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# Mineralogical and geochemical signatures of clays associated with rhyodacites in the Nefza area (northern Tunisia)

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ABSTRACT

The geology of northern Tunisia is marked by magmatic extrusion that occurred during the Middle Miocene (Langhian–Lower Tortonian), which led to the outcrops of rhyodacites in the Nefza-Tabarka region. This event is contemporaneous with the Alpine compressional phase, which is well-characterised in the western Mediterranean area, where intense fracturing and hydrothermalism occurred with evidence of metallogenic consequences.

In this paper, a detailed study is presented on the acid volcanic rocks that outcrop at the core of the Oued Belif structure in the Nefza area of northern Tunisia. The results indicate that these series have undergone various transformations subsequent to their extrusion. These alterations include ferrugination, silicification, argilitisation and devitrification of volcanic glass.

Petrographic observations demonstrated that the primary minerals, particularly feldspars, biotite and mesostasis glass, were affected by hydrothermal and meteoric weathering. The mineralogical study of the neogenic products revealed a nearly monomineral smectitic phase with relatively low levels of added illite and/or kaolinite. These neoformed smectites were classified as ferroan beidellites–nontronite based on thermal and crystallochemical analyses. Chemical analysis of the major elements, trace elements and rare Earth elements (REEs) show the presence of Al, Fe and K and an enrichment of REE in the clay fraction with a greater fractionation of light rare Earth elements (LREEs) compared with that of heavy rare Earth elements (HREEs). The abundance of these elements is attributed to their mobility during chemical weathering of acidic lavas and their adsorption by clay minerals.



## 1. Introduction

Previous studies on the weathering of volcanic rocks have demonstrated that the most common neoformed mineral is smectite, which is typically associated with illite and kaolinite. These neogene minerals are formed either by hydrothermal alteration or through supergene alteration of acidic or basic lavas (Grim and Güven, 1978; Meunier et al., 1984). Weathering affects primary minerals, such as feldspars, biotites, pyroxenes and mesostasis glass. The alteration products are closely related to the nature of the parent rock and the physicochemical characteristic of the geological environment, such as the transformation agent and the weathering intensity (Christidis, 1998; Ddani et al., 2005). This relationship has been observed in many bentonite deposits associated with volcanic rocks, such as in Trébia, Afrah and Ikasmeouen in Morocco (Ddani et al., 2005) and in Maghnia and Mostaghanem in Algeria (Abdelouahab et al., 1988). In the eastern extension of these north African volcanic provinces (i.e., the Nefza region of northern Tunisia), smectitic minerals have been reported as secondary products of the rhyodacite dome and its related pyroclastic flows or ash fall deposits (Dermech, 1990; Moussi, 2012; Sghaier, 2005; current study). This region presents a suitable environment for the neoformation of smectite by hydrothermal alteration and/or a meteoric alteration process.

The present paper discusses the results obtained from petrographic, mineralogical and crystallochemical studies of the Oued Belif rhyodacites and the identification of their mineralogical and geochemical responses to meteoric and hydrothermal alterations associated with magmatic activity. In addition, this study attempts to characterise the variation of the crystalline structure of smectite

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(as an alteration product) based on the physicochemical characteristics of the geological environment.

In the North African margin, the Miocene period corresponds to a compressive phase, which is typically known as the Alpine phase (Last Burdigalian–Early Serravalian) related to the convergence of the African and Euroasian plates (Tlig et al., 1991). This collision led to the southward overthrusting of the internal zone onto the African passive margin (Late Burdigalian–Langhian), the latter of which was deformed into a fold and thrust to later create the Tellian Zone during the Early Serravallian–Tortonian. This stage coevals with the Sardinia counter-clockwise rotation that led to the drifting stage of the Algiers-Provence West Mediterranean oceanic basin with an initial aperture in the Late Oligocene–Aquitanian (Cohen et al., 1980; Jolivet and Faccenna, 2000; Tlig et al., 1991).

A subsident perimediterranean basin was consequently formed and filled by the Late Oligocene–Early Burdigalian Numidian Flysch (a thick silicoclastic turbidite formation), which was overthrusted to the south onto the Tellian Zone at the end of the Burdigalian (Ould Bagga et al., 2006; Riahi et al., 2010; Rouvier, 1977). Post-dating of the thrusting, several of the volcanic rocks were emplaced along the faulted area (Dermech, 1990; Halloul, 1989; Laridhi Ouazaa, 1994; Mauduit, 1978; Negra, 1987; Rouvier, 1977; Talbi, 1998; Talbi et al., 2005). The last recorded magmatic activities in north Tunisia occurred during the Miocene–Basal Pliocene with a transition of calc-alkaline acid rocks to subalkaline and alkaline basic rocks (Bagdazarjan et al., 1972; Faul and Foland, 1980). The acid rocks primarily occurred in the Galite and Nefza-Tabarka regions during the Langhian to Lower Tortonian (15–8 Ma). On Galite Island, intrusive granitoids are composed of granodiorite, microgranite and granitic aplite. However, in the Nefza-Tabarka region, there are small-scale outcrops that include domes and flows of granodiorite (Ragoubet el Alia), rhyodacite (Ragoubet Es Seid, Aïn Deflaîa and Jebel Haddada) and Oued Zouara pyroclastics (Fig. 1). These acidic rocks are associated with basaltic sills and dykes that occurred during the Upper Tortonian–Messinian (8–5.8 ± 1 Ma) and outcrop in the localities of Boulanague and Mogods. Recently geophysical studies have shown that the extent of the subsurface igneous bodies beneath the Numidian nappes is actually larger than the area occupied by the outcropped volcanic rocks (Jallouli et al., 1996).

In both the surface and subsurface, these igneous rocks have undergone transformations subsequent to their emplacement. Previous studies have shown that post-magmatic alteration is extremely advanced in the pyroclastic rocks (Halloul, 1989; Laridhi Ouazaa, 1994), granodiorites (Dermech, 1990; Halloul, 1989; Kasaa et al., 2003; Negra, 1987; Talbi, 1998) and rhyodacites but is moderate in the basaltic lavas (Halloul, 1989; Laridhi Ouazaa, 1994; Negra, 1987; Talbi, 1998).

The acidic lavas and their pyroclastics have been frequently altered by fumaroles and hydrothermal circulation (Mauduit, 1978; Negra, 1987). As a result, the volcanic glass has been devitrified and transformed into phyllosilicates (Negra, 1987). However, the nature of the secondary phyllosilicates remains to be determined, and their crystallochemical characteristics have not been intensively studied until now. Therefore, this present work focuses on reviewing the clayey transformations undergone by the rhyodacites of Ragoubet Es Seid, which is located in the core of the Oued Belif structure.

## 2. Geological setting

The study area (Oued Belif) is located in the Nefza window that separates the Mogods and the Kroumirie mountains (Rouvier, 1987). This area is limited to the south by Ed Diss jebel (Fig. 1), where Rouvier (1977) defined the Ed Diss Tellian units (Upper Cretaceous to Eocene). This unit consists of alternating marls and limestones and is overlain by the so-called Numidian Flysch. The latter consists of approximately 3000 m of alternating turbiditic sandy and clayey formation of Oligocene–Lower Miocene age (Riahi et al., 2010; Rouvier, 1977; Yaich, 2000). In the north, the Oued Belif structure is bordered by two small post-nappe basins (the Sidi Driss–Tamra basins) which host minor Pb–Zn–Fe ores (Bouzouada, 1992; Decrée et al., 2008a, 2008b; Dermech, 1990; Doumbouya, 1999; Gottis, 1952; Gottis and Sainfeld, 1952; Sainfeld, 1952).

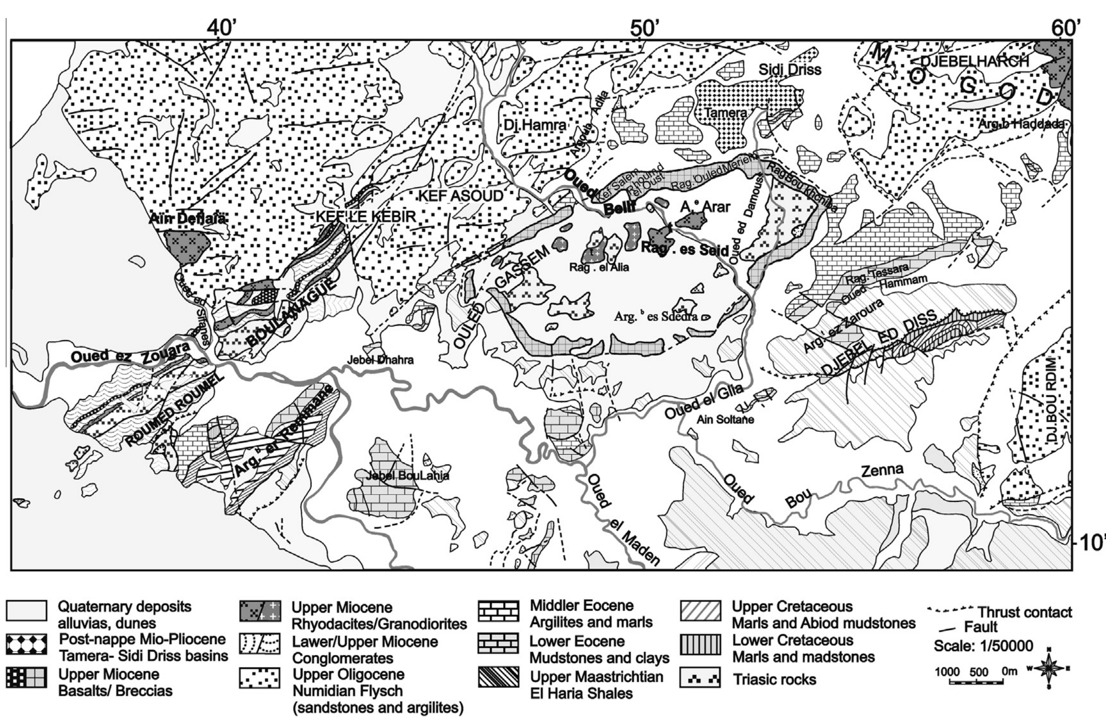


**Fig. 1.** Geological sketch map of the studied area (modified and redrawn from Rouvier, 1977).