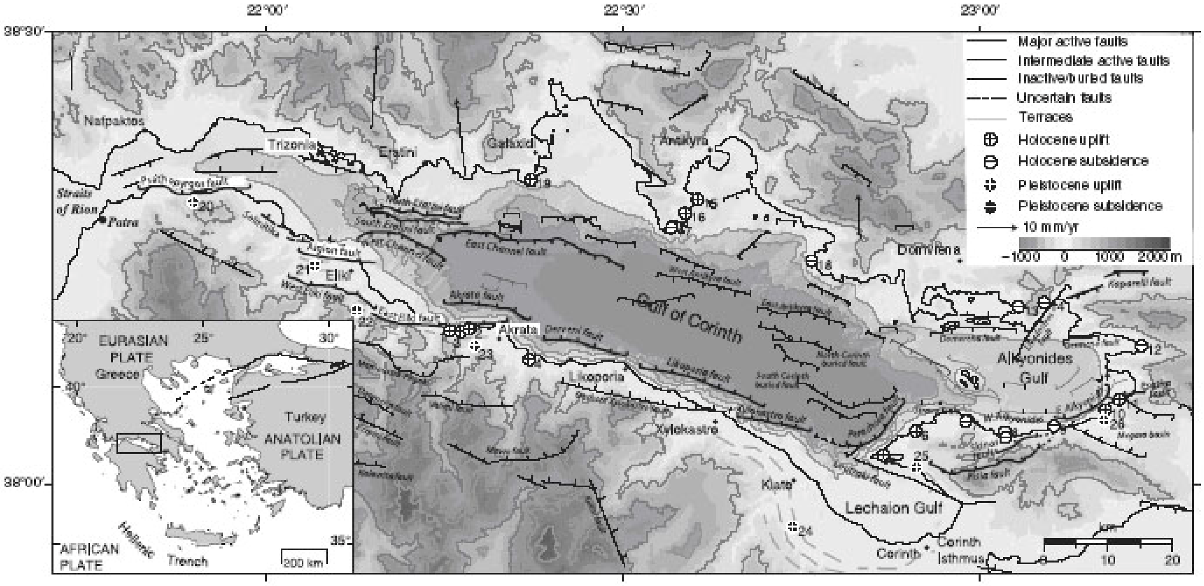

Fig. 2 : The Corinth Rift Zone (from Bell et al., 2009) with its onshore and offshore outcropping normal faults.

A complete 3D model remains to be developed provided additional constraining data may be obtained. Historical erosion rates from sedimentation rates as well as precise thermal profiles for the regional area would help constrain such models. Both quantities are retrievable from an appropriate drilling program in the soft sediments pile that fills up the rift central zone. This drilling program will be designed after taking advantage of the extensive seismic profiles collected by Taylor (2001, unpublished).

The sismicity shows a strong asymmetry within the Rift (Bourouis and Cornet, 2009), with occasional magnitude seven earthquakes on steeply dipping normal faults in the eastern part of the rift but sub continuous small magnitude activity on an apparently shallow dipping seismogenic zone in the western part near Aigion. The shallow dip of the source of the 1995 M6.2 Aigion earthquake (Bernard et al., 1997) together with preliminary results from the geometry of seismogenic sources as determined by careful events relocation (Rietbock et al., 1996), prompted a few authors to propose the existence of a shallow decollement zone in the western part of the Rift (Briole et al., 2000; Bernard et al., 2006).

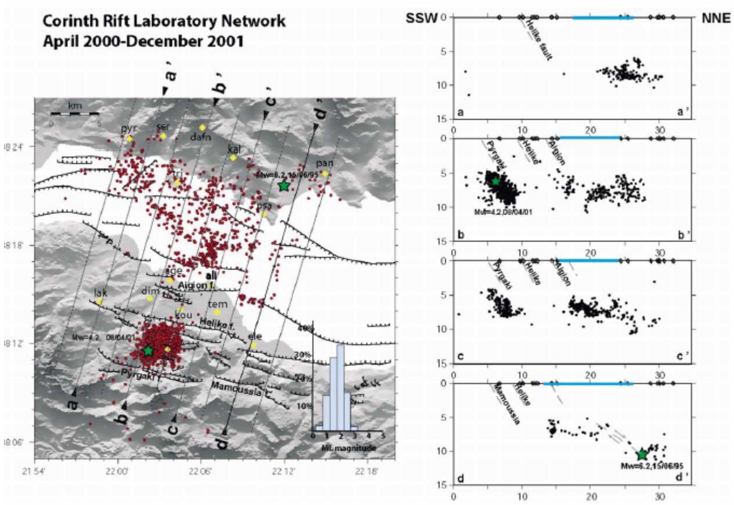

Figure 3. The shallow northerly dipping seismogenic zone of the western Corinth Rift (after Lyon-Caen et al., 2004)

However, numerical modelling (Cianetti et al., 2008) has shown that a simple elasto-plastic model that includes observed steeply dipping normal faults may fit accurately observed deformation rates and location of seismicity provided an active north dipping offshore fault exists north of Aigion.

Further, Bourouis and Cornet (2009) have showed that the observed shallow dipping seismogenic zone exists only near Aigion and results in fact from a complex faulting pattern that includes both steeply dipping normal faults (with at least two different azimuths), and shallow dipping slip surfaces activated by short fluid bursts resulting from dynamic effects associated with contractant plasticity. The localization of this seismic activity would be linked to fluid fluxes from deeper origin, hypothetically linked with the subducting plate.

Deep drilling through the active Aigion Fault between 3 and 4 km for fluid sampling and high frequency seismic monitoring would bring unique data on pressure transients to ascertain these models as discussed in the next section. It would in addition constrain efficiently the thermal profile at depth, an important datum for identifying a realistic plastic rule in the lower crust..

3. A laboratory for deep fluid flow investigations (WG4.4)

Bourouis and Cornet (2009) showed that the number of microseismic events near Aigion is unusually high while the corresponding total radiated seismic energy is somewhat comparable to that generated in the eastern section of the rift.

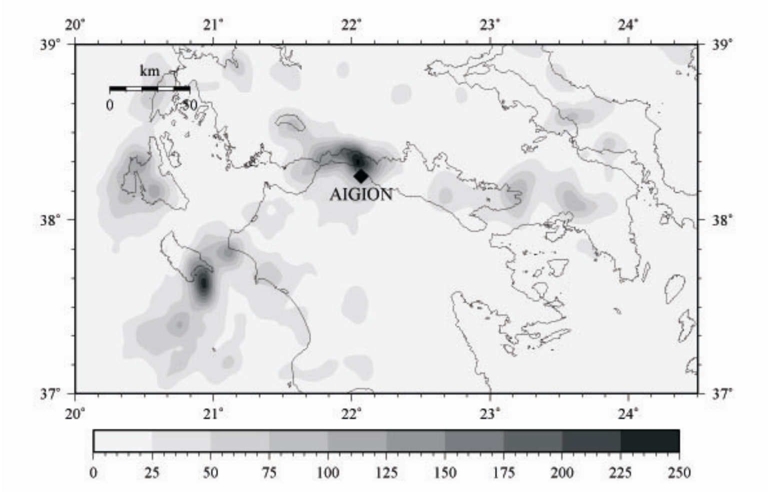

Figure 4. Number of microseismic events recorded with the National Greek network for the period 1970-2007 (NOA catalogue). All events with magnitude larger than 2.5 are detected (after Bourouis and Cornet, 2009). The number of events has been counted within squares with 7 km long sides.

They have argued that this intense activity is associated with fluid diffusion, some of which flows downward because of topography effects caused by the high mountain range, but some of which flows occasionally upward from sources deeper than 10 km. The origin of the deep fluid is yet unknown and has been proposed hypothetically to be linked possibly somehow to the subducting plate. Understanding better these occasional deep fluid fluxes has been proposed as target for a 3 to 4 km deep borehole intersecting the Aigion fault

Indeed, identification of fluids circulating through the faults by analysis of the calcite deposits in the cataclastic zone as well as isotopic analysis of carbonates in the fault gauge (Labaume et al., 2004; Koukouvelas and Papoulis, 2009) have demonstrated recurrent upflow of fluid at temperatures in the 80-100° C, i.e. fluids from about 3 km depths. However, analysis of Helium isotopic content has led Pick and Marty (2009) to demonstrate that no fluid of mantle origin reaches ground surface.

It may be proposed that the strong downgoing flux caused by the mountain range of the south shore prevents the fluid of mantellic origin to reach the surface but that the wellknown seismic pumping mechanism let water from 2 to 3 km depths reach the surface. Collecting fault gouge at depths in the 3 to 4 km range may help elucidate the nature of the fluid that is present around 6 to 8 km.

The role of faulting on fluid circulations in the 3 km thick alpine nappe pile has been well documented for the interaction between the Aigion fault and the Gavrovo Tripoliza carbonate nappe, in particular through its thermal signature (Doan and Cornet, 2007). It has been shown to be related to karsts likely developed during the Messinian sea level drop. Checking whether the same occurs for the offshore normal faults may help better understand fluid circulations down to depth of the order of 3 km below the rift floor, an important feature for thermal profiles. For this purpose it is proposed to drill through the offshore Derveni Fault for investigating the existence of possible karsts in the footwall.

4. A laboratory for seismic risk mitigation (WG5.1)

The high frequency seismic equipment that was deployed in the 1000 m deep AIG10 well that intersects the Aigion Fault around 760 m has demonstrated the existence of a sub continuous high frequency activity in the upper part of the fault (Cornet et al., 2009), when previous publications (Briole et al., 2000; Bernard et al., 2006) had suggested that the fault was stuck in its upper section. Further, the fault has been shown to sustain no shear stress in its upper km (Sulem, 2007). Hence it seems that the Aigion Fault is sub continuously creeping in its upper portion and becomes progressively seismogenic with depth.

But a very different fault mechanics seems to be at work in the eastern part of the rift where only occasional seismic activity is documented. In particular, Bourouis and Cornet (2009) have shown that no seismic energy has been radiated near the offshore Derveni Fault for the last 40 years.

Given the past experience with foreshocks in normal faulting regimes, in particular during the last Aquilla earthquake in Italy, installing high frequency monitoring equipment in a borehole intersecting the Derveni Fault would help confirm the absence of present creep in the upper part of the fault and may provide extremely helpful premonitory signs of motion in case of an impending earthquake.

5. A laboratory for offshore landslide monitoring (WG5.2)

The fast sedimentation rate observed in the rift leads to two kinds of slope stability issues (Lykoussis et al., 2008).

- Sediment failure on the very low angle (05° to 2°) prodelta slopes where gas content plays a very active role,
- Instabilities on the delta fans with slopes reaching 6 °.

The role of horizontal acceleration associated with local and distant earthquakes is different for both systems and an accurate monitoring of these instabilities, with particular attention to short term and long term pore pressure variations would help better constrain these models and their consequences for tsunami generation.

It is proposed to deploy continuous monitoring equipment in shallow boreholes drilled in soft sediments for better documenting these slopes instabilities issues.

6. A laboratory for investigating rapid climatic events (WG3.1)

The International Continental Drilling Program (ICDP) devotes a large part of its budget to continuously coring recent lake deposits for better documenting recent climate changes. Clearly, the alternate lacustrine and marine sedimentary sequences that makes up the more than 1 my old sedimentary sequence of the rift (Perissoratis et al., 2000) would provide unique material for documenting rapid climate changes over the same period.

7. An in-situ laboratory for testing new offshore observatories equipment (WG6.2)

Creep monitoring through direct displacement measurements is extremely difficult at depth, in particular because of coupling difficulties. Results from the AIG10 borehole have demonstrated that monitoring high frequency (up to 1000 Hz) acoustic activity provides means to monitor very small-scale ruptures associated with changes of effective stresses possibly linked with slow creeping rates. Hence passive acoustic monitoring offers interesting perspectives for monitoring slow creep.

Similarly, very high frequency active signals (mhz) may be used to detect changes in borehole geometry, in a manner somewhat similar to borehole televiewer, except that in this instance the sensors would be fixed. Accuracy in the micron range is attainable.

But both techniques require significant downhole automatic processing because of difficulty in transmitting and/or storing the huge volume of data involved. This has been rendered accessible today through recent developments in solid-state electronics.

Because of the fast deformation rates observed locally in the Corinth rift, this site provides a unique opportunity to investigate the real possibilities of this new technology and to calibrate its accuracy by comparison with complementary onshore data.

8. Conclusion : An IODP-ICDP workshop

The Corinth rift is a very young structure which offers unique possibilities for better understanding the development of margins after rifting. It is a unique place for investigating fluid-fault interactions and its consequences on creep and on the seismic engine. Because of the high sedimentation rate, it may provide unique data on recent climate changes, but also on soft sediment stability.

Many data have been already acquired and are progressively made available to the community at large. It is necessary today to discuss how to insure a proper accessibility of existing data and to identify needs for additional data collection.

The time has come for an interdisciplinary ICDP-IODP workshop for discussing these various issues and the future of this unique multifaceted natural laboratory.

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