6- Petrography and SEM investigations

Mudrocks are fine-grained sedimentary rocks consisting mostly of silt and clay. Mudrocks sometimes called argillite. Because of their small grain size, mudrocks are difficult to study, even with the petrographic microscope. The are importance of the mudrocks is based on their abundance, making up over 65% of all sedimentary rocks; further mudrocks are the source rocks for petroleum and natural gas, and are sometimes valuable ore deposits.
Classification of mudrocks is mainly based on observations in the field or at the level of hand specimen. The classification of mudrocks depends on the mudrock texture which includes, the fissility or the lack of fissility, and laminations mainly based on the grain size of the minerals making up the rock. The fissility of mudrock is depending on several factors, including the abundance, the degree of preferred orientation, and the recrystallization of clay minerals. Fissility is caused by the tendency of clay minerals to be deposited with their sheet structures [(001) crystallographic planes] parallel to the depositional surface. A fissile rock tends to break along sheet-like planes that are nearly parallel to the bedding planes.

The more clay minerals contained in the rock, the more likely the rock is to be fissile. Small clay minerals tend to adhere to one another if they collide during transport. This tendency is promoted by increased salinity of the water and the presence of organic matter in the water. Adhesion of small mineral grains is referred to as flocculation. If the clay minerals flocculate, then they are less likely to have a preferred orientation, and thus less likely to form rocks with fissility. If the clay minerals recrystallize during diagenesis, they will tend to do so with a preferred orientation with their (001) crystal planes oriented perpendicular to the maximum principal stress direction. This process also results in slatey cleavage and foliation in metamorphic rocks. If diagenesis occurs shortly after deposition, then it is likely that the maximum principal stress direction will also be oriented perpendicular to the bedding planes. The bioturbation of organisms within or on the surface of the sediment can disturb the preferred orientation of clay minerals, and thus lead to a non-fissile rock.

Laminations are parallel layers less than 1 cm thick. Such laminations can represent differences in grain size of the clastics in different laminae due to changes in current velocity of the depositing medium, or could be due to changes in the organic content and oxidation conditions at the site or time of deposition of the different layers.

Most mudstones fall into two classes in terms of their color. Gray to black color usually indicates the presence of more than 1% organic matter in the form of carbon or some carbon compound. Red, brown, yellow, and green colorations of mudrocks are a reflection of the oxidation state of Fe in the sediments. Under oxidizing conditions most of the Fe will be Fe^{+3} and give the sediment a red coloration as in hematite.

The petrographical investigation in the present work is mainly concerned with defining the mineralogical composition, texture, matrix and diagenesis which can be described and observed under the polarizing microscope. Most of the studied shales are exceedingly uniform in composition, relatively fissile and don't show bioturbation (burrows etc.). The Abu Zinema samples of Carboniferous age, Al Maghara coal mine samples of Jurassic age and both Abu Tartur phosphate mine and the lower part of Nile valley samples of Maastrichtian age are almost completely lacking fossils, while Quseir phosphate mines and the upper part of the Nile Valley section samples of Late Maastrichtian to Early Eocene age are rich in foraminiferal tests.The petrographical investigations of the studied carbonaceous shales and associated sediments reveal the following lithofacies:

6.1 Organic matter-rich black shale facies

This facies shows a dark gray to black colour. It is dominant in the black shale of Ataqa Formation of Carboniferous age at Abu Zinema, Safa Formation of Jurassic age at Al Maghara coal mine and Duwi Formation of Upper Cretaceous age at Abu Tartur phosphate mine. In thin sections, Ataqa Formation samples are composed of silty to sandy claystone, brownish in colour, carbonaceous, nonfissile, bioturbated, and nonfossiliferous. The quartz grains are of silt size grading into fine sand, angular to subangular, and are poorly sorted Appendix (Plate 1 A). This may reveal a rapid burial of the sediments during the time of deposition in lakes or lagoons with prevailing reducing conditions which leads to preservation of carbon and carbon compounds in rocks. The angular quartz grain shape in this facies indicates a near source area. Safa Formation samples are composed mainly of brown claystone, ferriginous, non fossiliferous, wisps of kerogen and dark organic matter filled burrows, wavey laminae and bioturbation Appendix (Plate 1 B). The oriented texture and disrupted shale lamination indicate bioturbation as the dominant fabric forming process during the deposition of this facies (Neal et al. 1998). This may indicate that Safa Formation was deposited in lagoons adjacent to the coastline. The black shale of Carboniferous and Jurassic age of Ataqa Formation at Abu Zinema and of Safa Formation at Al Maghara coal mine may have been deposited in reducing conditions. Reducing conditions usually occur in stagnant water where little circulation takes place. This can occur in restricted aquatic environments, like swamps, lakes or lagoons.

The SEM investigations show that kaolinite is the dominant clay mineral in the studied shales of Ataqa Formation at Abu Zinema and of Safa Formation at Al Maghara coal mine as it was also identified by XRD. The SEM observations show swirly textures with face to face arrangement of coarse detrital kaolinite Appendix (Plate 2 A), suggesting a detrital origin (Keller 1978; Manju et al 2001). Furthermore, kaolinite occurs as discrete, poorly crystallized clasts with angular or irregular geometry, an indication that reworking has taken place Appendix (Plate 2 B). The characteristic vermicular and booklet shape of authigenic kaolinite, as well as the blocky crystals of diagenetic kaolinite, are completely absent.

In diagenesis, the morphology of kaolinite changes from vermicular or aggregates of books to individual blockier crystals (Ehrenberg et al. 1993). In the studied shales there is no evidence for the role of diagenesis in the formation of clay minerals.
In thin section it is shown that the Duwi Formation is composed of brownish, ferriginous, nonfissil, nonfossiliferous, and massive claystone Appendix (Plate 3 A). The SEM observations show that smectite is the dominant clay mineral in the studied shales of Abu Tartur phosphate mine samples, Quseir phosphate mine samples and the Nile Valley section. Generally, all the smectite group minerals are characterized by extremely fine-grained, poorly defined particles, with diffuse outlines and curled edges. The montmorillonite particles can be regarded as aggregates a foliated and lamellar aggregate structure also addressed as (papery structure) (Plate 3 B). This may be the result of the expulsion of water and gas during the compaction and oxidation of organic matter see also (Keller et al. 1986).

Pyrite is very dominant in the black shales of Abu Tartur phosphate mine samples. The pyrite is found as disseminated particles, crystals, clusters globular framboids, irregular masses, bands and small nodules. The most common forms of pyrite observed under the SEM are framboidal and euhedral crystals or masses Appendix (Plate 4 A&B). These two textural forms are related to the availability of iron within the sediment, which control the trace element composition of these sediments. The formation of framboids can only be related to the abundance of carbonaceous matter intimately mixed with the detrital iron and preserved under the strongly anoxic stratified water column which is necessary for sulphide formation. Moreover, the dominant occurrence of the framboids, particularly the clustered forms, in organic-rich shales tends to indicate a biogenic origin as a consequence of the bacterial reduction of seawater sulphate (Berner 1982). This process cannot take place in the presence of dissolved oxgyen, because the bacteria that accomplish it are obligate anaerobes. In most pelagic sediments either dissolved oxgyen is present, or there is so little reactive organic matter that sulphate reduction does not take place and consequently, no pyrite forms (Berner 1981).

Thus, the studied highly pyritic shales from Abu Tartur must have formed under euxinic conditions at which H_2S exists above or at least at the sediment water interface. The presence of H_2S in turn, will react with Fe^{2+} which was probably delivered into the basin as colloidal material adsorbed on clay minerals to form iron sulphide. By increasing activity of the hydrogen sulphide in presence of iron and organic matter, a hydrophobic sulphide might have been formed (El-Dahhar 1987). As a result of the biological activity, precipitation of sulphide around bacteria in the gel will promote the development of pyrite globules rather than other forms. Preservation of the framboids from further deformation is accomplished partly by precipitation of an inorganic sheath-like envelope due to a slight increase of acidity (McBain 1954).

6.2 Foraminifera-rich shale facies

This facies is characterized by the presence of foraminifer's shells (Appendix, Plate 5 A&B). This facies rarely shows any sedimentary structure other than bioturbation, and sometimes microlamination; the latter is usually flexed around foraminiferal tests. This may reveal that these foraminiferal tests were deposited in situ, in calm water conditions. The foraminifer's shells are scattered througout the matrix. The matrix is composed of clay (mainly smectite and traces of kaolinite) and organic matter. Detrital quartz is relatively uncommon and iron oxides may be present within the foraminifer's tests and as pore fillings. This facies characterises the Dakhla Shale samples at Quseir phosphate mines and both Dakhla and Esna Shale at the Nile Valley section. The abundance of planktonic foraminifera in this facies gives evidence of a marine environment of deposition.

6.3 Carbonate facies

The carbonate lithofacies can be subdivided into bioclastic limestone and chalky limestone. Bioclastic limestone usually caps the underlying shales and phosphatic rocks at Quseir phosphate mines and Esna-Idfu at Nile valley. It consists mainly of oyster shell fragments, and few foraminiferal tests embedded in a micritic, microsparitic or sparitic matrix (Appendix, Plate 6 A) in Particular oyster limestone bed in Quseir is very rich in oyster fossils. The depositional regime in the bioclastic subfacies is revealed by the presence of micritic carbonate pellets and fossil fragments. This association may reflect a high energy marine environment (Longmann1980).

The chalky limestone subfacies is mainly represented by the Tarawan Chalk which overlies Dakhla Shale and underlies Esna Shale at the Nile Valley section. It is composed mainly of chalky, fossiliferous limestones, of micritic, microsparitic or sparitic texture (Appendix, Plate 6 B). Foraminiferal tests are embedded in the micritic matrix and sometimes filled with iron oxide (hematite).The presence of sparite in micritic ground mass in this subfacies reflects a marine environment with normal salinity, low energy and a considerable distance from the land mass (Dunham 1962).

6.4 Phosphatic facies

The term phosphorite is applied to rocks containing more than 18 % P_2O_5 (Kolodny1981; Slansky 1986). The petrography of phosphate is based on three categories: grains (coated and uncoated), biophases (bone fragments and fish teeth), and matrix. Apatite is the main constituent in the phosphorite beds in Abu Tartur phosphate mine, Quseir phosphate mines and in the Duwi Formation at the Nile Valley section. The apatite is represented by peloids (coated and non-coated grains), microfossils, microsphere aggregates and sometimes as megafossils, bone fragments and fish remnants (Appendix, Plate 7 A, B&C). Uncoated grains are predominant and represent about 80% of the phosphatic grains. The grains are oval, elongated or irregular shaped.

The coated grains represent about 10 % of the phosphatic grains. They are characterised by inorganic or biogenic nuclei surrounded by a cortex, various layers of phosphatic coatings. The biophases concentric mainly of bone fragments of different forms. The matix consists of carbonate, silica or carbonate - silica matrix. Selley (1988) stated that the bulk of the worlds bedded phosphates occur in the famous phosphate belt which stretches from Syria through the Levant, Sinai, Egypt, Morocco and into Mauritania. These phosphates resulted from the upwelling of oceanic currents from the Tethys onto the broad continental shelves along its southern shore. The optimum depth for phosphate formation is 30–200m. Based on morphological arguments, apatite particles in both modern and ancient phosphorite have been interpreted as phosphatized bacteria. It is established that microorganisms participate in the precipitation of a spectrum of minerals in aquatic environments (Simkiss and Wilbur 1989; Mclean and Beveridge 1990). The studied phosphate samples show that the phosphatic beds vary in composition from one area to the other. This may indicate a basically shallow water depositional environment, which was influenced periodically by both marine conditions and terrigenous influx.