Carbonates, Chalk and Oilfield Subsidence

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Tags: carbonates, chalk, ekofisk, land subsidence, limestone, secondary porosity, tech talk [list all tags]

This is a part of the continuing series of technical talks that I post on Sundays, and which can be found by clicking on the tech talk link at the top of the main page. Gradually these are getting a little more technical, so I would suggest if you are new to these that you start at the beginning and work your way up.

Having recently written about sandstones and permeability, and then about water flooding, I want to go on, this time to talk about carbonate rocks, as the general topic and secondary porosity, with some comments at the end on formations in chalk and the problems that this can bring to places such as Ekofisk. (Added for clarity - when I talk about carbonates I mean calcium carbonate and the related rocks such as limestone, chalk and dolomite, to name but three.) I again want to emphasize that, life being what it is, the true situation is often a bit more complex than I describe in this simplistic overview, and that I am very grateful when folk give more specific information about some of their experiences in the field.

When I wrote about sandstones, I mentioned that (as a general rule) carbonates are different to the conditions found with sandstone. For a start the rock itself is much finer grained than a typical sandstone. Even if there were oil in the body of the rock it would be more difficult to get out. Most of the oil is found in what is called **secondary porosity**. This is the network of fractures and bedding planes that are formed in the rock as it is compressed and moved after it has first been formed. The rock is largely limestone, though it may also be dolomite or related rocks. The rock is usually not a massive, solid rock (such as you might want to build a house or cathedral with).

Exposed limestone

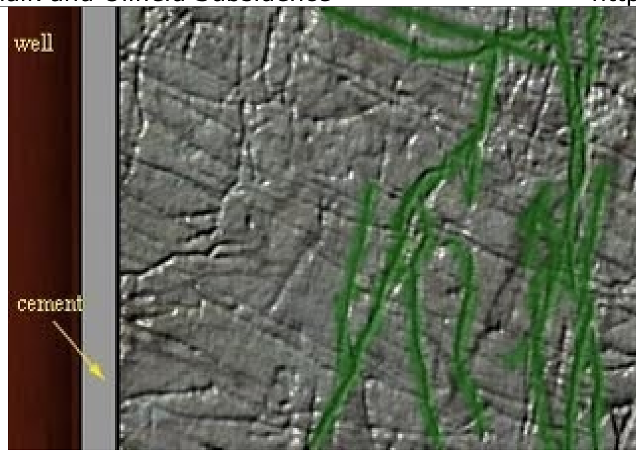
Rather oil will collect where there are spaces in the rock. These can be where there was a coral reef, or a lot of change in rock structure. You can see that sort of thing in some new road cuts

such as this one.

It is easier to explain some of the problems of getting the oil out, if one looks at a road cut that has weathered a bit

Weathered rock wall

You can see how the passage of water has opened the joints and dissolved small holes (or **vugs**) in the rock. These provide the spaces in the rock into which the oil can move and collect and be trapped. Perhaps it might be easier if I used a simpler sketch of a section through the rock to make the next point.



Section through a fractured rock, showing how the oil is in fractures that the well does not reach.

With the oil painted green, as it fills one crack system, but not them all, the well is just a little bit too far to the left to tap into the major fissure system and get all the oil. If only we could reach out a few feet and hit those cracks! And we can and do.

This is part of the reason that we send down the small explosive shaped charges that not only penetrate through the well case and the concrete, but also extend a hole out into the rock. By driving these **perforations** out into the crack system in the rock a path can be created from the oil-filled cracks to the well. Those cracks can also be cleaned up a bit (since they often have very small particles of carbonate filling them in the zone around the well) by having an acid pumped down into the completion zone. This acid will also open up some of the finer fissures in the rock so that a free path will develop from the well to the oil-filled cracks.

And so we can begin to produce oil. However after a while, for one of several reasons, the flow from the well will begin to decline. I mentioned last time that the underlying reason will be that the pressure in the reservoir will drop as the oil is withdrawn. But there are other reasons.

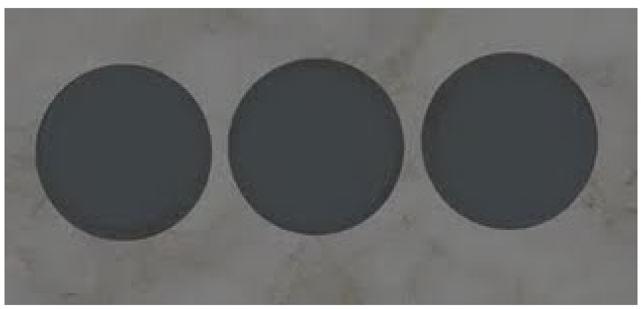
If the oil is removed too quickly we can generate, before we need to, a gas cap in the well. Fine rock can be carried through the cracks towards the well, and block the passages. Some of the oil contents, such as the waxes, can settle out of the oil, and fill the holes in the well casing. As the oil flows to the well, underlying water can follow it and cut-off blocks of oil in the rock. And the pressure difference between the oil further away from the well, and the well itself might not be enough to move that more distant oil towards the well. (Are you really sure you want to make this investment?)

Before I leave Carbonates let me go back to the other kind, where there is a reasonable amount of primary porosity, and where the oil is spread through the rock. This can happen when, for example, the rock is a chalk (another form of calcium carbonate or limestone).

Chalk, somewhat similar to that in which the oil at Ekofisk is found.

Chalk poses some different problems in production. Let me illustrate them with an abbreviated history of the Ekofisk field. The field was found in 1969, and started production in 1971. It produced from a fractured chalk that has “high porosity but low permeability.” When it was originally produced the driving force to move the oil to the wells was through pressure depletion of the oil, and in this way they were able to recover between 17 and 18% of the oil in place. In the process, however, there was a relatively unexpected problem.

To explain it let me make a very, very simple illustrative example.



Representation of Oil (grey) filling pores in a rock.

Now in the original condition the pressure of the oil in the pores (holes) in the rock above is equal to a significant portion of the pressure of the overlying rock. At Ekofisk the pore pressure was 7,135 psia at a depth of 10,400 ft. Porosity can be as high as 48%.

But as the oil is drawn off through the well that pressure reduces, and the load transfers to the rock columns that are one either side of the circular pores. (The well pressure was reduced to below 5,000 psi). When the load on these columns becomes higher than the strength of the rock then the pillars will collapse. This helps a little to squeeze some of the oil out, but it also (when it happens over a large enough volume) compresses the entire volume of the rock holding the oil. This can close some of the passage ways to the well (permeability), and make it harder to get the oil out, though that does not appear to have happened. But it also lowers the sea bed, on which some of the recovery oil platforms were standing. That subsidence has been up to 30 ft in places. (The platforms were elevated in 1987) but new platforms were ultimately required that would allow a subsidence of up to 66 ft. (20 meters).

In order to stop the collapse, and also to increase the flow of oil to the wells, a program using water injection at pressure was started in 1987, by injecting 820,000 barrels of water a day, it was anticipated that the field would allow the recovery of about 36% of the oil, and provide an additional 300 million barrels of oil. Current estimates are that it will increase overall recovery to 50% of the oil in place.

There are, however, now some concerns about the dissolution of some of the chalk by the water that is being used for the injection, weakening it further. One of the problems in analysis, as it turns out, has been in disregarding the temperatures at which the extraction is occurring. (For those who go to the reference the exchange rate is roughly 5 kr to the dollar.)

From which you will see that there is still lots to talk about. But, as before, if I have glossed over stuff, just ask a question and I (or others who contribute) will be glad to give an answer.