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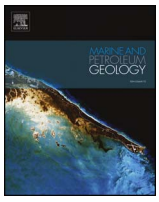

Research paper

Methods for source rock identification on seismic data: An example from the Tanezzuft Formation (Tunisia)

A. Amato del Monte[a], E. Antonielli[b], V. De Tomasi[b], G. Luchetti[b], E. Paparozzi[b], G. Gambacorta[b,*]

[a] ENI Norge SAS, Stavanger, Norway
[b] ENI S.p.A. Upstream and Technical Services, San Donato Milanese, Italy

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ABSTRACT

Source rocks occurrence, extension and quality in the subsurface are usually characterized directly from well data. Seismic characterization is however becoming an emerging technique for extending source rock properties beyond well locations and an effective tool for mapping their lateral and vertical heterogeneities. The Tanezzuft Formation in Tunisia, an extremely organic-rich source rock, was used as a test for applying and comparing different seismic methods aimed at organic-rich sequences characterization. The data used consist of a 2D seismic line shot in the northern flank of the Ghadames Basin (Tunisia), pre-stack gathers extracted from an inline of a 3D survey and four wells with a complete set of wireline and petrophysical logs. Impedance inversion, AVO and seismic attributes were computed on the seismic lines and compared to well data. Impedance inversion together with a rock physics model of the formation generated a quantitative estimate of total organic carbon (TOC) content in the studied 2D seismic line. AVO analysis showed a Class IV and a Base Class IV response for the upper and lower reflectors delimiting the organic-rich interval respectively. Seismic attributes analyzed the formation by exploiting its high impedance contrast and intrinsic anelastic attenuation. The three methods here discussed showed coherent results both when compared each other and when compared with the well data and the regional geological model. In particular, AVO and seismic attribute analysis are methods that can be applied without the need of well information, and are then feasible methods for the investigation of source rock properties in undrilled basins.

1. Introduction

Several authors have published papers analyzing the seismic response of source rocks as a function of their properties. Vernik and others have studied the relationship among velocity, anisotropy and organic content of source rocks (Vernik and Nur, 1992; Vernik and Landis, 1996; Vernik and Liu, 1997). Carcione (2001) and Sayers (2013a, 2013b) examined the theoretical aspects of rock physics and amplitude versus offset (AVO) response in organic-rich shales. Many recent works have then been published, addressing the problem of relating organic content of source rocks to their seismic response (Avseth et al., 2008; Løseth et al., 2011; Zhu et al., 2011; Sayers, 2013a, 2013b; Carcione and Avseth, 2015). We investigated and compared the capabilities of three geophysical techniques, acoustic impedance (AI) inversion, P-P waves AVO analysis, and seismic attributes, to detect the spatial distribution of organic content in source rock sequences. Even though examples of geophysical techniques for source rock analyses are not new in the literature (Løseth et al., 2011; Ogiesoba and Hammes, 2014), this work aims to both demonstrate the potential and assess the limits of such methodologies as tools for the geophysical investigation of source rocks. We also propose the use of sweetness as a promising attribute for kerogen detection.

We used pre- and post-stack seismic data, core and well log measurements, and total organic carbon (TOC) estimation obtained from ΔlogR (Passey et al., 1990) or laboratory core samples measurements to calibrate the seismic methods and obtain, wherever possible, a quantitative estimation of TOC from seismic surface data. In fact, each considered technique requires different input data, and detects different physical effects caused by the presence of organic matter. All three methods are fast and easy to implement; they are independent from each other and so can deliver independent estimation of the degree of presence of kerogen in the studied intervals. This can be helpful in improving the confidence in the interpretation and understanding of the petroleum system model of the basin under investigation.

In our study, we measured the amount of organic matter present at four different well locations in the Silurian Tanezzuft Formation (Tunisia), which constitutes an important example of an organic-rich sedimentary sequence. Well logs were interpreted in order to estimate

* Corresponding author.
E-mail address: gabriele.gambacorta@eni.com (G. Gambacorta).

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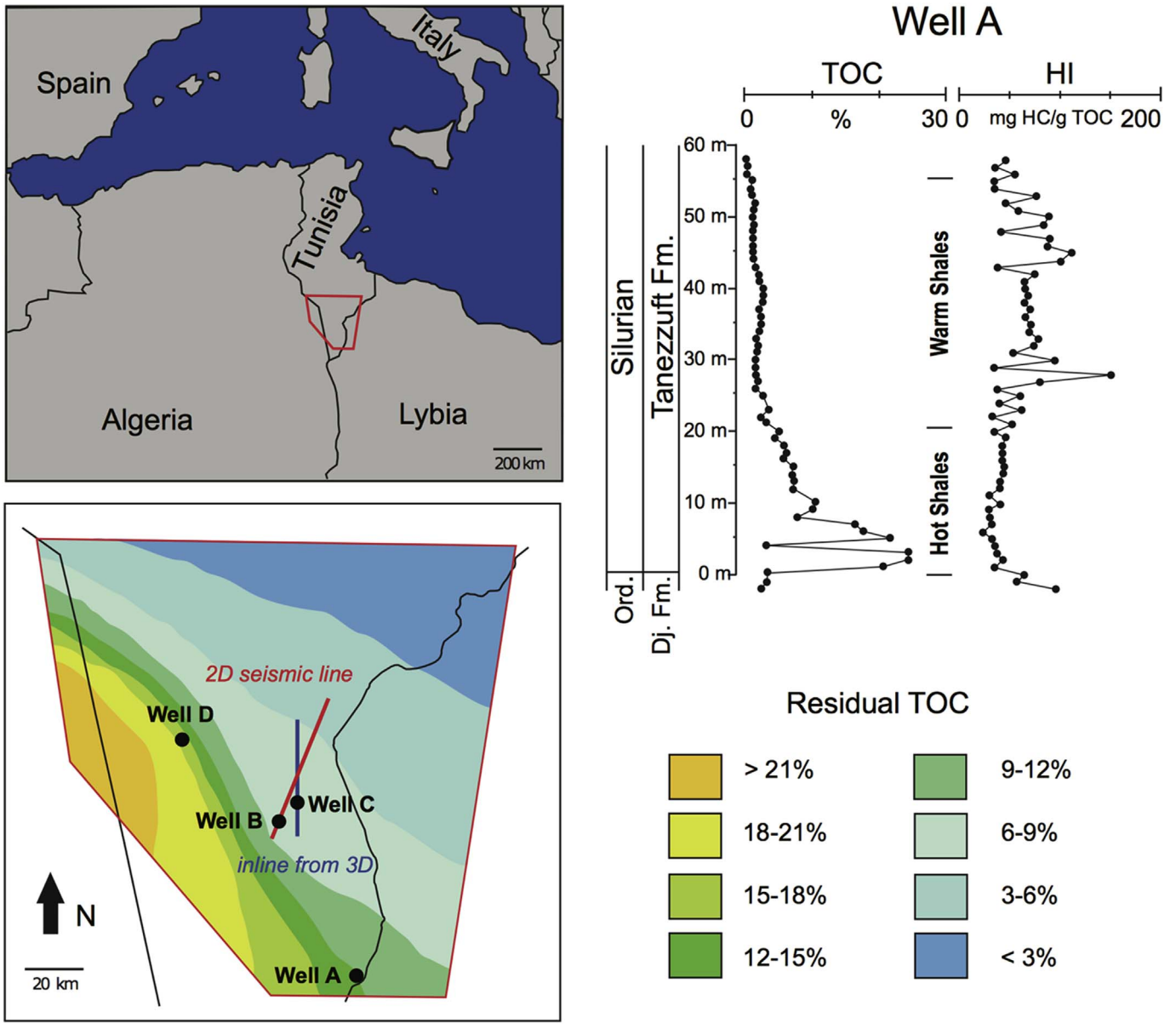

Fig. 1. Location of the study area. Available data and TOC map relative to the lowermost organic-rich interval of the Tanezzuft Formation. On the right, measured Total Organic Carbon (TOC) and Hydrogen Index (HI) for Well A.

TOC values through a calibration of the acquired logs with geochemical measures performed on core samples and cuttings. Surface seismic data acquired close to the wells were then analyzed with the three methods investigated, and results were compared to each other and with the established depositional model. We will discuss the relevant features, limits and benefits of each method used in the study.

2. Geological setting

The investigated area is located in the northern part of the Ghadames Basin in the southernmost part of Tunisia (Fig. 1). The Ghadames Basin is an intra-cratonic basin that experienced many tectonic phases (Echikh, 1998). After a first time of reactivation of Pan-African fault systems of a subsiding Paleozoic basin, the study area went through a phase of uplift and erosion during the Hercynian phase. Finally, during the Mesozoic, because of the rifting of Tethys, a northwest tilting and development of an extensional basin occurred. Latest Eocene (Pyrenean phase) movements affected the basin with little intensity. In the study area (Fig. 1), approximately 2500 km^2 wide, the Tanezzuft Formation is not outcropping. For this reason, well and seismic data represent a key information for geological characterization. Available data (Gambacorta et al., 2016) indicate that in the studied area the Silurian (Rhuddanian Stage to Ludfordian Stage) Tanezzuft Fm. has thicknesses up to 700 m and it is mainly composed by fine-grained layered sediments comprising a mixture of silts and muds with limited amount of fine sandstones deposited in relatively deep-water settings (Desio, 1936; Bellini and Massa, 1980; Klitzsch, 1981; Gambacorta et al., 2016). Detailed sedimentological analyses, integrated with geochemical and biostratigraphic data (Gambacorta et al., 2016), indicate that the Tanezzuft Fm. deposited in a very dynamic environment. Paleo-coastline was oriented northwest-southeast and moved through time repeatedly under the influence of relative sea-level variations. Such oscillations determined the observed depositional architecture characterized by repetitive coarsening-upward stacking patterns with a regional shaling-out from southwest to northeast. Organic matter distribution and type was strongly influenced by the overall depositional style and paleo-coastline orientation. In fact, as proved by optical kerogen and palynofacies analyses, continental

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