Solving the chalk mystery

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A piece of chalk in a laboratory at the University of Stavanger in Norway may be the key to unlock a great mystery. If the mystery is solved, it will generate billions in additional income for the oil industry. Associate Professor Merete Vadla Madland at the Department of Petroleum Engineering at the University of Stavanger is leading a group of geologists, petroleum engineers, rock mechanics, physicists, mathematicians and chemists who are now switching between modelling and experimental testing at the chalk laboratory. They are about to uncover the mechanisms behind water weakening. The answer to this riddle is crucial knowledge for oil companies to be able to predict the reservoirs' behaviour.

It was just before Christmas, an excited post doctor at the International Research Institute of Stavanger (IRIS) spotted something quite extraordinary through the scanning electron microscope she was using. Tania Hildebrand-Habel immediately called the manager of her research team to tell her the news: A dense layer of recently precipitated minerals had formed on the chalk grains she had been studying for some time.

To appreciate the importance of this discovery, we need to go back in time to an event which has sparked a lot of brain wringing within the oil industry. In 1984, it was revealed that the North Sea oil field Ekofisk, situated 70 metres below sea level, had subsided by 1-2 metres. This was not the first time in history that a reservoir had compacted as a result of oil and gas extraction.

But the scale of the seabed subsidence was unprecedented. The explanation to this phenomenon lay in the specific rock formation in this particular field. The Ekofisk rock reservoir is mainly made of chalk, as is the neighbouring Valhall field. The oil contained in the reservoir was subjected to high pressure and contributed to uphold the layers above. As the reservoir was depleted, the chalk had to withstand an increasing weight. We now know that the stress became too big, and the chalk formation eventually gave in.

Wrong predictions

The Ekofisk subsidence represented a huge challenge to both the field operator and the Norwegian authorities. It sparked two fundamental questions that needed to be answered: Was this going to affect future production from the field? And was it possible to prevent further subsidence? Engineers from all over Europe were involved in finding a solution to the problem, and in 1987 the platforms on the field were jacked up by six metres. But the problem of subsistence persisted, and another solution was introduced during the 1990s: The field had to be developed all over again. In 1998 production started from Ekofisk II, constructed to withstand a further 20 metres of subsidence.

Even before the dramatic subsidence was uncovered, engineers had observed that the mechanical properties of the Ekofisk chalk reservoir were completely different from what they had expected. Consequently, scientists were already involved in solving the puzzle, and in 1998, the Norwegian Petroleum Directorate launched its Joint Chalk Research Programme. Tens of millions of Norwegian kroner were spent on rock mechanical testing of the mysterious chalk.

But the scientists were unable to fully map the chalk's properties. They predicted that the rate of subsidence would decrease in the near future, but they were wrong. The Ekofisk field continued to sink. The models were obviously not good enough, and intensive research on the correlation between pore pressure and the rock's properties was inconclusive.

Water injection, as a means of keeping up the reservoir pressure and improve the oil recovery rate, was introduced on Ekofisk in 1987. To this day, water injection is the prime countermeasure to further subsidence on the field. But the problems of unstable wells, compaction and subsidence persist. The puzzle of the chalk's water weakening effect remains unsolved, and scientists are still confused as to why this happens.

Up until the new millennium, scientists were adamant that temperature was irrelevant when conducting research on rock mechanics. Hence, testing had been carried out in room temperature. In the 1990s, capillary effects were the most common explanation to reservoir subsidence. Chemical effects on the chalk had been introduced as an alternative explanation, but this line of enquiry was dismissed after a few laboratory tests.

However, by the end of the decade, Professor Rasmus Risnes at Stavanger University College had demonstrated that physical forces alone could not explain the subsidence phenomenon. His pioneering work is now carried on by Merete Vadla Madland and her team of researchers. Together with senior research engineer Aksel Hiorth at IRIS, she is managing the ‘Water weakening of chalk: Physical and chemical processes' project. They are now close to verifying the hypothesis they presented together with Professor L. M. Cathles at Cornell University a year ago: Seawater flooding induces chemical processes which cause significant changes in the mechanical properties of chalk, thereby weakening the chalk's strength.

"Chemistry - and implicitly temperature - is important," says Dr Madland.

"Until now, rock mechanics have not been too concerned about chemistry," adds Dr Hiorth.

"But the chemical models we apply are very conclusive. When chalk is exposed to saline water, mineralogical changes are triggered. These changes also seem to affect the way oil flows through the reservoir. As we gain a deeper understanding of these processes, this knowledge will be extremely important in order to be able to maximise oil extraction," he says.

Through the looking glass

At the core of the research project, there are twelve mechanical test cells with adjacent pumps. Inside these cells, which are operated from own developed computer programmes, the scientists are testing the chalk's behaviour when exposed to the same temperature as in the actual Ekofisk and Valhall reservoirs - which is 130 and 90 degrees centigrade respectively. The chalk contained inside the cells is also exposed to high pressure, and seawater is injected from below and flooded through it, as it is in the field when oil is extracted.

The chalk sample and the seawater are examined before and after testing. The porous rock is studied by applying rock mechanical testing, chemical analyses and a scanning electron microscope (SEM). By applying the SEM, chalk pores are examined down to nanometre scale - i.e. one billionth metre - which has barely been done prior to this project. And it was through this very microscope post doctor Hildebrand-Habel made her big discovery of the newly precipitated minerals.

"Our experiments show that flooding of seawater at high temperature affects the chalk so that minerals are precipitated," say Hiorth and Vadla Madland.

"It causes chemical reactions, in this case the precipitation of minerals which contain calcium and magnesium. We believe this precipitation of minerals leads to a dissolution of the chalk structure itself, which in turn may be one of the reasons why the sea bed collapses when oil is extracted and seawater injected. We assert that this dissolution and precipitation may be a key ingredient in the understanding of the water weakening effect - an effect which has been studied by scientists, including here at the UiS and IRIS, for the last twenty years."

In short, these findings add new elements to explaining the mystery of sea bed collapse in chalk formations - a chemical explanation in addition to the prevalent physical and chemical one.

Designing new models

Following the experimental observations performed in the lab, the scientists are now developing a completely new model for calculating the water weakening effect, based on chemical equations. This mathematical model will enable the scientists to predict how the injection of seawater dissolves the chalk, and is designed in collaboration with Professor L. M. Cathles at Cornell University in New York, USA.

By applying this model, they will also be able to prevent the chalk from collapsing. Right now, the team is about to find the answer to which water mixture is the most suited to achieve this aim.

Hiorth and Vadla Madland say the model is continually improved by performing new experiments.

"This is a two-way street: The new results yielded will be fed into the model and thereby improving it, and the model will provide us with information which can be applied to perform better experiments. We are enjoying a very good scientific collaboration here, and we don't think there are many who are as fortunate as we are, being able to switch between experimental and modelling research in this way."

The oil industry is following the project closely, cheering the research team. Tron G. Kristiansen is Rock Mechanical Advisor with BP, the company which operates the Valhall field.

He believes the results from this project will help the company predict the effects of water flooding more precisely and for a longer period.

"A better understanding of the physical and chemical interaction between seawater and chalk at high temperatures and under high pressure, will also improve our understanding of other surface-related processes which are important to the oil industry - such as wettability, precipitation of calcium sulphate, and the stability of production wells. The scale of enhanced oil recovery from water weakening will differ from field to field and within the reservoirs themselves, but water injection may improve oil recovery by five to ten percent. Depending on the oil price, this may give us billions in additional income," Kristiansen concludes.

More information: M.V. Madland, B. Zangiabadi, R.I. Korsnes, S.Evje, L. Cathles, T.G. Kristiansen & A. Hiorth 2009. Rock Fluid Interactions in Chalk with $MgCl_2$ and Na_2SO_4 Brines with Equal Ionic Strength. To be presented at the IOR 2009 symposium (EAGE) in Paris, France 2009

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