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General characteristics of quartz arenite types and their role in the recognition of sequence stratigraphic boundaries in ancient coastal and near shore sediments. A case study from Egypt and Saudi Arabia

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ABSTRACT

Quartz arenites are useful in the recognition of depositional sequences and cycle boundaries in ancient coastal and near shore facies. In this study two types of quartz arenite are recognized: 1) depositional quartz arenite (calcareous, dolomitic, ferruginous and kaolinitic quartz arenites), and 2) diagenetic quartz arenite (orthoquartzite, siliceous quartz arenite, compact quartz arenite, and dedolomitic quartz arenite). Depositional quartz arenite often occurs on the tops (upper boundaries) of the depositional sequences that are bounded by sequence boundaries (with or without evidence of subaerial exposure) or correlative conformity surfaces that mark the change from forced regression to lowstand normal regression. Therefore, depositional quartz arenite can define the upper boundaries of third and fourth-order depositional sequences, cycle bases and tops (boundaries) within lowstand, transgressive and high-stand systems tracts. Diagenetic quartz arenite (orthoquartzite, siliceous quartz arenite and dedolomitic quartz arenite) usually occurs at the tops (upper boundaries) of depositional sequences that have sub-aerial sequence boundary and have been subjected to prolonged subaerial weathering and hence is closely associated with subaerial unconformity sequence boundary surfaces and consequently indicates a sharp drop in sea level. Thus, diagenetic quartz arenite types can be used to recognize the tops (upper boundaries) of first and second-order depositional sequences. Compact quartz arenite that is considered the fourth type of diagenetic quartz arenite consists entirely of packed quartz grains, but lacking cement, occurs at the base of each fining-upward cycle (lower boundaries) in lowstand systems tracts and may define the bases of some different-order depositional sequences.

1. Introduction

The recognition of sequence boundaries either in the outcrop or in the subsurface is a fundamental task in sequence stratigraphic analysis. The sequence stratigraphic framework may consist of three different types of sequence stratigraphic units e. g. sequences, systems tracts, and parasequences (Catuneanu et al., 2011). Each type of unit is defined by specific facies relationship, strata stacking patterns and bounding surfaces. Sequence stratigraphic surfaces are surfaces that can serve, at least in part, as systems tract boundaries (Catuneanu, 2006; Catuneanu et al., 2011). Seven sequence stratigraphic surfaces have been attributed by Catuneanu et al. (2011) and Embry (1995, 2001) such as subaerial unconformity, correlative conformities, maximum flooding surface, transgressive revinement surface, maximum regressive surface, and regressive surface or marine erosion. In the present study we try to show the importance of each type of quartz arenite type in the above mentioned bounding surfaces.

The sequence boundary records a break in sedimentation and may juxtapose markedly different facies assemblages above and below the boundary (Miall and Arush, 2001). In fluvial sequences, the sequence boundary is defined as the surface at which erosion and fluvial incisions have taken place due to base level fall, with incised valleys reaching depths of tens of meters (Wright and Marriott, 1993; Shanley and McCabe, 1994). Some sequence boundaries can be recognized by different facies indicators in different settings. For example, in most fluvial environments sub-aerial exposure may lead to soil development, plant colonization and bioturbation by animal activity (Miall and Arush, 2001). Pedofacies paleosol is characteristic exposure of the alluvial plain (Kraus and Bown, 1988), and may define sequence boundaries in

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the interfluve and be used for sequence mapping (McCarthy and Plint, 1998; McCarthy et al., 1999). Sequence boundaries in shallow marine settings have several characteristic features the most important of which are hard ground, paleokarsts, bioturbation, plant roots, caliches, duricrust and pedogenesis.

One reason for studying quartz arenites and their characteristics is to help in recognizing cycle and depositional sequence (boundaries) in the depositional sequences in fluvial, coastal and nearshore facies. This may assist with some of the difficulties in the recognition of sequence boundaries either in outcrop or in the subsurface that result from: 1) the lack of recognizable unconformity surfaces; 2) the difficulty in identifying sequence boundaries in monotonous and homogenous clastic sequences; or 3) the absence of subaerial facies e. g. paleosol, calcretes, paleokarasts and caliches. The present study suggests sedimentological clues for the recognition of depositional sequence and cycle bases and tops (boundaries), based on the following facts: 1) quartz arenites are sensitive to climatic changes and weathering products (McBride, 1989; Abdel Wahab et al., 1998); 2) diagenetic quartzarenite can be formed from arkosic sandstone at deep burial due to increase in temperature and compaction and destruction of K-feldspar (Wilkinson et al., 2001), 3) Supermature quartzarenite is recognized near shallow burial in St. Peter Sandstone (Cook et al., 2011), 4) the diagenetic quartz arenites are recorded at the tops of sequence boundaries (Dapples, 1955; Sloss, 1988; Khalifa, 2015); and 5) quartz arenites are common in siliciclastic and mixed siliciclastic-carbonate depositional sequences in coastal and near shore shelf facies (Khalifa, 2015). Hence, the occurrence of quartz arenite in a stratigraphic sequence provides a clue, that with other criteria, to aid in the recognition of depositional sequence and cycle boundaries. The study of quartz arenite types and their petrographic characteristics may aid in the recognition of sequence boundaries as suggested by Zuffa et al. (1995) and discussed in detail in this paper, through identification of the compositional and temporal characteristics of sand grains. Amrosi and Zuffa (2011) stated that sand composition of arenite successions is sensitive to a suite of factors operating between initial grain production and final diagenesis on a variety of spatial and temporal scales. These results indicate that arenite petrofacies changes can be applied into a sequence-stratigraphic framework on multiple time scales.

The choice of studied sections from Egypt and Saudi Arabia (which are from different parts of the Paleozoic and Mesozoic Eras) is relevant to solving these problems. Because these sections occur in the stable shelves and were subjected to major tectonic movements that enable the sandstone to be subjected to numerous weathering processes on the unconformity surfaces.

The objectives of this study are: 1) to differentiate quartz arenite types, based on petrographic features (framework composition and cements); 2) to indicate the possible setting of each type of quartzarenite within the depositional sequence; 3) to unravel and discuss the links between the spatial and temporal distribution of quartz arenite types within depositional facies and the sequence stratigraphic framework.

2. Geological setting

2.1. Egypt

Egypt lies in the northeast of the African Plate, where it forms part of the Sahara Craton (El Emam et al., 1990), a passive continental margin of Gondwana. During its passive margin phase the North African margin was also influenced by stages of compression, strike-slip and extension in specific areas (Guiraud et al., 2005). Most notably in the Arabian-Egyptian region, the margin was affected by tectonic inversion along the Syrian Arc (Garfunkl, 1999). Geologically, Egypt includes three facies belts or units,: the Arabian-Nubian Massif facies belt in the south, southern facies belt in the central region; and the northern facies belt in the extreme north (Khalifa et al., 2016) (Fig. 1). The Arabian-Nubian facies belt (Neo-Proterozoic) occur in the southern Western Desert, the eastern parts of the Eastern Desert (Red-sea hills) and the southern Sinai and consists of gneisses, granitoids, and meta-sedimentary rocks. It was formed by early evolution from the accretion of island arcs (during New-Proterozoic) and of oceanic terrains (Stern, 1985; Guiraud et al., 1987, 2005). The southern facies belt (equivalent to stable shelf of Said, 1962) onlapped on the Arabian-Nubian Massif facies belt extending in a northeast-southwest direction (Fig. 1). It represents a platform consisting mostly of Araba (Cambrian), Naqus (Ordovician–Silurian), Malha, (Early Cretaceous), Bahariya (Early Cenomanian), El Heiz (Late Cenomanian), El Hefhuf (Turonian-Santonian), Ain Giffara (Campanian). The last sequence is capped by the Khoman Chalk (Maastrichtian) (Fig. 1). The northern facies belt (equivalent to unstable shelf of Said, 1962) is coeval to the southern facies belt, and was affected by the Syrian Arc System (Late Cretaceous), which formed trending northeast-southwest anticlinal and synclinal structures. The northern facies belt (sequences) in this study comprises the Araba (Cambrian), Naqus (Ordovician-Silurian), Um Bogma (Early Carboniferous), Abu Thora (Late Carboniferous), Qiseib (Permo-Triassic), Raqaba (Triassic-Jurassic), Malha (Lower Cretaceous), Galala/Raha (Cenomanian), Abu Qada (Cenomanian-Turonian), Wata (Turonian), Matulla (Campanian) and the Sudr Chalk (Maastrichtian) (Fig. 1). The Hercynian Orogeny affected the southern facies belts, where it retarded the deposition during Silurian, Devonian, Carboniferous, Permian, Triassic, and Jurassic (Fig. 1). This made a prolonged hiatus between the top of the Naqus Formation and the Lower Cretaceous Malha Formation (443.7–145.5 my) (Fig. 1). The Laramide Revolution occurred between the Lower Cretaceous Malha Formation and the Cenomanian Galala Formation, making a wide gap or hiatus starting from 112 to 99.6 my. Also, the Hercynian Orogeny affected the northern facies belts, where it retarded the deposition during Devonian. This made a prolonged hiatus between the top of the Naqus Formation and the Lower Carboniferous Um Bogma Formation (Fig. 1).

2.2. Depositional environments and sequence stratigraphy of the selected studied sequences in Egypt

The Cambrian Araba sequence overlies the Precambrian basement rocks on nonconformity. This depositional sequence consists of fluvial facies (fining-upward cycles) at the base of lowstand systems tract, transgressive tidal facies (shallowing-upward cycles) in the middle and highstand marginal marine (fining-upward cycles) in the upper parts (Khalifa et al., 2006) (Fig. 2A). The Ordovician-Silurian Naqus sequence unconformably overlies the Cambrian Araba sequence and is overlain by the Lower Cretaceous Malha sequence (Fig. 2A). The Naqus sequence was deposited in fluvio-glacial environments and includes one first-order depositional sequence (501–443.7 my) (Fig. 2A). Due to uplift during the Hercynian Orogeny, deposition of the Naqus sequence was followed by a long nondepositional hiatus that continued until the base of the Lower Cretaceous Malha sequence (443.7–145.5 my). At Gebel El Zeit (Red Sea, Egypt), the Lower Cretaceous Malha sequence overlies the Ordovician-Silurian Naqus and underlies the Cenomanian Galala sequences. Here, it consists mainly of fluvial facies (fining-upward cycles) and includes one second-order depositional sequence (125–99.6 my). It comprises siliceous sandstone with plant roots in its upper part (Fig. 2B). In the above locality, the Cenomanian Galala sequence comprises mixed clastics and carbonates of marginal to shallow marine environments (shallow