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Review

Feldspathic fluxes for ceramics: Sources, production trends and technological value

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ABSTRACT

Feldspathic fluxes are fundamental ingredients of many ceramic products, but little is known about the sources actually utilized by industry and the evolution over time. This paper reviews the sourcing of feldspathic raw materials over a long timespan (1971–2016) including viable substitutes (particularly recycled materials and end-of-life products). A large set of data was collected, critically assessed and elaborated to get an original insight into market dynamics. In addition, the technological value, based on composition and technological properties of different fluxes, is referred to ceramic use and batch design. A detailed analysis of ongoing trends, mainly driven by the technological innovation in the ceramic tile industry, disclosed possible criticalities in the medium-term supply of key raw materials, principally sodium feldspar from albitites. To mitigate this risk, three actions are envisaged to improve the resource efficiency and sustainability of feldspathic fluxes: 1) full valorization of primary deposits, 2) increasing recourse to alternative sources, 3) relaxing the technological constraints in ceramic applications.

1. Introduction

Feldspathic fluxes are fundamental ingredients of many batches for a wide range of ceramic products: wall and floor tiles, sanitaryware, tableware, and related glazes and glassy coatings. Their primary function is to melt during firing, so providing a liquid phase that is responsible for viscous flow sintering and partial vitrification (Kyonka and Cook, 1954; Cambier and Leriche, 1996; Zanelli et al., 2011).

Despite this crucial role, little is known about the production of feldspathic fluxes actually utilized in ceramic manufacturing and its evolution over time under the changing demand of the market. Although feldspar deposits are described in the literature (e.g., McLemore, 2006; Potter, 2006), information available on distinct sources – including substitutes and secondary raw materials – is insufficient to draw a reliable picture of the production and use of ceramic fluxes. Such a picture is essential to foresee industrial needs and unveil possible criticalities for secure supply of fluxes (De Wulf et al., 2016; Meinert et al., 2016), beyond the general assumption that reserves are huge, simply because feldspars are the most abundant minerals in the Earth's crust. Account must be taken that industry demand is linked to the technological behavior of feldspathic fluxes, which varies according to their source, composition, and mineralurgical processing (Dondi et al., 2001; Lewicka and Wyszomirski, 2010). Without these pieces of information, any attempt to predict the future scenario for the supply of ceramic fluxes and to address possible actions is shortcutting or not reliable (Schneider et al., 2015; Speirs et al., 2015).

Official statistics provide a valuable background for commodities like *feldspar* and *nepheline syenite* (Reichl et al., 2015; Brown et al., 2016a, 2016b; EC-RMIS, 2017) even extended over decades (USGS, 1971–2017). However, these databases are not intended to distinguish the various sources, and often do not consider unconventional fluxes, e.g. feldspar substitutes like sericite and volcanic ash, that are locally important for the ceramic industry. In addition, there are problems with nomenclature, since some flux sources are classified in a different way (for instance, the boundary from *feldspathic sand* to *silica sand* varies from country to country). These circumstances generate some gap and mismatch in the figures of feldspar production between the various databases.

About the use of feldspathic raw materials, an up-to-date link between flux properties and ceramic application is lacking in the literature, also because it varies with the technological innovation that is changing processes and products, thus reflecting on batch formulations and raw materials requirements (Dondi et al., 2014). Consequently, not every feldspar source has the same importance from the ceramic industry viewpoint, and some typologies can turn into *key raw materials, i.e.* those commodities essential for given ceramic products and/or to achieve important technical performances (Calas, 2017; CRAM, 2017).

The present contribution aims at providing an up-to-date and complete picture of the production of feldspathic fluxes for ceramics,

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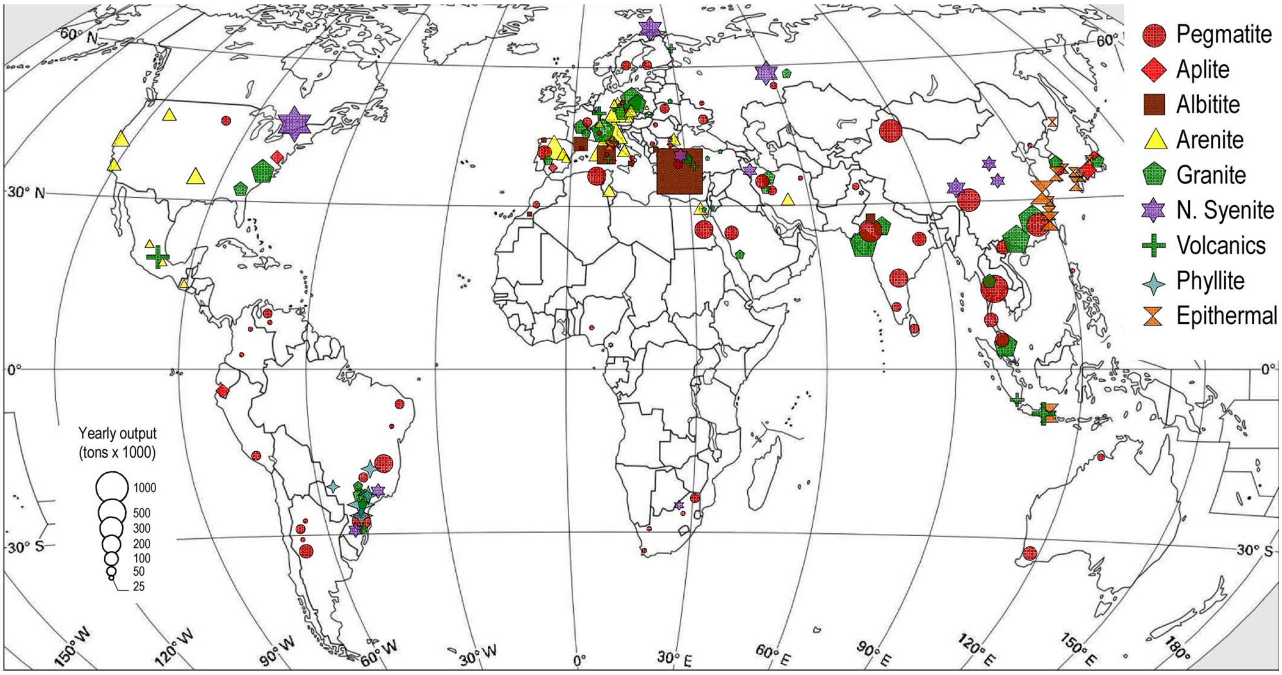

Fig. 1. Distribution of the main mining districts of feldspathic raw materials currently in operation (Dondi, 2018).

through collection, critical assessment and elaboration of data from a wide range of literature as well as statistical and industrial sources. The goal is to get an insight into the dynamics that are taking place in the market of feldspathic raw materials, as dictated by changes in the demand by the major end-users, firstly ceramic tiles and sanitaryware industries. This is essential to draw future scenarios, which can be helpful to assess any risk for secure supply and plan sustainable actions on both industrial sides: producers and end-users of feldspathic fluxes.

2. Methodological approach

Data on the production of feldspathic materials were collected from the official statistics of each country, when accessible, integrated with general databases (Taylor et al., 2005; Brown et al., 2016a, 2016b; Reichl et al., 2015; USGS, 1971–2017; EC-RMIS, 2017) and information made available by mineral suppliers (ICerS, 1995–2016). For some countries, a reverse estimation of the actual flux consumption was carried out, based on the ceramic tiles production figures (Baraldi, 2017), in order to check the declared feldspar outputs and get reliable and robust figures. This operation was performed for any ceramic typology, whose amount of flux is known on average, under the assumption of reasonable values for bulk density and thickness of ceramic tiles in order to convert the tile production (expressed in square meters) into mass of ceramic body (expressed in tons).

Additional information was gathered and elaborated to extract the share attributable to different feldspar sources. This step was accomplished country by country, through a careful evaluation of the literature (e.g., McLemore, 2006; Potter, 2006) including reports of national geological surveys and mining authorities (e.g., Coelho, 2009; Starý et al., 2016; Indian Minerals Yearbook, 2017). However, an exhaustive referencing goes beyond the scope of the present paper and the reader is addressed to an extensive review of flux deposits (Dondi, 2018).

A particular attention has been paid to fluxes that are in use as substitutes of feldspars, with special care on recycled materials, such as mining residues, waste glasses, and so on.

Although the whole set of data extends along the period 1971–2016, the discussion has been focused on the last two decades (since 1994 through 2016).

3. Sources of feldspathic raw materials

3.1. Naturally-occurring raw materials

Feldspathic raw materials are mined from a wide range of deposits in different geological contexts (Fig. 1 and Table 1). In addition, fluxes are recovered from secondary sources too.

The main sources are granitic suites, including acid differentiates (pegmatites and aplites) and the corresponding extrusive and hypabyssal terms (rhyolites, porphyries). Leucogranites are the most important resources among granitoids. Relevant deposits are in operation at: Spruce Pine, North Carolina, and Monticello, Georgia, United States (Potter, 2006); in the *Serie dei Laghi*, Piemonte, Italy (Grisoni and Boriani, 1990); Montebras, Allier, France (Dudoignon et al., 1988); Lower Silesia, Poland (Ciesielczuk et al., 2008; Lewicka and Wyszomirski, 2010); Jundiaí, Itupeva, Sorocaba and Mogi das Cruzes, São Paulo, Brazil (Motta et al., 1998; Motta, *pers. comm.*)

Pegmatites are the traditional source of feldspar and dozens of aplito-pegmatitic fields are mined all over the World (Černý and Ercit, 2005; Dill, 2015). The major districts are in:

- India, Rajasthan (Joshi et al., 2014) and Andhra Pradesh (Sarkar, 2001).
- Thailand, in the Ratchaburi, Ranong and Tak provinces (Suwimonprecha et al., 1993).
- Argentina, in the Sierras Pampeanas (Galliski, 2009).
- China, in Fujian (Yueqing et al., 1987) and Altaj Range in Xinjiang (Zhang and Chen, 2010).
- Iran, particularly in the Sanandaj-Sirjan zone (Masoudi et al., 2002; Khalaji et al., 2007).
- South Africa, in various areas of the country (Von Backstrom, 1976).
- Portugal, in the north and centre of the country (Antunes et al., 2013; Neiva et al., 2012).
- Brazil, principally in Borborema-Seridó, Paraíba and Rio Grande do Norte (Beurlen, 1995) and the Eastern Brazilian pegmatite province, Minas Gerais and Bahía (Bilal et al., 2001).

The major deposits of ‘aplite’ are in the Shigaraki area, Shiga and Mie prefectures, Japan (Hirano and Sudo, 1994); Botro ai Marmi,