AAPG Annual Meeting
March 10-13, 2002
Houston, Texas

Relationships between hydrocarbon leakage and retention capacities in the Haltenbanken and North Sea areas offshore Norway.

Nordgard Bolas, Hege Marit, Statoil ASA, 7005 Trondheim, Norway; and Hermanrud, Christian, Statoil ASA, 7005 Trondheim, Norway

Associations of abnormal pressures with hydrocarbon accumulations are well known, as very little production potential exists for reservoirs with fluid pressure gradients in excess of 1.96 g/cm^3 (Law and Spencer, 1998). Such a relationship has also been noted in the Central Graben of the North Sea, where retention capacities less than 6.8 MPa have been reported to coincide with an increased frequency of leaky reservoirs (Gaarenstroem et al., 1993). Similar relationships were noted by Grauls and Baleix (1994), who suggested that leakage is initiated when the pore pressures reach 70 – 90 % of the overburden weight (depending on tectonic regime). The existence of such direct relationships between hydrocarbon leakage and pore pressure will significantly influence prospect risking in overpressured regions. As high pore pressures are frequently encountered also in the Viking Graben and Haltenbanken areas offshore Norway (Fig. 1), investigations were carried out to see if relationships like those suggested by Gaarenstroem et al. (1993) could be recognized in these areas as well.

These investigations included compilation of pore pressure and leak-off pressure (LOP) data for 17 wells or oil fields in the Viking Graben area and 25 wells in the Haltenbanken area. Only wells targeting different structural traps of Middle Jurassic age were included. The wells included both hydrocarbon discoveries and water-bearing structures, ranging in depth from 2000 to 5500 m.

The fluid pressures were taken from high quality RFT measurements. The LOP data are less accurate and may carry uncertainties of 5- 10 % in individual cases, although the average errors are probably significantly less (Nordgard Bolas and Hermanrud, in press). The LOP measurements in each well mostly originated from the cap rocks above the reservoirs. These pressures were extrapolated to the reservoir depths by assuming a LOP gradient with depth of 2.3 g/cm^3, in accordance with the observations of Gaarenstroem et al. (1993).

The Haltenbanken data (Fig. 2) include both wells in the overpressured (western) and the close to hydrostatically pressured (eastern) areas. Note that the three overpressured discovery wells in the western area (6406/2-3T3, 6406/2-6 and 6406/2-7) were drilled later (and deeper) than the wells penetrating the leaky reservoirs in this area, and thus obscure the previously reported perfect correlation

between high pore pressures and exploration failures in this area (Koch and Heum, 1995).

The Viking Graben wells (Fig. 3) include most of the highly overpressured structures in the area. Of these, four were exploration failures possibly related to hydrocarbon leakage. These, and the hydrostatically pressured well 30/11-4, appear to be the only exploration wells in the area that failed because of vertical hydrocarbon leakage (Hermanrud and Nordgård Bolås, in press).

As is clear from these figures, neither of the investigated areas exhibit identical characteristics to those reported by Gaarenstroem et al. (1993). The Haltenbanken data show an increased frequency of exploration failures at low retention capacities. These wells, which in almost all cases failed because of vertical leakage (Hermanrud and Nordgard Bolas, in press), all have higher retention capacities than the 6.8 MPa reported by Gaarenstroem et al. (1993). This difference may however be due to the fact that these authors applied a minimum LOP envelope to their calculations of retention capacity, whereas the generally higher values from each individual well were applied in this study. The overpressured hydrocarbon-bearing structures were penetrated at greater depth than any of the leaky structures.

To the contrary, retention capacities from several of the Viking Graben traps were calculated to be significantly below 6.8 MPa, despite the fact that LOP measurements from individual wells were invoked. Furthermore, almost all of these traps were hydrocarbon bearing. The two water-bearing structures in this area, penetrated by wells 30/4-1 and 25/1-10, were the deepest of the investigated structures, contrary to the observation at Haltenbanken.

These differences are suggested to be indicative of different hydrodynamic characteristics in the two areas. Vertical fluid discharge appears to dominate in the western part of Haltenbanken. This suggestion is supported by fluid pressure measurements in this area, which demonstrate a consistent fluid pressure increase with depth with little or no horizontal variation (Hermanrud and Nordgård Bolås, in press). These observations are consistent with vertical fluid discharge and a lack of horizontal fluid communication. Fluid pressures in the Viking Graben, on the other hand, scatter significantly in any given depth range, pointing to a probable more widespread lateral fluid flow between pressure compartments.

Such lateral fluid flow may in fact be the cause for hydrocarbon preservation in these highly overpressured reservoirs. As the reservoirs subside, quartz cementation leads to reduced porosity in the reservoir sandstones. This porosity reduction has been shown to progress irrespective of high fluid pressures (Bjørkum and Nadeau, 1998). Accordingly, fluids must be expelled from the reservoirs, either vertically or laterally. Hydrocarbons will stay trapped if horizontal fluid discharge between pressure compartments in downflank positions is the main mode of fluid discharge. Likewise, vertical fluid discharge from downflank positions may cause hydrocarbons to be trapped upflanks.

The location of a pressure compartment’s leakage valve is determined by the stress regime, the fault and cap rock permeabilities and the ductility of the involved rocks during the time of leakage. It is suggested that these factors differ between the two

investigated areas, and that these differences have resulted in the different relationships between overpressuring and hydrocarbon preservation.

The interplay between these noted factors may be quite subtle and hard to identify ahead of drilling. Accordingly, assessments of seal capacity based on relationships between calculated retention capacity and hydrocarbon occurrence should be used with caution in areas with little well control. Such relationships may however be of significant importance in more mature provinces, such as the Viking Graben and the Haltenbanken areas.

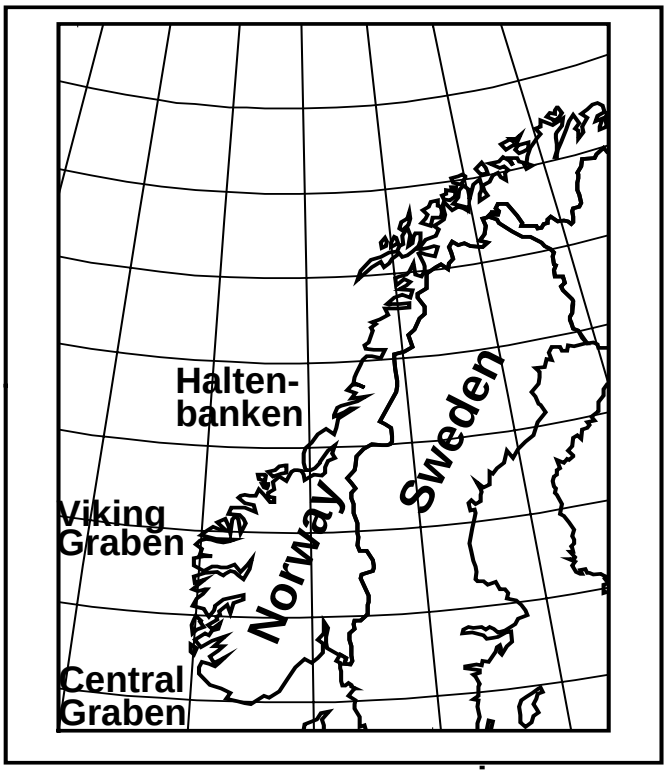

Fig. 1: Study area

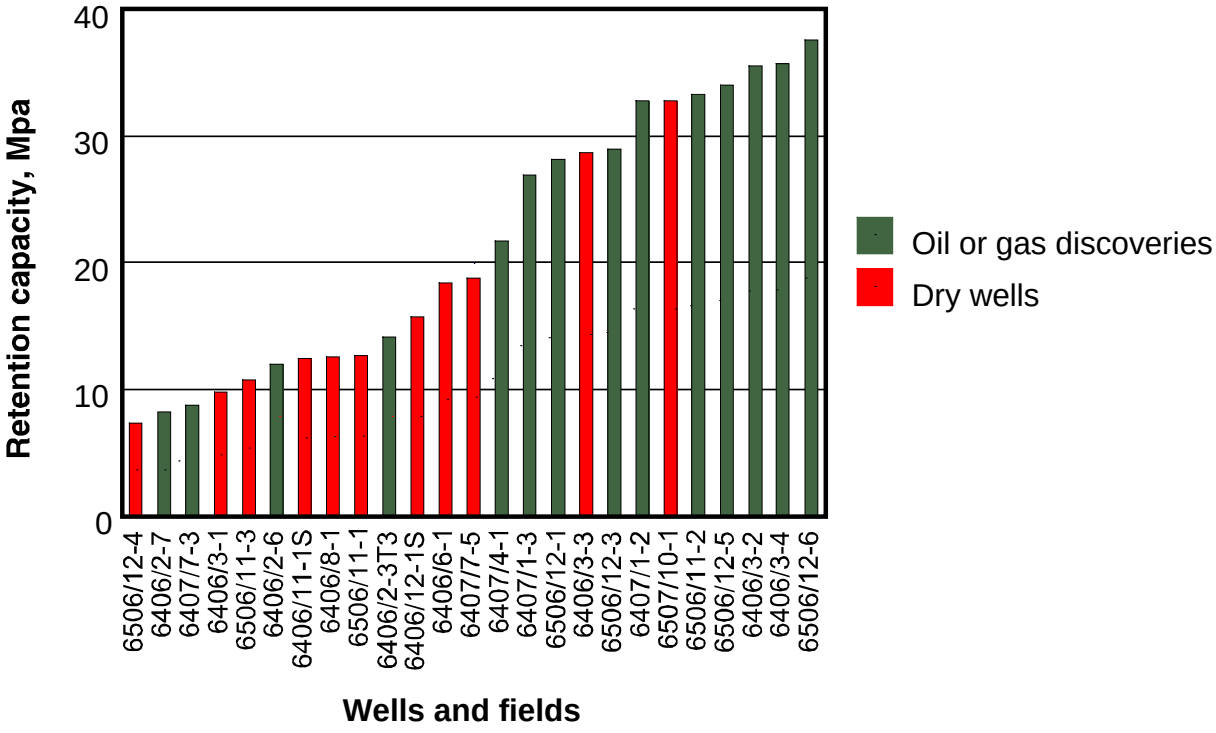

Fig. 2: Retention capacities – Haltenbanken, Norwegian Sea

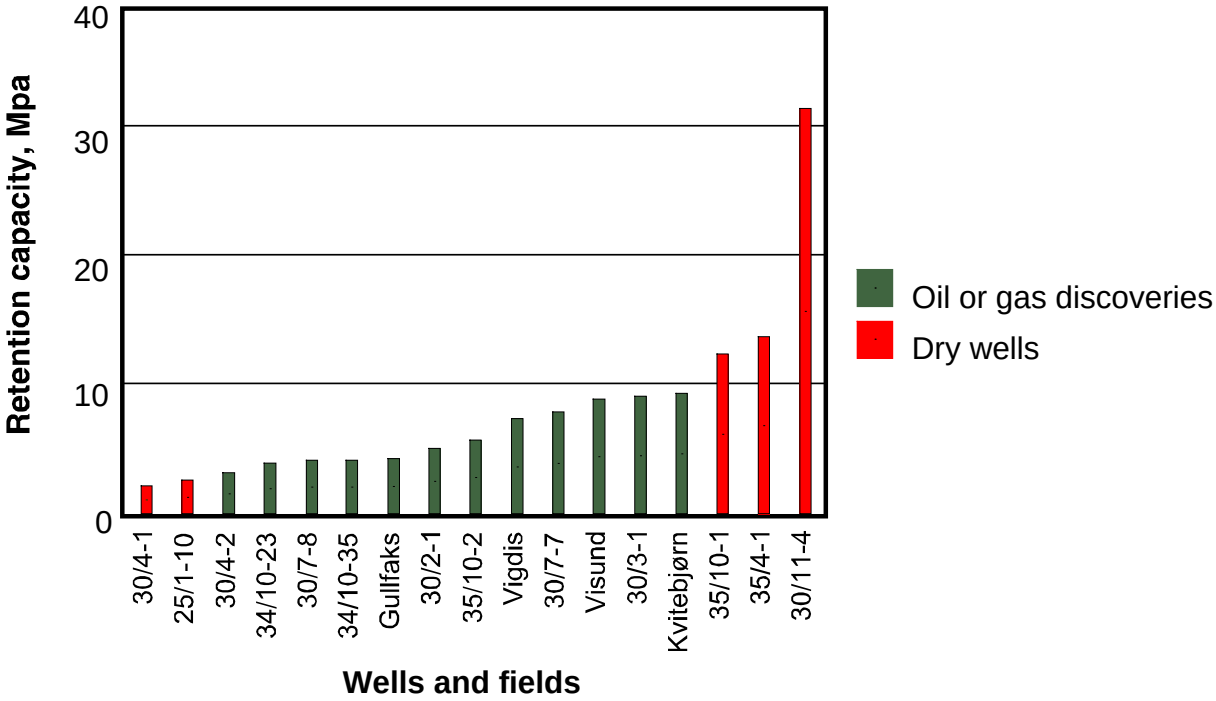

Fig. 3: Retention capacities - Viking Graben, Norwegian North Sea

References:

Bjorkum, P. A. and Nadeau P. H., 1998, Temperature controlled porosity/permeability reduction, fluid migration, and petroleum exploration in sedimentary basins: APPEA Journal, v. 38, part 1, p. 453-465.

Gaarenstroem, L., Tromp, A. J., de Jong, M. C. and Brandenburg, A. M., 1993, Overpressures in the Central North Sea: implications for trap integrity and drilling safety, *in* J. R. Parker, ed., Petroleum geology of northwest Europe: Proceedings of the 4th conference, The Geol. Soc. London, 1305 – 1313.

Grauls, D. J. and Baleix, J. M., 1994, Role of overpressures and in situ stresses in fault-controlled hydrocarbon migration: a case study: Marine and Petroleum Geology, v. 11, p. 734-742.

Hermanrud, C. and Nordgard Bolas, H. M., *in press*, Leakage from overpressured hydrocarbon reservoirs at Haltenbanken and in the northern North sea, *in* A. G. Koestler and R. Hinsdale, eds., Hydrocarbon Seal Quantification, NPF Spec. Publ., Elsevier, Amsterdam.

Koch. J.-O. and Heum, O. R., 1995, Exploration trends of the Halten Terrace, *in* H. Hanslien, ed., 25 Years of Petroleum Exploration in Norway, NPF Spec. Publ., 4, Elsevier, Amsterdam, p. 235-251.

Law, B. E. and Spencer, C. W., 1998, Abnormal Pressure in Hydrocarbon Environments, *in* B. E. Law, G. F. Ulmishek and V. I. Slavin, eds., Abnormal Pressures in Hydrocarbon Environments, AAPG Memoir 70, p. 1-11.

Nordgard Bolas, H. M. and Hermanrud, C., *in press*, Rock stress in sedimentary basins - implications for trap integrity, *in* A. G. Koestler and R. Hinsdale, eds., Hydrocarbon Seal Quantification, NPF Spec. Publ., Elsevier, Amsterdam.