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ScienceDirect
Applied Clay Science 33 (2006) 287–297
Applied CLAY Science
www.elsevier.com/locate/clay

A fuzzy expert system application to the evaluation of ceramic- and paper-quality kaolin

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Received 24 April 2006; received in revised form 14 June 2006; accepted 18 June 2006
Available online 14 July 2006

Abstract

This paper describes the results obtained from the application of a fuzzy expert system to the zonification of a deposit in terms of kaolin of a quality suitable for the paper and ceramic industries. In the first stage of the study, mineralogical, chemical and paper quality indices were characterized for samples taken from a kaolin deposit located in Galicia in NW Spain. In the second part of the study the expert system was trained and adjusted on the basis of analytical data, and its reliability in classifying samples in different quality groups was tested.

Data analysis and the design and training of a fuzzy-logic expert system furnish the tool not only with general information inherent to kaolin mining but also with an input in the form of the local characteristics of the studied deposit. This method enables mining experts to identify the areas of a deposit containing kaolin that meets the criteria necessary for enrichment and subsequent use in the ceramic or paper industry. This kind of tool is not only indispensable in planning extraction tasks, but also permits technical and financial risk to be minimized. The model is innovative in that it automatically classified kaolin quality in terms of saleability, thereby emulating the logical reasoning processes of the human expert.

Keywords: Kaolin; Expert system; Fuzzy logic; Fuzzy controller; Ceramic industry; Paper industry

1. Introduction

Kaolin is a mineral resource with many useful properties that is widely used in industry. It is composed of kaolinite, nacrite, dikite ($Si_4O_{10}Al_4$ $(OH)_8$ polytypes) and halloysite and also variable amounts of micas (illite and biotite), feldspars and quartz. The precise composition of kaolin depends on its origins; primary or residual kaolins develop as a result of hydrothermal alterations or silicate meteorization, whereas secondary or sedimentary kaolins are formed by the erosion, transportation, sedimentation and authigenesis of primary kaolins (Prasad et al., 1991; Konta, 1995).

A wide range of industrial sectors make use of kaolin in products such as pesticides, plastics, paints, cosmetics and drugs. However, the industries which make the greatest use of kaolin are the paper and ceramic sectors. The properties required for kaolin for the paper and ceramic industries tend to vary. For paper filling and coating, whiteness, low abrasivity and a high proportion of fine granulometric fractions are important, whereas for ceramic, in addition to a high whiteness index, it is important for

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doi:10.1016/j.clay.2006.06.003

the material to have relatively low viscosity at high solid concentrations. All these properties depend on raw material kaolinite content, the degree of mineral crystallinity (structural order), particle size, specific surface, and the presence of any impurities that might alter the colour of the initial mix and the mix after firing (Bundy and Ishley, 1991; Prasad et al., 1991; Konta, 1995; Galán et al., 1996; Raghavan et al., 1997; Galán et al., 1998; Galán, 2003).

Research into kaolin deposits has focused on analysis and interpretation of mineralogical, chemical and rheological properties of the samples collected during prospection (Ligas et al., 1997; Yuan and Murray, 1997; Cravero et al., 1997, 2001; Dondi et al., 2001; Saikia et al., 2003). However, unlike other mineral resources (Taboada et al., 1997, 1998, 1999; Taboada et al., 2002), no methodologies have been described for zonification of kaolin deposits on the basis of saleable resource quality. In Galicia (NW Spain), non-metallic mining for minerals such as kaolin is a key economic resource; although published works represent an indispensable reference in relation to the extensive mineralogical and chemical information on the different kaolins in the region (Campillo et al., 1987; Conde-Pumpido et al., 1988; Ferrón et al., 1990a,b; Gámiz et al., 2005), yet lacking are methodologies for exploitation planning. Raw mineralogical composition and granulometry are not homogeneous throughout a kaolin deposit, as there are areas containing good quality material and other areas in which the material fails to meet with the criteria required for the product to be considered saleable. The availability of an automated tool for characterizing the quality of a kaolin deposit prior to exploitation would be extremely useful, as it would improve exploitation planning by minimizing technical and economic risk; it would also significantly reduce the environmental impact of mining, as extraction benches would only be opened for saleable-quality kaolin.

Among the different computerized data treatment systems available, expert systems are programs that simulate the human reasoning process. The first systems of this type, dating from the 1960s, were developed in the artificial intelligence field (Kandel, 1991). The basic idea behind an expert system is that expertise – a vast body of task-specific knowledge – is transferred from a human to a computer. Expert systems have become very popular in recent years; see, for example, Liao (2005) and Bojórquez-Tapia et al. (2002) for descriptions of different applications. Expert systems applied in the ornamental rock mining field to the evaluation of final quality have also produced successful results (Taboada et al., 2004; Matías et al., 2004a,b; Bastante et al., 2004, 2005).

In expert systems, the efficacy in emulating human reasoning is enhanced by the use of fuzzy logic. Fuzzy logic is an approach to handling imprecise data that simulates the natural human reasoning process, permitting less precise and logical behaviour than in conventional computerized systems. See Kandel (1991) for a description of the theory of fuzzy logic and fuzzy expert systems; applications of fuzzy procedures to different problems in engineering are also described in Baja et al. (2002), Bojórquez-Tapia et al. (2002), and Carrasco et al. (2004), among others.

Given that decisionmaking is not always a simple matter of 'true' or 'false', a fuzzy logic approach to data processing is useful in several research areas. Kaolin mining – where quality criteria are not fixed – falls under the umbrella of the kind of problem that can be resolved by the application of an expert model. Kaolin quality is assessed as good or poor on the basis of a number of variables (chemical, mineralogical, etc.) defined by a range of values, some of which have a greater weighting than others in the definition of good quality kaolin. A fuzzy-logic expert system would ideally emulate the process of evaluation of these variables as performed by a human expert using experimental data.

In this work we describe a fuzzy-logic expert system applied to the evaluation of the quality of a kaolin deposit. The method implemented in this work uses a modified Mamdani Controller (Mamdani and Assilian, 1975), which establishes an ordered decision sequence, specified by the programmer, that can be adapted to a resolution of the different problems. The fuzzy system described here is novel in terms of its design, as it is adjusted following training with a local sample. The procedure is also original, as this is the first time that a methodology of this kind is applied to the classification of samples of mineral into quality groups on the basis of commercial value.

The article is structured in two basic phases. In the first stage, mineralogical and chemical composition and paper quality indices are determined for kaolin samples taken from the studied deposit. In the second stage, on the basis of the results obtained in the first stage, the parameters that define ceramic and paper quality are identified and the fuzzy expert system is applied to the classification of samples, resulting in the development of an automatic mineral classification system.

2. Materials and methods

2.1. Geological context

The kaolin deposit that forms the basis for our study is located in Vimianzo (A Coruña) and belongs to one of the most important kaolin mining areas in Galicia (NW Spain). These deposits date from the Upper Eocene and are associated with the Malpica-Tui Unit, a geological formation that stretches across