Decompression sickness bubbles: formation of gas micronuclei on flat hydrophobic surface

Ran Arieli and Abraham Marmur

Israel Naval Medical Institute and Technion-Israel Institute of Technology, Haifa, Israel

Gas micronuclei are required to initiate the formation of bubbles on decompression

Harvey et al. 1944. Bubble formation in animals:

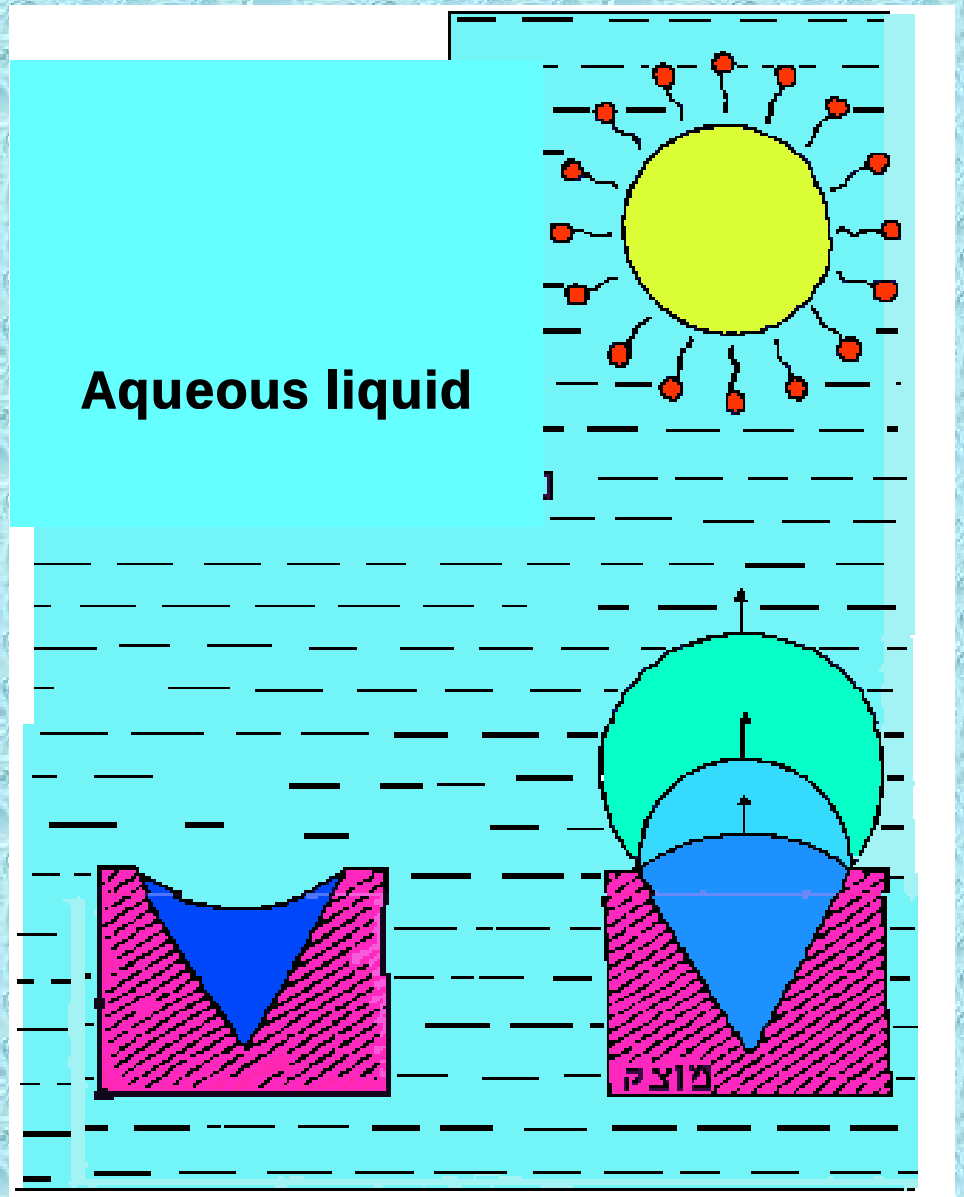
“We believe that most bubbles formed in a resting animal come from minute gas nuclei, whose origin is at present obscure”

Common assumptions regarding stable gas micronuclei

1

Tiny gas bubbles produced by tribonucleation (separation of solid surfaces in a liquid) are carried away to be trapped in stabilizing environments.

Hayward, 1967



2a

Surface active molecules

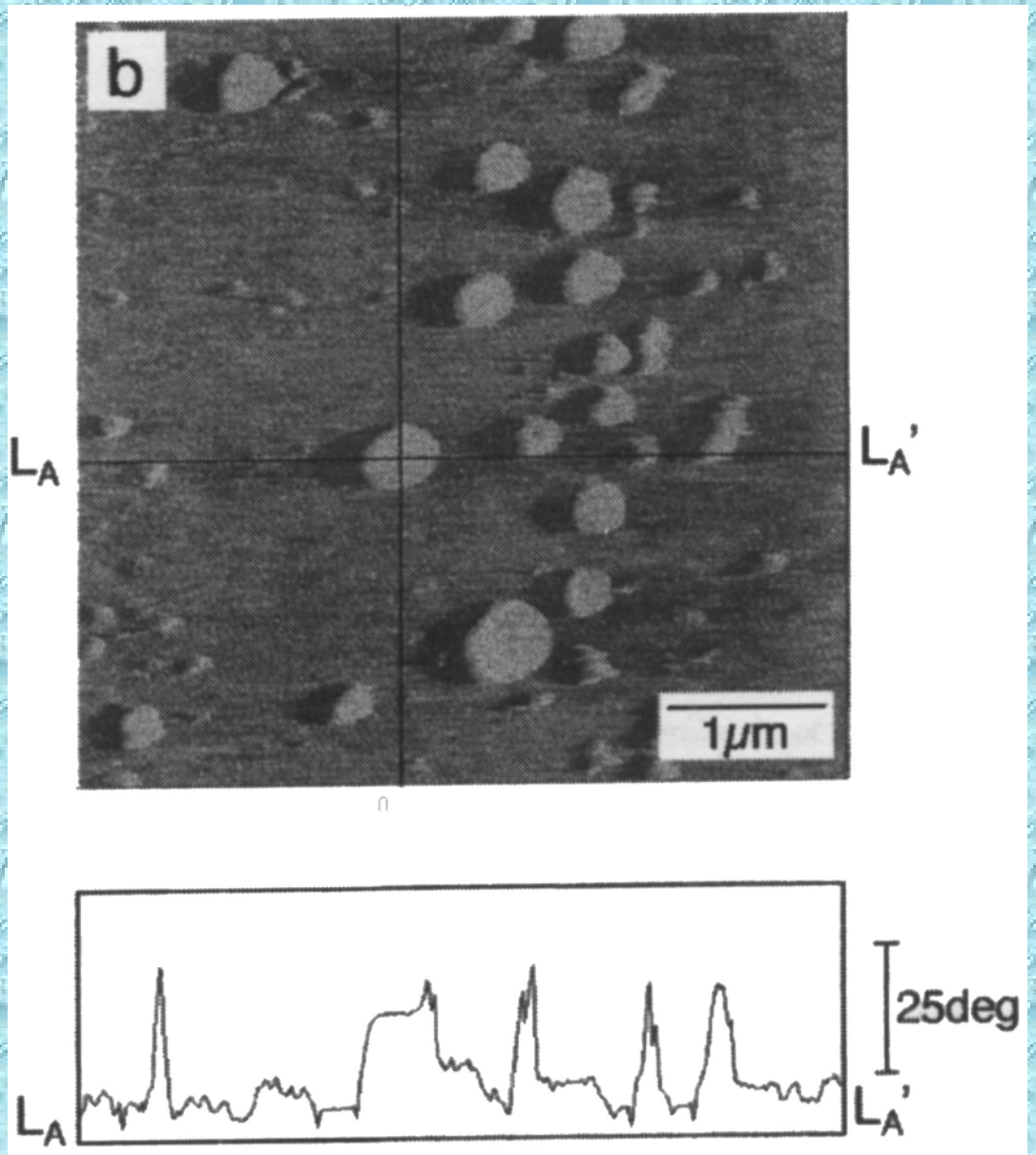
Yount, 1977

2b

Hydrophobic crevice

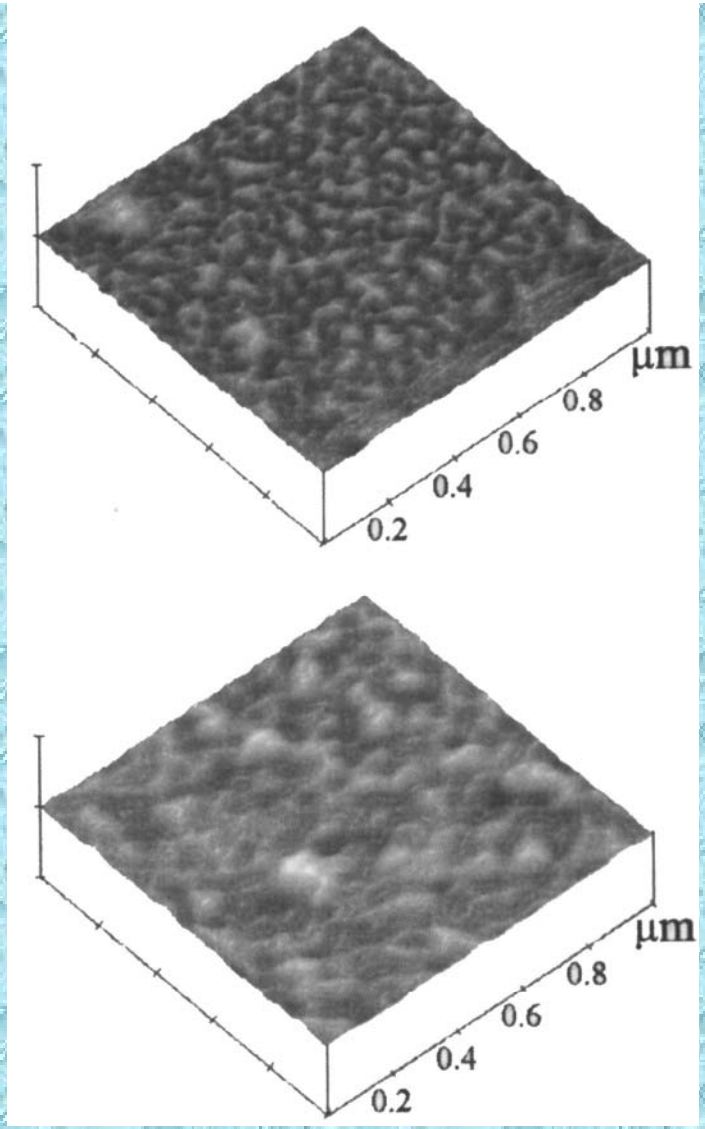
Harvey, 1944

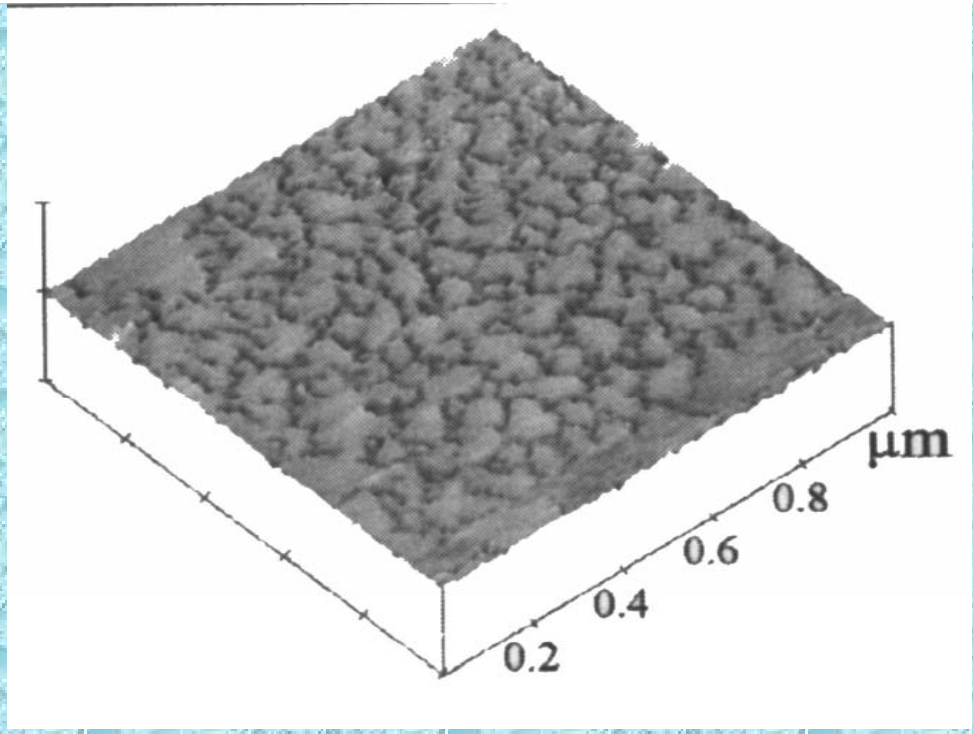
Recently, using Tapping-Mode Atomic Force Microscopy, nanobubbles were found to grow on hydrophobic but not hydrophilic surfaces.



Tiny flat gas nanobubbles 5-30 nm appeared only when inert gas was dissolved in the water.

Ishida et al., 2000

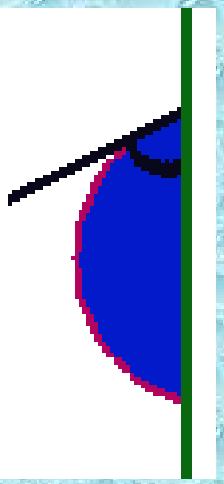




Tyrrellet al, 2001

This finding is still controversial, due to the absence of an underlying theory by which it may be understood.

However, if it is true, there are a number of hydrophobic surfaces in the living body, such as the subcutaneous adipose tissue, nervous myelin sheath, visceral fat and the inner surface of large blood cavities, which may be sites where gas micronuclei are formed.



Hydrophobicity of biological surfaces (angle for a drop of water)

HYDROPHILIC

HYDROPHOBIC

Angle	Animal	Tissue
7	sheep	Duodenal epithelium
22	sheep	Skeletal muscle
34	sheep	Pulmonary artery
54	sheep	Right ventricle
69	human	Umbilical vein
73	sheep	Aorta
78	sheep	Left ventricle
79	sheep	Pulmonary vein

Hills, 1992

Three types of gas cavities are further defined as:

1.Nanobubbles - the tiny spherical cap shaped gas cavities which are formed on hydrophobic surface.

2. Gas micronuclei – nanobubbles that are effective as bubble seeds.

3. Bubbles – visible bubbles of any size.

METHODS

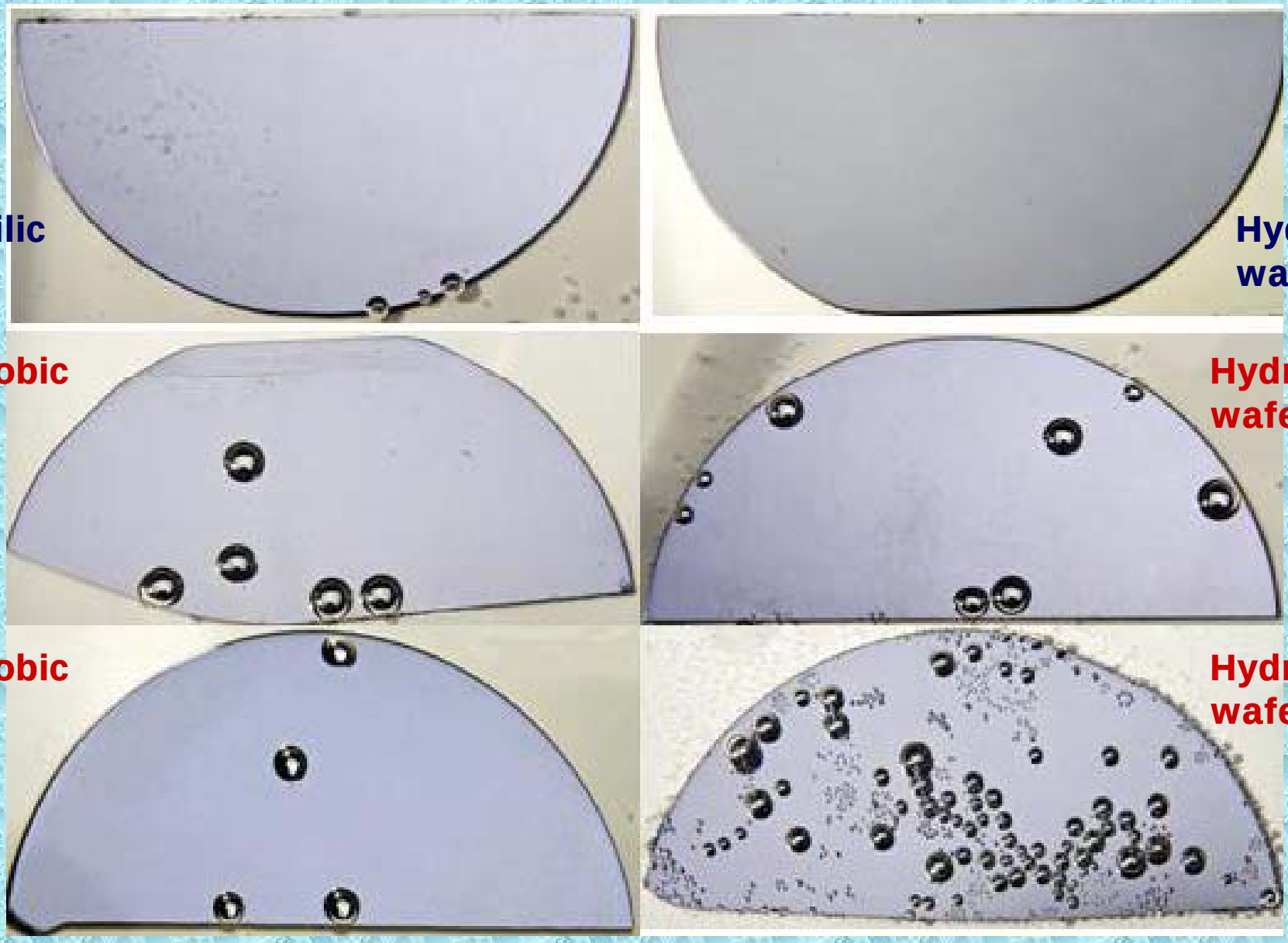
1. Flat almost uni-molecular, silicon wafers were coated with a uni-molecular hydrophobic layer – Trichloro(octadecyl)silane.

2. Double distilled water was degassed at low pressure, 5.60 kPa, and hydrophobic and hydrophilic silicon wafers were placed in the bowl of water overnight at normobaric pressure. The bowl was then placed in the hyperbaric chamber for 15 h at a pressure of 10 ATA and decompressed at 1 ATA/min.

RESULTS

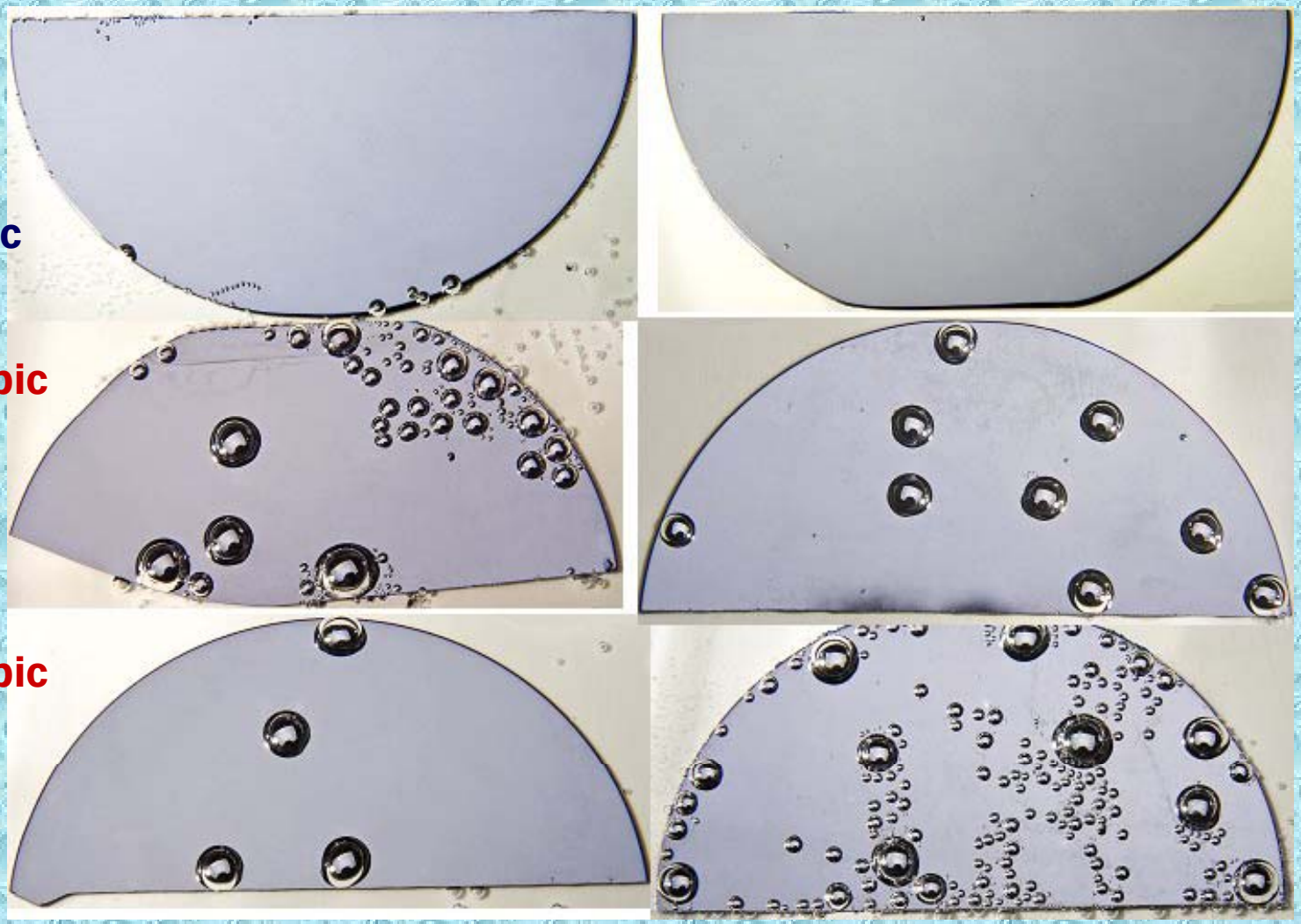
15 min after decompression

Bubbles appeared only on hydrophobic wafers.



At 30 min after decompression, more bubbles appeared.

30 min after decompression



Hydrophilic wafer 1

Hydrophilic wafer 2

Hydrophobic wafer 1

Hydrophobic wafer 5

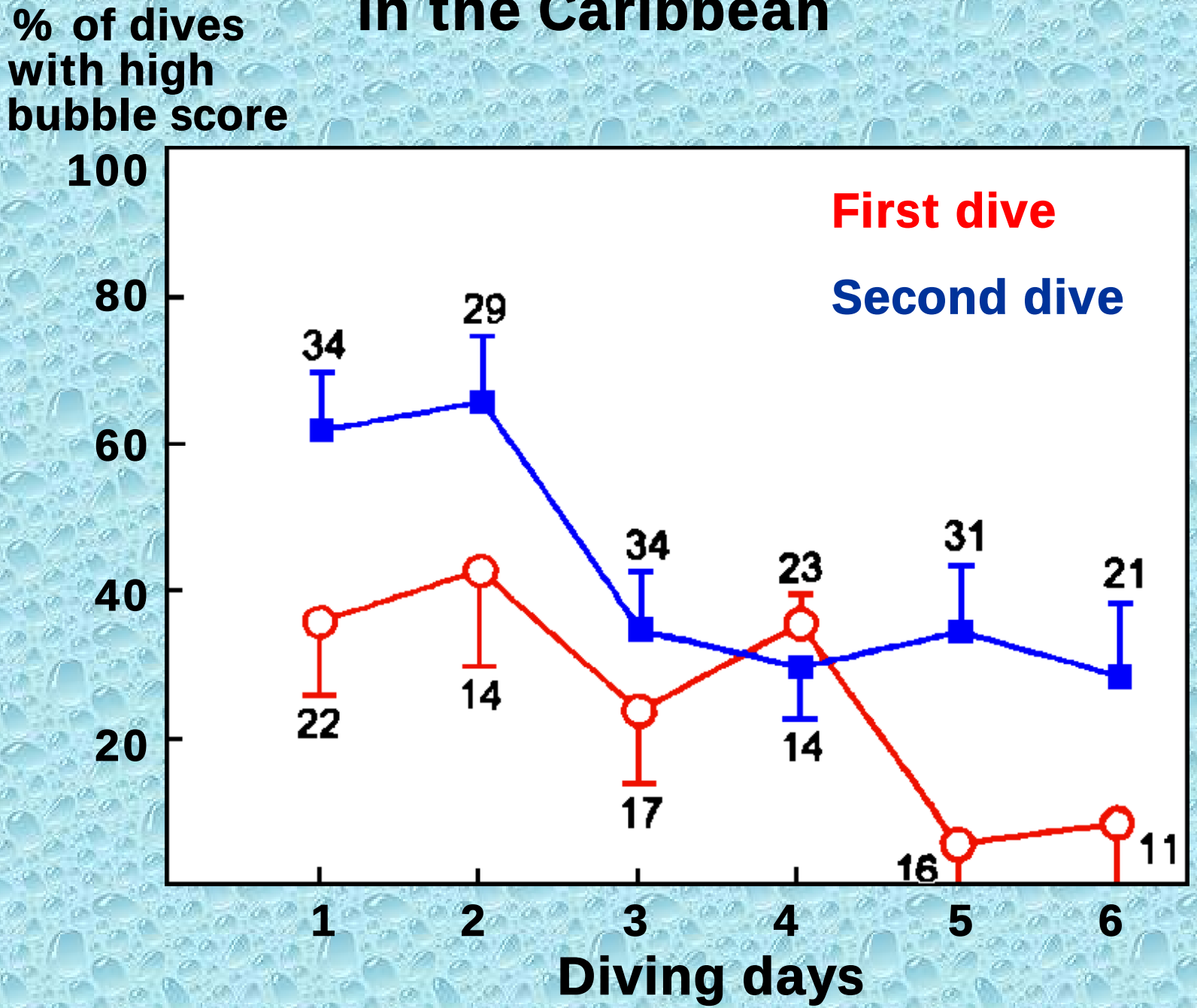
Hydrophobic wafer 2

Hydrophobic wafer 6

1 cm^2 of hydrophobic wafer 35 min after decompression

The bubbles seen earlier had grown, whereas tiny bubbles had just become visible. Probably large micronuclei were the first to bring about bubble nucleation, whereas small micronuclei were responsible for late nucleation.

Bubble score after scuba dives in the Caribbean



Bubble score was higher in the second dive on the same day in the first 2 days of diving.

Dunford et al., 2002

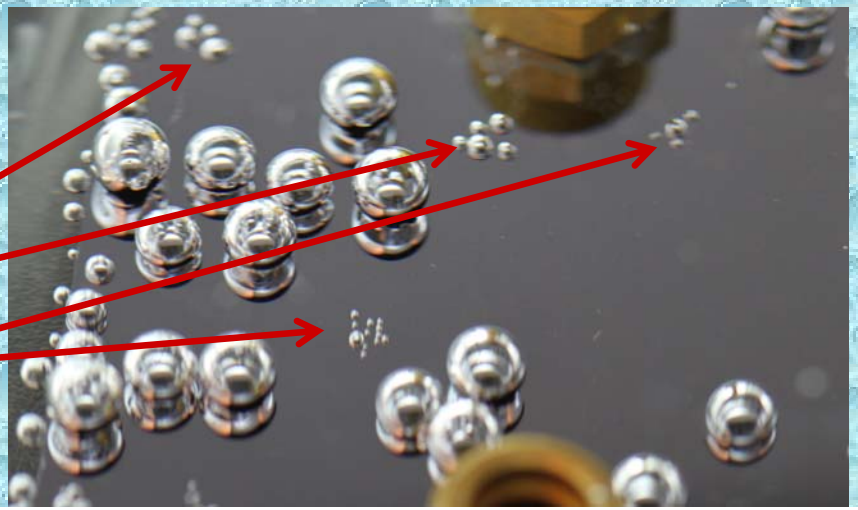
After a large bubble is released to the surface of the water, many bubbles are formed on the space it has cleared. This may explain the high bubble score in a second dive on the same day.

Time after decompression:

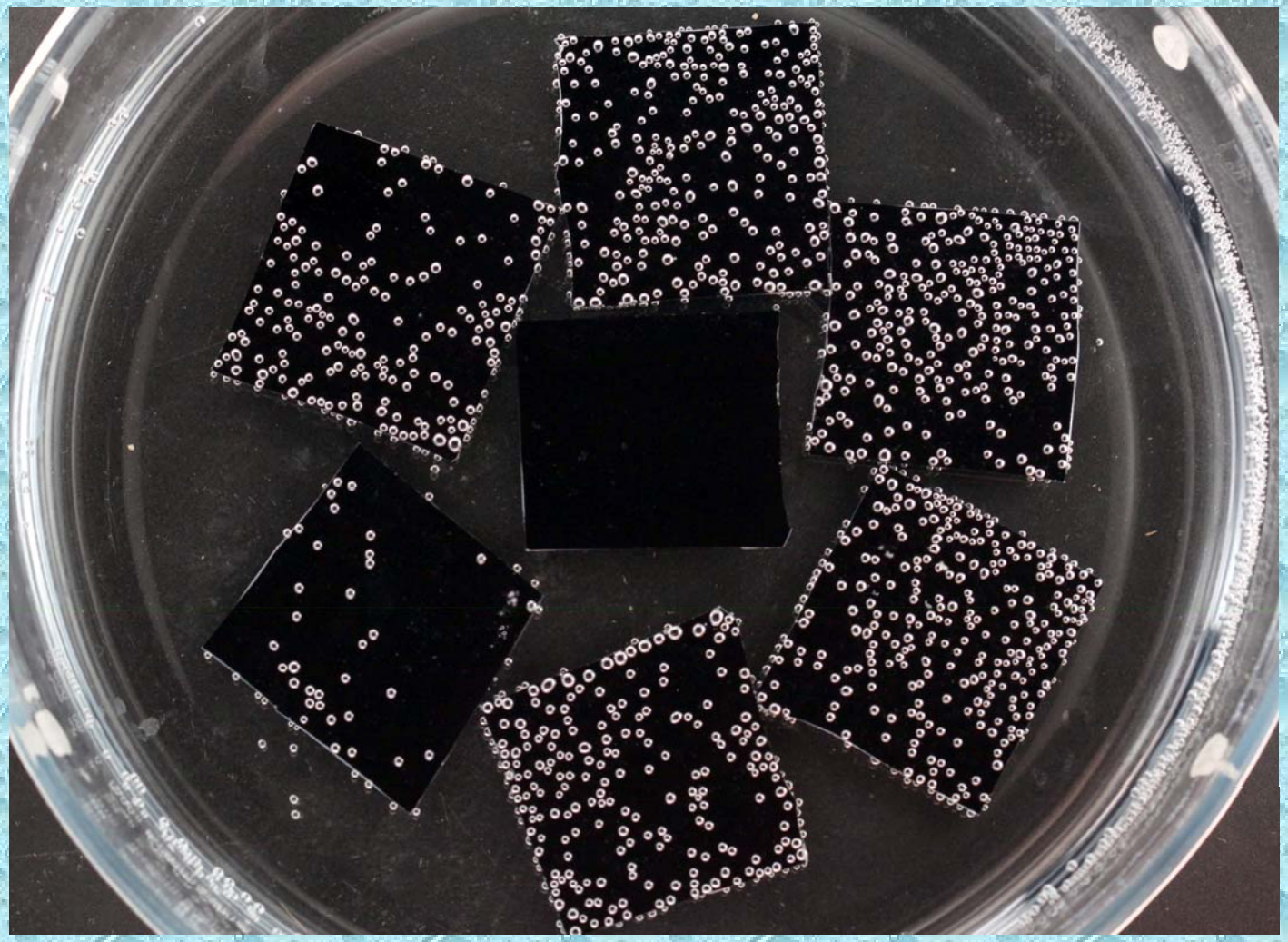
85 min

150 min

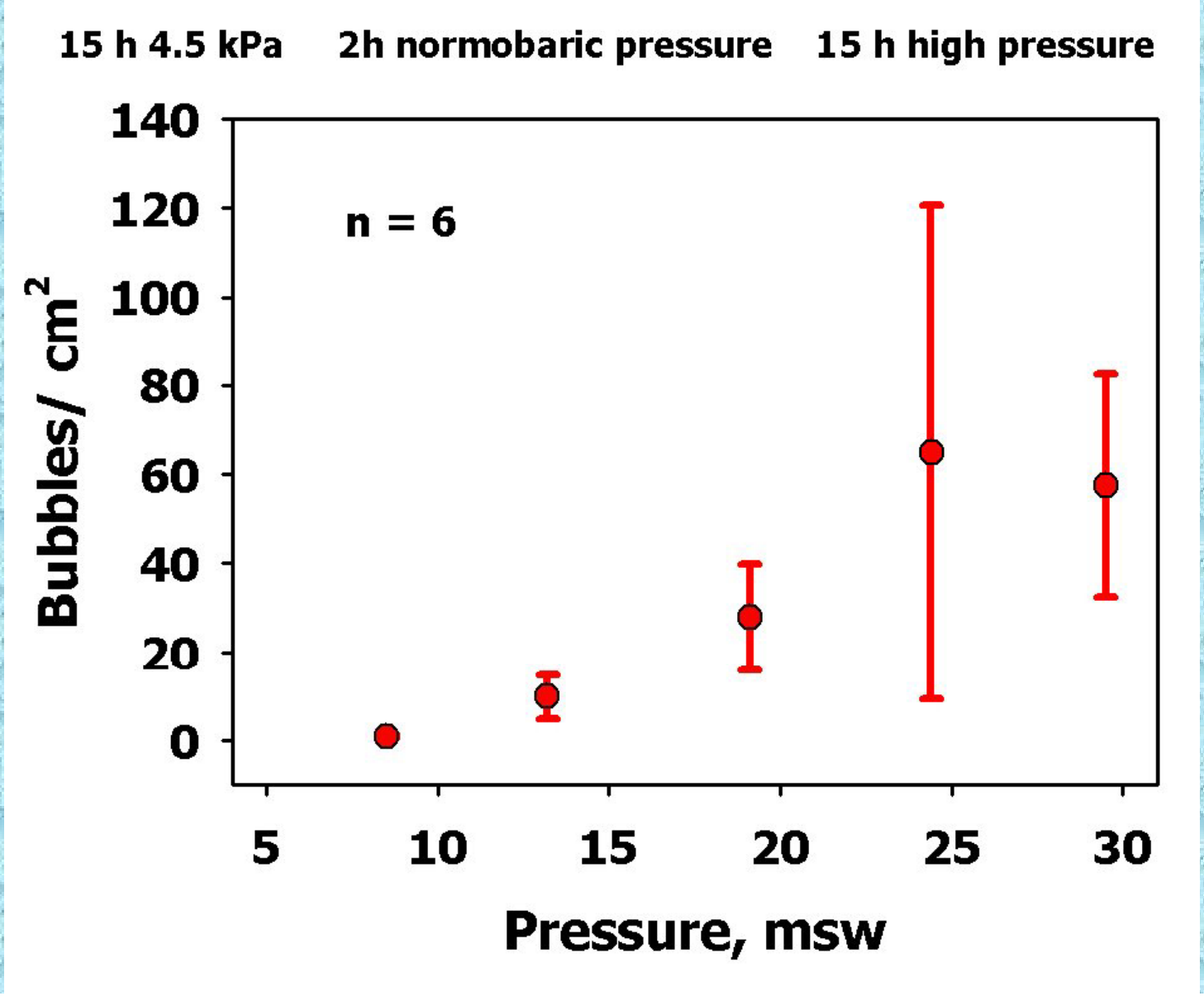
Few nucleations apeared on the spot from which bubble floated



For a study of the kinetics of gas micronuclei, 6 hydrophobic wafers are placed around a hydrophilic wafer and photographed immediately following decompression.



With increased hyperbaric pressure from 10 msw to 25 msw and elevated gas supersaturation, the density of bubles increased. Density leveled off between 25 and 30 msw.



CONCLUSIONS I

1. Gas micronuclei are formed on flat, hydrophobic surfaces.

2. More gas micronuclei are formed on part of a hydrophobic surface cleared by an earlier bubble.

3. Density of effective gas micronuclei increase as hyperbaric pressure is raised from 10 to 25 msw and stabilized thereafter.

4. This new concept may help construct better diving tables.

CONCLUSIONS II

5. Adiposity is a risk factor for DCS not only because of the high solubility of nitrogen, but also due to the production of gas micronuclei.

6. Knowledge of the location and nature of gas micronuclei may help advance research on denucleation as another way of challenging the risks of decompression. For example: our suggested method of oxygen prebreathing.