

# **It's A Small World After All - The Pore Throat Size Spectrum\***

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## **Abstract**

As extraction of oil and gas from poor-quality reservoir rocks becomes more prevalent in the United States, knowledge of the size and character of pore throats and pore space in these reservoirs with respect to their potential for producing hydrocarbons becomes even more important than in the past. This small “world”, which ranges from angstroms to nearly a millimeter, is viewed through such tools as the optical microscope, scanning electron microscope, mercury injection and computational chemistry. Permeability provides a length scale that is strongly, but not uniquely, related to pore-throat size. Nor can pore-throat size be determined unambiguously with other techniques. Each method of investigation, whether microimaging, mercury injection or gas-flow experiments, requires a physical model of pore-throat geometry in order to convert the measurements to a microscopic size. The choice of a flow model influences the choice of a statistic (mean, median or single value) to represent pore-throat size in a given sample. Experimental results drawn from past studies are combined into a spatial spectrum to help envision the relations among pore-throat sizes in sandstones, tight sandstones and shales.

## **Selected References**

Katz, A.J. and A.H. Thompson, 1986, Quantitative prediction of permeability and electrical conductivity in porous rock, *in* Society of Exploration Geophysicists, 56th annual meeting: SEG Abstracts, v. 1, p. 6-7.

Luffel, D.L., W.E. Howard, and E.R. Hunt, 1991, Travis Peak core permeability and porosity relationships at reservoir stress: SPE Formation Evaluation, v. 6/3, p. 310-318.

Luffel, D.L., K.L. Herrington, and C.W. Harrison, III., 1991, Fibrous illite controls productivity in Frontier gas sands, Moxa Arch, Wyoming, *in* J.W. Crafton, chairperson, Proceedings; SPE Rocky Mountain regional; Low permeability reservoirs symposium and exhibition, p. 695-704.

Nelson, P.H., 2009, Pore throat sizes in sandstone, tight gas sandstones and shales: AAPG Bulletin, v. 93/3, p. 329-340.

Wardlaw, N.C. and J.P. Cassan, 1979, Oil recovery efficiency and the rock-pore properties of some sandstone reservoirs: Canadian Petroleum Geology, Bulletin v. 27/2, p. 117-138.

# IT'S A SMALL WORLD AFTER ALL- THE PORE THROAT SIZE SPECTRUM

PHIL NELSON  
JUNE, 2009

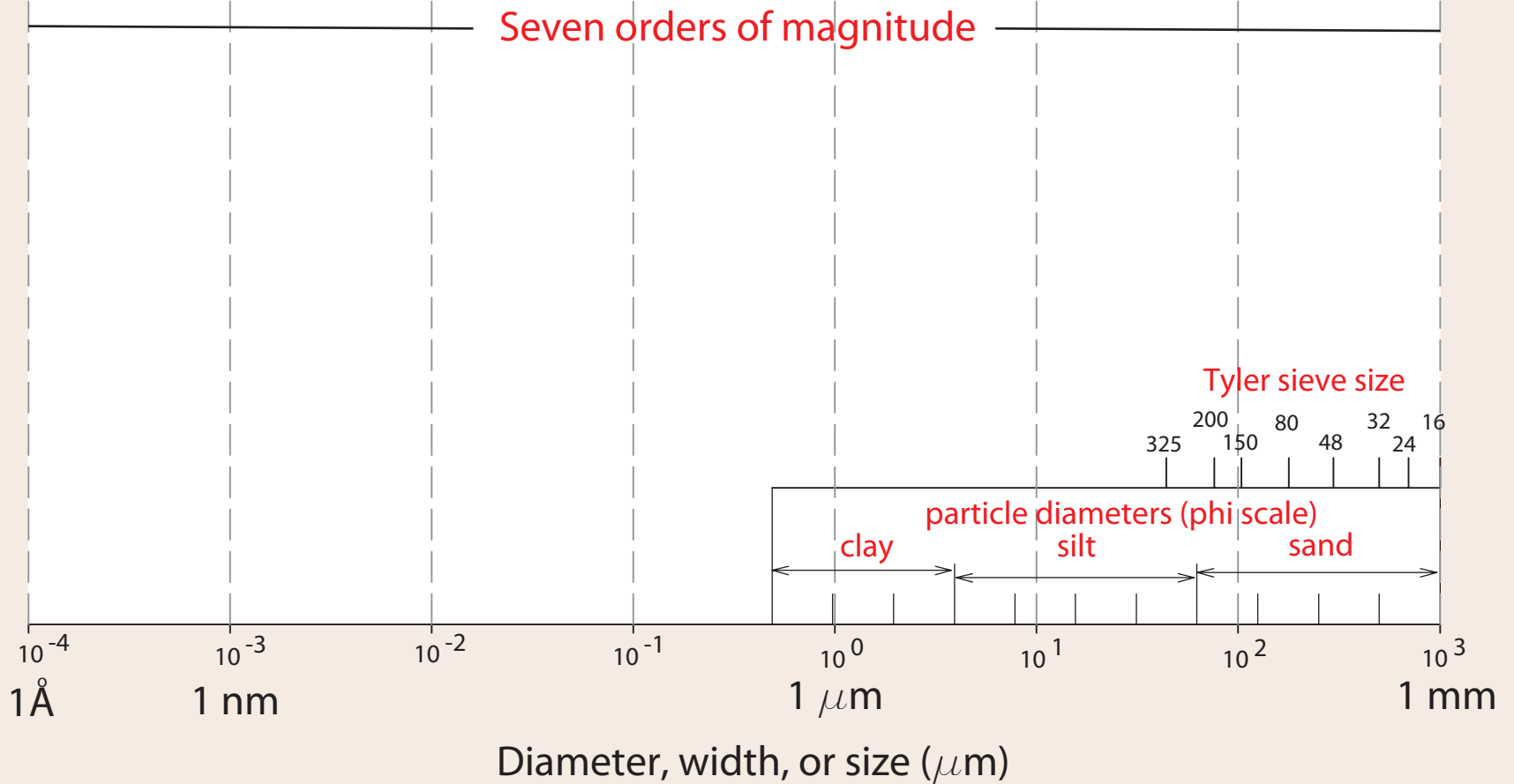


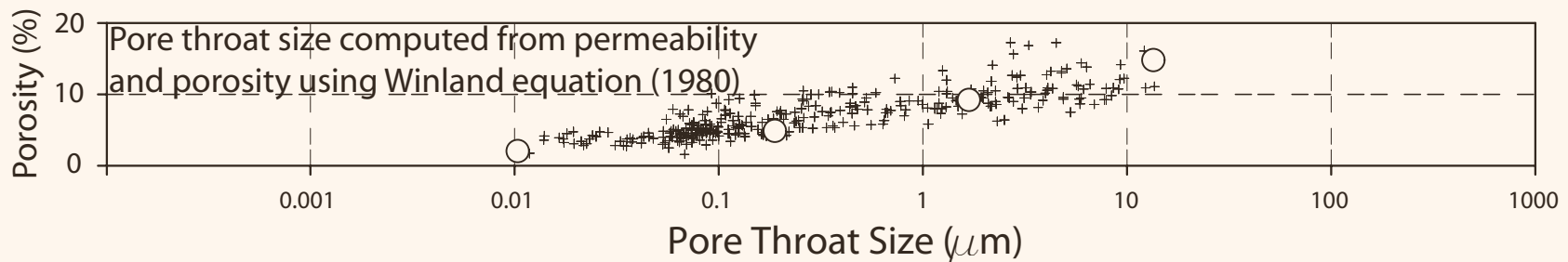
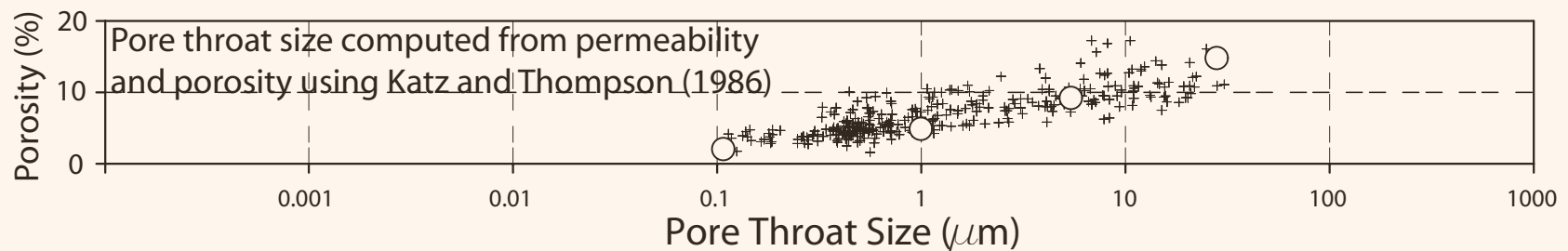
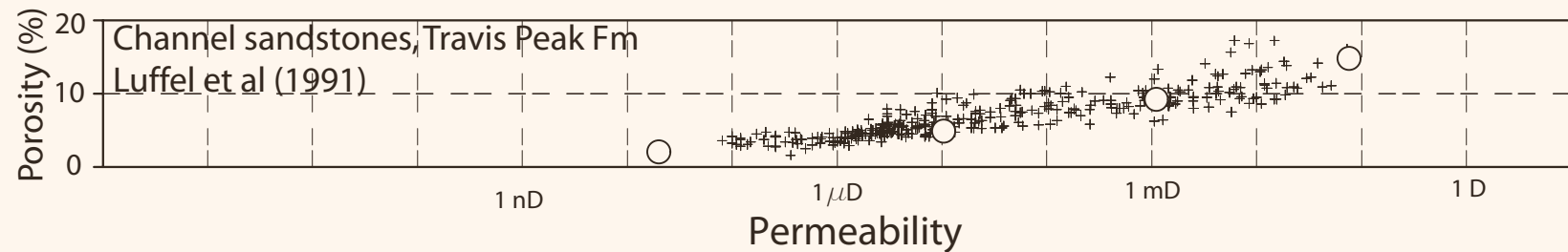
This talk is an elaboration of a short paper:

Nelson, P.H., 2009, Pore throat sizes in sandstones, tight gas sandstones, and shales, American Association of Petroleum Geologists Bulletin, v. 93, n. 3, p. 329-340.

References for information given on the following slides are cited in the paper.

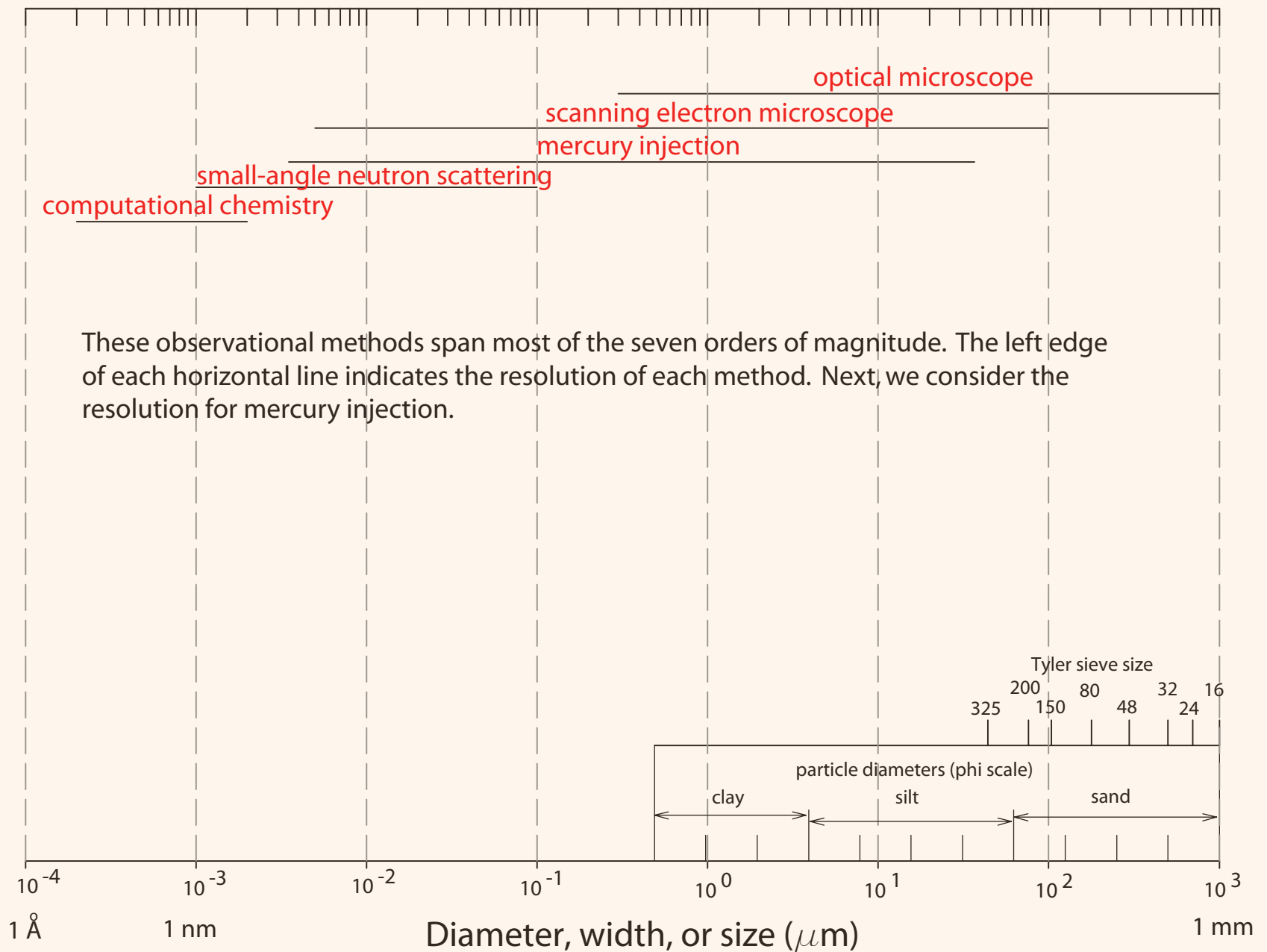
This talk is devoted to populating this graph with sizes pertinent to movement of fluids in siliciclastic rocks. Seven orders of magnitude span the range from molecular sizes to sizes visible to the unaided eye. We start with two scales used for measuring solid grains-- the Tyler sieve size scale and the sedimentologic phi scale.





Although we specify permeability in units of darcies (D), millidarcies (mD), microdarcies ( $\mu\text{D}$ ), or nanodarcies (nD), the physical dimension of permeability is the square of length. The permeability scale at the top is compressed so that two decades of permeability correspond to one decade of pore throat size. The two transforms used to compute a pore throat size give different results because the porosity factor differs between the two transforms. The four open circles show the migration of the two extremes and two intermediate permeability values.

Because using permeability data to derive a size presents some problems, other measurement methods will be used in the remainder of this discussion rather than permeability data.



Capillary pressure in cylindrical capillary  
at static equilibrium:

$$P(\text{dynes}) = 2 \sigma (\text{dyne/cm}) \cos\theta / R(\text{cm})$$

For a mercury-air system and converting  
to units of psi,  $\mu\text{m}$ :

$$P (\text{psi}) = 213 / D(\mu\text{m})$$

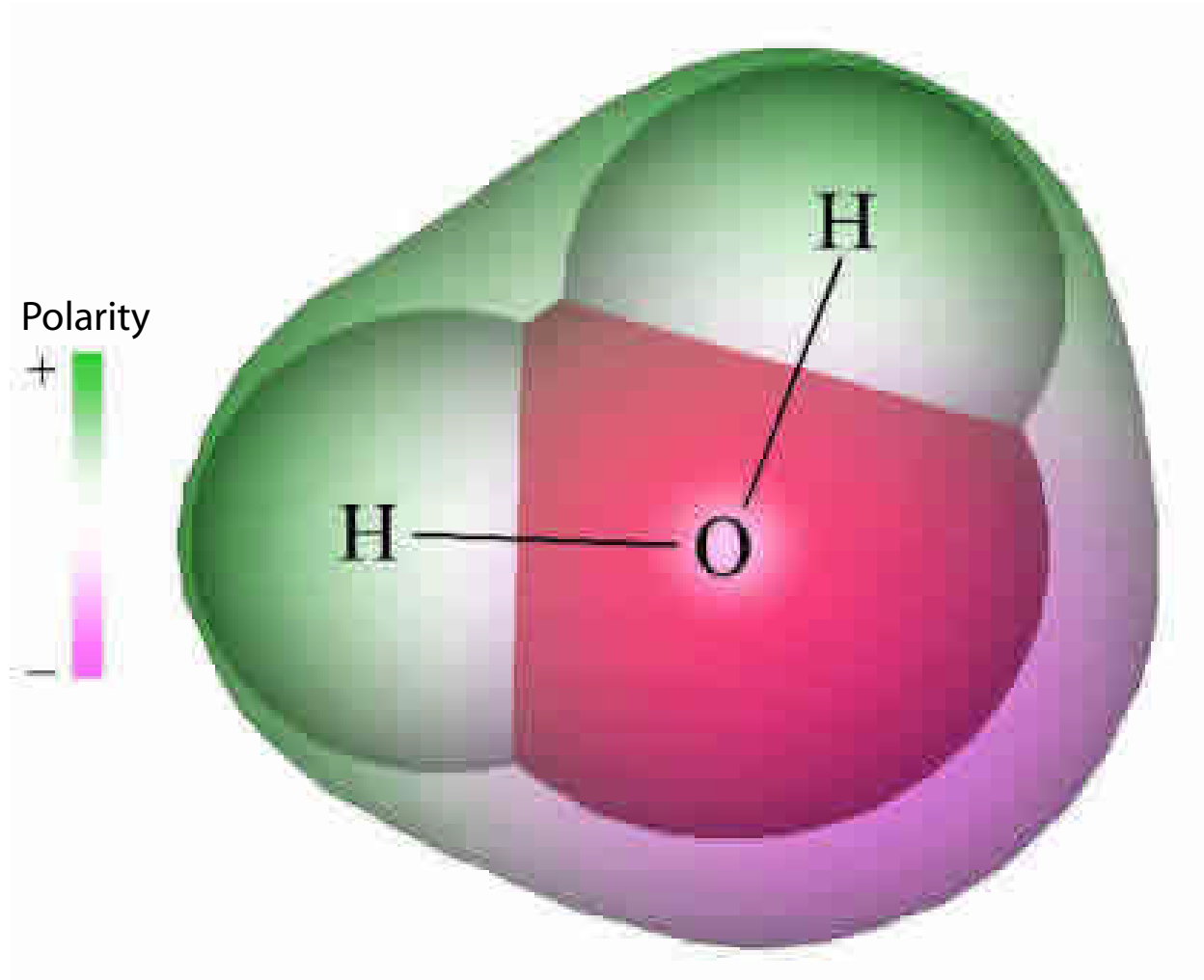
At maximum pressure of 60,000 psi

$$D(\mu\text{m}) = 213 / 60,000 \text{ psi} = 0.00355$$

$$\text{or } D = 3.55 \text{ nm}$$

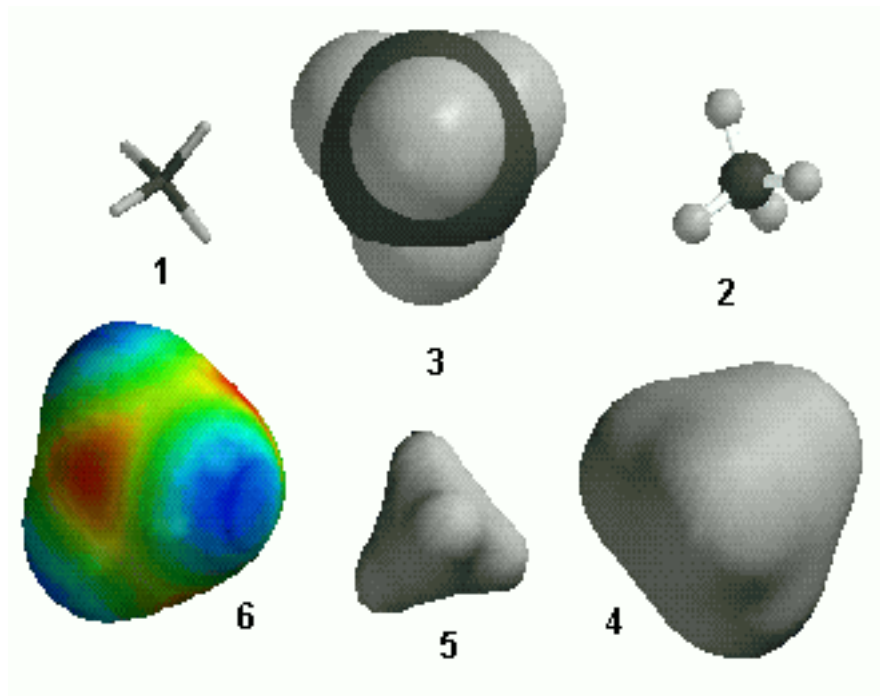


# Water Molecule



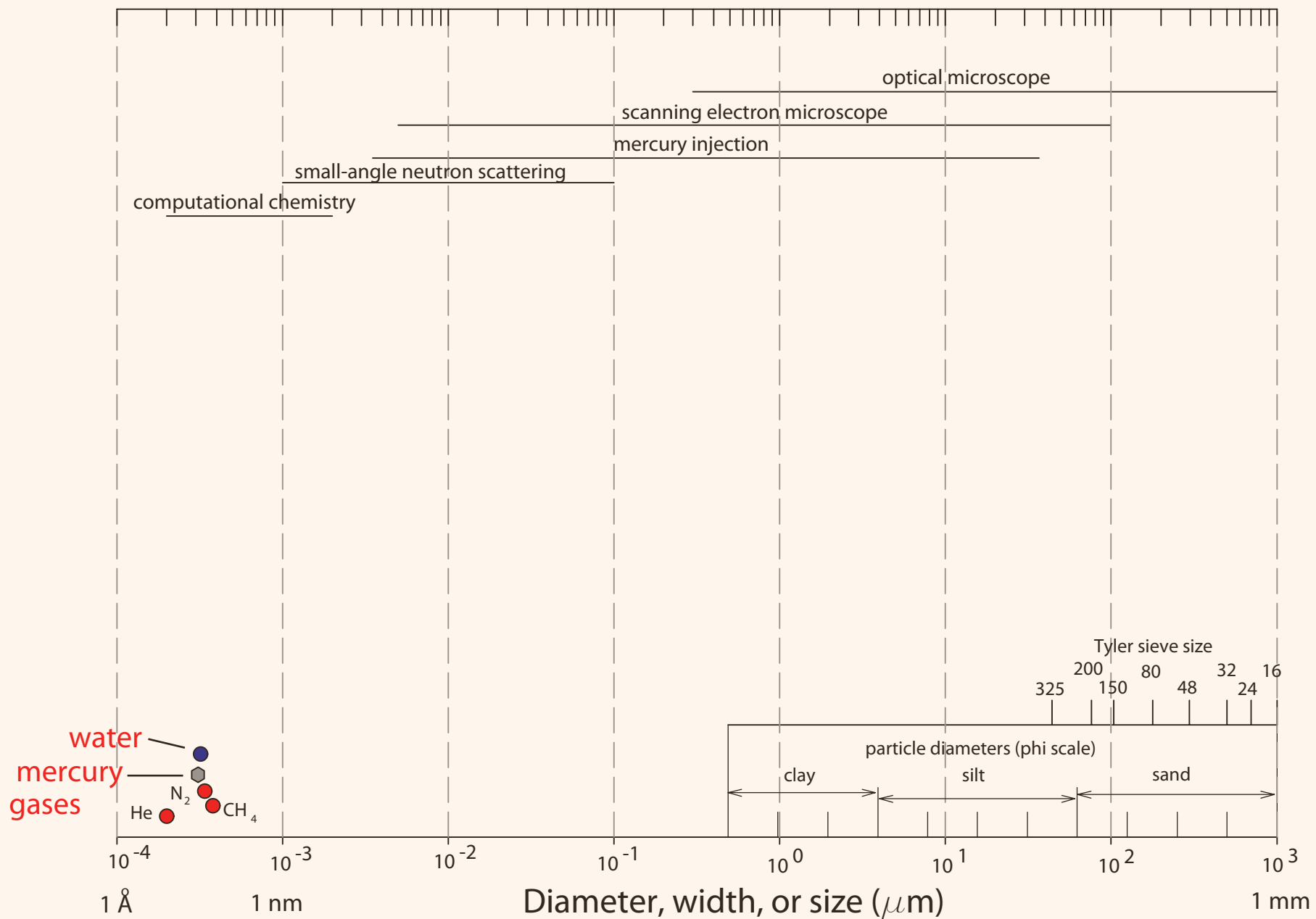
From:  
<http://www.lsbu.ac.uk/water/molecule.html>

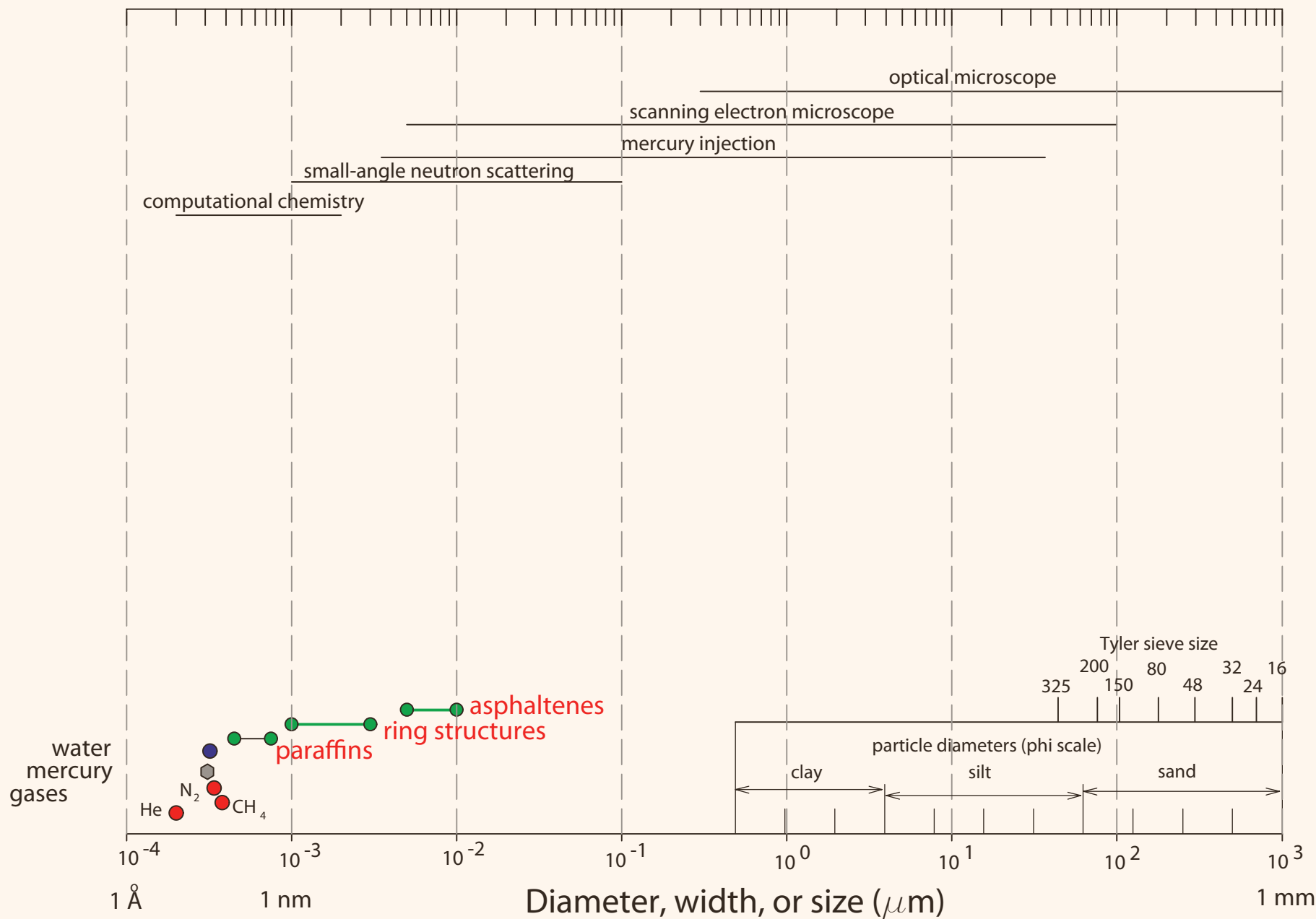
# Methane



From:

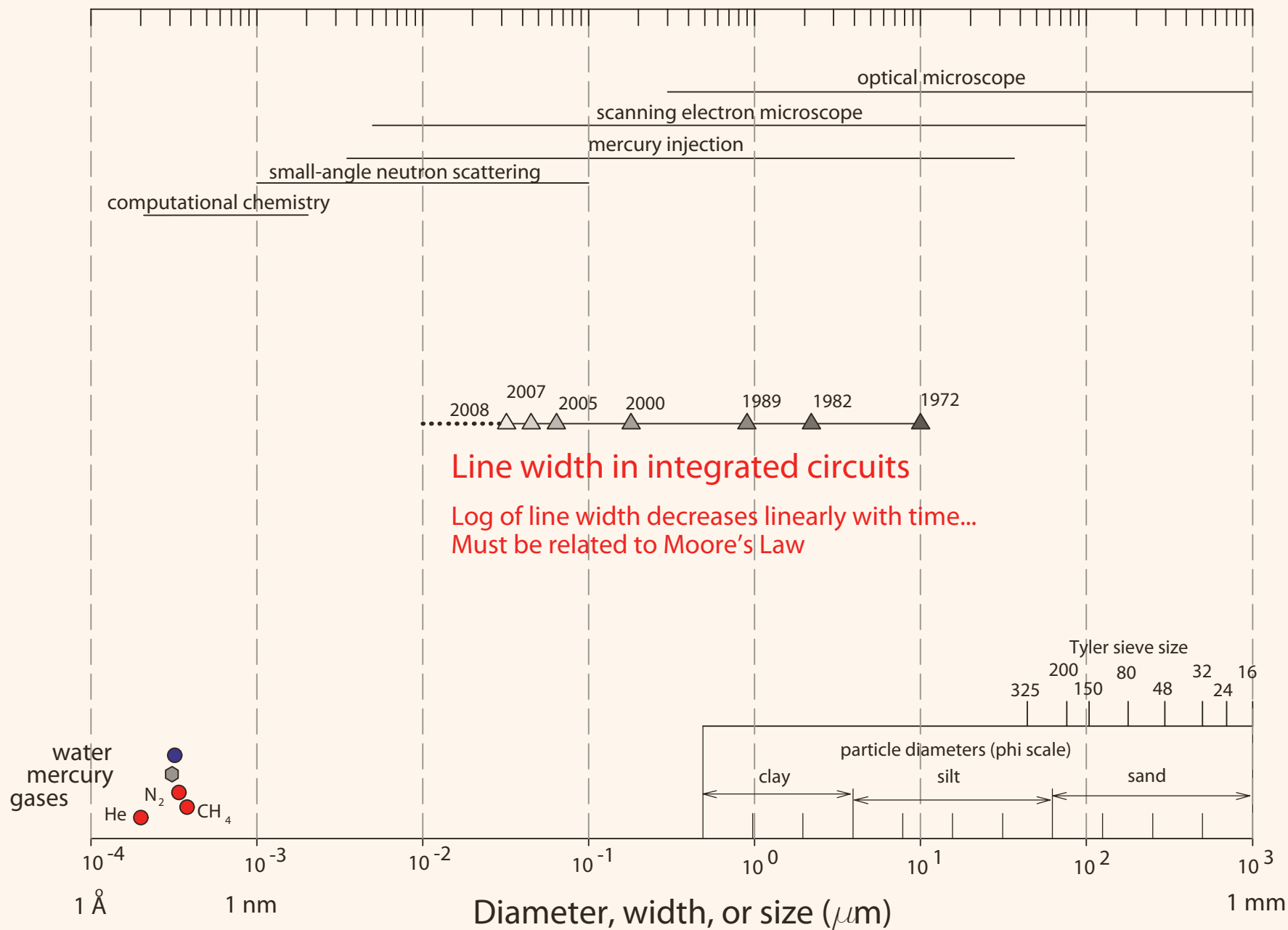
<http://courses.chem.psu.edu/chem38/mol-gallery/methane/methane.html>

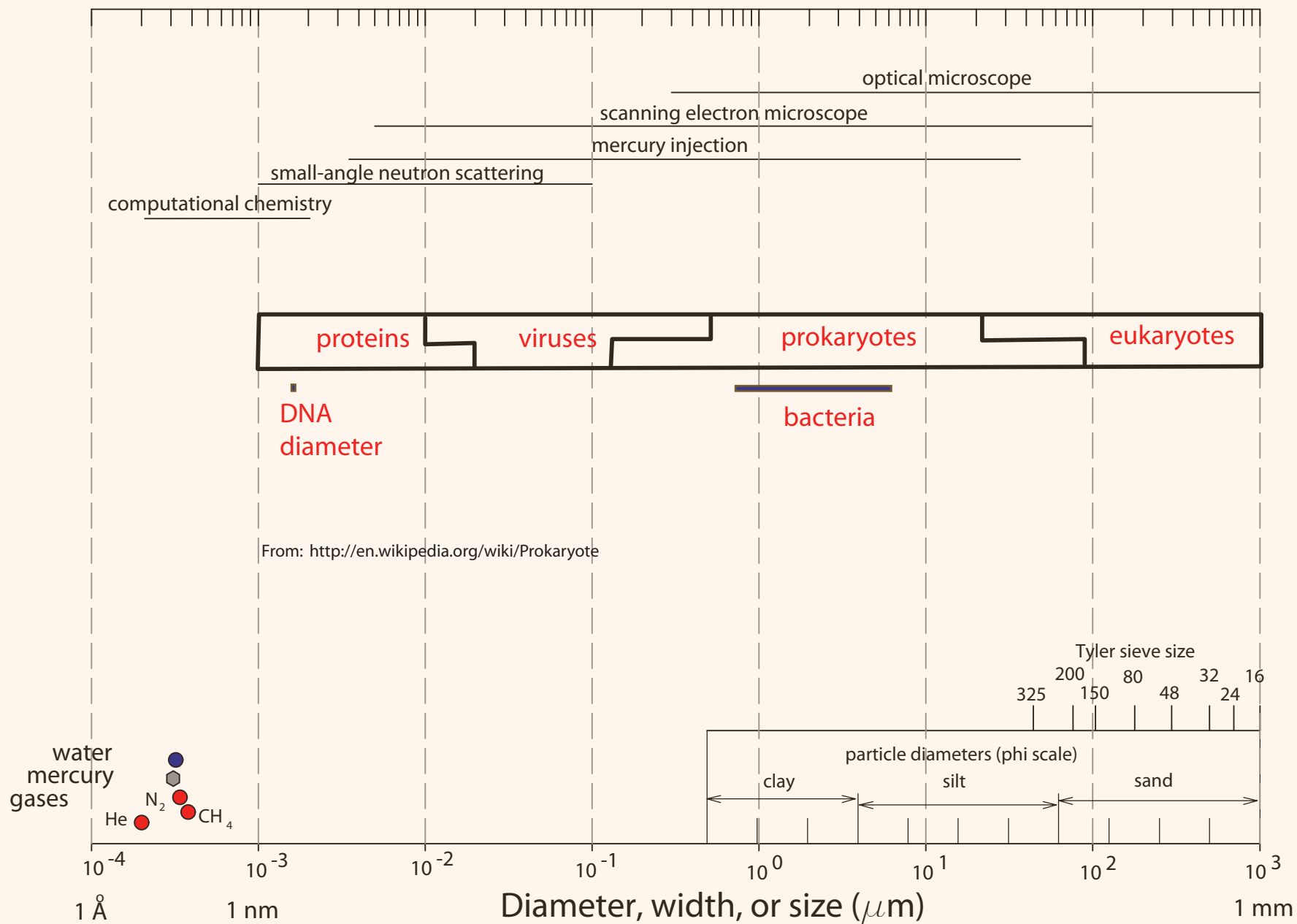




That's it for molecules. Before going on to rocks, in the next two slides consider two other areas of inquiry where the small world is of paramount interest:

(1) fabrication of integrated circuits and (2) biology.





Wardlaw and Cassan (1979) measured 27 sandstone samples:

Mean particle size from thin section.

Mean pore size and standard deviation  
from resin casts of pore space.

Pore throat diameter by mercury injection at threshold pressure  
and at 50% mercury saturation.

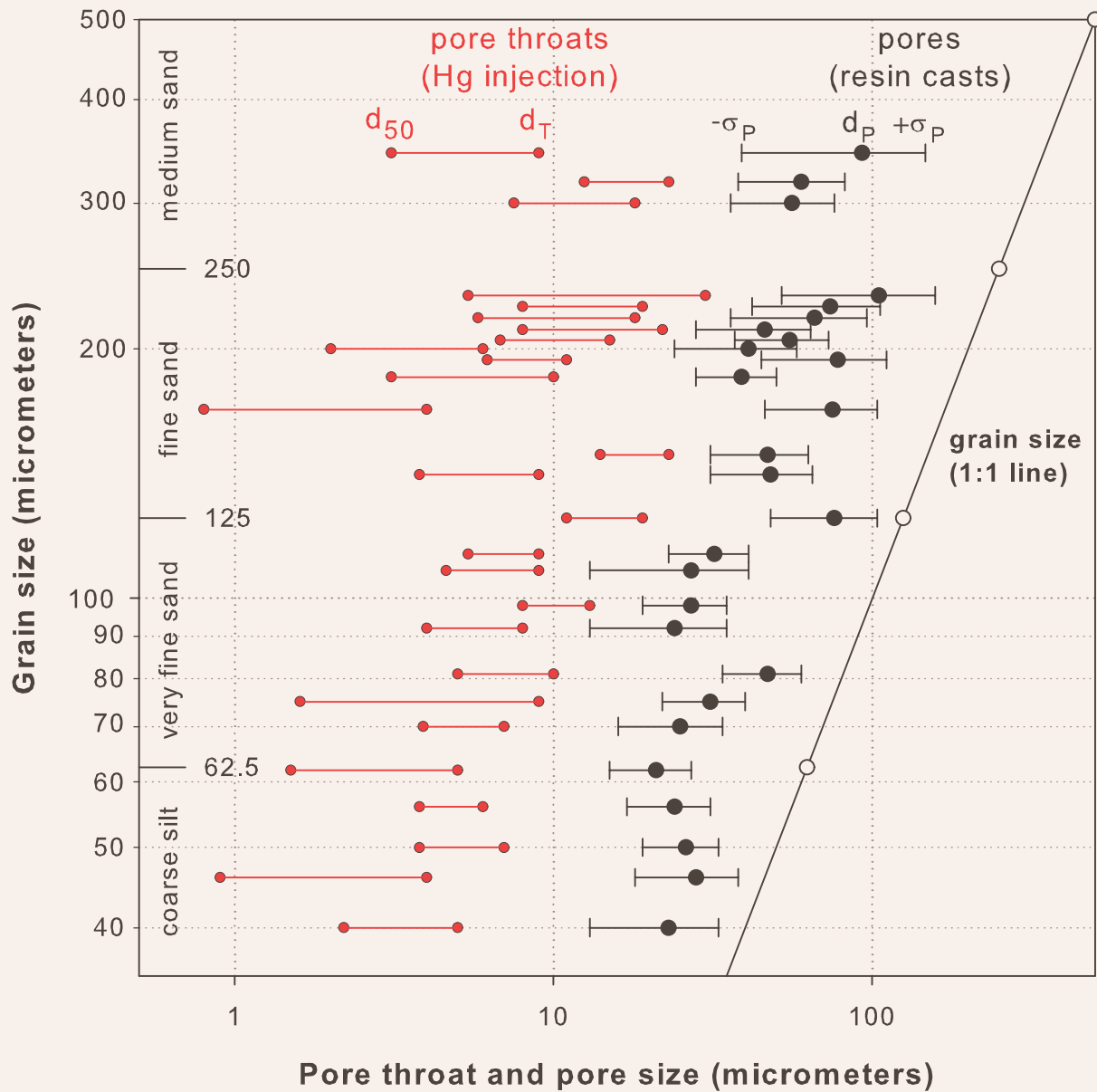
The next slide shows their data on a plot similar to their original  
publication, where  $d_{50}$  represents the pore throat size at 50%  
mercury saturation and  $d_T$  represents the size at entry pressure.

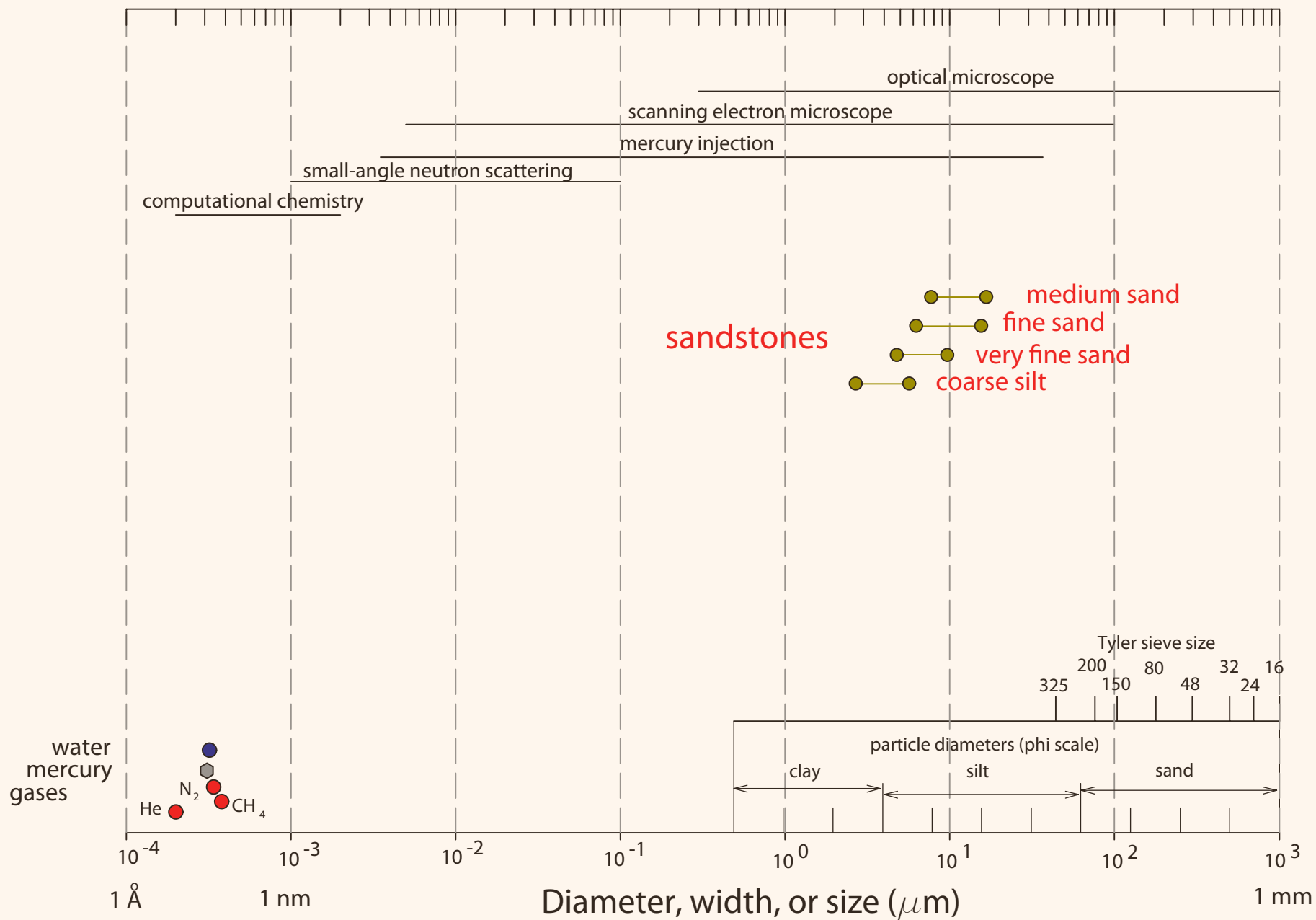
The following slide shows their data plotted on the pore throat size  
spectrum. These data represent good quality reservoir sandstones.



Wardlaw and Cassan, 1979

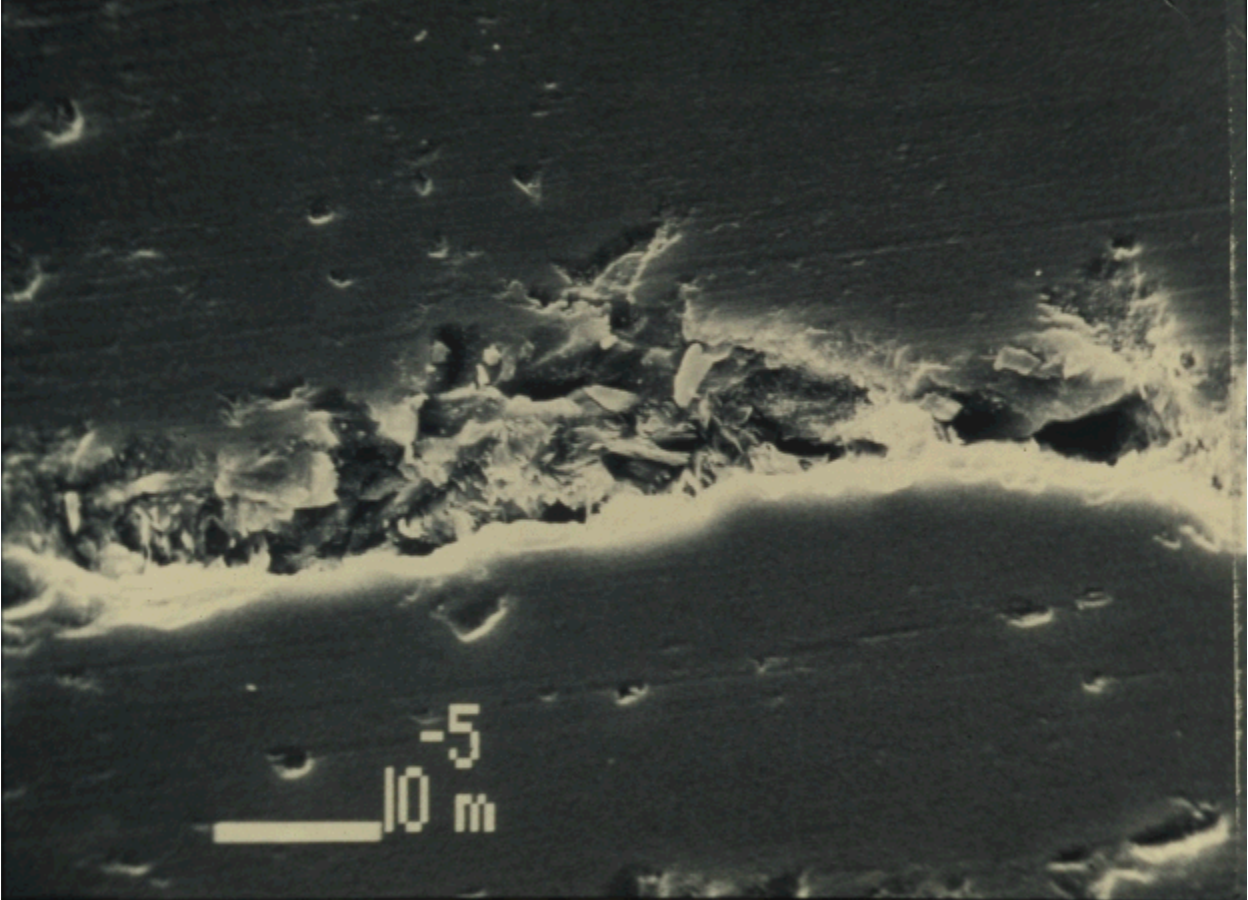
27 sandstones





Slot-like pores have been observed in tight gas sandstones, as shown in the next slide. Some investigators use a slot pore model to compute pore throat size, instead of the cylindrical model used for mercury injection measurements.

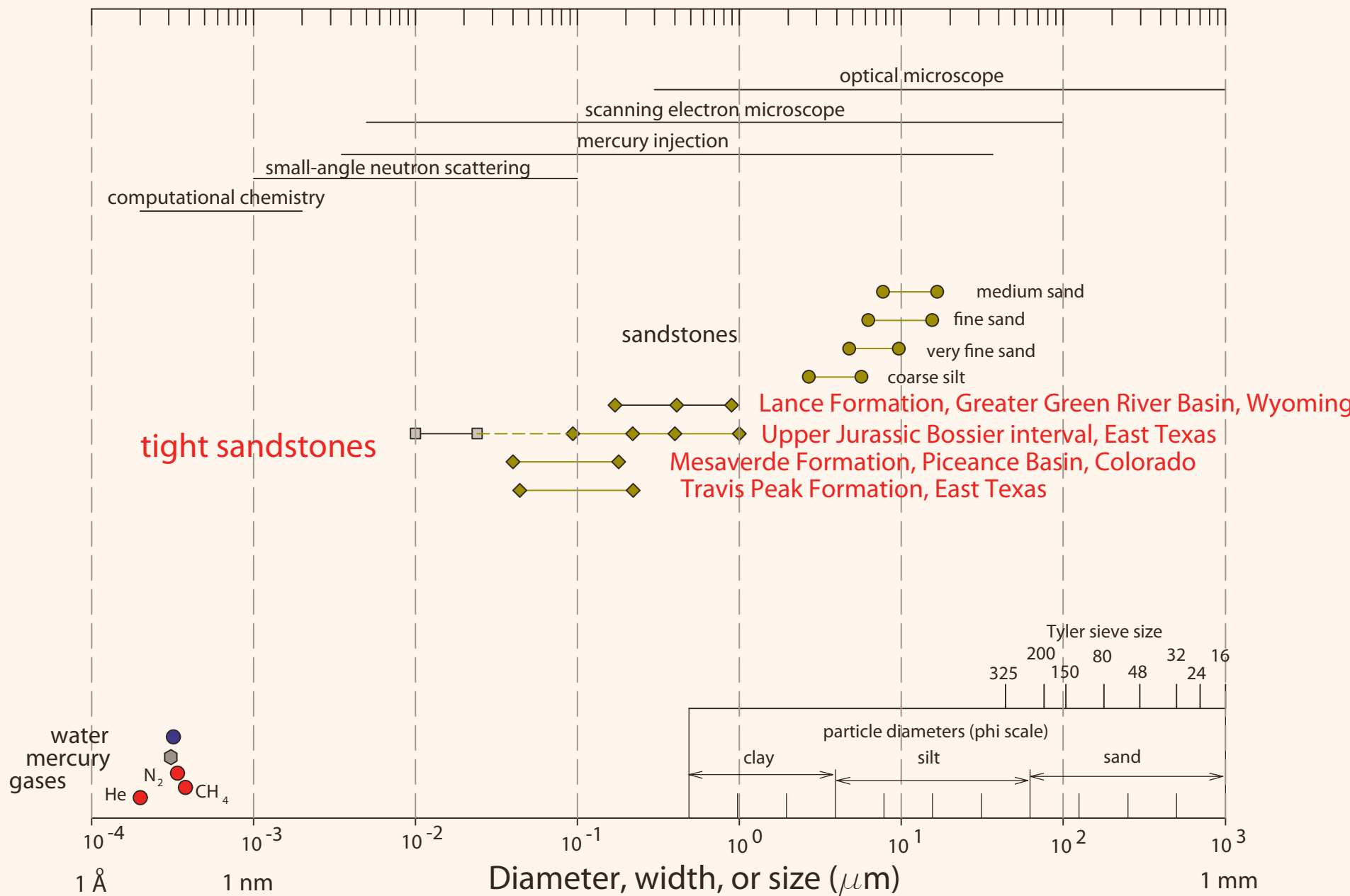
Pore throat sizes for tight gas sandstones are plotted on the pore throat size spectrum -- values are generally less than one micrometer.

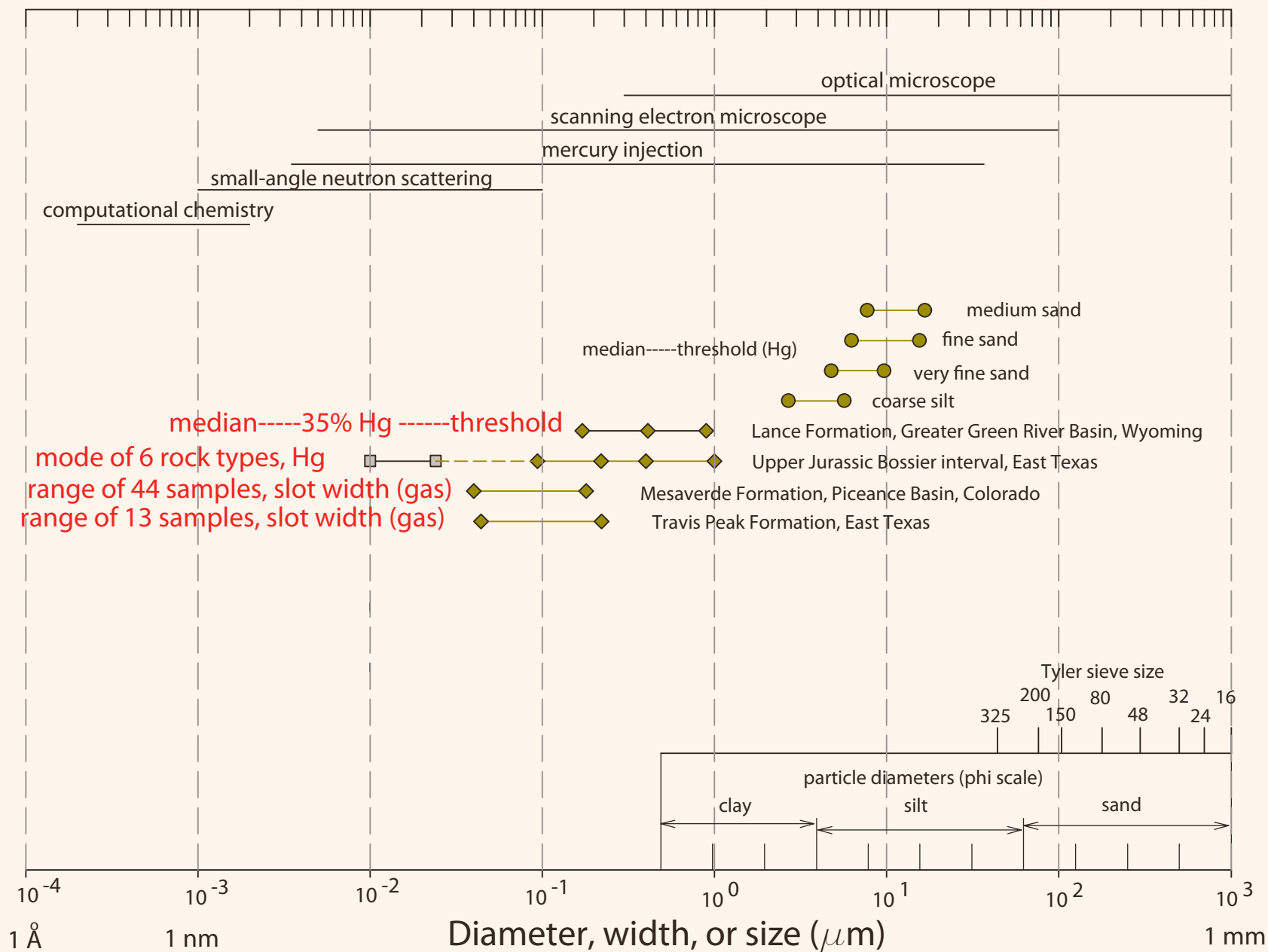


MW-3 5830 SLOT PORE

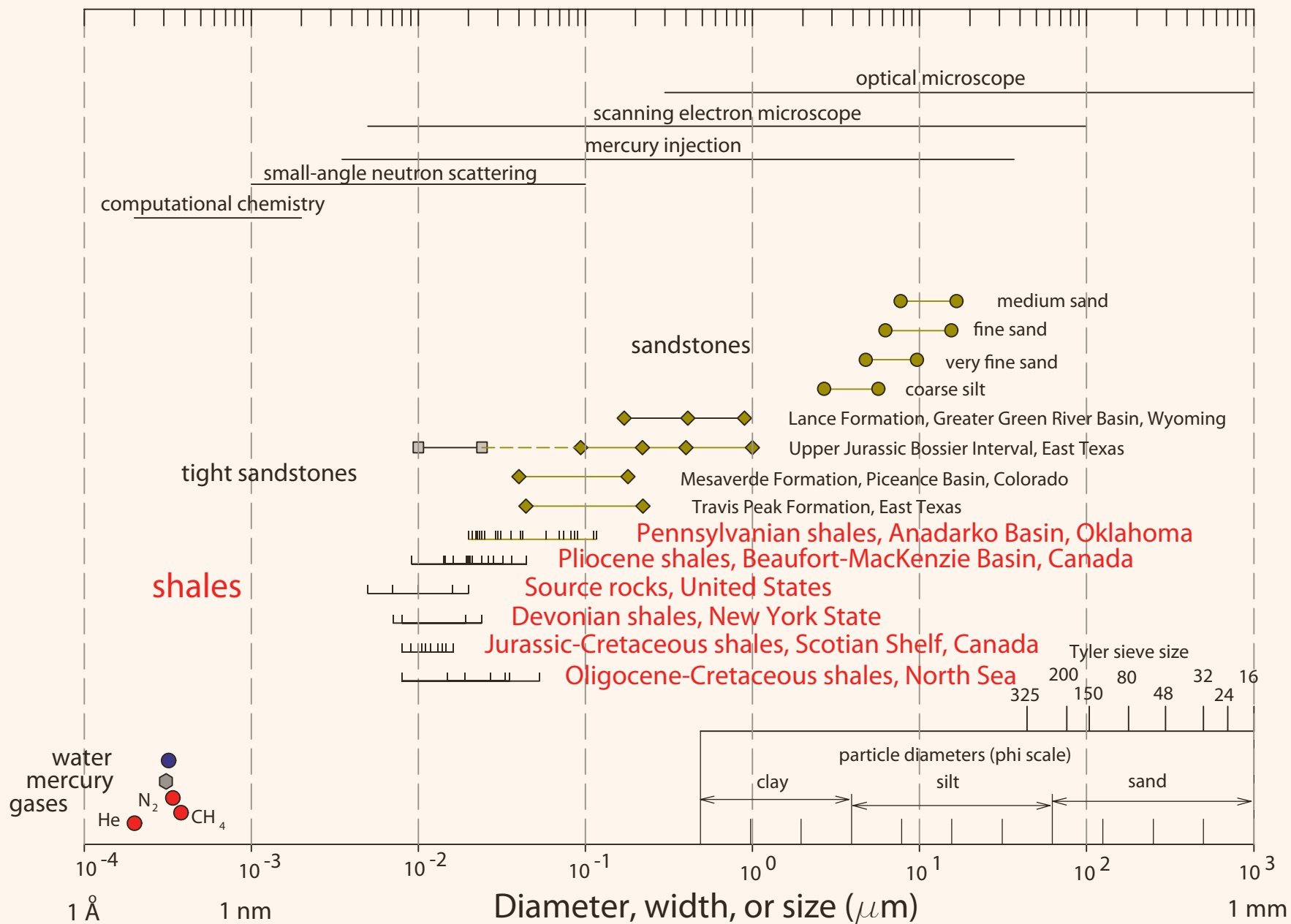
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Provided by  
Dan Soeder

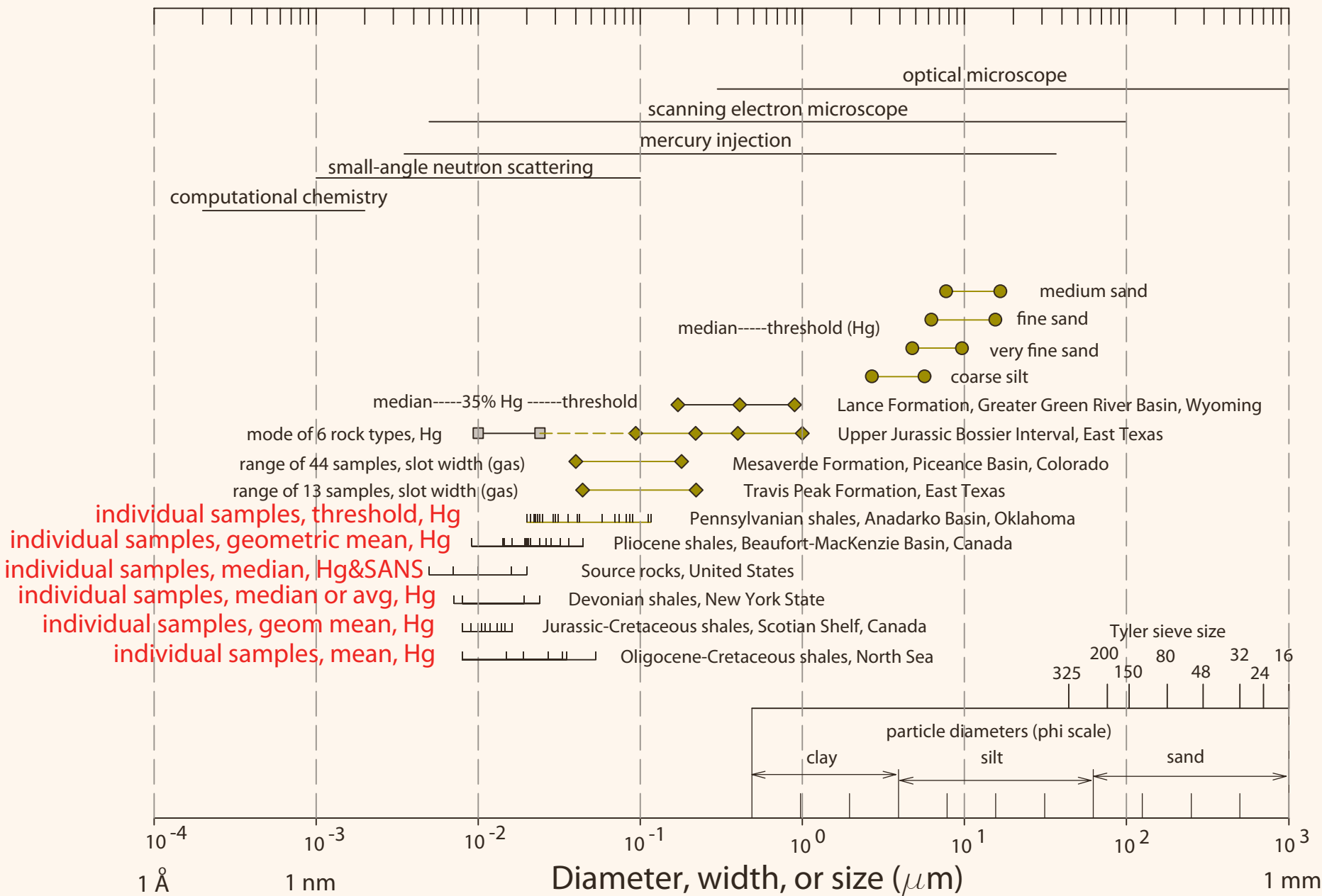


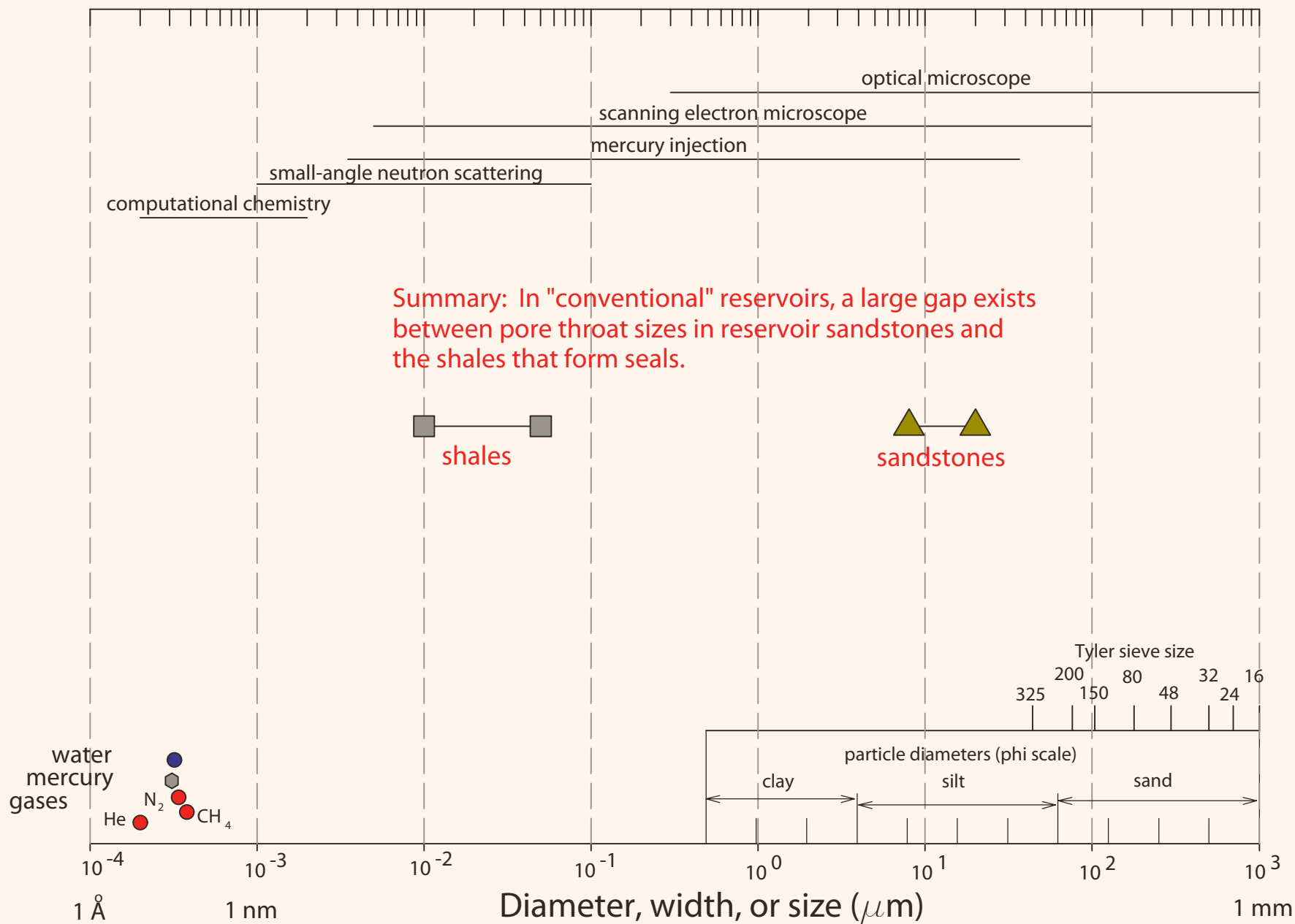


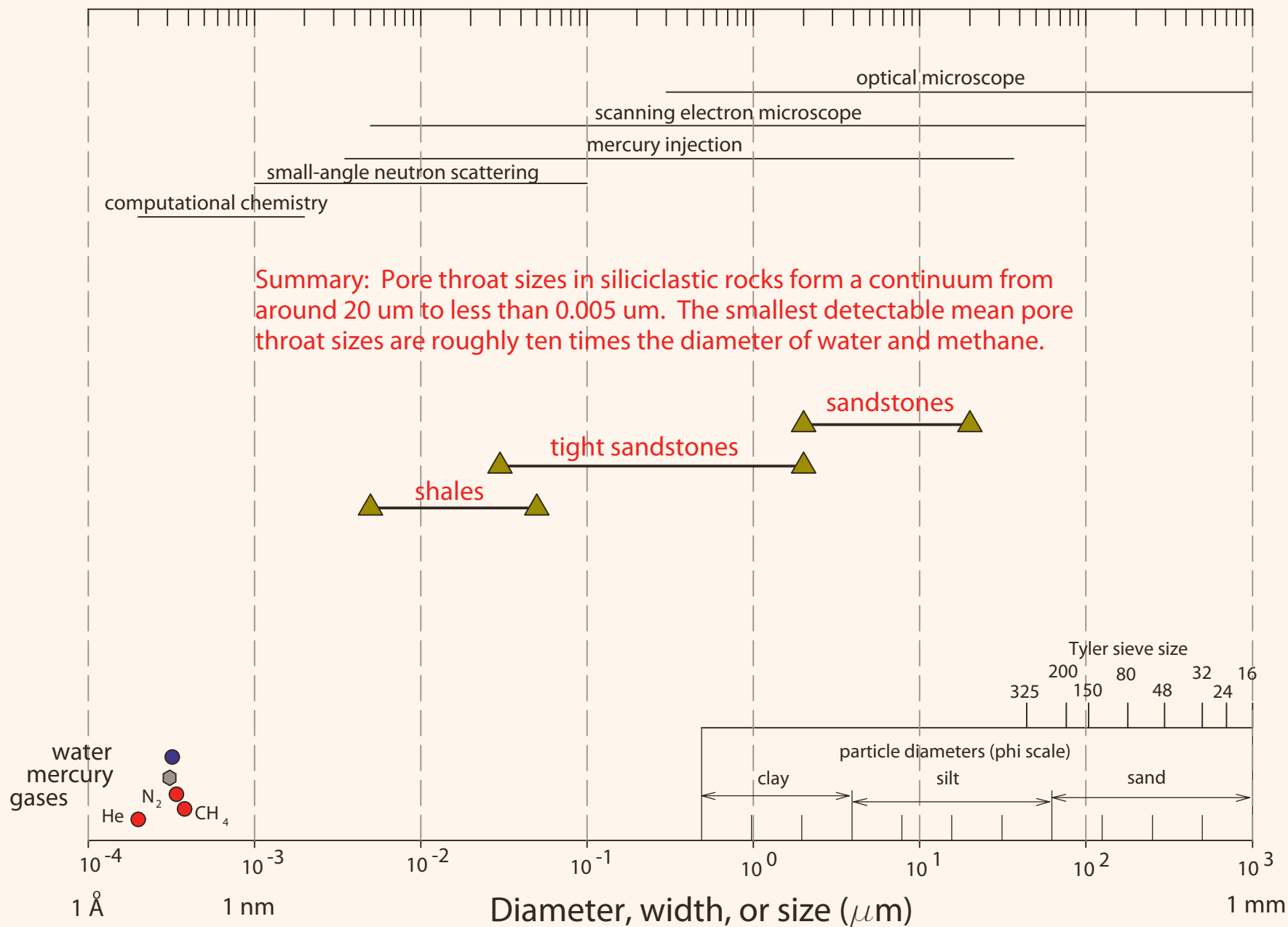
Values for shales are shown next. As was the case with tight gas sandstones, different investigators give different measures of the pore throat spectrum. However, such differences are relatively unimportant on the logarithmic scale used for the plot.











Exploitation of tight gas sandstones and shales requires access to smaller and smaller pore spaces within the pore-size spectrum.

It is hoped that this overview provides a useful perspective on these new developments.