Physical Modeling of Fluid Overpressure and Compaction During Hydrocarbon Generation in Source Rock of Low Permeability*

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Abstract

Although many authors have suggested that hydrocarbon generation can lead to fluid overpressure, there is no consensus as to the mechanism. Is the overpressure due to a volume increase during transformation of solid kerogen to oil or gas, or is it due to chemical compaction? We have investigated these problems by using scaled physical models. Our model materials were mixtures. The basic material was a silica powder (Millisil C4). Its grain size was less than 0.15 mm, and its intrinsic permeability was about 1.6 darcy. To simulate source rock, we mixed the silica powder (50% by volume) with micro-spheres of beeswax, 1 mm in diameter. The melting point of the beeswax was 61.5 °C. The housing for the models was a rectangular box, 28 cm long, 18 cm wide, and 15 cm deep. It had a thermally conducting basal plate of aluminum and transparent thermally insulating sidewalls. Each model consisted of several layers. We poured them successively into the box, scraping their upper surfaces flat. Then we saturated the model with water. The final water level was 1 cm higher than the upper surface of the model. To measure fluid pressure within a layer, we inserted a thin glass tube vertically down to the required depth. A fine sieve prevented solid grains from entering the tube, while allowing water to do so. The water in the tube rose to the level of the water outside. Then we heated the box from below with an electric flatbed heater. This had fine controls on temperature and power. The rate of heating was about 1°C per minute. When the temperature in the source layer reached the melting point of the wax, the water level in the glass tube started to rise. It soon reached a steady head, which was equivalent to the effective weight of the overburden (allowing for buoyancy). During partial melting, the source layer compacted. Liquid wax migrated upward through pore space, displacing water. In some experiments, the wax also filled flat-lying hydraulic fractures. We attribute these fractures to seepage forces, resulting from Darcy flow through the porous medium. Locally, the overpressure exceeded the weight of overburden. In some experiments, liquid wax breached an uppermost sealing layer of silica powder and extruded at the surface, forming structures like lava tubes or lava flows. The experiments illustrate the power of chemical compaction as a mechanism for generating high overpressure in maturing source rock.

References

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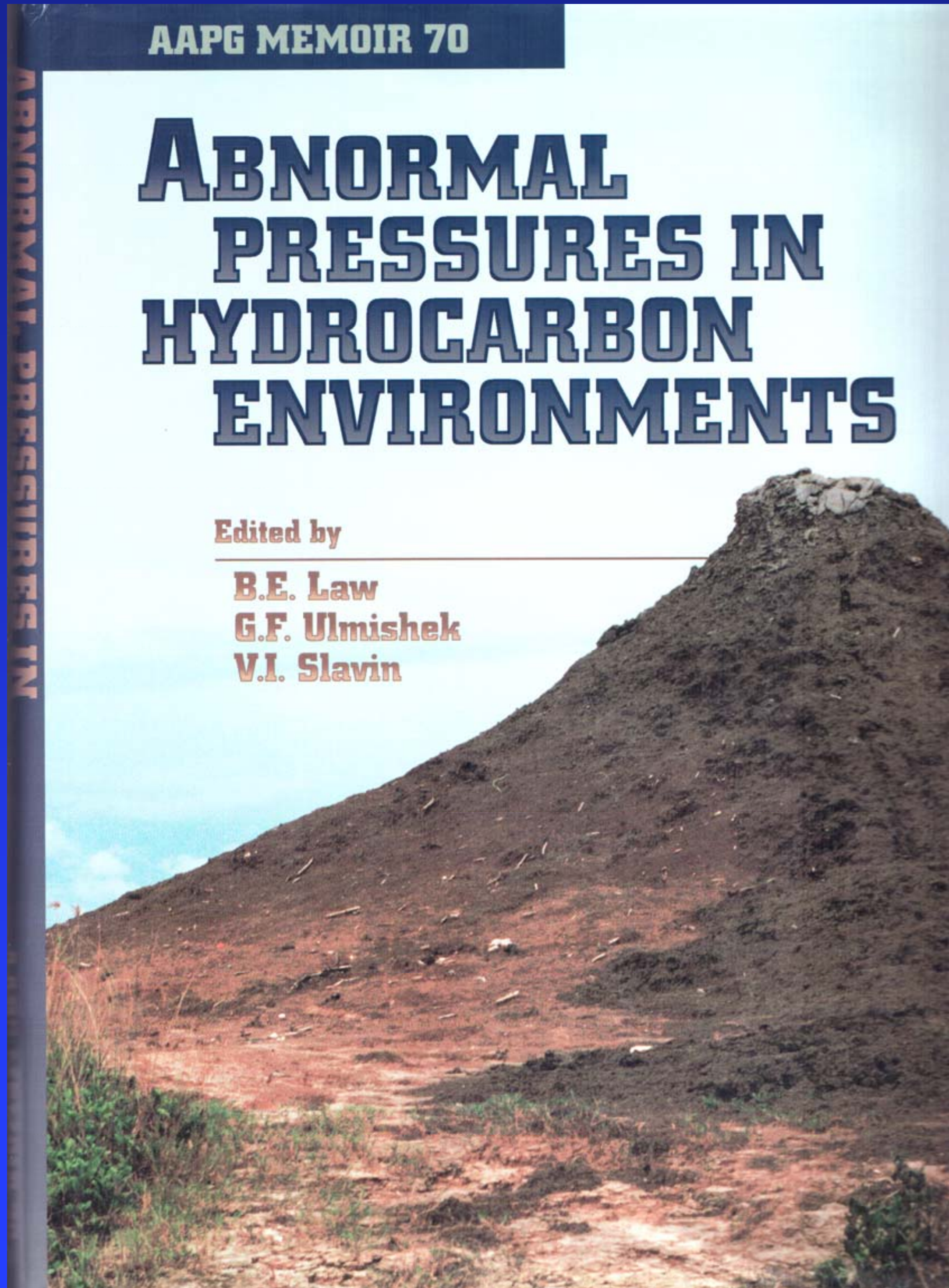


1998
a book to
remember!

Global distribution of overpressure
(Law & Spencer, 1998)

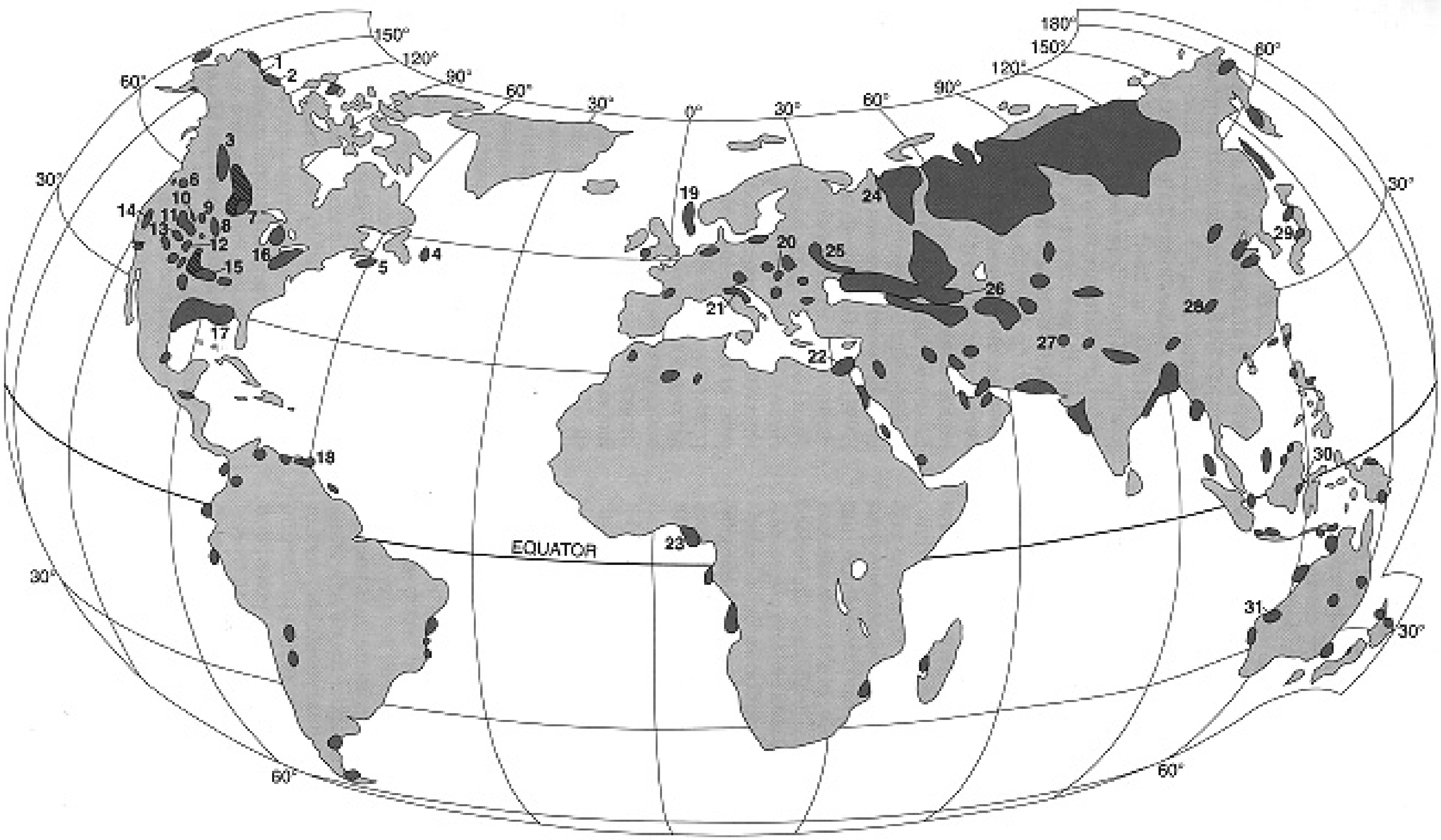
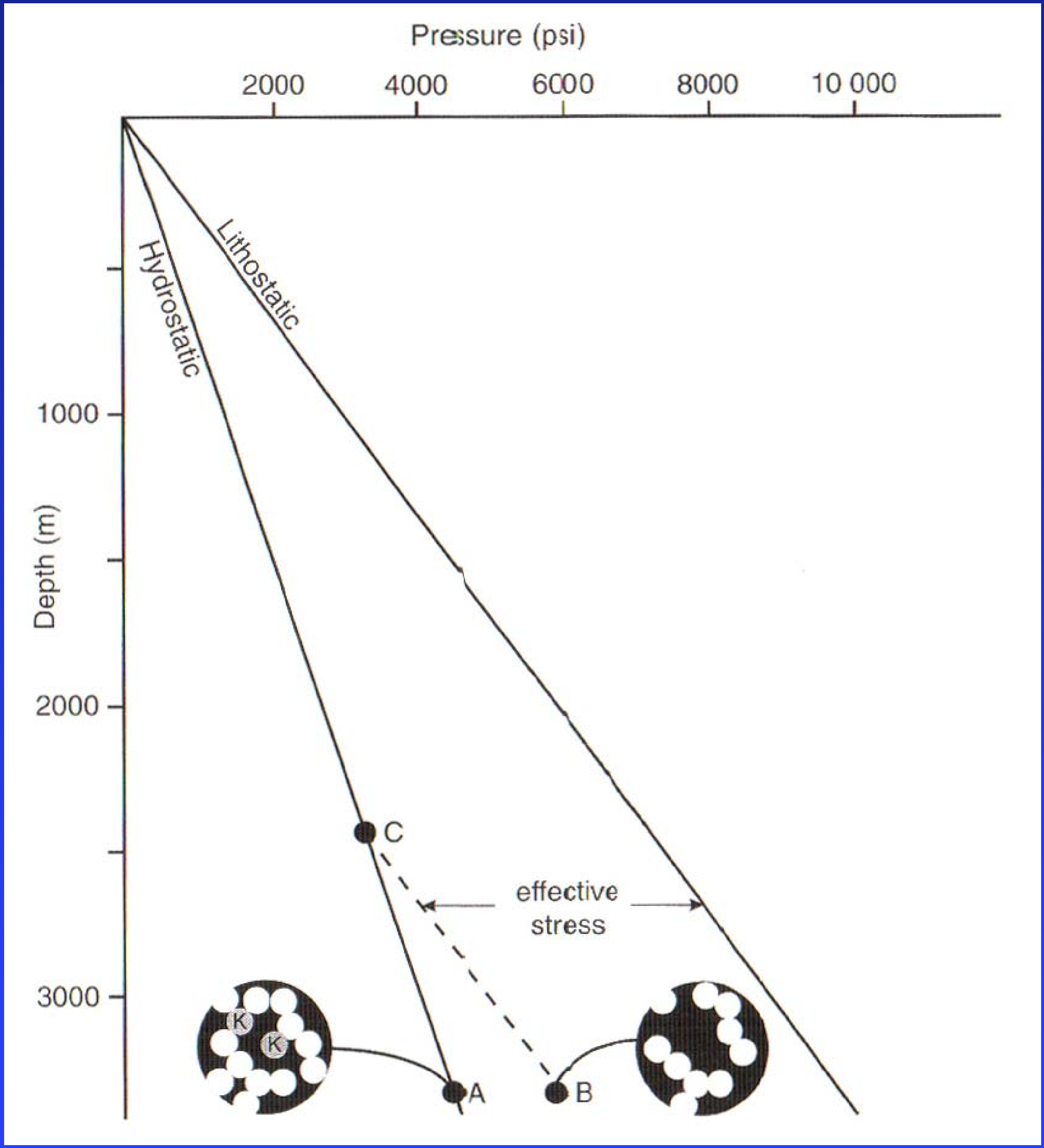


Figure 1. Map showing the global distribution of abnormal pressures. Heavier shaded, diagonally ruled patterns are used to avoid masking of darker patterned areas listed on Table 1. Index numbers adjacent to selected abnormally pressured areas refer to additional data provided in Table 1.

Possible causes of overpressure
(Swarbrick & Osborne, 1998)

- Hydraulic head
- Hydrocarbon buoyancy
- Mechanical compaction
- Aquathermal expansion
- Dehydration reactions (e.g. gypsum to anhydrite)
- Volume increase due to oil generation
- Volume increase due to gas generation
- Chemical compaction

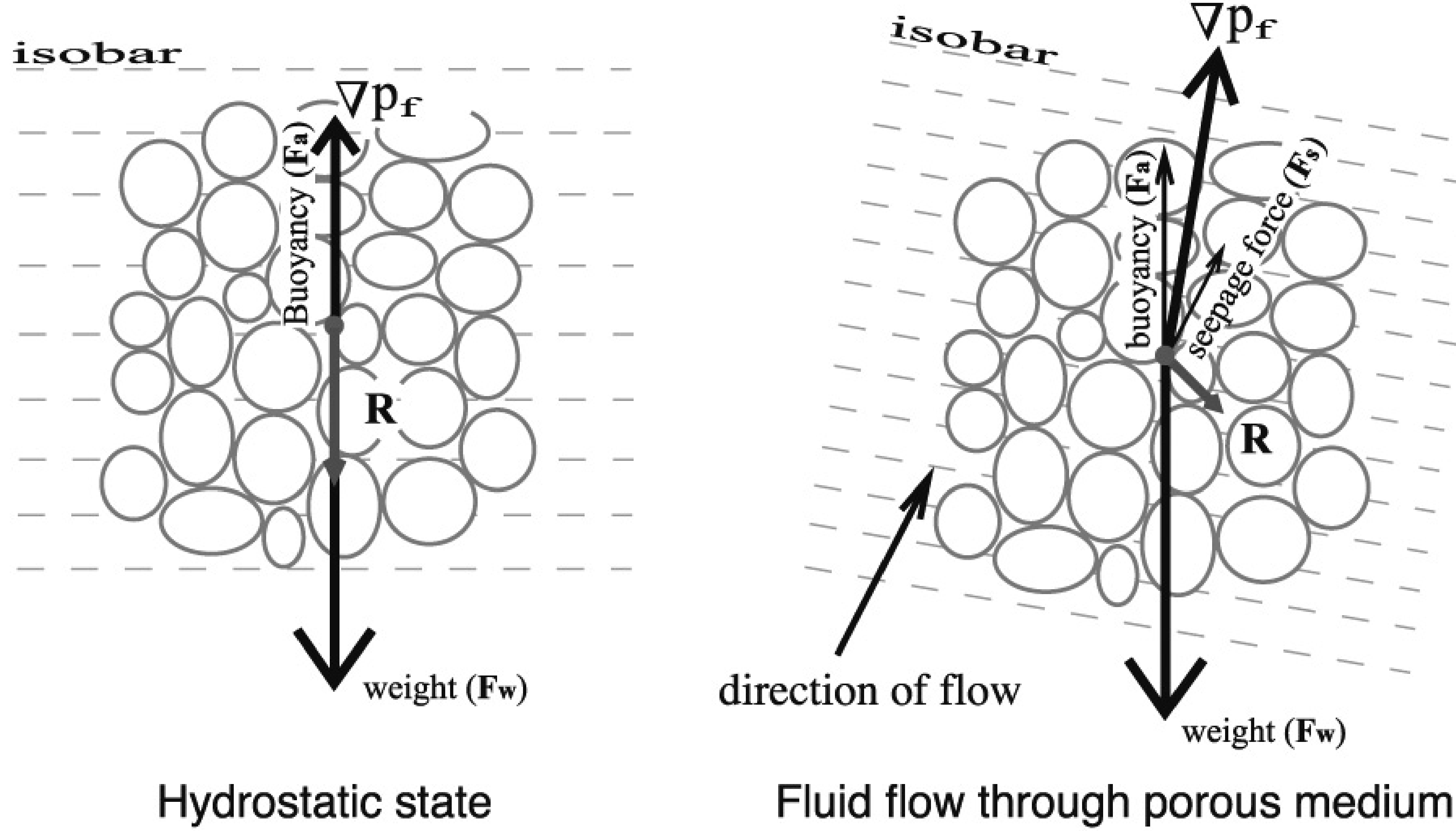
Chemical compaction (Swarbrick & Osborne, 1998)



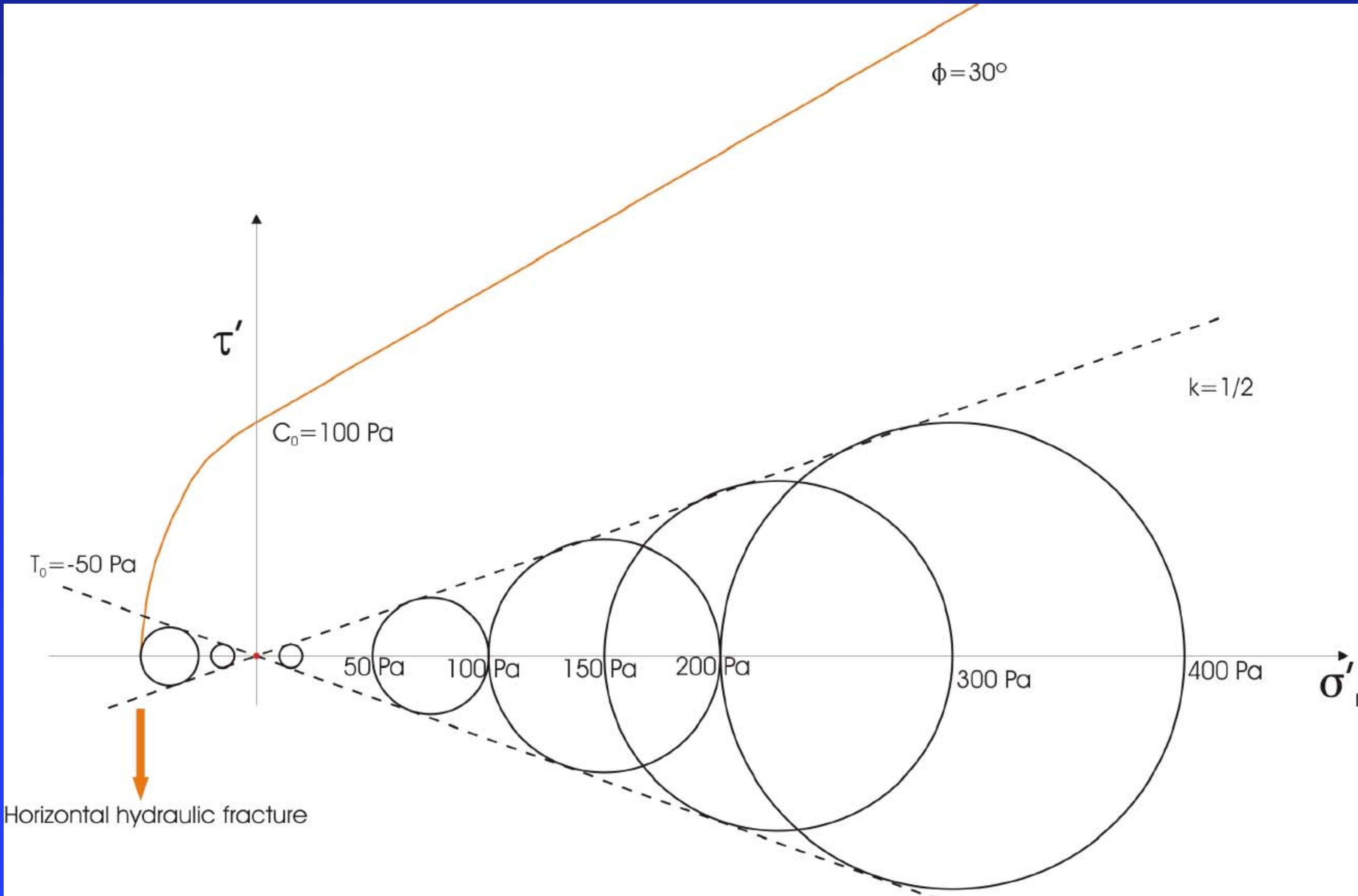
Horizontal hydraulic fracture due to seepage

(Rodrigues & Cobbold, 2007)

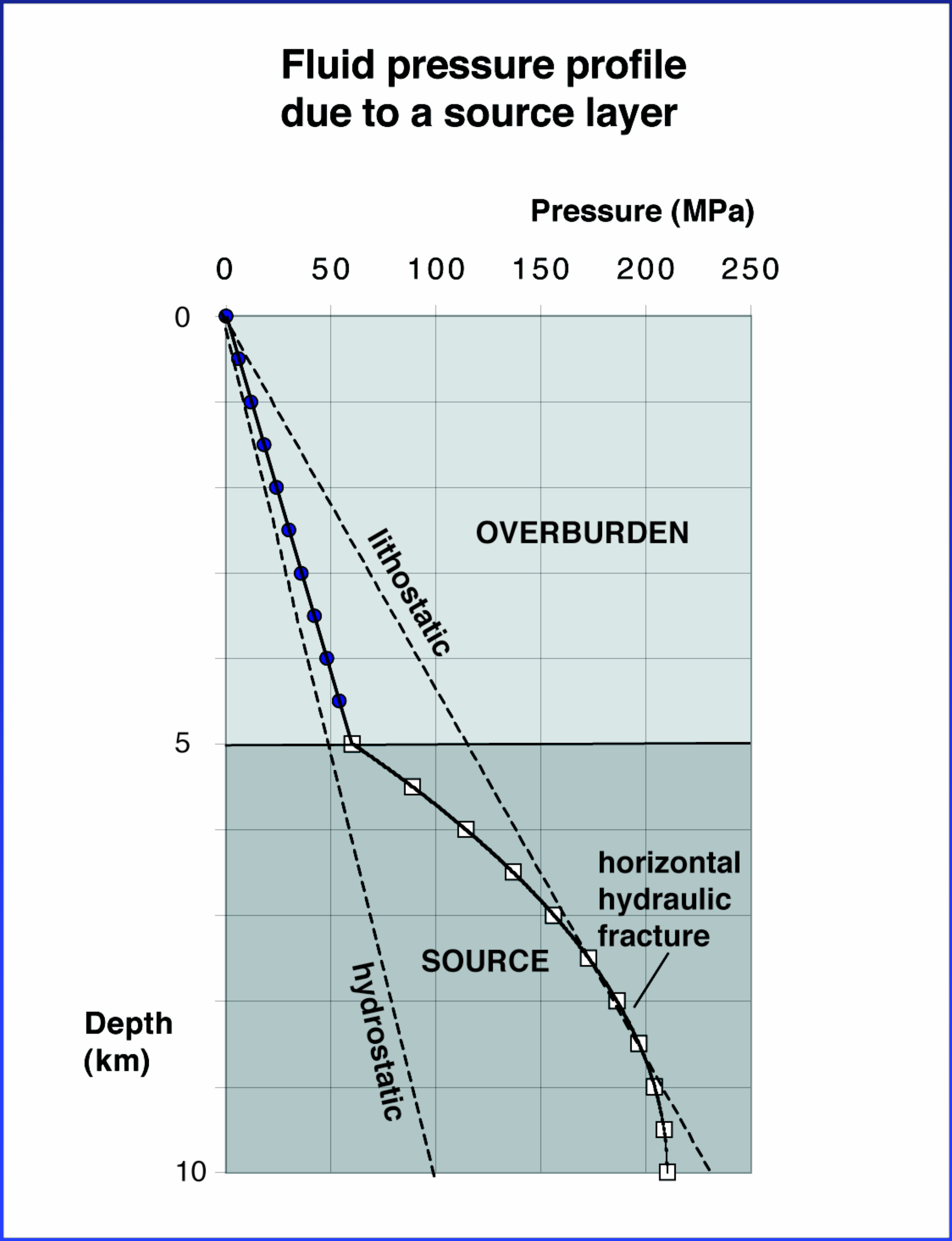
Forces acting on a porous medium
(Mourgues & Cobbold 2003)



Vertical seepage forces and failure
(Cobbold & Rodrigues, 2007)



Pressure profile
in and over a
source layer
(Cobbold & Rodrigues,
2007)

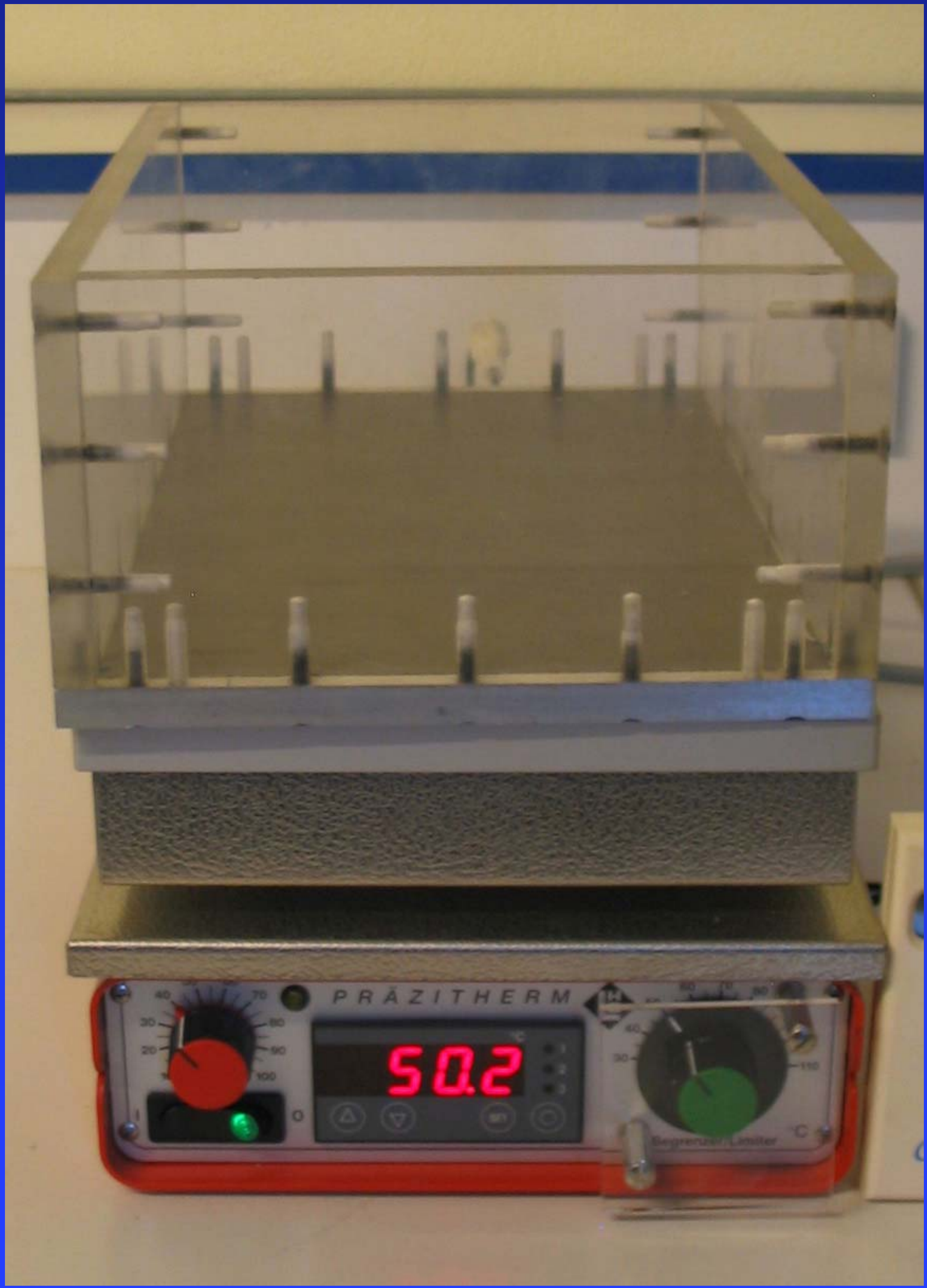


NEW EXPERIMENTS

Rectangular box

Aluminium baseplate

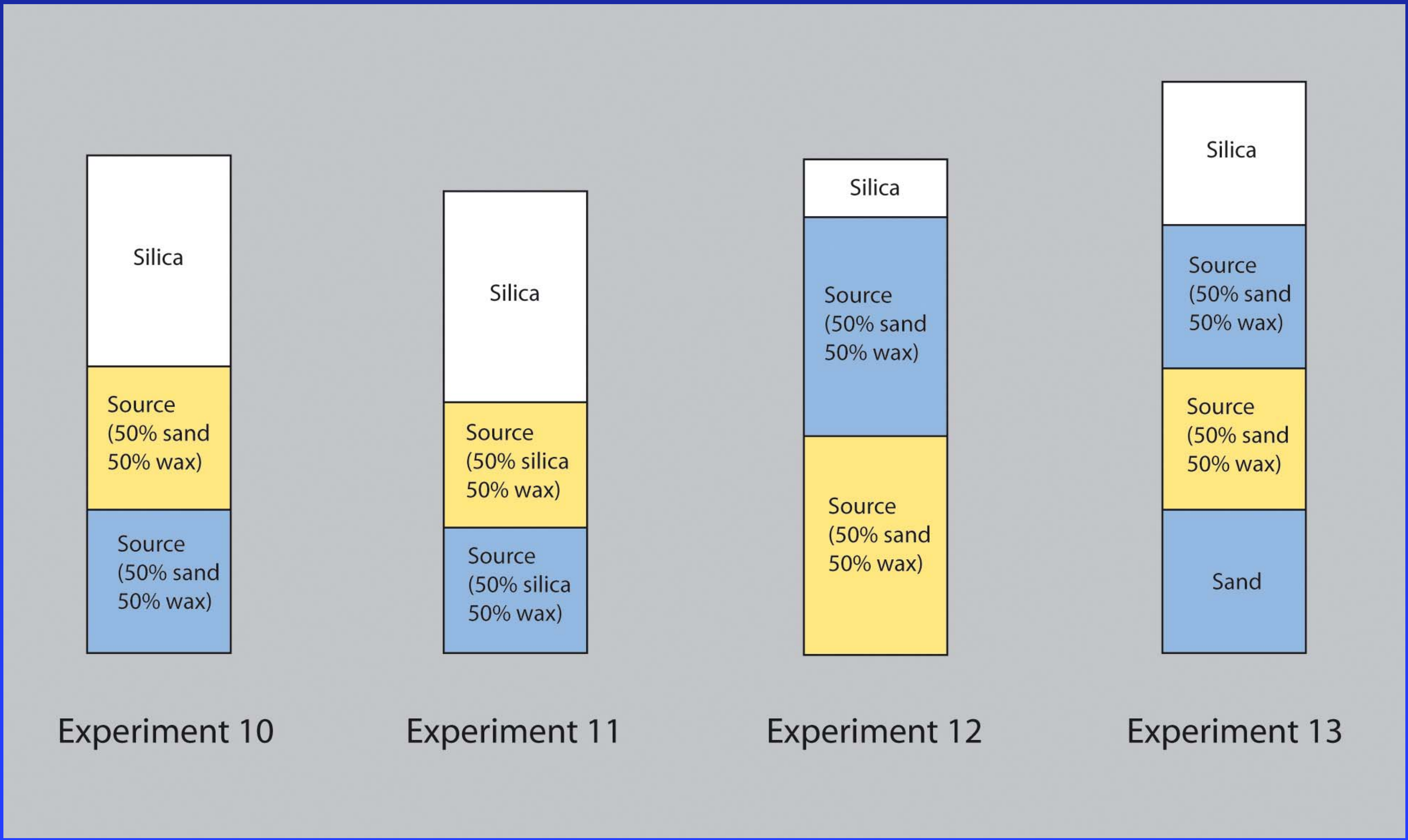
Electric flatbed heater



Model materials

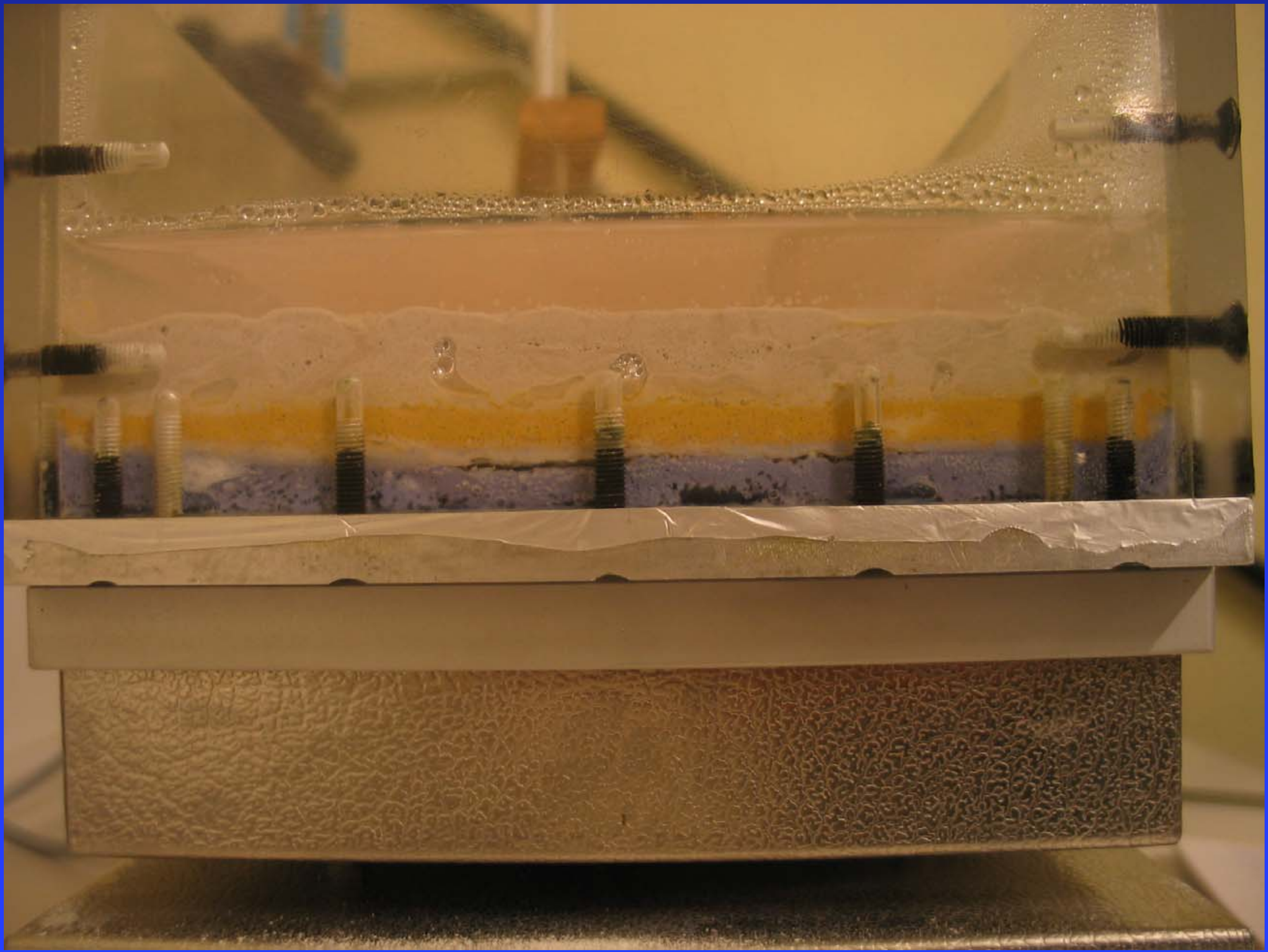
- Silica powder, Millisil C4 (d = 0-150 µm, ρ = 1.34 g/cm^3, k = 1.6 Darcy)
- Quartz sand (d = 0-160 µm, ρ = 1.43 g/cm^3, k = 14 Darcy)
- Beeswax microspheres (d = 1 mm, ρ_s = 0.96 g/cm^3, M.P. 61.5 °C)
- Source mixture (50% by volume sand or silica powder, 50% by volume beeswax)
- Liquid beeswax (ρ = 0.82 g/cm^3, μ = 14 mPa s)

Models of Series B



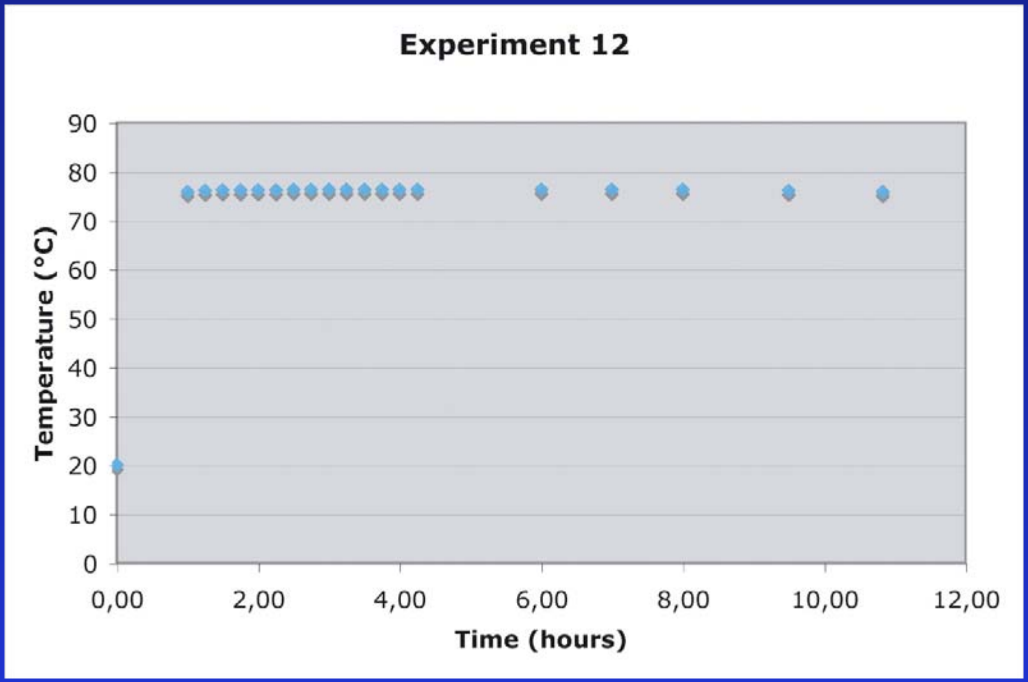
Experiment 11
(before heating)

Experiment 11
(during heating)

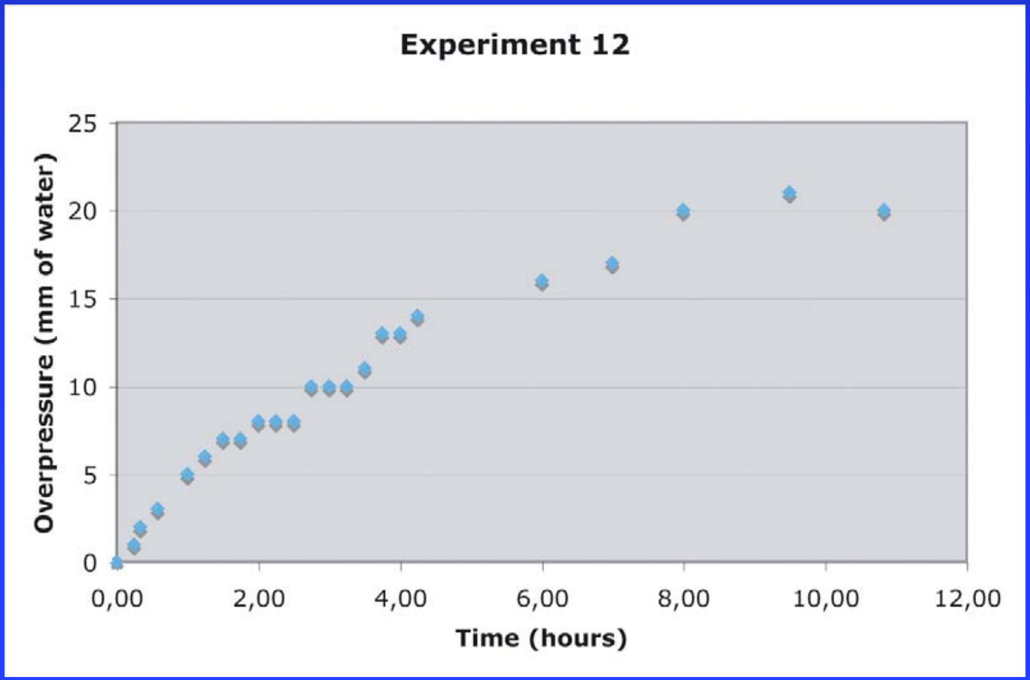


Experiment 12

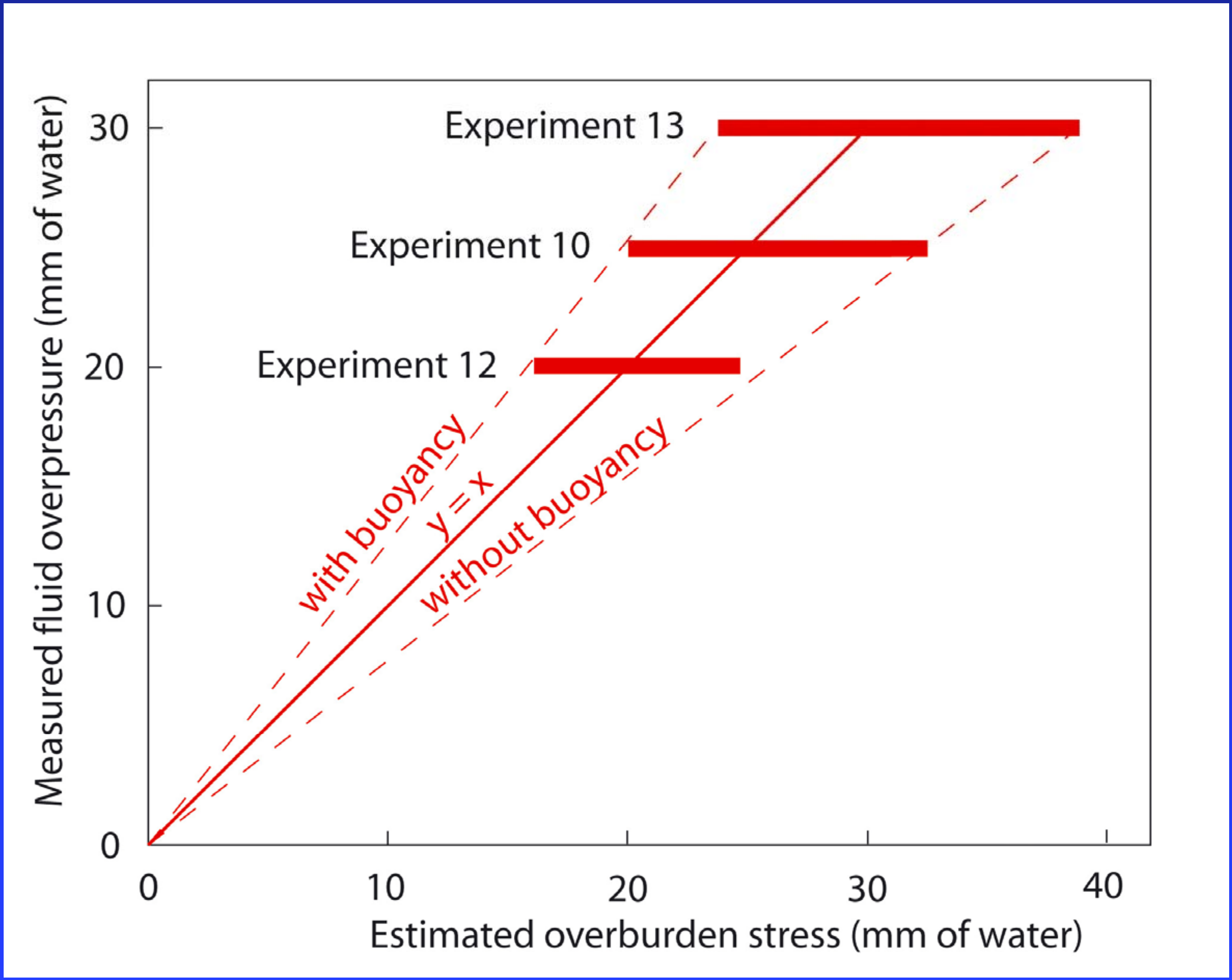
Temperature



Overpressure



Maximal overpressure versus overburden stress



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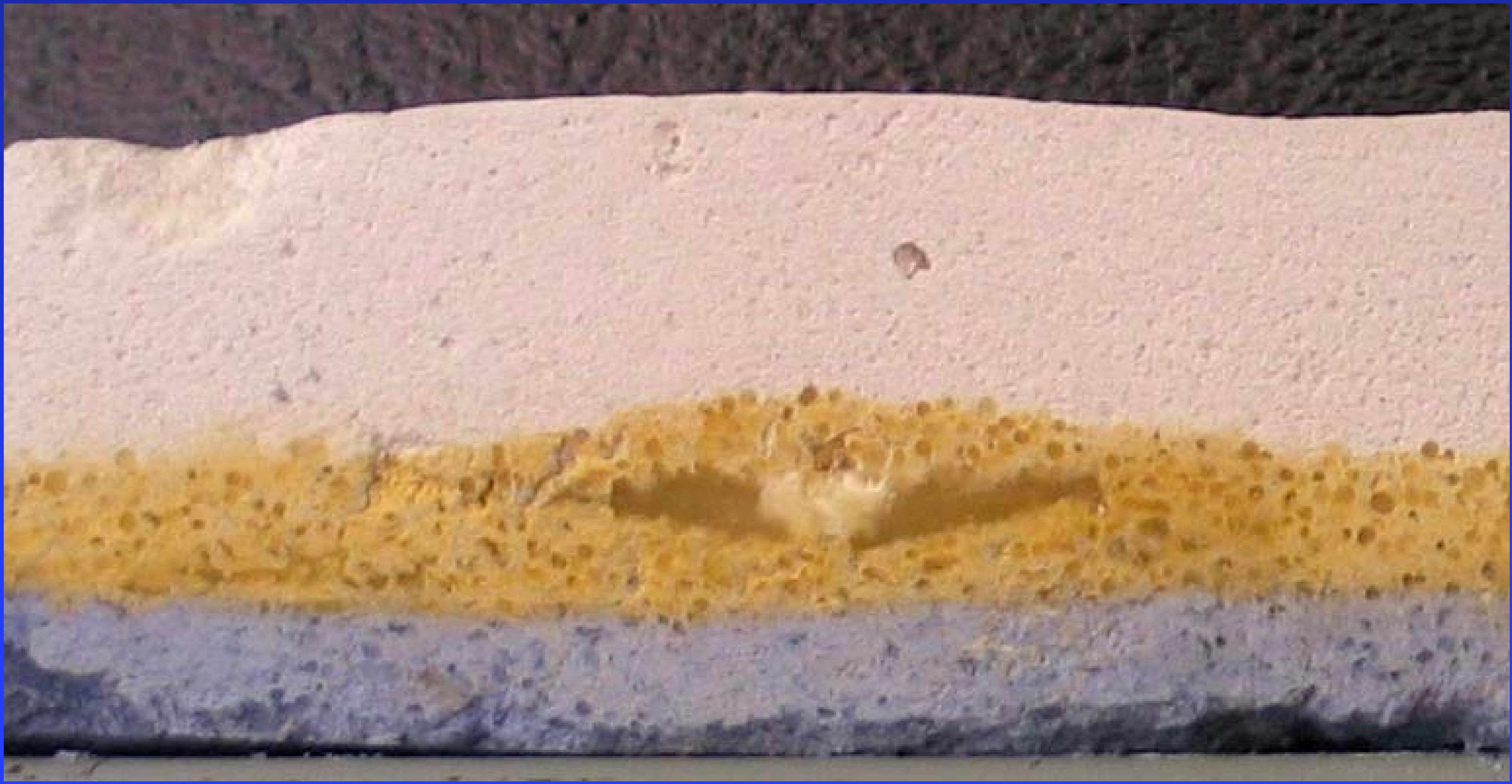
Experiment 11, section 10

Experiment 11, section 12

Experiment 11, section 10

(sill and overlying dome, which nucleated around an air bubble)

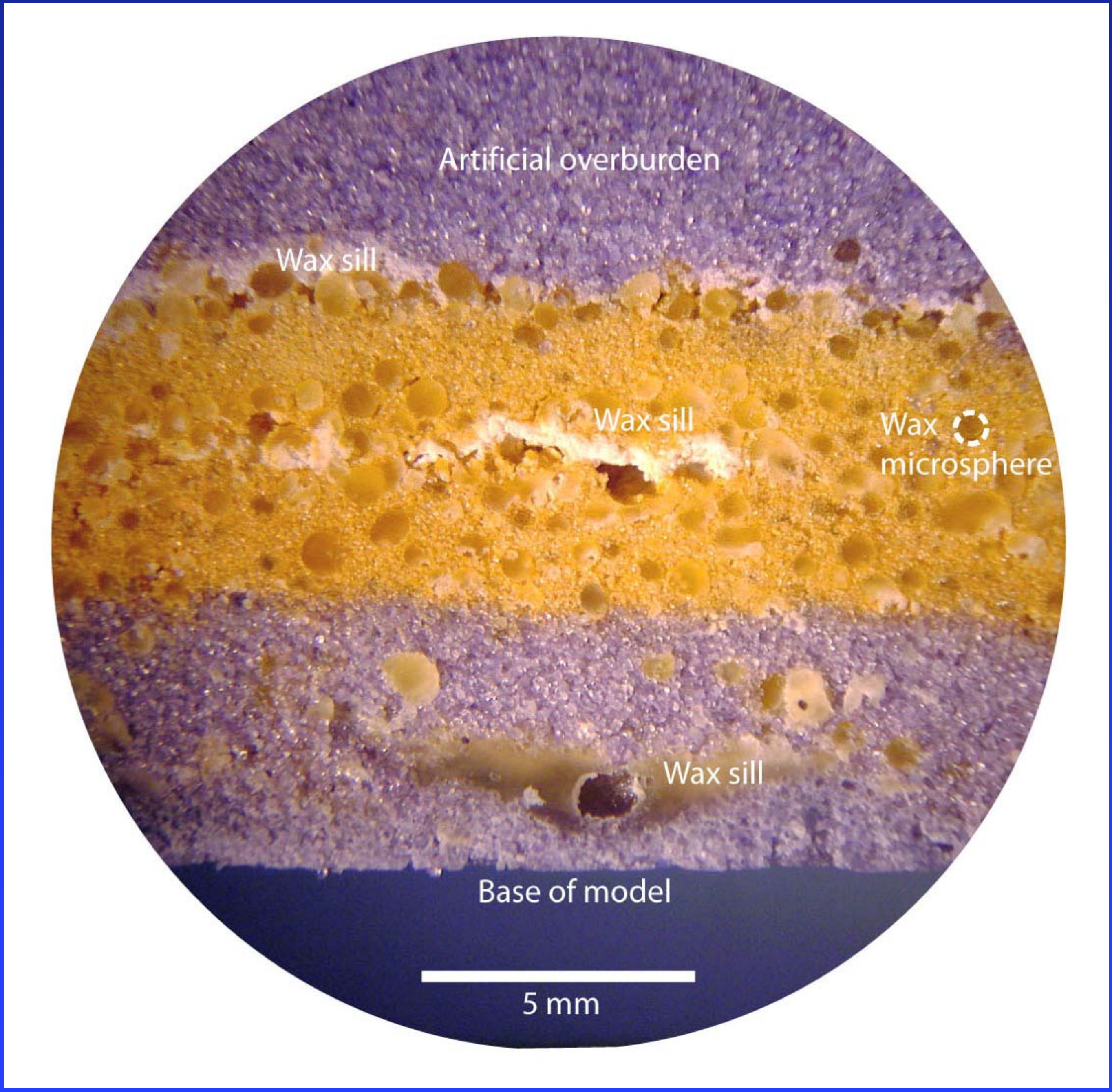


Experiment 10
(view under binocular microscope)

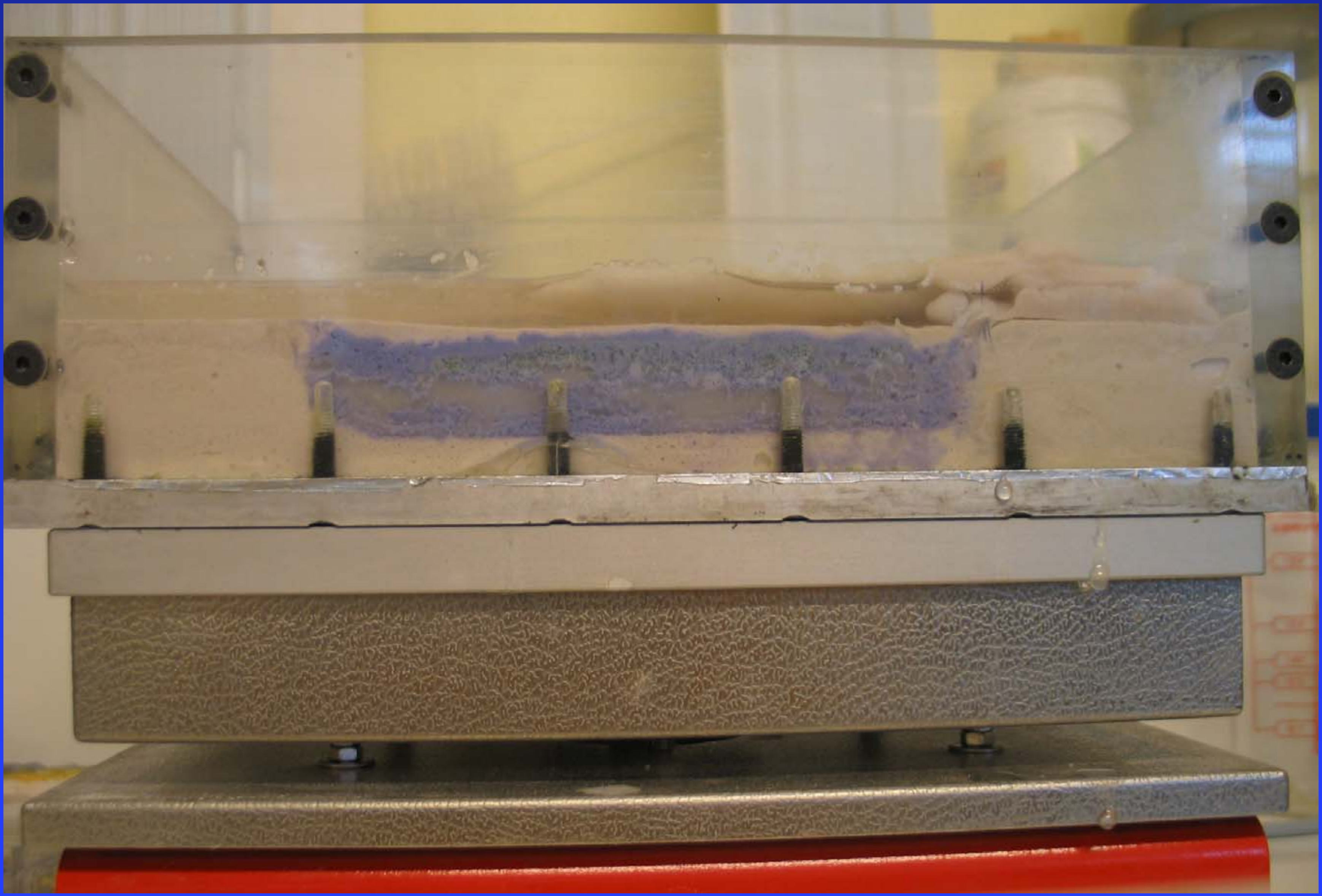
Layer 3: artificial

Layer 2:
50% microspheres,
originally

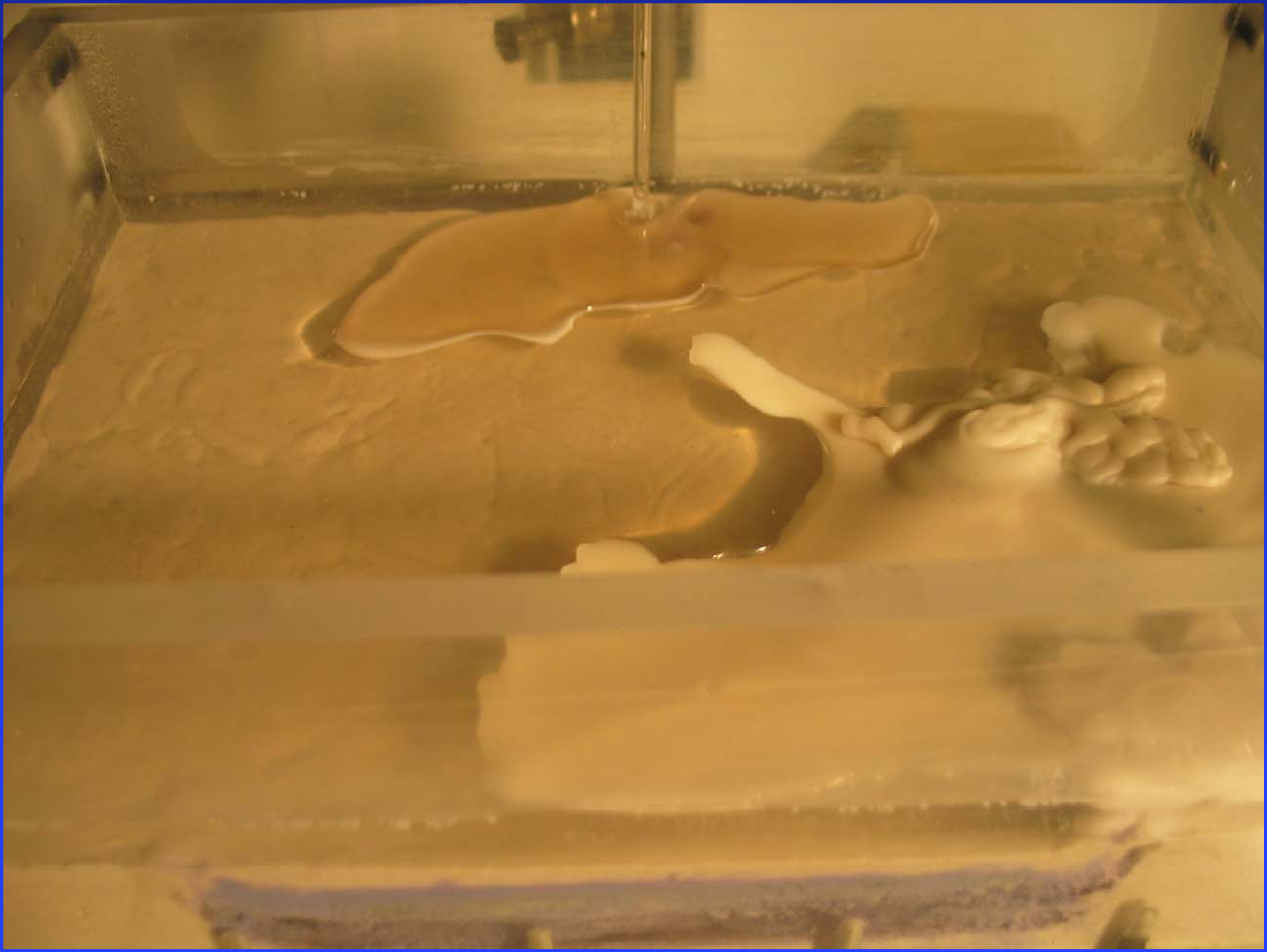
Layer 1:
50% microspheres,
originally



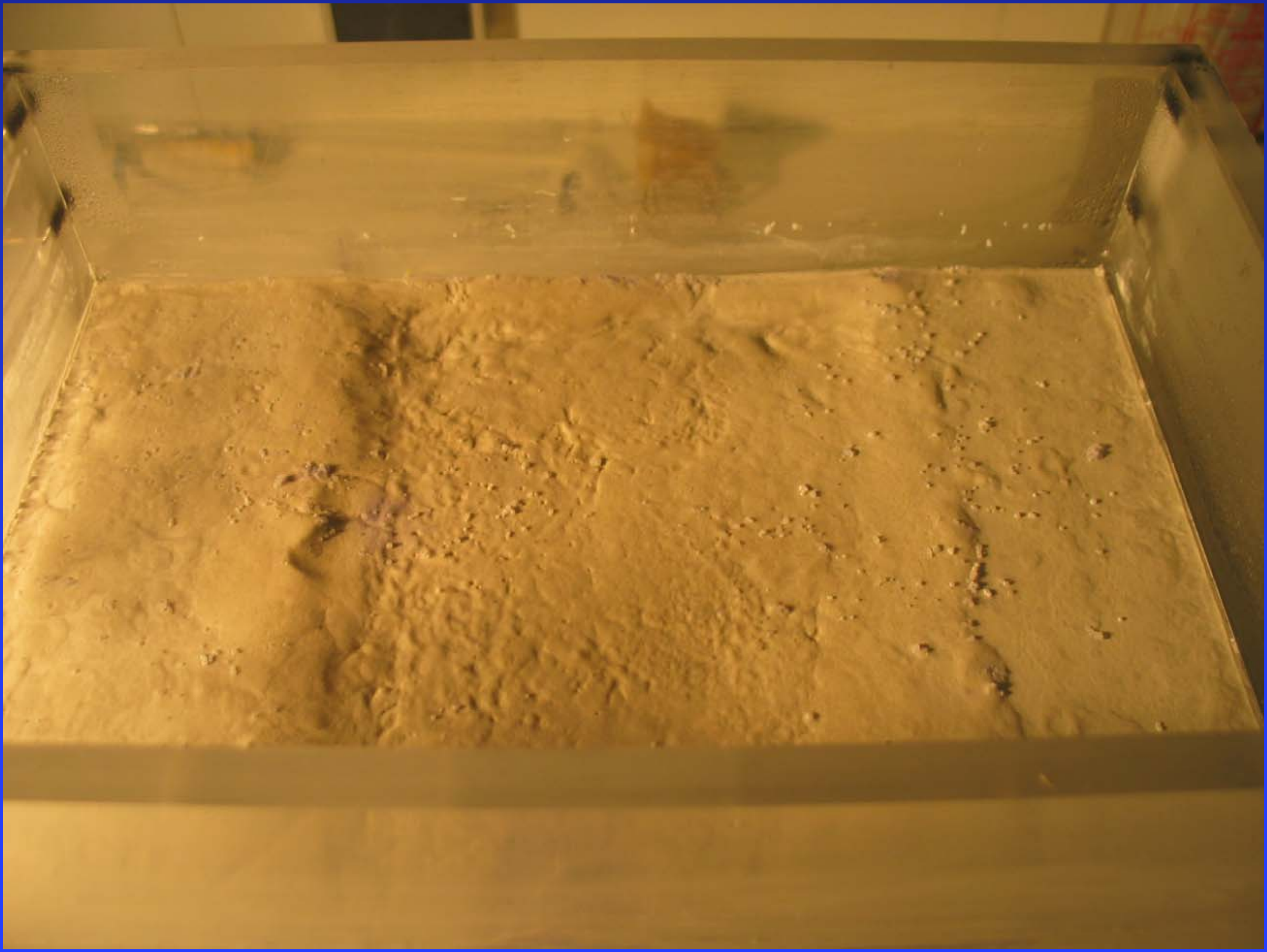
Experiment 14
(source pod surrounded by silica powder)



Experiment 14
(extrusion of wax at upper surface)



Experiment 14
(oblique view of upper surface, showing compaction of source pod)



Conclusions

- In our experiments, partial melting at depth allowed compaction.
- Pore fluid took up most of weight of overburden, acquiring strong overpressure.
- Volume increase of wax (15%) may have contributed.
- Overpressure gradient induced migration of melt through pore space, either upward or downward.
- We infer that horizontal hydraulic fractures were due to seepage forces.
- Some melt moved into hydraulic fractures.
- Excess melt extruded at free surface.
- These processes are relevant to (1) petroleum systems and (2) magmatism in the Earth's crust.

Los Castaños bitumen mine, Neuquén
(Borrello, 1956)

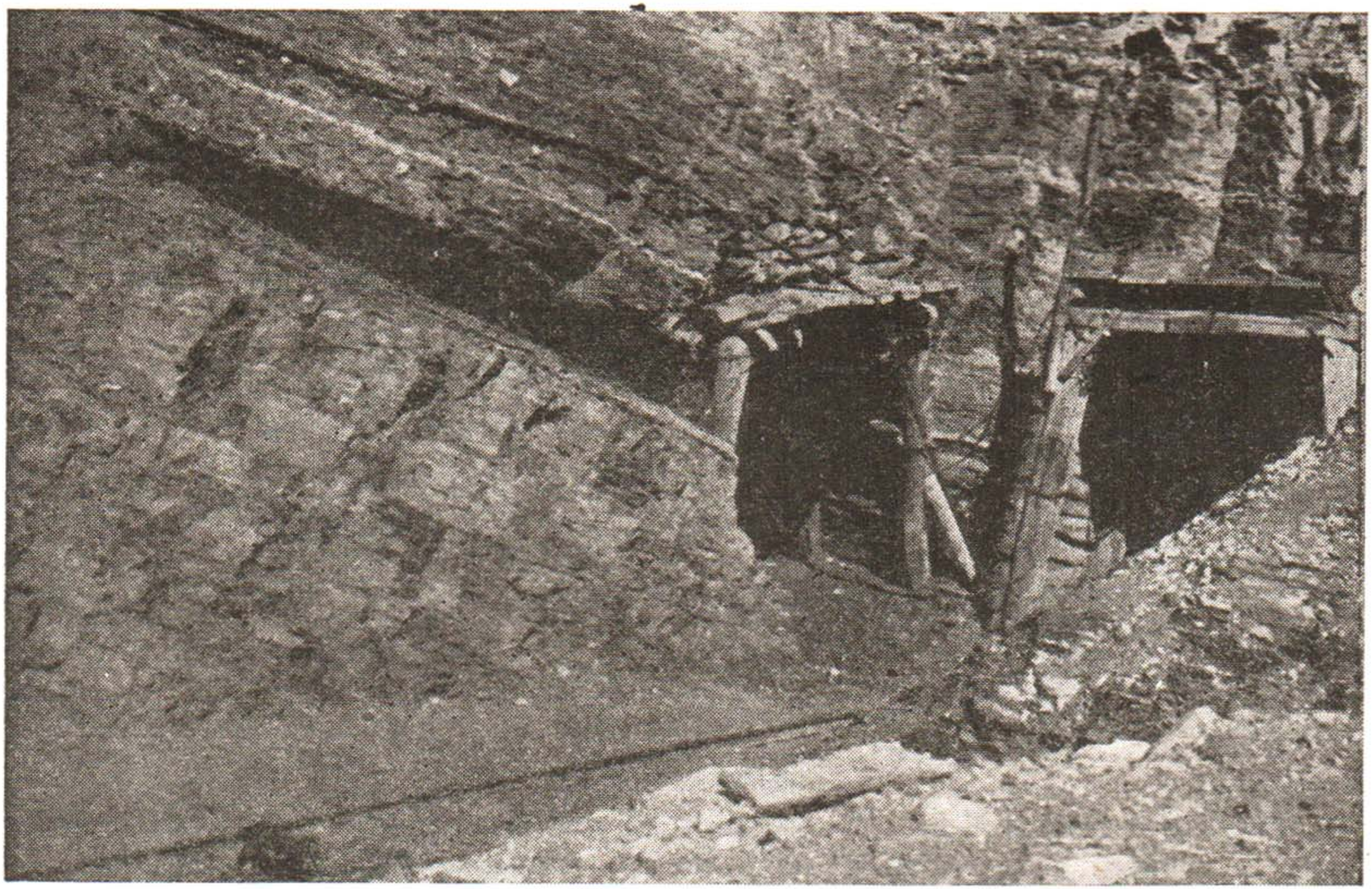


Fig. 96. — Mina « Los Castaños », río Salado, Mendoza. Afloramiento asfaltitífero abierto por una galería exploratoria en dirección. A la derecha, bocamina del chiflón Nº 4. (Fotog. A. V. Borrello, 1951)

Beef, Neuquén (Rodrigues, Cobbold & Loseth, 2009)