Marine and Petroleum Geology 78 (2016) 848–869

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

Research paper

Compaction of smectite-rich mudstone and its influence on pore pressure in the deepwater Joetsu Basin, Sea of Japan

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A R T I C L E I N F O

Article history:
Received 17 November 2015
Received in revised form
8 July 2016
Accepted 11 July 2016
Available online 16 July 2016

Keywords:
Overpressure
Mechanical compaction
Chemical compaction
Diagenetic transformation
Illitization of smectite
Deepwater Sea of Japan

A B S T R A C T

Pore pressure prediction is needed for drilling deepwater wildcats in the Sea of Japan because it is known from past experience that there can be drilling problems can arise due to overpressure at shallow depths. The “Joetsu Basin” area is located offshore to the southwest of Sado Island on the eastern margin of the Sea of Japan. The sedimentary succession of the Neogene is mainly composed of turbidite sediments which contained smectite-rich mudstones. The cause of overpressure in the study area is expected to be a combination of mechanical disequilibrium compaction and chemical compaction, especially from the illitization of smectite.

We have constructed basin models and performed numerical simulations by using 1D and 3D PetroMod to understand clearly the history of fluid flow and overpressure development in the lower Pliocene Shiya Formation and Middle to Upper Miocene Teradomari Formations. A compaction model coupled with both mechanical and chemical compaction for smectite-rich sediments is used for pore pressure calibration. We have examined three key relationships: porosity-effective stress, porosity-permeability, and the kinetics of smectite-illite transformation. We determined the ranges for the parameter values in those relationships that allow a good fit between measured and modelled pore pressures to be obtained. Results showed that for the most likely case, high pore pressure in the Lower and Upper Teradomari developed since 8.5 Ma and 5.5 Ma, respectively. Pore pressures in studied structures have approximately doubled since 1 Ma due to the high deposition rate of the Pleistocene Haizume Formation and smectite-illite transformation in the lower Pliocene-Shiya and Middle to Upper Miocene- Lower and Upperr Teradomari formations. In three cases (high case, most likely case and low case), the overpressures in the Shiya, Upper and Lower Teradomari Formations are less than 1 MPa, 15 and 30 Ma, respectively.

The results provide a basis for planning future wells in the “Joetsu Basin” area and in other basins where geological conditions are similar, i.e., deepwater, high sedimentation rate, high geothermal gradient and smectite-rich sediments.

1. Introduction

Knowledge of pore pressure is essential in well design and execution for the selection of mud weight and casing points. The accurate prediction of pore pressure and leak-off pressure is particularly important for deepwater drilling operations because of extremely high drilling cost (e.g., Huffman, 2002; Elliott et al., 2011).

The “Joetsu Basin” area is spread on the Western part of the Niigata Basin in the Sea of Japan (Fig. 1). The Niigata basin has been known as a petroleum basin and produced oil and gas since 1880's in onshore (Hirai et al., 1995). At recent years, petroleum exploration is conducted for offshore area too. Among others, deep water exploration has been consulted on the “Joetsu Basin” area where is

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http://dx.doi.org/10.1016/j.marpetgeo.2016.07.011

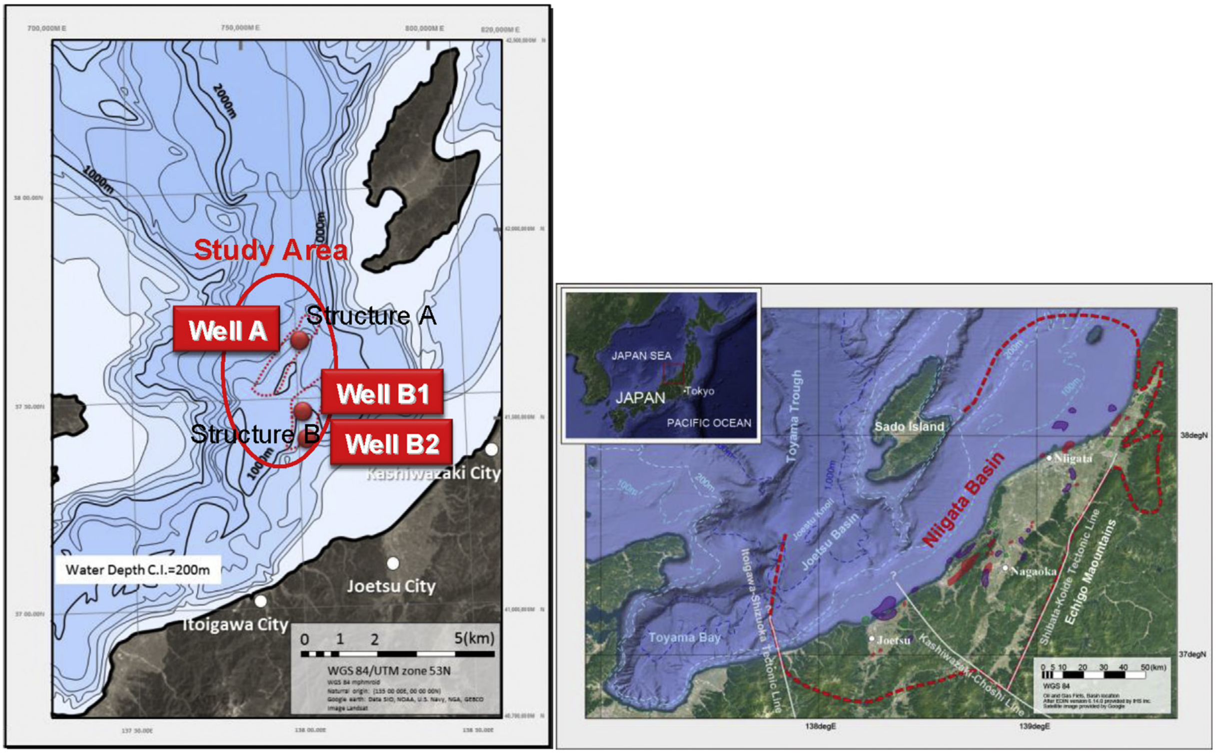

Fig. 1. The location of study area.

in water depth of 800–2000 m. Moreover the "Joetsu Basin" area is recently highly regarded by methane hydrates discovery (Matsumoto et al., 2009; Hachikubo et al., 2015). The regional tectonic setting of the "Joetsu Basin" area is under NW–SE trending compression at the present day. Shallow overpressure starts at less than 1200 m below the seafloor (mbsf) and magnitudes are up to 16 MPa. Three hydrocarbon exploration wells including Well A, Well B1 and Well B2 have been drilled in the basin, and significant rig time was lost when drilling through the smectite-rich overpressure transition zone. The Well B1 was side tracked due to encounter high over pressure at the Lower Teradomari formation. Moreover the Well A was not able to reach deeper section by the narrow pressure window even though conducted pre-drill pore pressure estimation by using several methods, including Eaton, Bowers and basin modelling (Okawa et al., 2016). Measured pore pressures at depth were higher than those we predicted. The primary motive for this post-well study is update our model using new data obtained from wells newly drilled, and to gain better understanding of the pore pressure distribution for future well planning in exploration of the basin. A second motive is that the pore pressure distribution is an important parameter for seal analysis above potential hydrocarbon accumulations.

X-ray diffraction analysis of the Miocene to Quaternary sediments from ODP sites 794, 795 and 797 in the Sea of Japan showed that the section from the upper Miocene to the lower Pliocene section contains 30–60% of smectite derived from the volcanic arc (Fagel et al., 1992; Aoki et al., 2008). Smectite-rich sediments may be intimately linked to the overpressure, with the smectite-illite transition affecting the onset of overpressure in the subsurface (Powers, 1967; Colten-Bradley, 1987). Illitization of smectite in the Miocene mudstones is completed in the southern part of Niigara Basin over depths ranging from ~800 mbsf to ~3800 mbsf, and depends on palaeotemperature and the chemistry of the mudstones (Niu et al., 2000). Compaction of smectite-rich mudstones depend on mechanical compaction and chemical compaction resulting from clay diagenesis, dominated by the kinetic reactions involved in the transformation of smectite to illite. In this study, we present basin modelling simulations using Petromod 1D and 3D in which pore pressure is generated from the coupled processes of mechanical compaction and clay diagenesis.

The thermal history was calibrated by using a combination of apatite fission track analysis (AFTA), vitrinite reflectance (VR), Rock-Eval pyrolysis to determine Tmax, and fluid inclusion data. By conducting a sensitivity analysis, we propose a workflow for pore pressure prediction by using basin modelling for deepwater areas where there are smectite-rich sediments.

The basic work flow in this study involves the following steps:

- Define lithology and clay minerals in the formations. Carefully construct porosity-effective stress and porosity-permeability relations for each type of lithology, especially smectite-rich mudstone.
- Run 1D basin modelling for pore pressure evolution. Calibrate the thermal history by using Horner-corrected bottom-hole temperature (BHT) data, VR, Tmax, AFTA and fluid inclusion data. Use pressure measurements from MDT tests and porosity measurements on rock samples and estimated from density logs to calibrate the pressure modelling.
- Conduct a sensitivity analysis on 1D models to see how much difference it made to the estimated pore pressures when the porosity-effective stress and porosity-permeability relationships were changed and different kinetic parameters were used to model smectite-illite transformation.
- Use the 1D models to give a reasonable input dataset for 3D modelling.

This procedure can be used in similar geological settings with deep water, high sedimentation rates, high geothermal gradients and thick smectite-rich mudstones. The results should substantially reduce the risk of erroneous pressure predictions before drilling,