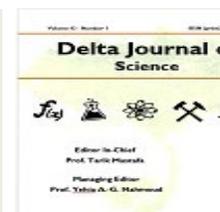




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Research Article

**GEOLOGY**

## DELINEATING THE GEOMETRY AND MODELING OF THE UNCONVENTIONAL IGNEOUS INTRUSIONS BY SEISMIC ATTRIBUTES; A CASE STUDY IN RUD EIS-SIDRI FIELD, GULF OF SUEZ, EGYPT

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### KEY WORDS

Unconventional igneous intrusion, Seismic attributes, Rudeis-Sidri field, Reservoir characterization and 3-D modeling

### ABSTRACT

The present work aims to recognize the geometry to build modeling of the Oligo-Miocene unconventional igneous intrusions of the fracture reservoir in Rudeis-Sidri field, Gulf of Suez, Egypt. These reservoirs, much more difficult to predict, evaluate and to build modeling than the conventional reservoirs. Seismic attribute is a quantity extracted or derived from the seismic data that analyzed in order to enhance information that might be subtler in a traditional seismic image, leading to a better understanding and interpretation of the data. Two attributes (Local Structural Dip), through detecting the scattered dip from the seismic events, (Sweetness), through recognizing the variations of reflectors, that have potential to predict possible fracturing and absorption effects, to recognize the geometry and to get criteria to build the modeling process to differentiate between sedimentary and basalt intrusions. As a result, the combination and integration of the two types of seismic attributes, the available well log data analysis as control points to establish building 3-D models, which help to differentiate between the sedimentary and non-sedimentary rocks, to delineate the geometry, distribution, and to follow the new oil potentially at Rudeis-Sidri field.

## 1. Introduction

Rudeis-Sidri oil field is one of the major hydrocarbon-producing fields on the eastern side of the Gulf of Suez, Egypt (Fig. 1). There are many drilled wells stopped the drilling in Rudeis-Sidri field, after encountering basement section in the past, due to the lithologic complexity and the difficulty to drill. Basement reservoirs are documented in several countries, such as Algeria, China, Vietnam, Canada, India, Yemen and Egypt (Nelson, 2001) and (Luthi *et al.*, 2005). The production from Rudeis-Sidri oil field comes from Nukhul formation, Matulla and Nubia Formation (Sitta and Volpi, 2012). A new discovery (ARM-14 well) was drilled in unconventional igneous fractured reservoirs, that interbedded in the sedimentary rocks in 2014 and opened a new challenge for oil potential of the Rudeis-sidri field. However, the main challenge of the unconventional igneous fractured reservoir is to delineate the geometry and complexity of such hydrocarbon features in the future. Several contributes were introduced, to evaluate the fractured basement reservoir characterizations (Sircar, 2004; Gutmanis, 2009; Lefranc *et al.*, 2012; Gupta *et al.*, 2012; and Suardana *et al.*, 2013).

Exploration of this particular play requires a careful plan of execution, in order to define the intersection of faults or fracture sets. This study utilizes the 3D seismic attributes and builds a reliable model, to understand and to follow the potential of unconventional igneous reservoir in Rudeis-Sidri field.

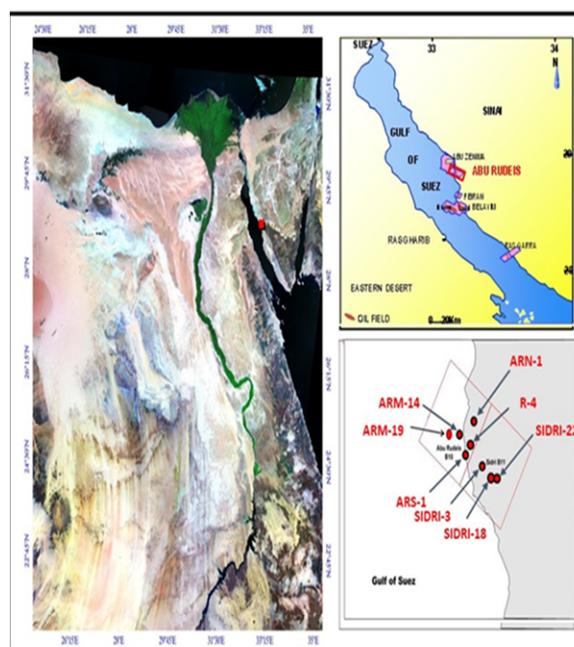


Fig. 1: Location map of Rudeis –Sidri field.

### 1.1. Geological setting

The stratigraphic sequence of the study area ranges in age from Precambrian to Recent (Fig. 2). Detailed description of the pre-rift and syn-rift stratigraphy present in Khalil, (1988); Darwish, (1992); Patton *et al.*, (1994); McClay *et al.*, (1998) and Plaziat *et al.*, (1998). Tectonically undisturbed pre-rift section, including

continental, deep and shallow marine clastics, and carbonates deposits of Paleozoic to Eocene age is found. Syn-rift sediments, including Late Oligocene continental clastics, with minor basalts and Early Miocene shore face to shallow marine clastics and evaporitic deposits are occurred. Post-rift section, consisting of predominantly evaporates, with interbedded shallow marine to continental clastic deposits is also existed.

The Miocene and Pre-Miocene plays of the Gulf of Suez are well established, with important oil discoveries in the marine sandstones of primarily Rudeis, Nukhul and Belayim formations of the Miocene, and mainly the Nubia and Lower Senonian of the Pre-Miocene rocks. The reservoir of Sidri-South prospect is the Nukhul Formation, which represents the oldest target of the Miocene Syn-rift. The Nukhul Formation is mainly composed of sandstone, claystone, conglomerates, marl and argillaceous limestone and fossiliferous. It represents the first shallow marine transgressive deposits in the Gulf of Suez. The Nukhul Formation, unconformably overlies the so-called Oligocene Abu Zenima Formation and is conformably overlain by the Lower to Middle Miocene Rudeis Formation.

The Thebes and Duwi formations are the main source rocks, in which the

average Total Organic Carbon (TOC) is 2%, the kerogene type is mainly type II and the hydrocarbon are oils (API values range from 23 to 29 units). Pre-Cambrian basement, in Rudies-Sidri area, penetrated at some wells, as well as in Abu Zenima area, at shallow depths (Sidri-6, Sidri-6R, Wadi El-Naqa, South Markha and South Zenima areas) along the main bounding fault, that shown in the schematic stratigraphic column of (Fig. 2).

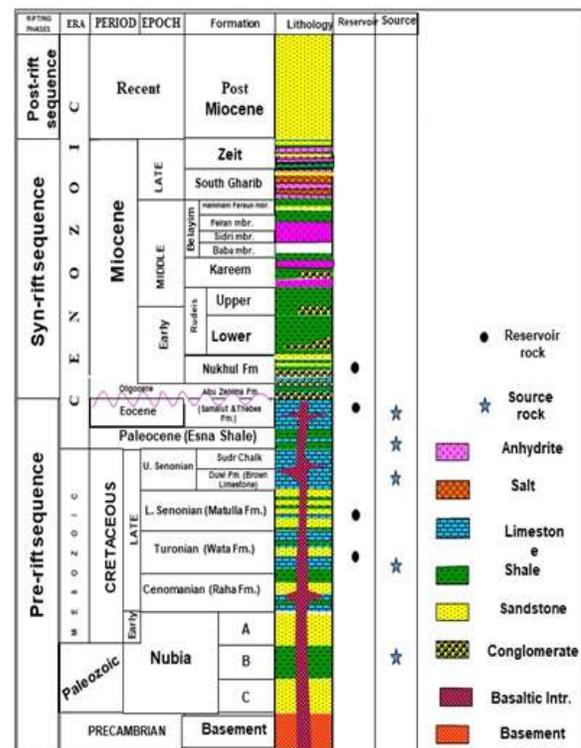
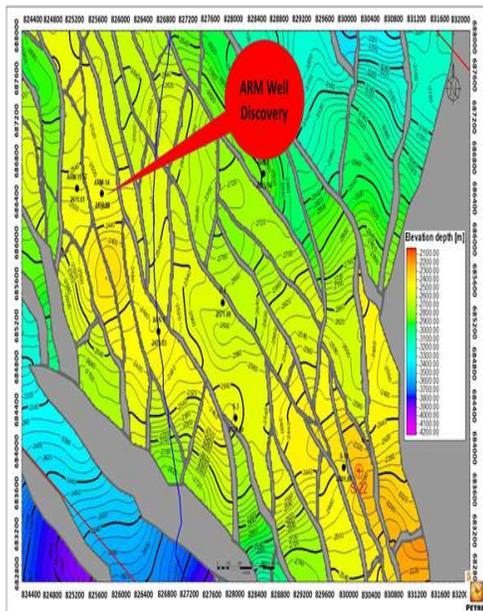


Fig. 2: Schematic stratigraphic column of Rudies-Sidri area, Gulf of Suez province (Petrobrel, 2014).

## 1.2. Structure contour map

The structural setting of the study area, identified in (Fig 3) is interpreted by using the latest Post-Stack Seismic Depth Map (PSDM)

volume, performed by Eni high quality data in 2014. The structure contour map of the study area shows that, the area was affected by faults trending (NW-SE and NE-SW), crossing the interested igneous area. A set of normal faults, forming horst, graben and step-fault blocks that are very convenient for oil accumulations, with block categories.



**Fig. 3:** Structure contour map of interested igneous area top surface of Nukhul Formation.

## 2. Material and methods

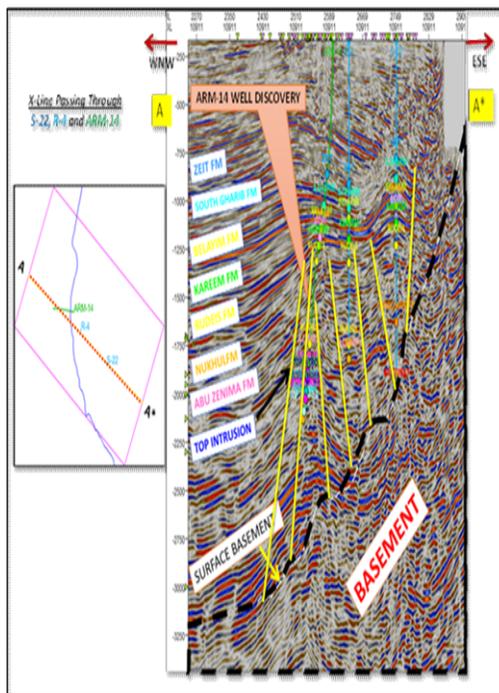
The start study was with ARM-14 well, as an exploratory well, after achieving unexpected igneous intrusion reservoir target, that was confirmed by a production test. The challenge was to outline the geometry and building a model to recognize the unconventional igneous intrusion blocks, as sills and or dykes. Related to the definition of the basement adopted, in which the

basement rocks are considered as metamorphic and or igneous rocks, that unconformably overlain by the sedimentary sequence (**Landes et al., 1960**). Thus, what potential encountered make trying to solve this challenge, by identifying the bed boundary of the igneous intrusions, interbedded with sedimentary layers as controlled by the borehole wells and seismic data, but the seismic data are not clear enough to differentiate between the dykes and or sills, that are interbedded in the sedimentary layers, as shown in (Fig. 4). The seismic attributes are need to enhance information, that might be subtle in conventional seismic, leading to a better understanding and interpretation of the data. Two seismic attributes, the Local Structural Dip, to detect the scattered dips from seismic events and the Sweetness, to recognize the variations of reflectors, that have potential to delineate the possible fracturing and absorption effects. Both types of attributes support to solve completely and build reliable criteria to differentiate between the sedimentary layers and igneous intrusive bodies. A combination of the arbitrary seismic lines and seismic attributes helps to differentiate between the sedimentary and non-sedimentary rocks. Determining the reservoir characterization and building a 3-D

model for the igneous intrusions of three dykes are controlled by the available wells, to support the next development wells.

### 3. Results and Discussion

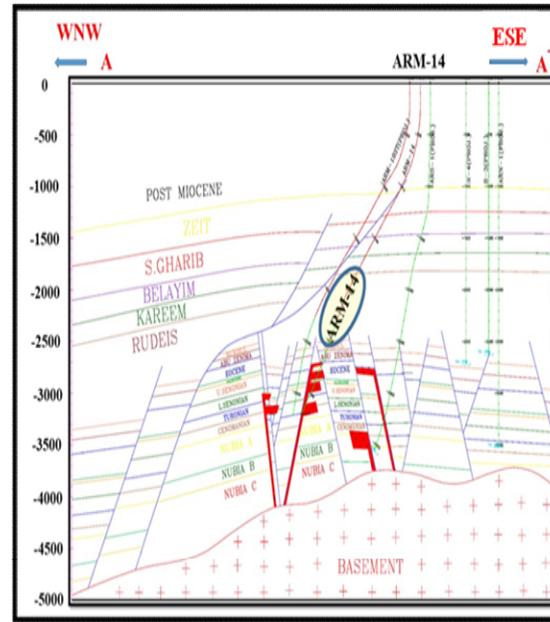
The seismic response of the basement section is a complex rock-structure interaction problem that depends on many different factors such as nature of the input motion, dynamic response of the backfill rock and flexural response of the walls. The current state of practice for the seismic design of basement walls in the United States is shown by (Lew *et al.*, 2010) and (Lew, 2012). The seismic X-line through path Arm wells, discovery seismic data display depth by meter cannot differentiate between the basement and sediments in (Fig. 4).



**Fig. 4:** Seismic X-line through Arm wells discovery.

### 3.1. Geologic cross section

The geologic cross section (Fig. 5) shows the trajectory path of the studied wells, the intrusions of the igneous dykes and sills in the sedimentary section.

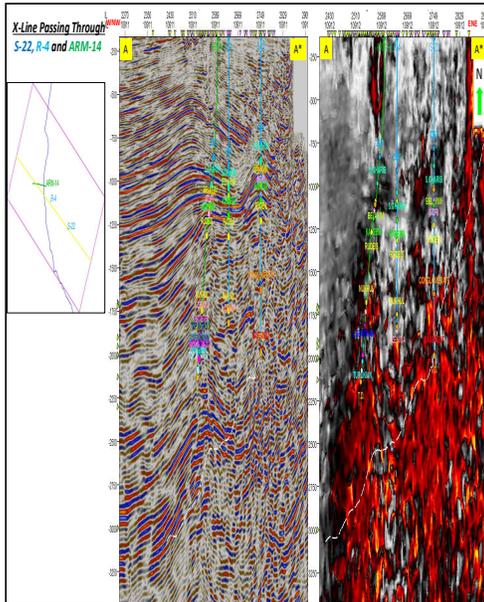


**Fig.5:** Geologic cross section, after drilled the discovery wells.

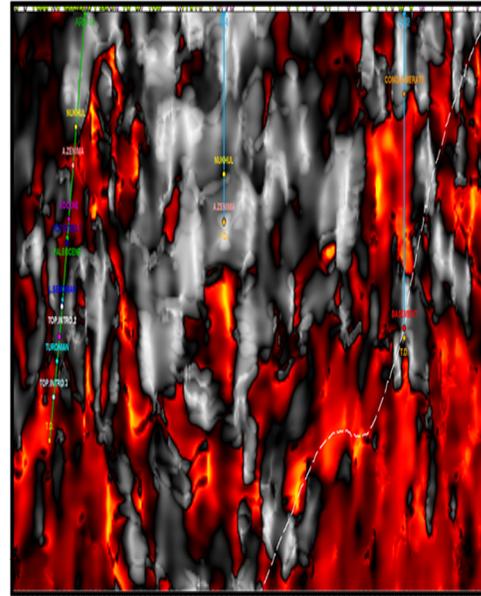
### 3.2. Seismic attributes

Derived from the 3D seismic data, in order to enhance the seismic image, and to help enhancing the information, that might be subtle in conventional seismic data, leading to better understanding and interpretation of the ambiguous condition. Two seismic attributes: Local Structural Dip, to detect the scattered dips from the seismic events and Sweetness, to recognize the variations of reflectors

that have potential to delineate the possible fracturing and faulting effects. Both types support the solution of the problem and establish the criteria to differentiate between the sedimentary and igneous intrusions, (Figs 6 and 7) shows the 3D arbitrary lines and their seismic attributes, as a case study. The fermented comment in clearer zoomed in (Fig. 7) for the boundary, that the mutual occurrence of the red (expressing the basement rocks) and the grey (expressing the sedimentary rocks) attest the foregoing conclusions, regarding the seismic attributes.



**Fig. 6:** 3D arbitrary seismic lines, integrated with the seismic attribute image.

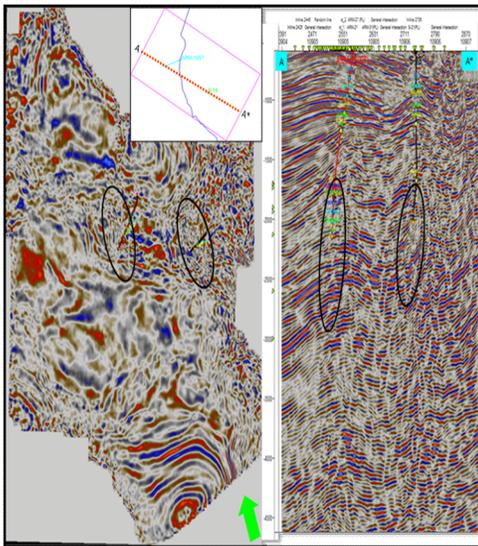


**Fig.7:** Zoomed Seismic attribute image of igneous with sedimentary reservoir.

### 3.3. Time Slice

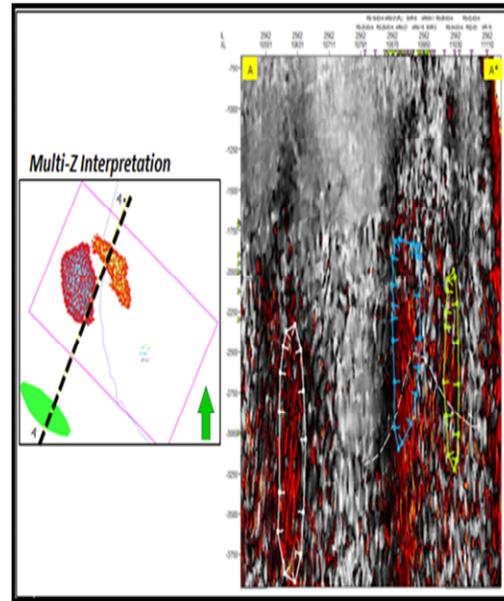
Time slice contains the seismic events from more than one reflected horizons at the same time level. A spatially high-frequency event on a time slice is either a steeply dipping event or a high-frequency event in time. Thus, from the time slices, it can be inferred steep dips at the locations from the high-frequency characters of the events and gentle dip at the locations from low-frequency characters. Additionally, the contours associated with a reflection horizon can be traced through the time slice. If the contours are narrow between a shallow and a deeper time slices. A then the feature is a structural low. Conversely, if the contours are widen between a shallow and a deeper time slices, then the feature is a structural high.

Time slices are used to generate the structure contour maps. Some 2-D smoothing are applied to the time slices, to ease contouring. Edge enhancement are used to better delineating the zero crossings. Some image processing tools are also used, to detect and enhance the subtle structural features on the time slices, as in (Fig. 8), that have made pioneering use of the time slices in the 3-D interpretation.

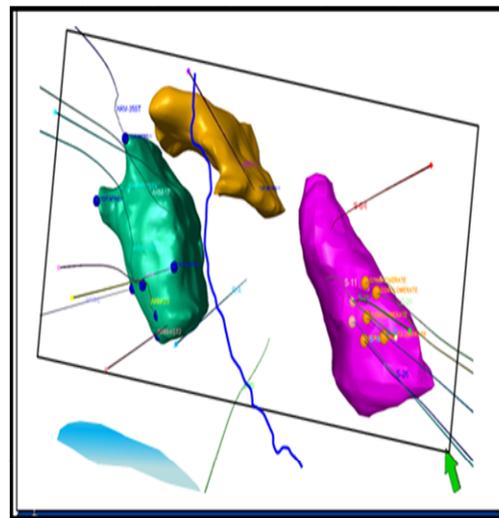


**Fig. 8:** Time slice image processing with showing the low and high frequency features.

A measurable property of the seismic data, such as amplitude, dip, frequency, phase and polarity. Attributes are measured on a single trace, or on a set of traces, or on a surface interpreted from seismic data, to build dykes in the 3-D model were achieved by the well log data, as control points (Figs. 9 and 10).



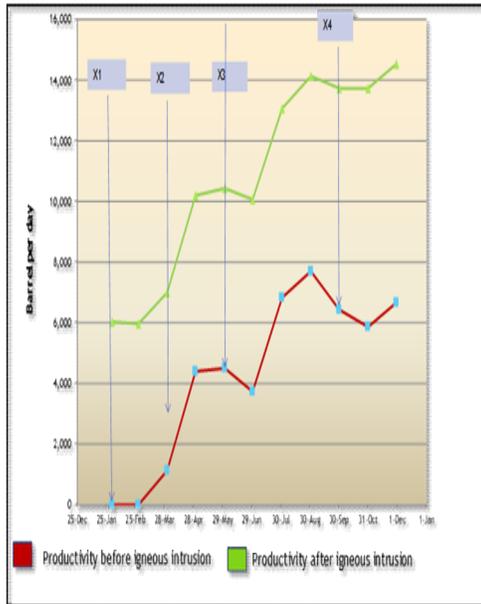
**Fig. 9:** Build 3D model from dykes and sills boundary on seismic attribute image.



**Fig.10:** 3-D dykes model and achieved through trajectory of Arm wells, stopped within basement, as control points.

### 3.4. Production enhanced

Production profile supports the reliable criteria, to follow the igneous intrusion, as dykes and or sills, confirmed by production in (Fig. 11).



**Fig.11:** Production profile before and after igneous intrusion.

#### 4. Conclusions

The conventional seismic data are not clear enough to differentiate between the dykes and or sills interbedded in the sedimentary layers. A combination of seismic attributes helps to differentiate between the sedimentary and non-sedimentary rocks. Building a 3-D model of three-dyke bodies, controlled by the available wells log data, and supported for the next development wells. After confirming with the production data by the natural flow, establishing the test criteria of Igneous Intrusion, to delineate the geometry, distribution and building the 3-D intrusion model. Oil production from the igneous intrusions (dykes and or sills) have their impacts on the future production plan for the unconventional reservoirs.

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## تحديد هندسة ونمذجة التداخلات النارية غير التقليدية: دراسة حالة بحقل روديس – سيدري بخليج السويس مصر.

يهدف هذا العمل الحالي إلى التعرف على الهندسة لبناء ونمذجة خزان Oligo-Miocene غير التقليدي للتداخلات النارية في حقل روديس-سيدري ، خليج السويس ، مصر. هذا الخزان أكثر صعوبة للتنبؤ والتقييم وبناء النمذجة من الخزانات التقليدية. السمة الزلزالية هي كمية مستخرجة أو مشتقة من البيانات الزلزالية ، والتي يتم تحليلها من أجل تعزيز وتحسين المعلومات التي قد تكون أكثر دقة في الصورة الزلزالية التقليدية ، مما يؤدي إلى فهم وتفسير أفضل للبيانات. سمتان (Local Structure Dip) من خلال اكتشاف الانحدار المتناثر من الأحداث الزلزالية و (Sweetness) من خلال التعرف على الاختلافات في الانعكاسات ، والتي لديها القدرة على التنبؤ بتأثيرات الصدع والامتصاص المحتملة ، للتعرف على الهندسية والحصول على معايير معينة لبناء النمذجة والتفريق بين التداخلات الرسوبية والبارزنتية.

ونتيجة لذلك ، فإن الجمع والتكامل بين نوعي الصفات الزلزالية ، وبيانات تحليل سجل البئر المتاحة كنقاط تحكم لإنشاء نماذج بناء ثلاثية الأبعاد ، والتي تساعد على التمييز بين الصخور الرسوبية وغير الرسوبية ، وتحديد الهندسة والتوزيع ، لمتابعة النفط الجديد المحتمل في حقل روديس – سيدري، خليج السويس، مصر.