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Quantitative analysis of the clay minerals in the Shurijeh Reservoir Formation using combined X-ray analytical techniques

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Abstract

The Shurijeh Reservoir Formation of Neocomian age is represented by a sandstone sequence, occasionally interbedded with shale, in the Gonbadli gas field, Kopet-Dagh Basin, Northeastern Iran. In this study X-ray diffraction (XRD) and X-ray fluorescence (XRF) techniques were used together to characterize the Shuirjeh clay minerals in 76 core samples collected from two deep Gonbadli wells. The results of XRF analysis showed high percentages of silicon and moderate to low percentages of aluminum, sulfur, calcium, potassium, sodium, magnesium, and iron in both wells. The XRD analysis indicated that the above elements were concentrated in the form of quartz, anhydrite, dolomite, calcite, plagioclase, K-feldspar, hematite, and clay minerals. Further XRD examination of the clay fraction revealed that illite, chlorite, and kaolinite were the major types of clay minerals. Unlike, glauconite, smectite, and a mixed layer clays of both the illite–smectite and chlorite–smectite types were observed only in very few samples. The percentages of individual clay minerals were determined using external standard calibration curves and successfully validated by a system of simultaneous linear equations acquired from detailed elemental information based on the XRF analysis. The error reached ±5% for the main mineral constituent and ±15% for minor minerals. A local regression relationship was also derived, based on the XRF elemental information, which can be used to estimate the clay contents of other Shurijeh drilled wells with data of pulsed-neutron spectroscopy tools. According to the proposed quantitative approach, the amount of illite varied considerably, reaching 18.3%. In contrast, the amounts of kaolinite and chlorite were generally small, i.e., less than 8.4%. The amount of total clay minerals changed greatly from a minimum of 5% to a maximum of 32.5%. An increase in illite with increasing burial depth and temperature was an obvious indication of deep burial diagenesis in this formation.

Keywords: clay mineralogy; Shurijeh Reservoir Formation; X-ray diffraction; X-ray fluorescence; quantitative mineralogical analysis

Introduction

Clay minerals are of prime importance in the hydrocarbon reservoirs, due to their direct contribution to the production strategy. The most abundant clay minerals in the sandstone reservoirs are kaolinite, illite, chlorite, smectite, and a mixed layer of illite-smectite. Since they can greatly affect the chemical and physical properties of the reservoirs (Worden and Morad, 2003), a good knowledge of types as well as the absolute amounts of clay minerals is necessary for the characterization studies of clastic reservoir. The important role of quantitative clay mineralogy in the provision of a successful and reliable reservoir description has been intensely studied (Bandaru, 2010; Hurst, 1987; Hurst and Archer, 1986; Sarkisyan, 1972; Soto Becerra et al., 2010; Wilson and Pittman, 1977). In most studies, X-ray diffraction (XRD) method has shown the remarkable ability to calibrate the well logs in terms of mineralogy; especially for the fine grained clay minerals (Bouchet et al., 2000; Causey, 1991; Crain, 2000; Krinari et al., 2014; Pierce and Siegel, 1969). It is known that under ideal conditions, the peak intensities of an XRD diffractogram are proportional to the concentrations of individual minerals present in the sample. Hence, the qualitative mineralogical data obtained from X-ray diffraction method can be quantified, using either the internal or external standard methods (Chung, 1974a, 1974b), or the whole pattern methods (Smith et al., 1987) such as the Rietveld algorithm (Rietveld, 1967, 1969), Arquant model (Blanc et al., 2007), and the so-called Le-Bail and Pawley method. Explanation of some other methods using

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absorption intensity factors or just intensity factors can be also found in Kahle et al. (2002). The conventional XRD standardization is mainly based on conducting a regression analysis against datasets obtained from the standard patterns. The external standard quantification method is based on using standard samples with identical diffraction characteristics to the same minerals in the original samples.

Johns et al. (1954), Sudo et al. (1961) (see also Aoki et al., 1974), Biscaye (1965), and Siegel et al. (1981), have studied clay minerals semiquantitatively, assuming 100% of the <2 μm fraction represented by the sum of the weighted peak areas of the clay minerals. A review of quantitative analysis of clay minerals is given by Ronald (1967), Alexiades and Jackson (1966); Pierce and Siegel (1969), Cody and Thompson (1974), Heath and Pisias (1979), Brindley (1980), Smith et al. (1987), Snyder and Bish (1989), Thornley and Primmer (1995), Moore and Reynolds (1997), Hillier (2000), Ottner et al. (2000), Ruan and Ward (2002), Kahle et al. (2002), Ouhadi and Yong (2003), Chittoori and Puppala (2011), and Wang et al. (2011). However, if very accurate quantitative mineralogical data are required, then the X-ray method alone is unable to obtain it, due to many factors such as the peak interferences (Moor and Reynolds, 1997), varying microstructures and different mass absorption coefficients in minerals (Ouhadi and Yong, 2003), various defects in crystals (Srodon et al., 2001), the suitability level of standard sample (Mitchell and Soga, 2005), amorphous existence (Jackson and Barak, 2005), disaggregation state (McManus, 1991), various possible alterations from initial chemical pretreatments (Moor and Reynolds, 1989), separation of particle sizes (Brindley, 1945), some variation in the packing of samples (Jackson and Barak, 2005), preferred crystallites orientation in the prepared slides (Dollase, 1986), and, finally, method of assessing proportions from the diffraction pattern (McManus, 1991). Klute (1986) has reviewed the detailed influence of the mentioned factors on the diffraction maxima. The clay contents of sandstones represent only a very small fraction of the whole sample and since the other phases, notably quartz, dominates in them, quantification becomes more difficult. As a result, if a more precise quantification is needed, it should be achieved by the help of elemental composition information obtained from the X-ray fluorescence or any other instrumental techniques of the elemental analysis (Calvert et al., 1989; Thornley and Primmer, 1995). In this combined method, the percentages of each mineral identified by the XRD are obtained by solving a number of simultaneous equations. The results of many studies (Braun, 1986; Engler and Iyengar, 1987; Hodgson and Dudeney, 1984; Hussey, 1972; Johnson et al., 1985; Kolka et al., 1994; Laird and Dowdy, 1994; McNeal and Sansoterra, 1964; Paktunc, 2001; Pearson, 1978; Prandel et al., 2014; Rosen et al., 2004) imply that employing both methods can provide efficient quantitative mineralogical data with sufficient accuracy, which is applicable to the technical needs.

Although many previous studies of the quantitative clay mineralogy in the sandstone reservoirs have been carried out, comparatively little attention has been given to the study of clay minerals in the clastic reservoirs with complex lithology. The heterogeneous sandstone Shurijeh Formation is one of the most important as well as the most challenging gas reservoirs, which properly characterize the eastern Kopet-Dagh sedimentary Basin, Northeastern Iran. In this study, having known the types of clay minerals in the Shurijeh Formation, relevant percentages present in 76 core samples from two deep drilled wells in the Gonbadli gas field were calculated by the external standard method and validated by the detailed elemental information obtained from the XRF analysis.

Geological setting

The core data for this study were collected from a gas producing and other nonproducing deep vertical wells drilled in the Gonbadli gas field of Eastern Kopet-Dagh sedimentary Basin, NE Iran. The Kopet-Dagh, an Iranian tectonosedimentary unit, extends from east of the Caspian Sea to Northeast Iran (Fig. 1). It formed in an extensional regime after the closure of Palaeo-Tethys in the Middle Triassic (Alavi et al., 1997) and the opening of Neo-Tethys during the Lower to Mid Jurassic (Buryakovsky et al., 2001). The sedimentation in the eastern Kopet-Dagh went on rather continuously and over 8000 m sediments were deposited from Jurassic through Miocene (Afsharharb, 1979). The Jurassic–Cenozoic sedimentary sequences unconformably overlie the Palaeozoic basement and Triassic rocks (Ulmishek, 2004). This region hosts both the Khangiran and Gonbadli gas fields.

The Gonbadli gas field was drilled in 1969 on the Gonbadli structure, an elongated and symmetrical anticline, located in the eastern part of the Kopet-Dagh sedimentary Basin, some 25 km southwest of Sarakhs town, between two productive structures of Dowlat-Abad in the east and Khangiran in the west (NIOC, 1986). The reservoir rock in the Gonbadli field consists of the Lower Cretaceous, Shurijeh sandstones, deposited under arid and warm conditions, in a variety of continental, coastal, and marine environments (Moussavi-Harami and Brenner, 1993). The Shurijeh Formation includes mixed red bed siliciclastic sediments, mostly fine to medium grained rocks (shales, siltstone and sandstones) with occasional intercalations of evaporates and carbonates lithofacies, overlying the limestone of Mozduran Formation (Upper Jurassic) and capped by the Tirgan Formation (NIOC, 1986). The Shurijeh Formation approximately starts some 3 km below the rotary tables with a varying thickness from 174.5 m to 259.1 m in the Gonbadli drilled wells (NIOC, 1986). Based on extremely variable lithology, Shurijeh was divided onto upper, middle and lower parts with five lithological units as lithofacies A, B, C (subdivided into C_1 and C_2 units), D (subdivided into D_1 and D_2 units) and E (Table 1) within which, the sand rich unit of D_1 is characterized as the main sweet gas bearing zone in the area under study, with production capacity of 1.1 Mcm/d (NIOC, 1986). Four of the main points of difference between D_1 and D_2 and C_1 and C_2 units, are summarized in the degree of cementation, formation fluid type, the amount of porosity and matrix (NIOC, 1986). The thickness of reservoir unit, D_1,