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Identification of altered basic igneous rocks from well logs and drill cuttings samples

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Abstract

The correct identification of igneous rocks during well drilling is essential. However, rock alteration can make its identification difficult. In this work, we gather different methods and propose a new one for identifying unaltered and altered igneous rocks through the crossover between K and Fe from spectral-gamma and lithogeochemical well logs, together with cuttings samples observation. Zones with significantly higher K than Fe were identified as acidic to intermediate igneous rocks, zones with significantly lower K than Fe as little to unaltered basic igneous rocks, and zones with similar K and Fe values as altered basic igneous rocks or possibly shales. The inclusion of Ca and Si logs in the same track also allows us to identify the presence of carbonate and sandy rock layers. Differentiation between altered basic igneous rocks and shales can be made through cutting samples observation. We have included photos with examples of altered basalt from two wells.

Introduction

Basic igneous rocks (basalt and diabase) are the magmatic rocks most found during well drilling in Brazil, being present intruding sedimentary sequences or as the basins' economic basement, including being hydrocarbon reservoirs (Mizusaki et al., 2008). The correct identification of these rocks during well drilling is essential in the case of reservoirs (Oliveira, 2023), but it is also relevant if they are part of the basin's basement, to determine when to end drilling. However, alteration – the hydrothermal type generally being the more intense (Mathieu, 2018) – generates changes in the texture and physical properties of these rocks, which can make their proper identification difficult.

Hydrothermal alteration of basic rocks generally changes their color to lighter tones (Schwartz, 1939; Gill and Fitton, 2022), turns cohesion from hard to semi-hard or soft, decreases density and resistivity, and increases porosity, transit time (Pereira et al., 2024) and radioactivity due to potassium enrichment and thus K/Th ratio increase (Mamouch et al., 2022).

Some methods have been proposed by different authors to identify basic igneous rocks through well logs (Souza-Lima et al., 2006; Zou et al., 2013; Ran et al., 2014; De Oliveira et al., 2019; Oliveira et al., 2022). However, little attention has been paid to altered rocks. In this work, we bring together different methods and propose a new one for the identification of acidic to intermediate igneous rocks, unaltered and altered basic rocks.

Method

For this work, eight wells drilled in the Campos and Santos basins were analyzed, including the well logs differential caliper (DCAL), gamma ray (GR), spectral-gamma with potassium (K), thorium (Th) and uranium (U), resistivity (Deep, Medium and Shallow), compressional transit time (DTCO), neutronic porosity (NPHI or TNPH), density (RHOB or RHOZ), photoelectric effect (PEF or PEFZ) and lithogeochemical including the elements Si, Fe, Al, and Ca. These well logs were interpreted using the Interactive Petrophysics (IP) software.

Six wells have laboratory lithogeochemical analyses (major, minor, and trace elements) performed in sidewall core samples. All data mentioned above was made available by the Brazilian National Agency for Petroleum, Natural Gas and Biofuels – ANP. Two wells were analyzed by this work's authors through drill cuttings samples description, X-ray diffractometry (XRD) and X-ray fluorescence (XRF) analysis. The samples were provided by BP.

In this work, we present one well as an example of the results obtained and the new method proposed.

Results

The laboratory lithogeochemical and XRF analysis results were plotted in the diagram by Pearce (1996). Almost all samples are of basalts and alkali basalts.

In this work, we propose the use of the crossover between K and Fe (from spectral-gamma and lithogeochemical well logs) to identify altered igneous rocks. Intervals with Fe considerably higher than K indicate basic igneous rocks while intervals with K considerably higher values than Fe indicate acidic to intermediate igneous rocks.

Intervals of basic rocks with K values above 1% without a decrease in Fe were interpreted as hydrothermally altered rocks. The higher the K value, the greater the alteration. And intervals with similar K and Fe values, where the lines are above each other, were interpreted as highly altered basic igneous rocks or shale.

Differentiation between altered basic igneous rocks and shales can be made through cutting samples observation. Altered basic igneous rocks lack shale's fissility and present dark grey to greenish gray (mainly due to chloritization) and even white (Schwartz, 1939) or reddish (Gill and Fitton, 2022) color, soft to semi-hard cohesion and possibly distinguishable hydrothermal grains as quartz and feldspars. Examples of altered basalt cutting samples from two wells were provided to facilitate the identification of these rocks (**Figure 1**).

Ca and Si were plotted on the same track to help with lithology identification. Intervals with elevated Ca values indicate carbonate rocks and intervals with high Si content and low Ca and Fe content indicate clastic rocks.

Acidic to intermediate igneous rocks can also be identified using the K x Fe crossover. In these rocks, K content increases significantly in relation to Fe, generating a mirrored crossover in comparison to that of basic igneous rocks.

Well 7-LL-15D-RJS is presented here as an example (**Figure 2**). The K x Fe crossover can be used to identify intervals with acidic to intermediate (orange shade between Fe and K) and basic igneous rock (red shaded between Fe and K), with basic intervals with higher K values indicating increased alteration.

Conclusions

The use of the K x Fe crossover combined with the Si and Ca logs proposed here can be used to quickly and effectively identify the presence of basic igneous rocks and differentiate them from intervals with siliciclastic and carbonate rocks. In addition, K x Fe enables hydrothermal alteration estimation in basic igneous rocks and identification of acidic to intermediate igneous rocks.

Limitations to the method are found in intervals with similar values of Fe and K, which can be misidentified as shales. For this case, image examples of altered basalt cutting samples from two wells were provided to facilitate the identification of these rocks and enable basalt and shale differentiation.

Another limitation encountered is the possible unavailability of spectral-gamma and lithogeochemical logs. In these cases, the density x photoelectric effect and Igneability feature (Ig) x gamma ray logs crossovers, proposed by Oliveira (2024), were presented in this work as an alternative to identify the presence of igneous rocks and possibly estimate hydrothermal alteration.

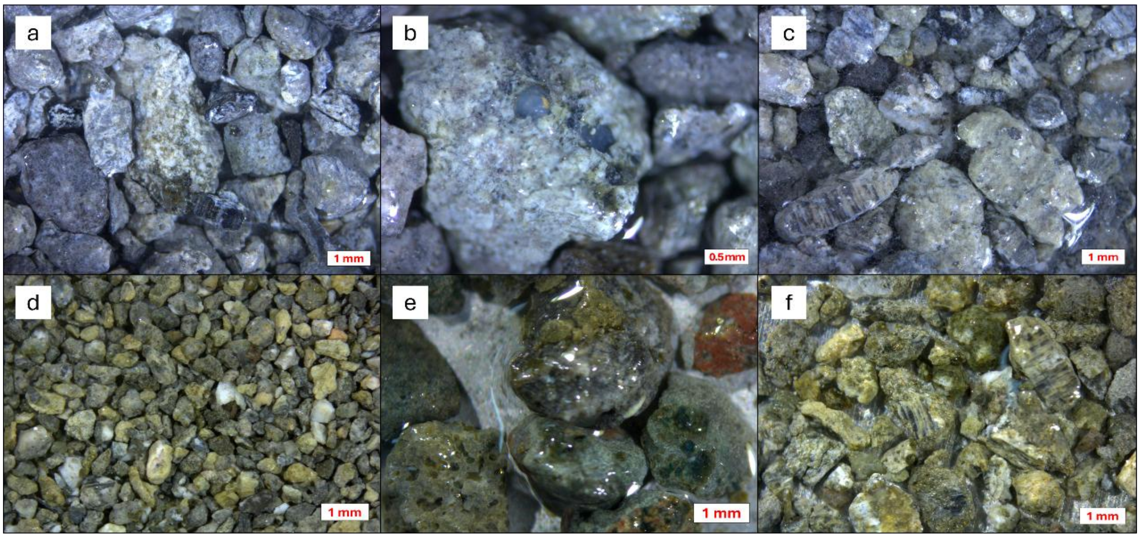

Figure 1: Examples of altered basalt drill cuttings samples from the Cabiúnas Fm. in two wells, presenting grayish to greenish colors, with the presence of an apparent quartz vein (figure b) and other mineralogical alterations (figure e). Figures a-c are from well 3-BP-11-RJS and figures d-f are from well 6-DEV-18P-RJS. Depths of each sample: (a) 6445-6448m; (b), 6463-6466m; (c) 6517-6520m; (d) 5519-5522m; (e) 5561-5564m; (f) 5588-5591m.

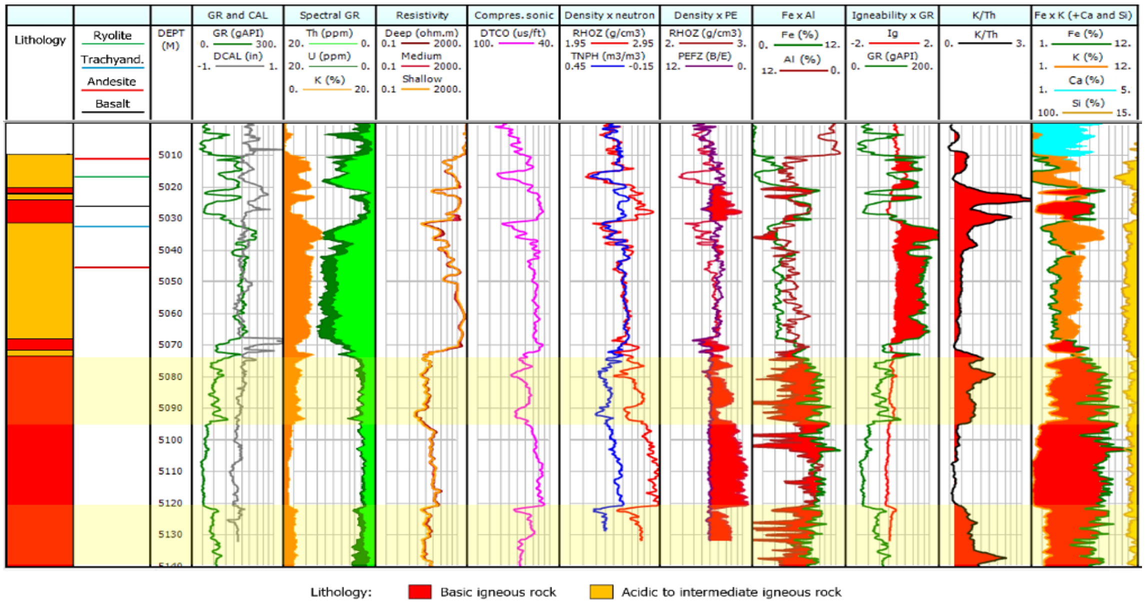

Figure 2: 7-LL-15D-RJS lithology, samples' igneous classification, and well logs. The basal range (5075-5140m) can be interpreted as composed of basic igneous rocks due to RHOZ x PEFZ (De Oliveira et al., 2019), Fe x Al (De Oliveira et al., 2019), and **K x Fe** crossovers. The upper (5075-5095m) and lower (5122-5140m) intervals of this basal range, highlighted in yellow, present indications of alteration, with a high K/Th ratio (Mamouch et al., 2022), decrease in RHOZ and resistivity and increase in K, TNPH, and DTCO in comparison with the middle interval (5095-5122). The acidic to intermediate intervals (lithology track) can be interpreted by the Igneability feature (Ig) x GR (Oliveira et al., 2022) and **K x Fe** crossovers.

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