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Subsidence monitoring network: an Italian example aimed at a sustainable hydrocarbon E&P activity

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Abstract. According to the Italian law in order to start-up any new hydrocarbon exploitation activity, an Environmental Impact Assessment study has to be presented, including a monitoring plan, addressed to foresee, measure and analyze in real time any possible impact of the project on the coastal areas and on those ones in the close inland located.

The occurrence of subsidence, that could partly be related to hydrocarbon production, both on-shore and off-shore, can generate great concern in those areas where its occurrence may have impacts on the local environment.

ENI, following the international scientific community recommendations on the matter, since the beginning of 90's years, implemented a cutting-edge monitoring network, with the aim to prevent, mitigate and control geodynamics phenomena generated in the activity areas, with a particular attention to conservation and protection of environmental and territorial equilibrium, taking care of what is known as "sustainable development".

The current ENI implemented monitoring surveys can be divided as:

- Shallow monitoring: spirit levelling surveys, continuous GPS surveys in permanent stations, SAR surveys, assestimeter subsurface compaction monitoring, ground water level monitoring, LiDAR surveys, bathymetrical surveys.
- Deep monitoring: reservoir deep compaction trough radioactive markers, reservoir static (bottom hole) pressure monitoring.

All the information, gathered through the monitoring network, allow:

1. to verify if the produced subsidence is evolving accordingly with the simulated forecast.
2. to provide data to revise and adjust the prediction compaction models
3. to put in place the remedial actions if the impact exceeds the threshold magnitude originally agreed among the involved parties.

ENI monitoring plan to measure and monitor the subsidence process, during field production and also after the field closure, is therefore intended to support a sustainable field development and an acceptable exploitation programme in which the actual risk connected with the field production is evaluated in advance, shared and agreed among all the involved subjects: oil company, stakeholders and local community (with interests in the affected area).

1 Introduction

A large part of ENI extraction activities in Italy is located in the central-northern Adriatic offshore, this area being characterised by shallow water depth and by a naturally subsiding sedimentary basin (Teatini et al., 2005). The coast is characterized by the presence of lagoons, deltaic areas and marshes with the average lands elevation around 2 m a.m.s.l. and some areas even below, up to −5 m. Most of the domestic offshore ENI exploited fields are located in this environmentally sensitive area, at a variable distance from the coastal line ranging from 3 km up to over 50 km. In this situation the risk of subsidence propagation toward the coast, especially for the field located closer to the shoreline, has to be carefully managed.

ENI, as any other Oil Company operating in Italy, to carry out its hydrocarbon extraction activities and in particular before starting any oil or gas production, especially for the offshore fields located in the central-northern Adriatic sea, is obliged, by authorities, to define a monitoring plan able to foresee, measure and analyse any possible impact, direct or indirect, of the production project on the coastal areas and on those ones in the close inland located.

Therefore ENI with the aim of a sustainable development of its activities and to safeguard the integrity of a territory, characterised by the presence of a high number of very important naturalistic and artistic sites some of which with unique features as Venice and Ravenna, implemented, since 90's years, a cutting edge geodynamics monitoring network. For its design the recommendations set out and presented to the *Seventh International Symposium on Land Subsidence* in Shanghai (Gambolati et al., 2005) have been largely followed. The network has been implemented, during the years, with innovative technologies in order to ensure an accurate understanding of the altimetrical variation of the land surface in every components of the movement with high resolution (sub-centimetric resolution in z component).

Inside the Company dedicated departments have been set up with the mission to prevent, mitigate and control all the geodynamic territory phenomena, with particular attention to the protection of the territorial and environmental equilibrium.

In the ENI subsidence prediction and control programme three are the main intervention steps followed:

- Subsidence prediction, in the phenomenon interested area, through the use of numerical Finite Element models
- Design of a monitoring plan
- Prevention of the anthropic subsidence expected or mitigation of the subsidence recorded during hydrocarbon production.

The information gathered through the monitoring network allow:

- To rapidly and continuously ascertain if subsidence phenomena are evolving according to initial forecast and if necessary to put in action all the remedial activities to mitigate subsidence effects to safeguard the territory's environment and economy.
- To provide data for the periodical calibration of the numerical forward models for subsidence prevision and control, according to the following sequence:
  - Monitoring → check → model calibration

2 The geodynamic monitoring network

Geodynamic monitoring showed in the last decade a very high technological improvement that allows nowadays to define, together with the reservoir developing program, an effective monitoring plan of the environmental effects due to subsidence.

In particular the following measurements are regularly acquired:

- Formation pressure both in the gas bearing layers and aquifer
- Gas bearing layers deep compaction
- Ground vertical displacements (subsidence/rebound)

To distinguish between anthropic subsidence induced by hydrocarbon extraction and natural subsidence and/or due to fresh water withdrawal from shallow aquifers, the measurements of soil vertical displacements are performed on a larger area than reservoir dimension and the shallow compaction of layers subjected to fresh water extraction it is also measured.

The beginning of the monitoring phase always starts before the hydrocarbon production, it continues during the reservoir production life and it is extended for several years (roughly between 5 to 10 years) after the end of production, to record residual subsidence and/or partial ground rebound due to layers pressure re-balance (Gambolati et al., 2007).

The monitoring technologies used are a set of complementary technologies, each one of them is not exhaustive on its own, but only if used in conjunction with all the others. In such a way it is possible to reach the desired measurement precision and a general data reliability in order to obtain in the following step a trustfully synthesis and interpretation data.

The current ENI implemented monitoring survey can be divided as:

- Shallow monitoring:
  - High precision levelling surveys
  - Continuous GPS surveys in permanent stations
  - SAR surveys
  - Assestimeter subsurface compaction monitoring

Figure 1. The Adriatic ridge of the levelling network.

- Ground fresh water level monitoring
- LiDAR surveys
- bathymetrical surveys

– Deep monitoring:

  - reservoir deep compaction trough radioactive markers
  - reservoir static (bottom hole) pressure monitoring

The high precision levelling surveys is nowadays the technology for subsidence monitoring with the theoretical highest precision. The ENI implemented network (Fig. 1) consists of 1822 km and it allows to monitor all the central-northern Adriatic coast facing the main offshore gas fields. All the network is linked to stable external benchmarks with nil movements with respect to those ones present in monitored area.

The entire network is completely surveyed, respecting an high precision standard, every year since 2002 till 2009, every three years since 2011.

The Continuous GPS monitoring network currently consists of 65 permanent recording stations of which 48 located on production platform offshore and 17 onshore (Fig. 2). Any CGPS station of the network is linked to the international reference network EUREF, the acquired data is processed and solved according to the ITRF2008-IGB08 network. Among the onshore stations, 6 are in a configuration called by ENI: Satellite Survey Unit (SSU) (Fig. 3) where a GPS antenna,

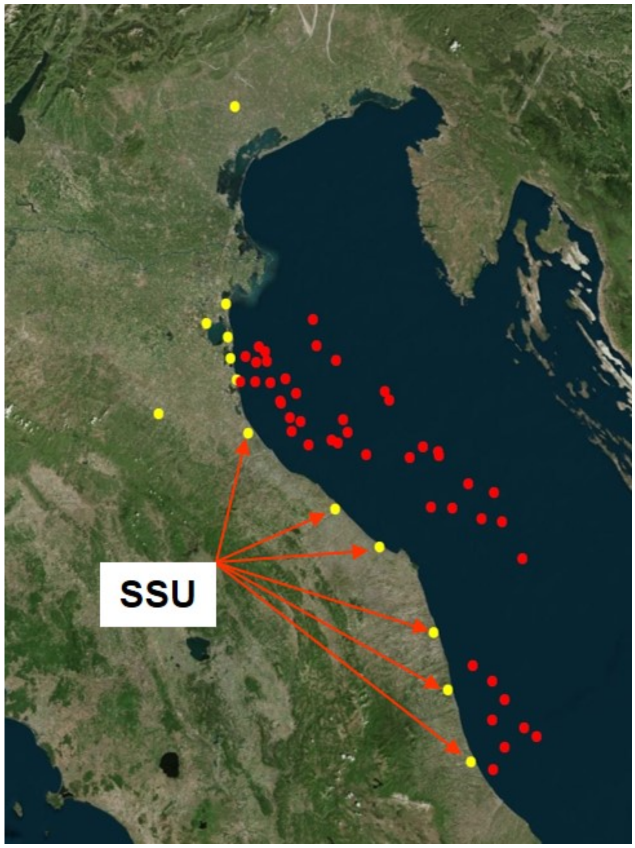

Figure 2. CGPS network, yellow dot onshore stations, red dot offshore stations. SSU locations are also indicated.

a SAR totem corner reflector and a levelling benchmark are mounted on a concrete base so that to have the same soil movement recorded simultaneously by the three different systems (SAR, GPS and levelling). The SSU stations allow to calibrate SAR data, linking them to a point with known absolute movements (GPS antenna/levelling) (Werner et al., 2003).

The Synthetic Aperture Radar (SAR Interpherometry) data (Fig. 4) provide measurements of surface deformation (mean trend and instantaneous variations) by radar interpherometric studies (Strozzi et al., 2001). The interferometric analysis consists in the radar signal phase evolution study between two different (in time) radar surveys. One of the causes of phase signal variation is the soil movements. Because the method provides only relative movements the SAR data are linked, as said above, to GPS station and/or levelling benchmarks.

To monitor and identify the amount of the contribution to the total subsidence of an area, provided by the shallow multi-aquifer system, assestimeters are used. They provide the low-depth compaction assessment to compute the water extraction contribution to subsidence (Bonsignore et al., 2010).

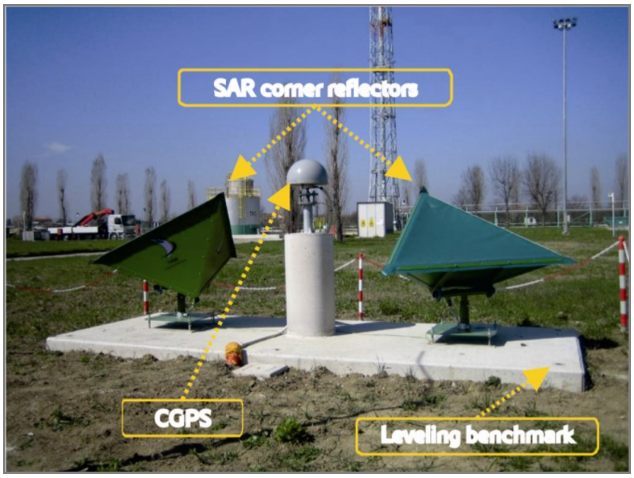

Figure 3. SSU station. Unique configuration assembling in a only one position three measuring methods.

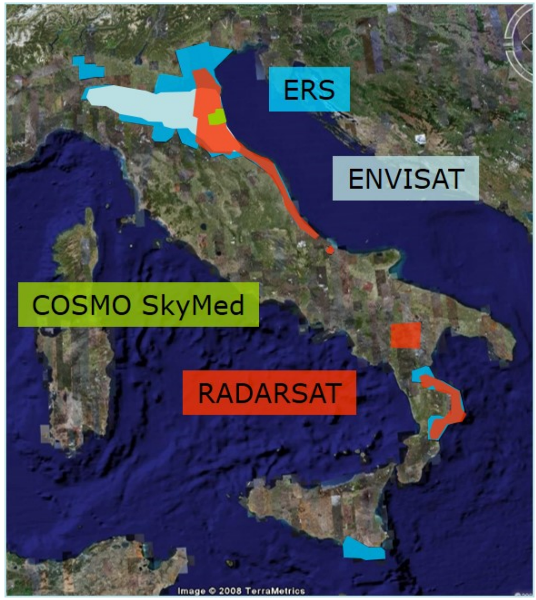

Figure 4. SAR Image coverage yearly processed. Cosmo SkyMed: 1200 km^2, ERS: 1500 km^2, ENVISAT: 6300 km^2, RadarSAT: 26 000 km^2.

The assestimeter tools have been installed by Eni in 6 stations along the Adriatic coast (Fig. 5).

The stations are in a configuration named by ENI: EPSU (Extensometric Piezometric Survey Unit) where the assestimeters are associated to one or more piezometers, monitoring the main exploited fresh water aquifers of the area. The deepest assestimeters installed by Eni, reaching the depth of about 370 m, are in the north, whereas the southward installed tools reach an average depth of 45 m. All the assestimeter installations are anchored below the deepest known drained aquifer for water supply.

Further monitoring technologies, useful in a sustainable development of hydrocarbon resources, are altimetrical and bathymetrical surveys (LiDAR, LADS, single/multi beam surveys), for fields located in offshore or close to the coast. Although these surveys don't reach the requested precision for subsidence monitoring, unless when the soil movements are very high, their use is important to fulfil the knowledge picture of the area subjected to hydrocarbon exploitation. ENI, depending on field location (close or faraway from the coast), always acquires the most appropriate survey before the start of every project, to have a "white" picture of the sea bottom morphology. Then the survey will be repeated over time in accordance with expected changes to constantly follow its evolution and to monitor any possible subsidence bowl formation.

A reliable subsidence prevision, using numerical modelling, of the expected subsidence due to a field exploitation requires a regular "in situ" monitoring of two important parameters: Compaction of gas/oil bearing layers and pressure of the layers fluids. These information are obtained by ENI with the use of the radioactive markers method to obtain reservoir/aquifer layers deep compaction and with the reservoir static (bottom hole) pressure monitoring (Cassiani and Zoccatelli, 2000). Both the radioactive and the bottom hole pressure surveys are acquired every year (Fig. 6).

3 Conclusions

In Italy, since 1997, for each new hydrocarbon development project an EIA (Environmental Impact Assessment, in Italian VIA) has to be submitted to the Ministry of Environment (in Italy MATTM) in order to start-up activities.

All the VIA decrees contains rules about subsidence monitoring that have to be respected through the whole life of the field and even after the end of the exploitation.

The monitoring network set up over the years in order to satisfy the assigned rules has gradually increased and now it is likely to be one of the widest and most complex monitoring network worldwide.

It allows to combine data acquired through different technologies and to integrate them with the double goal to (1) continuously update the simulation model and (2) be aware of the evolution of the phenomenon in order to be able to implement remedial actions if necessary (Verdecchia et al., 2010).

The implementation of the subsidence monitoring network described here represents a piece concurring to the puzzle of a sustainable development that is the result of a sharing of goals, risks and remediation activities between ENI and its stakeholders.

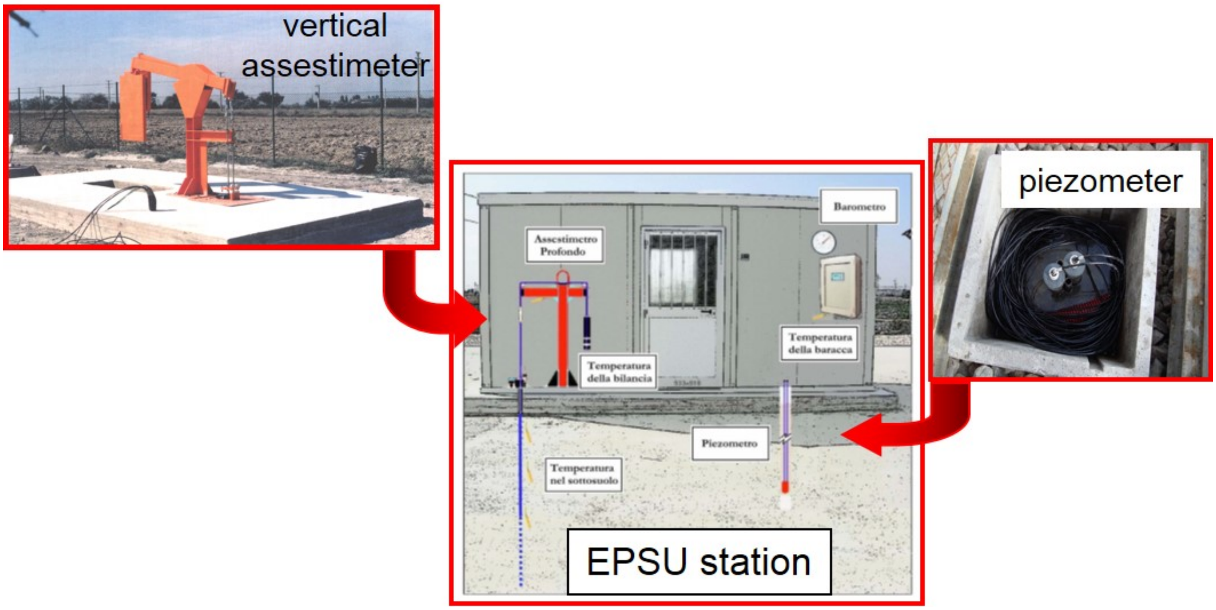

Figure 5. EPSU station, provide shallow compaction assessment, to compute the water extraction contribution to subsidence.

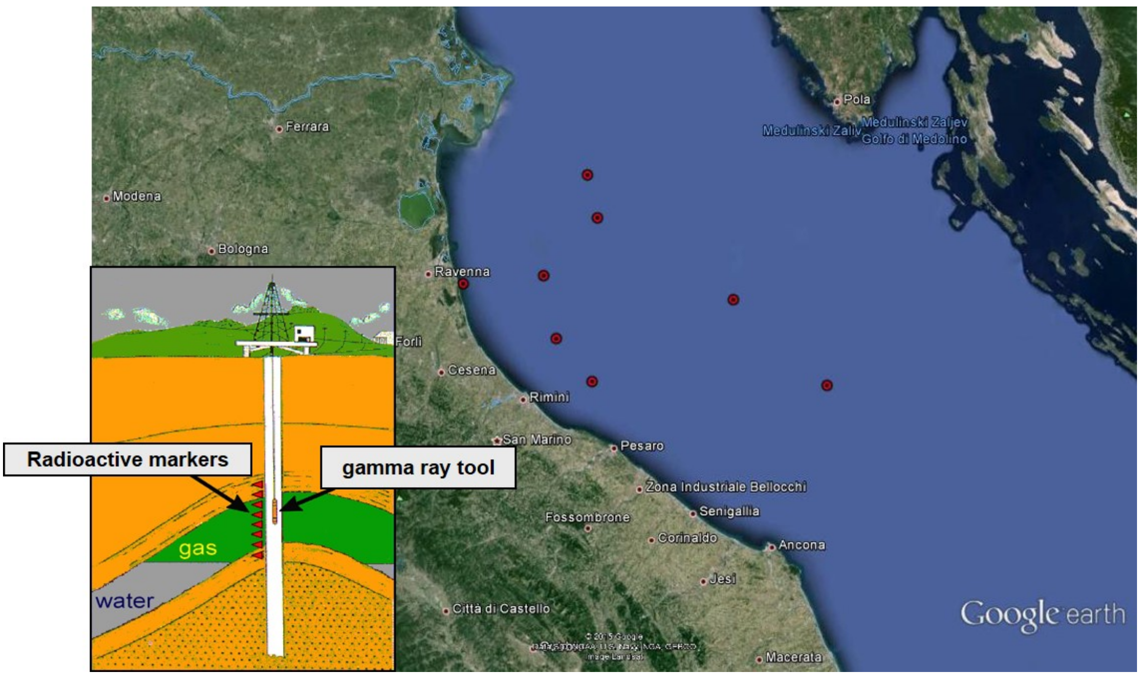

Figure 6. Wells instrumented with radioactive markers.

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