Petrophysics of Palaeogene sediments

Changes of physical properties of sedimentary rocks with increasing burial depth have implications in hydrocarbon explorations. Physical properties of buried sediment are controlled by several factors such as mineralogical composition, depositional texture and burial depth. The main theme for this Ph.D. study is petrophysics of Palaeogene sediments, aiming to gain better knowledge and understanding of the petrophysical characteristics of the studied sediments. To limit the scope, the Ph.D. study focused only on three selected lithologies: 1) the Eocene chalk of the Atlantic Ocean basins, 2) the siliceous ooze sediments from the Norwegian Sea, and 3) the Palaeogene shale from both the Atlantic and the Danish basins. The three geological settings differ in water depths, temperature, effective stress and pressure. If the factors governing physical properties of the studied lithologies are well defined and understood this would benefit various areas in petroleum industry.

The three studied lithologies are relatively soft and weak sediments, but they are economically important especially in petroleum industry. Drilling through intervals of shale or siliceous ooze sediments could result in severe and very costly borehole instability problems which are closely connected with the "bulk properties" of shale. In practice, the main technological challenge is to keep the borehole sufficiently stable until casing is set. Knowing the real in-situ effective stress is crucial to understand and to predict the geomechanical behaviour of shale. Biot's coefficient (β) for elastic deformation is an important parameter involves in the estimation of effective stress. However, engineers usually assume β equal to one when estimating in-situ vertical effective stress on buried sediments, but, this assumption is not always right, especially for the deep-sea cemented sediments where the water depth is high, and it may underestimate the real effective stress which may lead to severe engineering consequences such as a petroleum reservoir may suffer compaction or deformations as a result of changing in stress state during drilling operations and hydrocarbon production, or even during massive excavations for building tunnels. If the effective stress exceeds the strength of the rock, failure develops. Thus, estimating a more realistic effective stress allows determining the optimum drilling parameters to reduce problems related to borehole stability. This Ph.D. study stressed on the importance of using correct β value in estimation of vertical effective stress especially on deep-sea sediments. To assess the geomechanical stability and the stiffness of the three studied lithologies, their β was found and used to calculate the in-situ vertical effective stress.

The primary objectives of this Ph.D. study were: 1) to investigate and evaluate the influence of mineralogical composition, depositional texture and burial depth on petrophysical properties of Palaeogene sediments and to find out how the physical properties are related; 2) to know the stiffness of the studied lithologies based on their β values; and 3) to link the diagenesis of siliceous ooze with logging interpretation. The secondary goals were: to show how crucial is the use the correct value of β on estimation of vertical effective stress especially on deep-sea sediments; to establish a relationship between static and dynamic modulus of shale which could be used to estimate geotechnical drained elastic modulus from bulk density and sonic velocity. The influence of burial depth on physical properties of Atlantic Palaeogene shale and Eocene chalk has been studied. Changes in physical properties of the Atlantic Palaeogene shale as a function of burial depth was related to the vertical effective stress and shale mineralogy. The influence of choice of β value on estimation of effective stress on deep-sea shale was shown. The obtained results could be relevant for drilling, basin analysis, seismic interpretation and hydrocarbon exploration. The diagenesis of Eocene chalk was studied. The changes of porosity and sonic velocity trends of the studied chalk were related to effective stress and time–temperature index (TTI) of thermal maturity of chalk. For each depth, effective stresses as defined by Terzaghi and by Biot were calculated. It is concluded that the use of the Biot's effective stress concept provides more realistic estimate of vertical effective stress of the studied chalk. Bottom-hole temperature data were used to calculate the TTI as defined by Lopatin. Porosity and compressional wave velocity data were correlated with effective stresses and to TTI. Based on the results, an equation to predict porosity reduction with increasing burial stress in chalk was proposed. The proposed equation is relevant for basin analysis and hydrocarbon exploration to predict porosity if sonic velocity (e.g. seismic velocity) data for subsurface chalk are available.

A possible hydrocarbon prospect of the Mere Basin siliceous ooze in the Norwegian Sea has been proposed, but siliceous ooze is significantly different in texture from most commonly known hydrocarbon reservoirs. This Ph.D. study includes results of petrophysical and the amplitude versus offset (AVO) analyses of siliceous ooze. Based on fundamental relationships, ways of correcting density and neutron porosity logs were proposed. Additionally, the values of β and the AVO signature of water saturated siliceous ooze were obtained. A new approach for deriving reliable and accurate porosity of siliceous ooze is proposed here. The true density porosity was calculated by taking the number of electrons per unit volume into account. The true density porosity is similar to the corrected neutron porosity which indicates that the proposed interpretation is consistent. The proposed approach can be applied elsewhere and could be useful for petrophysics community. The studied siliceous ooze intervals apparently do not contain hydrocarbons.

X-ray diffraction (XRD) analyses and surface area by BET method have been done on 116 sediment samples collected from different geological units in the Fehmarn Belt area which is located between Denmark and Germany. Based on the XRD and BET results, ten preserved whole-core samples of the Palaeogene clay were selected and used in the laboratory testing for studying the elastic deformation properties of the naturally water saturated Palaeogene clay. Hence, this Ph.D. study presents the results of a wide characterization of Palaeogene clay. The main focus was on elastic properties which were examined and analysed in terms of mineralogical, physical and geotechnical properties. Elastic wave velocity is controlled by the elasticity and the density of a material. The deformation properties and the velocity of elastic waves were measured here simultaneously during triaxial testing under drained conditions. Geotechnical and elastic wave velocity data were used to model the elasticity and to relate it to clay mineralogy and BET. The mineralogy, BET, classification parameters, elastic wave velocities and strain caused by mechanical loading on the ten studied clay samples were measured and used together to interpret the geotechnical data and
to observe the effect of mineralogy on elastic properties. The aim was to see which physical property is a main controlling factor for the elasticity of the Palaeogene clay and whether the deformation behaviour can be explained from elasticity alone. The obtained results can aid in the estimation of geotechnical drained elastic modulus from bulk density and elastic wave velocity and may have implications in engineering practice, including structural design and slope stability analysis.