

Small-angle neutron scattering

A new technique to detect generated source rocks

Andrzej Radlinski¹

Despite all its sophistication, geochemistry cannot distinguish source rocks that have generated hydrocarbons from those that merely have the potential to do so. In recent years, in collaboration with neutron scientists in the Oak Ridge National Laboratory (USA) and Institute Laue-Langevin, Grenoble (France), AGSO has developed a new low-cost technique for detecting the invasion of rock pore space during primary hydrocarbon migration, thus enabling the identification of hydrocarbon-generation zones in organic-rich rocks.

Small-angle neutron scattering (SANS) is a routine technique available at neutron-scattering facilities associated with research nuclear reactors. For over 50 years, SANS has been used to study the microstructure of alloys, ceramics, polymers, colloids, and other materials. SANS was preceded by its sister technique of SAXS (small-angle X-ray scattering), and sedimentary rocks (in particular, coals) provided some of the first systems studied with this method.

The early SAXS and SANS results for sedimentary rocks were puzzling and could not be appropriately interpreted owing to the lack of theoretical models for such complex systems. This obstacle was removed in the 1980s with the advent of fractal geometry and pioneering SEM, SANS, and SAXS work on shales, sandstones, coals, and carbonates, which demonstrated that sedimentary rocks are often self-similar on the microscale.

In a typical SANS curve for a hydrocarbon source rock (Fig. 33), the quantity (Q) on the horizontal axis is a measure of the (small) angle between the incident beam and the scattered beam of neutrons. Q is related to the average size, R , of structural features that contribute most to the scattering intensity,

$I(Q): R = 2.5/Q$. On the double-logarithmic scale, the scattering curve approximates a straight line, which is indicative of self-similarity of the rock structure. The pore-size distribution and the internal surface area of the pore space can be readily calculated from such SANS curves.

The SANS technique distinguishes thermal neutrons scattered at the rock-pore space interface. Experimental data can be interpreted to provide specific information about the geometry of the pore space in the range 1 nm to 10 μm , which covers the entire pore-size range for a shale. Typically, the specific internal surface area can be measured and the pore-size distribution quantified.

The intensity of scattering signal depends on the type of fluid present in the pore space. When pores are filled with gases or water, the scattering intensity is high. When the rock becomes invaded with freshly generated bitumen in the process of primary migration, however, the scattering intensity decreases markedly. Such a drop of scattering intensity is a typical SANS signature of hydrocarbon generation in a source rock.

SANS intensity provides an indication of the depth of hydrocarbon generation (Fig. 34). The neutron-scattering intensity measured for a selected value of Q is determined by the scattering properties of the pore-filling fluid. The minimum intensity, at a depth of 3150 ± 50 m, corresponds to pores filled with generated bitumen, thus indicating the position of the hydrocarbon source kitchen.

The SANS method has been tested on artificial rock-like laboratory preparations, as well as on the artificially and naturally matured series of source rocks. The results have been compared with other geochemical maturity indicators. The proc-

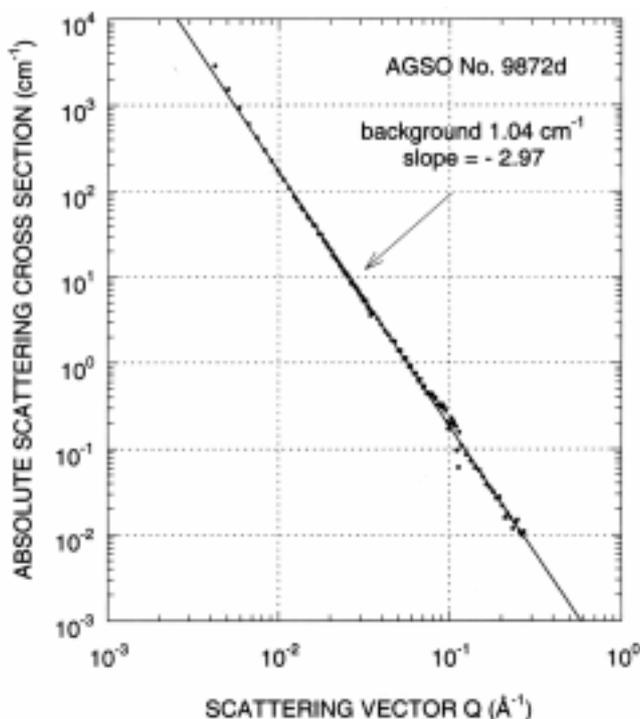


Fig. 33. Plot of absolute SANS intensity versus the scattering vector, Q , for a hydrocarbon source rock.

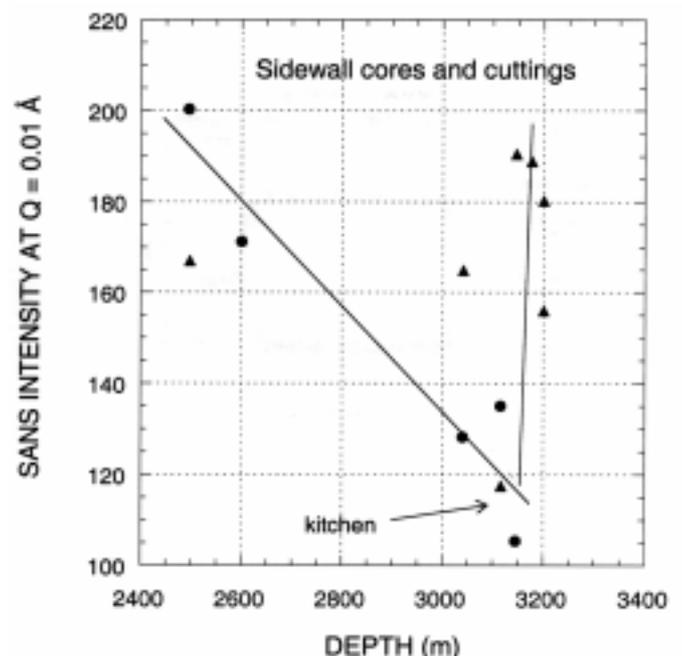


Fig. 34. SANS intensity at the Q -value corresponding to average pore size of 25 nm for a series of potential source rock samples from a recently drilled well on the North West Shelf. Circles correspond to sidewall cores and triangles to cuttings.

ess of hydrocarbon generation and associated internal overpressure may lead not only to a decrease in scattering intensity but also to the deformation of pore spaces, which can be readily detected through changes in the scattering intensity pattern. Thus, the value of slope of the scattering curve for a natural maturity series of source rocks reflects the degree of complexity of the pore–rock interface. In Figure 35, for example, it varies from -4 for flat, crystal-like interfaces to -3 for extremely convoluted ones, and the slopes for large pores (small Q -values) and small pores (large Q -values) are different above a particular maturity level owing to pore-space deformation by forced migration of generated hydrocarbons.

SANS is most effective when it is performed in conjunction with Rock-Eval pyrolysis and TOC determination. The cost of commercial SANS analysis is in the mid-range of other geochemical methods.

¹ Petroleum & Marine Division, Australian Geological Survey Organisation, GPO Box 378, Canberra, ACT, 2601; tel. +61 2 6249 9549; email andrzej.radlinski@agso.gov.au.

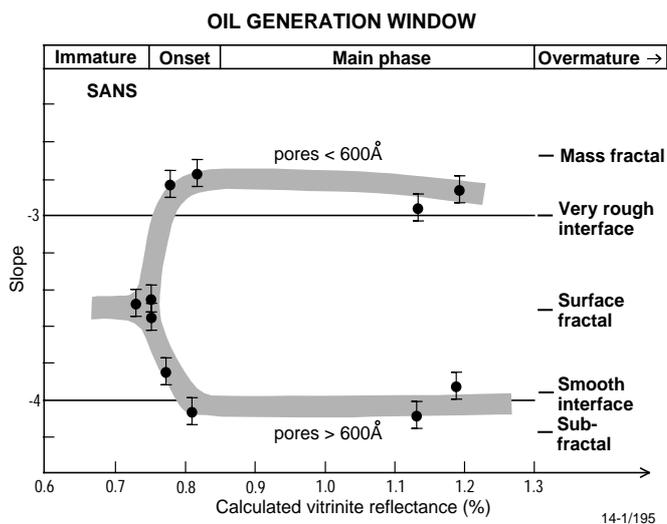


Fig. 35. Slope of the scattering curve versus the value of vitrinite reflectance calculated from the MPI index for a mid-Proterozoic natural-maturity series of source rocks from Urupunga No. 4 well, McArthur Basin (NT).