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Geochemical and thermal effects of a basic sill on black shales and limestones of the Permian Irati Formation

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ABSTRACT

Intrusive rocks are an important heat source for the maturation of organic matter contained in sediments from the Paraná Basin, South America. In this study, we have investigated the geochemical effects induced by the thermal effect of a 13-m thick basic sill intruded on carbonates and black shales of the Permian Irati Formation, which constitutes one of the most important oil source horizons in the Paraná Basin.

Detailed sampling was performed on the sedimentary host rocks located in the upper and lower contacts. XRD mineralogical examination of the host rocks reveals major mineralogical changes induced by the basic intrusion that led to the formation of talc, serpentine and pyroxene. Trace elements and neodymium (Nd) isotopes across the contact indicate that geochemical interaction between the basic magma and the sedimentary rocks was not significant, suggesting that heat was transferred predominantly by diffusion. The data also reveal that: (i) the sedimentary rocks located below the sill are more enriched in hydrous minerals than those in the upper part, suggesting that the sill behaved as a hydraulic barrier to fluid percolation; and (ii) carbonate samples show a systematic decrease in carbon (C) and oxygen (O) isotope values towards the contact, indicating release of CO_2 from carbonate consumption during metamorphic reactions.

Thermal effects are also observed on spores present in black shales. They show coloration index (SCI) values up to 10 for distances below 1.65 m from the lower contact with the basic sill. Beyond this point, the spore coloration index drops to 4–4.5 at 12 m from the contact, which is the deepest point from which samples could be collected.

Assuming that heat was transported by diffusion, we modeled the variation of temperature near the contact using a one-dimensional transfer model of a one-dimensional infinite slab. Modeled temperature across the contact is, however, not compatible with the SCI values, which indicate a narrow thermally affected zone. We argue that heat was absorbed by mineral dehydration, pore water volatilization, organic matter maturation and decarbonization reactions.

1. Introduction

Maturation of organic matter contained in black shales is one of the main sources of hydrocarbons. Maturation is induced by heat, among other factors, related either to the local thermal gradient or to igneous intrusions (Cooper et al., 2007; Golab et al., 2007; Gurba and Weber, 2001; Finkelman et al., 1998; Galushikin, 1997). The thermal effect of an igneous intrusion depends on a variety of different factors, including intrusion and host rock temperatures, nature of the magma and of the host rocks, geometry and depth of the intrusion, mechanism of heat transfer, and other parameters (Galushikin, 1997). Most studies that have addressed the thermal effect of igneous intrusions on coals and black shales have concentrated on the transformations of the organic matter (e.g. Cooper et al., 2007; Amijaya and Littke, 2006; Gurba and Weber, 2001; Flores and Bader, 1999; Meyers and Simoneit, 1999) and on the extent of the thermal maturation (Galushikin, 1997). For instance, modeling calculations suggest that intrusion can affect host rock organic matter maturity up to a distance corresponding to 1–1.5 times its thickness, implying that it may play an important role in hydrocarbon generation, depending on its dimension and extent.

The presence of gas in the Paraná Basin is well-known. It is related to the thermal decomposition of organic matter within rocks from the Irati and the Ponta Grossa Formations. In addition to the thermal effects of burial, another important heat source may have been Cretaceous basaltic magmatism that extended over a large area of the basin. Although these organic-rich rocks provide

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one of the most important gas source horizons in the basin, only limited data exist concerning their thermal evolution and its relationship to the basaltic magmatism.

In the northwestern part of the basin, close to Perolândia city, Goiás (GO), limestone quarries expose sedimentary rocks from the Irati Formation that are affected by basic sill intrusions, allowing a detailed study of the thermal effects of the magmatism on the sedimentary host rocks (Fig. 1). In this report, we have used trace elements and stable (C and O) and Nd isotopes to perform a detailed study across the contact between the intrusive and the sedimentary host rocks in order to better understand their thermal and geochemical interactions and the effects on organic matter maturation. We also address the heat transfer mechanism (advection or diffusion) across the contact and possible fluid-rock interactions.

2. Geology of northwestern Goiás state area

The intracratonic Paraná Basin extends over most of the southern part of South America and has a maximum thickness of 8 km. Six Supersequences are represented in this basin, ranging from Late Ordovician to Late Cretaceous (Milani et al., 1994; Milani and Zalán, 1999) (Fig. 2): Rio Ivaí (Rio Ivaí Group of Ordovician–Silurian age), Paraná (Paraná Group, Devonian), Gondwana I (Tubarão and Passa Dois Groups, Carboniferous-Permian), Gondwana II (Triassic units), Gondwana III (São Bento Group, Jurassic-Cretaceous) and Bauru (Cretaceous) Supersequences.

The Irati Formation, which is well-known for its oil-bearing rocks and fossils, is part of the Permian Passa Dois Group and extends throughout most of the basin (Fig. 1). This unit is divided into the lower Taquaral Member, composed of siltstones and gray claystones, and the upper Assistência Member, formed from organic-rich claystones intercalated with limestone lenses. The organic-rich rocks are black laminated claystones in which the total organic carbon content can be as high as 16.3% (Araújo, 2001). Rocks of the Passa Dois Group are cut by Cretaceous basic intrusions, which represented an important heat source for the maturation of organic matter in the claystones. This unit is stratigraphically located at the base of the Passa Dois Group, which represents the regressive phase within the major Upper Paleozoic transgressive–regressive cycle of the Gondwana I Supersequence (Milani and Zalán, 1999). The paleoenvironmental reconstruction of the Irati Formation and its depositional setting are still controversial and are thought to be either a succession deposited in an epicontinental sea or a continental sequence formed in a lagoon or gulf with variable salinity (Araújo, 2001). This unit has an average thickness of 40 m and extends over an area of 4 million km^2 (South America and Africa). This formation was previously estimated as Late Permian (Daemon and Quadros, 1970; Schneider et al., 1974; Milani et al., 1994). Recent dating of volcanic ash layers have indicated,

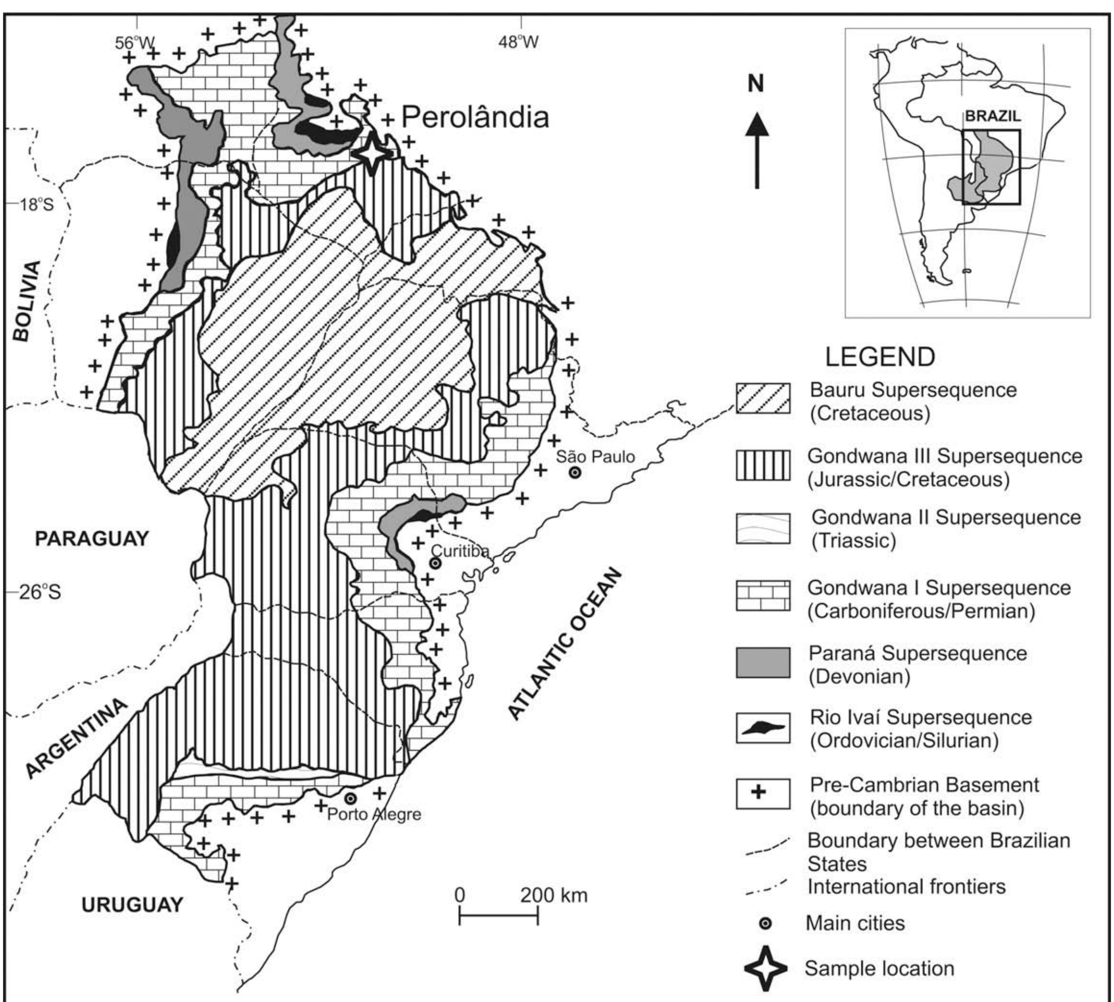

Fig. 1. Geologic map showing the main sequences of the Paraná basin and the location of the Perolândia quarry.