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Petroleum exploration in Africa from space

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ABSTRACT

Hydrocarbons are nonrenewable resources but today they are the cheaper and easier energy we have access and will remain the main source of energy for this century. Nevertheless, their exploration is extremely high-risk, very expensive and time consuming. In this context, satellite technologies for Earth observation can play a fundamental role by making hydrocarbon exploration more efficient, economical and much more eco-friendly. Complementary to traditional geophysical methods such as gravity and magnetic (gravmag) surveys, satellite remote sensing can be used to detect onshore long-term biochemical and geochemical alterations on the environment produced by invisible small fluxes of light hydrocarbons migrating from the underground deposits to the surface, known as microseepage effect. This paper describes two case studies: one in South Sudan and another in Mozambique. Results show how remote sensing is a powerful technology for detecting active petroleum systems, thus supporting hydrocarbon exploration in remote or hardly accessible areas and without the need of any exploration license.

Keywords: Hydrocarbons, exploration, microseepage, remote sensing, multispectral images, satellite, oil&gas, Africa

1. INTRODUCTION

1.1 Background

An increasing number of papers clearly point out that Earth observation systems in the optical domain have unquestionable economic advantages in many operational scenarios and can successfully complement conventional geological and geophysical surveys [1, 2]. Besides, remote sensing technologies do not require on-site access to the study area. This means the analyses can be made in a safe place, even when the study area is affected by civil war or is subject to potential terrorist attacks or when natural hazards made the site inaccessible. This is particularly true for satellite surveys. In addition, while seismic surveys have negative implications on the environment, remote sensing analyses have zero-impact, which is now a priority in the modern sustainable development approach adopted in many African countries [3]. However, in the oil and gas industry today there is still skepticism on the effectiveness of this unconventional geophysical technology for hydrocarbon exploration.

With respect to the phenomena observed, macroseepage is a spill of hydrocarbons moving along faults, fractures or carrier beds from the reservoir to the surface, ruled by heavy hydrocarbons that often form invisible gas or visible solid and liquid ponds [4]. Macroseepage is well-known since the ancient civilizations of Mediterranean and Middle East and in the history have led to the discovery of many oilfields. Nevertheless, since macroseepages may also be located very far from the hydrocarbon kitchens/reservoirs, this manifestation is not regarded as proxy for the locationing of underground petroleum deposits.

On the other hand, microseepage is a very different phenomenon. It is ruled by light hydrocarbons that flow within a carrier through the reservoir's seal to the surface [5]. Once at surface, microseepage creates a soil atmosphere containing volatile hydrocarbons that interacts with the soil's particles, minerals and the above vegetation. While the scientific community is still debating on the effects of microseepage on the environment [6], more and more studies propose this phenomenon as marker for the detection of active petroleum systems [7, 8, 9, 10].

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Among the pedological, mineralogical and botanical alterations driven by microseepage, the last are probably the most difficult to detect. In fact, a large amount of phenological variables such as canopy, biomass and intraspecific differences make difficult the study of microseepage-induced alterations in the vegetation's health. Anyway, multispectral and hyperspectral data can discover these signals.

With reference to soil alterations, remote sensing technologies are able to point out some specific markers [6, 11, 12]. For example, the presence of Kaolinite driven by acidic conditions could be the main clue to follow when studying a very complex geological framework [13]. Or the bleaching of red beds, caused by the reduction of ferric oxides to ferrous oxides, is another sign to seek microseepage effect [14].

The formation of carbonate and carbonate cement is another effect of microseepage. However, carbonates also came from precipitation in natural environment [15].

1.2 Research objectives

Past case studies of Uganda [7] and Kenya [8] demonstrated the effectiveness of satellite remote sensing to suggest the presence of active petroleum systems over large areas and in different ecosystems such as:

- Savannah with strong seasonal effects on vegetation for Lake Albert case study [7]. We should note that while early deposition in the Lake Albert basin was supposed to occur in the Late Miocene, a recent study proposed it occurred in Early Miocene (17.0 Ma) [16];
- Arid zone without seasonal variations in the case study of Lake Turkana [8].

In this paper, we extend the analysis to two new onshore case studies:

- Block 5A in South Sudan, already explored;
- Blocks PT5-B and PT5-C in Mozambique, partially unexplored yet.

The goal is to show how Earth observation is a natural complement to Gravity and Magnetic modelling (gravmag) and how it can help the oil and gas industry to optimize expensive seismic surveys.

2. DATASET

The study made use of the following satellite data to create the map of microseepage signals:

- A time series made of 15 Landsat-7/ETM+ images, collected in South Sudan from 1999 to 2003;
- A time series made of 27 Landsat-7/ETM+ images, collected in Mozambique from 1999 to 2003.

Besides, the following multi-source data were used for interpretation and validation of the microseepage maps:

- Location of oilfields and wells in South Sudan [17, 18];
- Location of oilfields and wells in Mozambique [19];
- Bouguer gravity map of the West and Central Africa Rift System [20];
- Tectonic overview of the Mozambique Channel [21];
- Enhanced digital elevation model released by NASA's Shuttle Radar Topography Mission [22];
- Robertson Tellus Sedimentary Basins [23].

3. METHODS

The multi-temporal satellite images were co-registered, calibrated and atmospherically corrected with the ATCOR radiative transfer code, thus obtaining reflectance data. Then, clouds were masked using the LTK algorithm [24].

Next, the multi-temporal sets of data were analyzed with a multivariate analysis [7, 8, 25] searching for time invariant absorbers in the spectral domain of microseepage. Finally, the microseepage maps were correlated with all available multi-source data and a failure analysis was performed on existing dry wells to understand if the failure was ascribable to the petroleum system, the reservoir, the sealing, the trap or if there were logistic and/or technical problems during the spudding (e.g. old wells or outdated technologies).

4. RESULTS AND DISCUSSION

4.1 South Sudan – Block 5A

The first case study is Block 5A. The site is located in the northern part of South Sudan, in the Unity State within the Greater Upper Nile region, and has a total extension of 20,591 km^2. The White Nile Petroleum Operating Company (WNPOC), a joint operating company between Petronas of Malaysia and Sudapet of Sudan, is operating the Block (Figure 1).

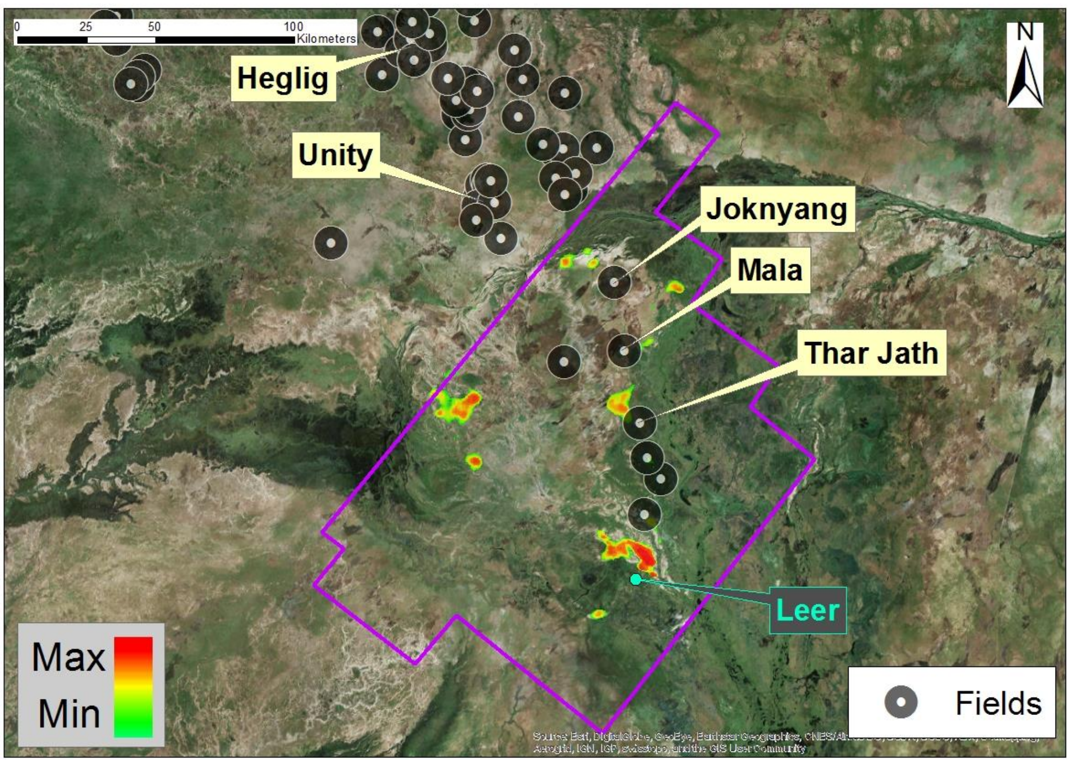

Figure 1. South Sudan, Block 5A: licensing block, oilfields and microseepage signals detected from space.

The land-cover includes two main classes: black cotton soil (vertisol), a soil rich of Montmorillonite (clay), and wetlands nearby the White Nile [26]. With respect to the geological setting, the study area is inside the Muglad Basin that extends for 120,000 km^2 from Sudan to South Sudan. The basin is composed by three rift cycles: Early Cretaceous (140–95 Ma), Late Cretaceous (95–65 Ma) and Paleogene (65–30Ma) and is well-known for its hydrocarbons accumulations [20]. The largest oilfields until now discovered are Heglig and Unity [17] (Figure 1a): the first is outside Block 5A and the second adjoins the block. Inside Block 5A we find the Mala and Thar Jath oilfields [18, 27] (Figure 1) that are well known for their Nile Blend, a medium low-sulfur waxy crude oil [27].

Figure 1 shows the map of microseepage signals. The satellite analysis pinpoints some spectral anomalies on top of seasonal vegetation cover, or within unvegetated areas, in the eastern part of the block. Starting from the northern part of Block 5A and moving along the North–South string of discoveries we can see:

- A group of small microseepage signals located in the northern part of the block, nearby Joknyang oilfield;
- A well-defined microseepage signal located on the north-western side of the Thar Jath oilfield;
- A strong microseepage signal in an unexplored area nearby Leer;
- A group of microseepage signals located in the unexplored western part of the block.

4.2 Mozambique – Blocks PT5-B and PT5-C

The Mozambique basin is composed by an onshore section extended 275,000 km^2 and an offshore section extended 105,000 km^2, structured by an asymmetric depression bounded on the North-West by the Nuanetsi-Sabi monocline and on the South-West by the Lbombo monocline [28]. Petroleum exploration in this area started in 1904: four onshore fields were discovered to date (i.e. Pande, Temane, Inhassoro and Buzi) [19] and there are still great potentialities, as confirmed by the recent offshore discoveries [29].

This second case study focuses on the area of Pande, Temane and Inhassoro oilfields, containing gas, condensate and light oil coming from the Upper Cretaceous Lower Grudja formation [19]. Today there are two onshore Blocks around these oilfields: PT5-B and PT5-C. Sasol Petroleum Mozambique exploration Ltd. awarded Block PT5-C on October 2015, with the fifth Mozambique licensing round by Instituto Nacional de Petroleo, while Block PT5-B is still unassigned at the time of writing (May 2017) [30].

Figure 2 shows the map of microseepage signals. We can see:

- A group of microseepage signal on the north-western part of Block PT5-B, west side of the Save river. While no discoveries were found to date, however these signals seems interesting because follow the Shire graben [21] along a North-South alignment;
- Two strings of microseepage signal running parallel to the main faults from the north-eastern corner of Block PT5-B to the south-western corner of Block PT5-C.

Figure 3 shows a detail of the microseepage signal extending from the Temane and Inhassoro oilfields into north-east of Block PT5-C. No wells seems drilled or planned inside the spectral anomalies, except Inhassoro-5,8 and Inhassoro-14 (gas) and Columbia-1 and Cherimira-1 (gas shows) [19]. It’s worth noting they are all inside the microseepage effect detected from space.

5. CONCLUSIONS

This study analyzed the onshore licensing blocks 5A in South Sudan and PT5-B and PT5-C in Mozambique. Results show the presence of interesting microseepage signals in areas partially unexplored yet. Some signals are related to known petroleum accumulations or graben with potential for hydrocarbon exploration.

Regarding producing oilfields, there is plenty of literature showing that non-permanent microseepage effects could quickly disappear when the oilfield enters production, due to the prompt reduction of overpressures. This happens in both the South Sudan and Mozambique case studies, where the satellite does not see any signal on top of producing oilfields. Nevertheless, in some cases microseepage may still be present as a “halo” nearby produced oilfileds, such as those nearby Joknyang and Thar Jath in South Sudan and nearby Inhassoro/Temane in Mozambique.

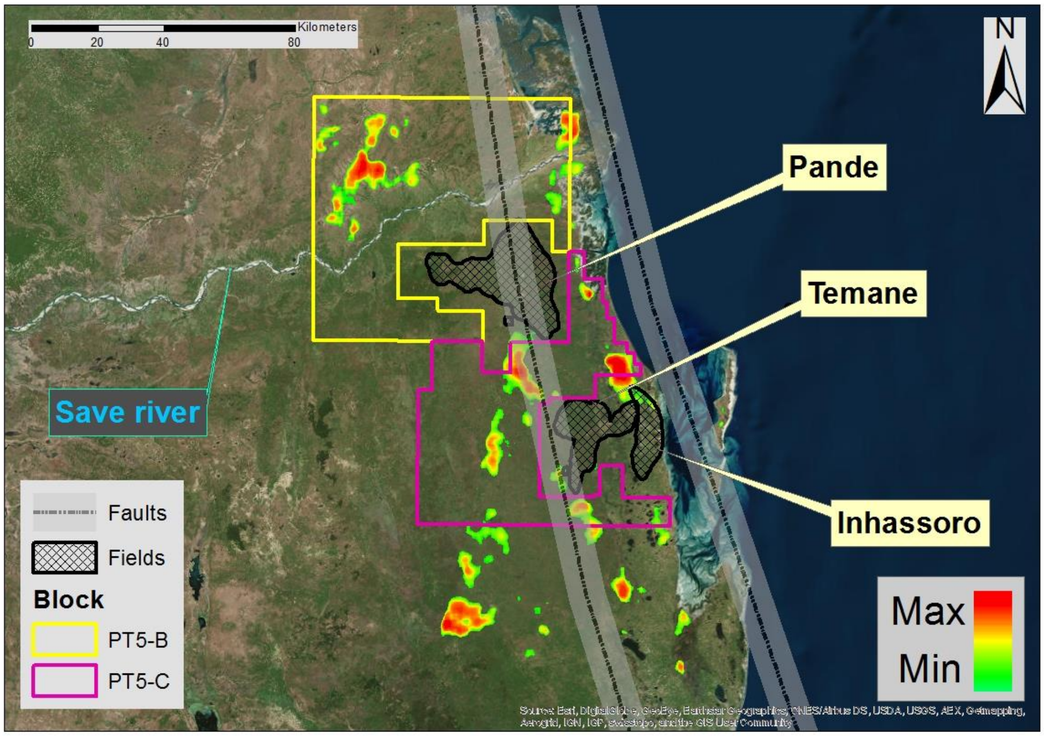

Figure 2. Mozambique: licensing blocks, oilfields and microseepage signals detected from space.

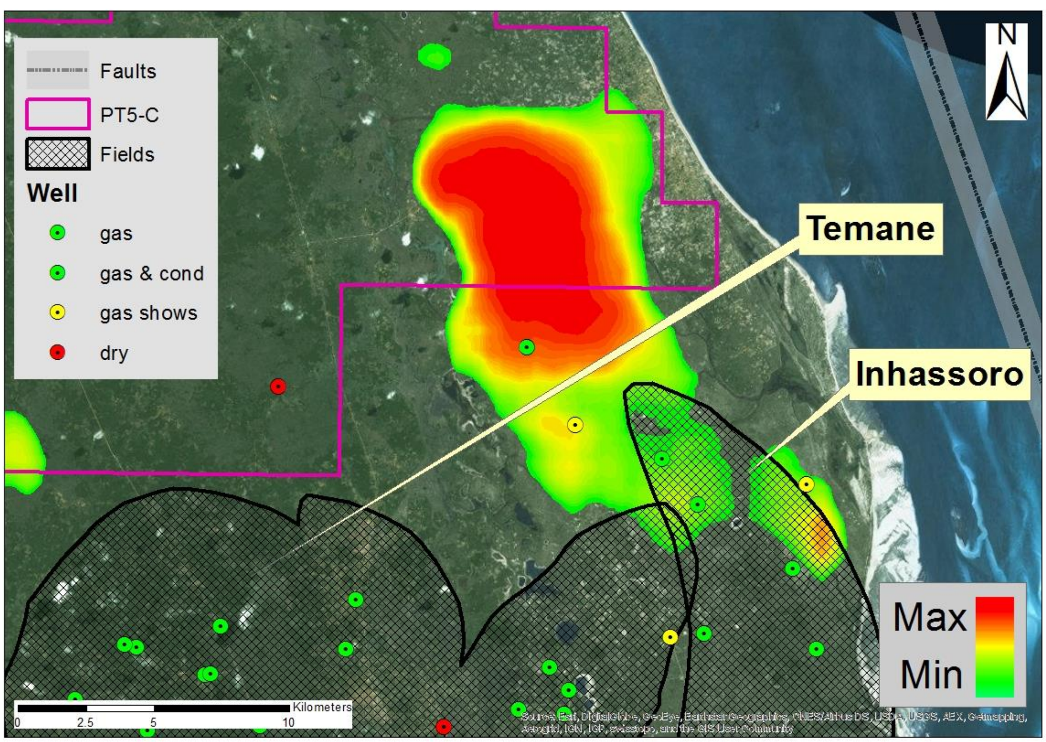

Figure 3. Detail of the microseepage signal extending from the Temane and Inhassoro oilfields into Block PT5-C.

Figure 4 gives an overall picture of a wider geographic area: the Bouguer gravity map of the West and Central Africa Rift System [20] is superimposed to the licensing blocks of South Sudan, Lake Albert [7] and Lake Turkana [8] case studies. The location of microseepage signals, included in the sedimentary basins, clearly highlight the presence of (discovered) oilfields.

Overall, the study points out there is still potential to further develop onshore exploration activities in South Sudan and Mozambique. Unfortunately, the area were is located Block 5A is tormented by civil war and great instability that makes stall on operational activities, while Block PT5-B is still unassigned. In this scenario, Earth observation is a powerful technology to study and highlight active petroleum system from remote, thus reducing operating expenses, optimizing resources and derisking exploration activities.

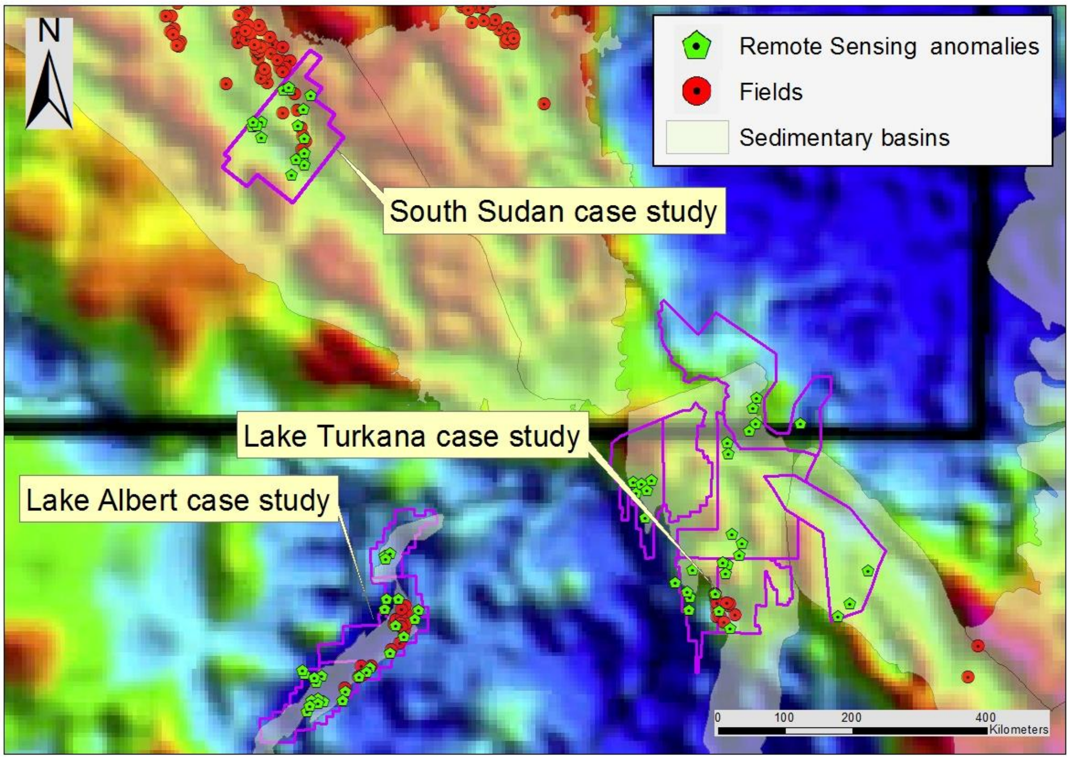

Figure 4. Bouguer gravity map of the West and Central Africa Rift System (from [9]) with superimposed the licensing blocks of South Sudan case study, Lake Albert case study [5], Lake Turkana case study [6], sedimentary basins and discovered oilfields and microseepage signals.

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