論文の内容の要旨

論文題目

A study on the shallow overpressures and related geohazards in deepwater environments: a case study in the Ursa Basin, Gulf of Mexico.

(大水深域における浅部過剰間隙水圧発生および関連する地質災害に関する研究ーメキシコ湾 Ursa 堆積盆地を例としてー)

氏　名: グエン　ビン　テイ　タイン

To explore and produce hydrocarbons safely and efficiently in deepwater environments, it is important to have good understanding on pore pressure, hydrogeology, and distribution of physical properties of the sediments in shallow subsurface. It is because occurrence of shallow overpressures can relate to geohazards such as shallow water flows, submarine landslides, mud volcanoes, and so on.

Shallow water flows are the uncontrolled flow of unconsolidated sands and pore water that occur during drilling operations under the marine environment. They generally occur at shallower depths below the seafloor but in deepwater, and are marked by a variety of seafloor damage including: (1) uncontrolled flow of sands up and around the annulus of the borehole being drilled; (2) sand and pore fluid 'volcanoes' on the seafloor near the drill site; (3) craters on the seafloor; (4) borehole washouts; and (5) cracks on the seafloor. Another important geohazard at shallower depths is the slope failure which can be caused by the combination of the lower effective stress condition and the lower shear strength of the sediments due to the existence of shallow overpressures and the delay of compaction.

This thesis aims to understand the evolution of shallow overpressures and the possible occurrence of related geohazards in the deepwater environments by conducting three-dimensional basin modeling studies together with laboratory experiments.

In Chapter I, the occurrence of shallow overpressures and related geohazards are reviewed and previous studies on the topics are summarized. It is shown that there are few data on rock physical properties in shallower sections and also few studies on shallow overpressures. Thus, acquiring knowledge on the physical properties and processes which affect the pore pressure development, conservation and dissipation in shallower depths in sedimentary basins is expected to provide the information on the distribution and magnitude of overpressures and shallow water flows. Following the reviews, the objectives of the thesis work and approaches taken are presented together with the structure of the thesis.

Chapter II describes an overview of the geological framework of the Ursa basin, deepwater Gulf of Mexico, and well sites where samples were taken and in-situ pore pressure and temperature measurements were conducted.

Chapter III presents methods, apparatus, and results of the laboratory experiments conducted to obtain physical properties of the sediments.

Consolidation tests were first carried out on soft sediments including silty clays, clays and hemipelagic clays to obtain porosity/permeability relationships, preconsolidation pressures, porosity/effective stress relationships and earth pressure coefficient at rest. Consolidated undrained triaxial compression tests were also conducted to obtained strength parameters.

Major results obtained from laboratory experiments are summarized as follows:

Two porosity/permeability relationships for hemipelagic clays and silty clays/clays were obtained. Hydraulic conductivities were indirectly evaluated from both incremental load (IL) tests and constant rate of strain (CRS) tests. Good agreement exists between the obtained relationships from the IL tests and CRS tests.

Preconsolidation pressures (Pc) were obtained from IL and CRS tests using the Casagrade's method. Based on the obtained preconsolidation pressures and calculated in situ vertical effective stresses of the samples tested, the in situ pore pressures were estimated.

Three different porosity/effective stress relationships for hemipelagic clays, clays and mass transport deposits were obtained. These relationships were obtained from intervals with hydrostatic pore pressure conditions. To determine the pore pressure conditions, both in-situ pore pressure measurements and pore pressures calculated from preconsolidation pressure were used.

Strength parameters including cohesion (c') and internal friction angle (ϕ') for clays and mass transport deposits were obtained from consolidated undrained triaxial compression tests. To conduct the tests under the in situ condition, it was necessary to estimate horizontal effective stress. Here, the K_0 ring tests were conducted to estimate the ratio of the horizontal effective stress to the vertical effective stress, and used the ratio to set up the experimental condition.

Chapter IV shows a detailed study on the compaction process, especially the temporal change of the pore pressure and fluid flow patterns in the Ursa basin from 100,000 year ago to present using the three-dimensional basin modeling technique. The distribution of overpressured sands obtained from 3D basin simulation was consistent with the areal distributions of shallow water flows recognized from petroleum exploration and production wells. Obtained results also showed that disequilibrium compaction and existence of sheet sands in the Blue Unit and the channel sands within canyons of the overlying sequence, i.e., the Ursa Canyon and the South West Pass Canyon systems, mainly controlled shallow overpressures and lateral flow.

Overpressures built up soon in the Ursa basin after sediments started to deposit above the Blue Unit due to the high sedimentation rates of low permeability sediments. These overpressures almost dissipated at 50 ka due to the reduction in sedimentation rate and deposition of silty clays with slightly higher permeability. Severe overpressures built up again during the rapid deposition from 22 ka to 17 ka. From 5 ka to present, overpressures have partially dissipated due to the lower sedimentation rate. Modeling results indicated that, at present day, the sands within the Blue Unit and the channel-fills above have pore pressures about 0.9 and 1.2 MPa above hydrostatic pressure, , respectively, corresponding to the pore pressure ratios of 0.2 and 0.6.

Results from 3D simulation also showed that the paleo-fluid flows in the sands of the Blue Unit seemed to be affected by the Ursa Channel. In addition, paleo-lateral flows may have played important roles in transmitting pressure from upslope area to downslope area and resulted in changing effective stress conditions and consequently changing the consolidation stage of sediments in the downslope area.

The rapid sedimentation and resulting overpressure during the Holocene turned out the sediments with shear strengths low enough for gravity sliding to occur on the slope of the Ursa basin. Based on the estimated overpressures from the simulation, estimated vertical effective stress and measured strength parameters from laboratory experiments, failure of the upper sedimentary column in the Ursa basin could occur on slope angles as small as 6°. Deep seated failure which rooted at least 200 mbsf can occur with slope even smaller of about 5.5° due to higher pore pressure ratio and lower cohesion intercept.

Finally, in Chapter V, the results of this study are summarized and future perspectives are presented.