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Methane ebullition and fate in the Rhone River delta: Hydroacoustic evaluation of ebullition

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Motivation

- Inland water bodies have been neglected as sources of methane¹
- River deltas in large lakes can be CH₄ ebullition hot spots²
- Ebullition is the most efficient CH₄ pathway to the atmosphere from shallow waters^{1,3}
- Ebullition's spatiotemporal variability makes quantification quite difficult¹

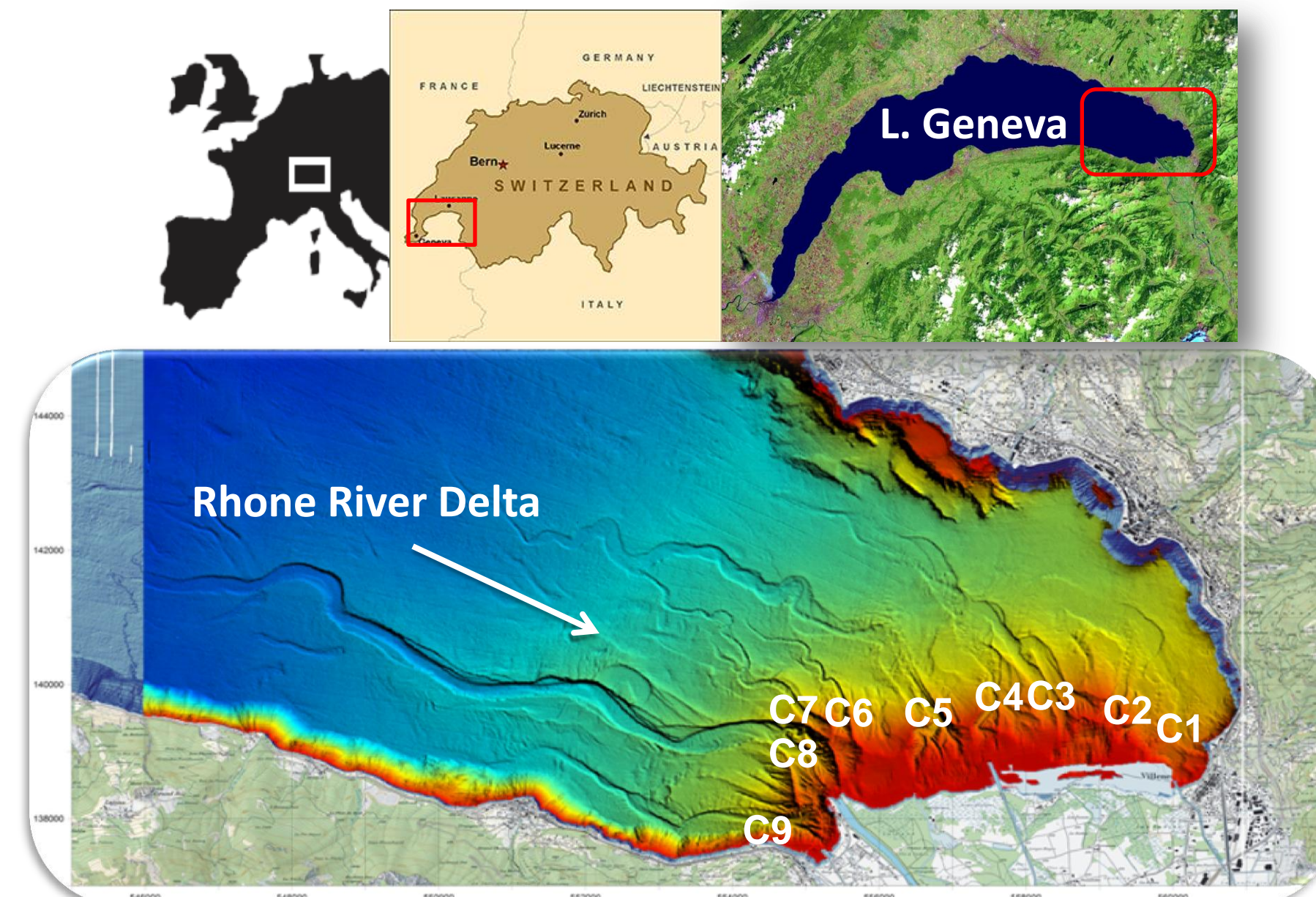


Figure 1. Results shown below are from surveys of the Rhone River Delta in Lake Geneva (Switzerland), which has 9 subaquatic canyons. Multibeam data from Sastre et al. 2010⁵

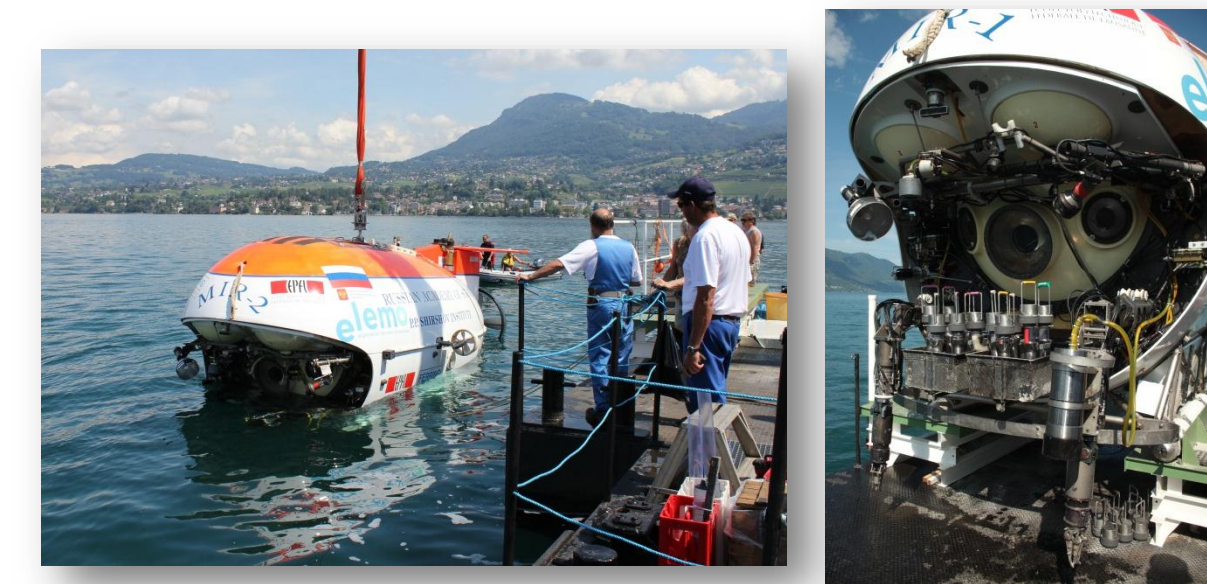


Figure 2. MIR submersible with cores and core heads in front

- Within the framework of the Elemo project (elemo.ch), ebullition was investigated in the Rhone River delta of Lake Geneva (Fig. 1). The EPFL-hosted project included the use of the Russian MIR submersibles (Fig. 2) for various projects during summer 2011.

Echosounder calibration

- A 120 kHz echosounder (Kongsberg Simrad EK60) was calibrated for bubble size at 10 m depth in a natural lake

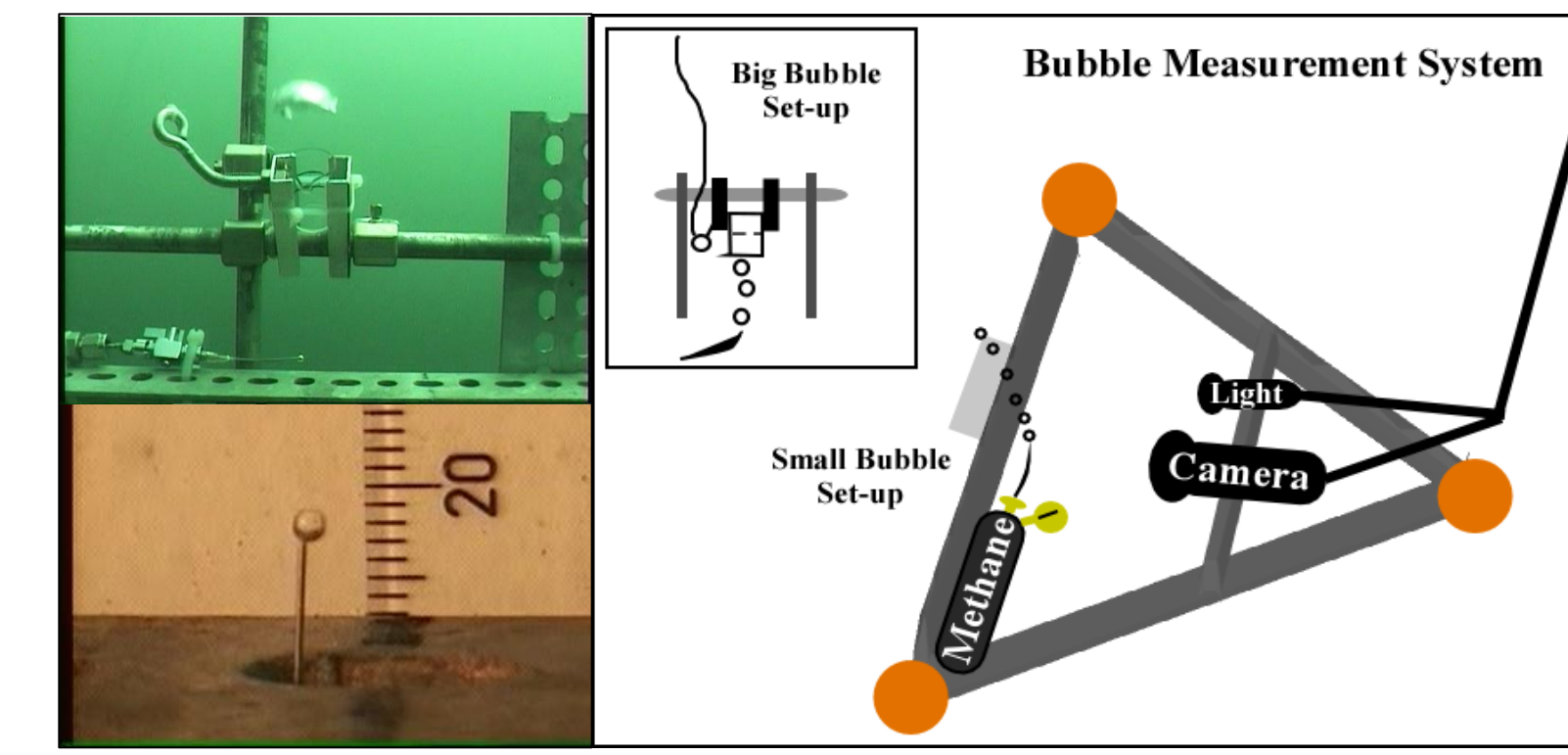


Figure 3. Bubble measurement system for making and recording bubbles for the calibration

- Bubbles of known volume or measurable size were created *in situ* (Fig. 3) and related to the backscattering cross-section (σ_{bs}) seen by the echosounder (Fig. 4)
- Our calibration agreed with a lab calibration performed with another 120 kHz echosounder⁴

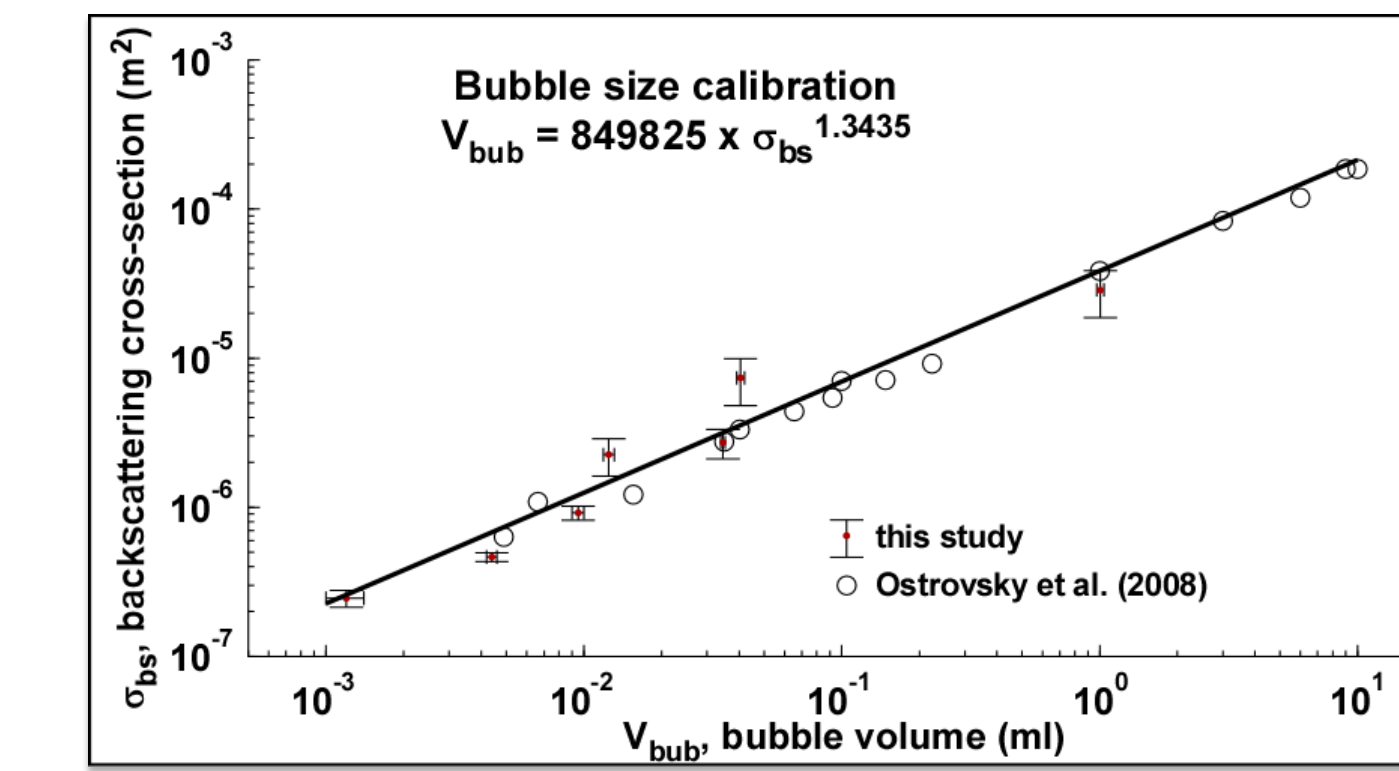


Figure 4. Echosounder calibration results for bubbles size from this study and a similar one

Hydroacoustic analysis of ebullition flux

I. Use rise velocity (V_z) to distinguish between fish (~0 m/s) and bubbles (15-50 m/s, Fig. 5)

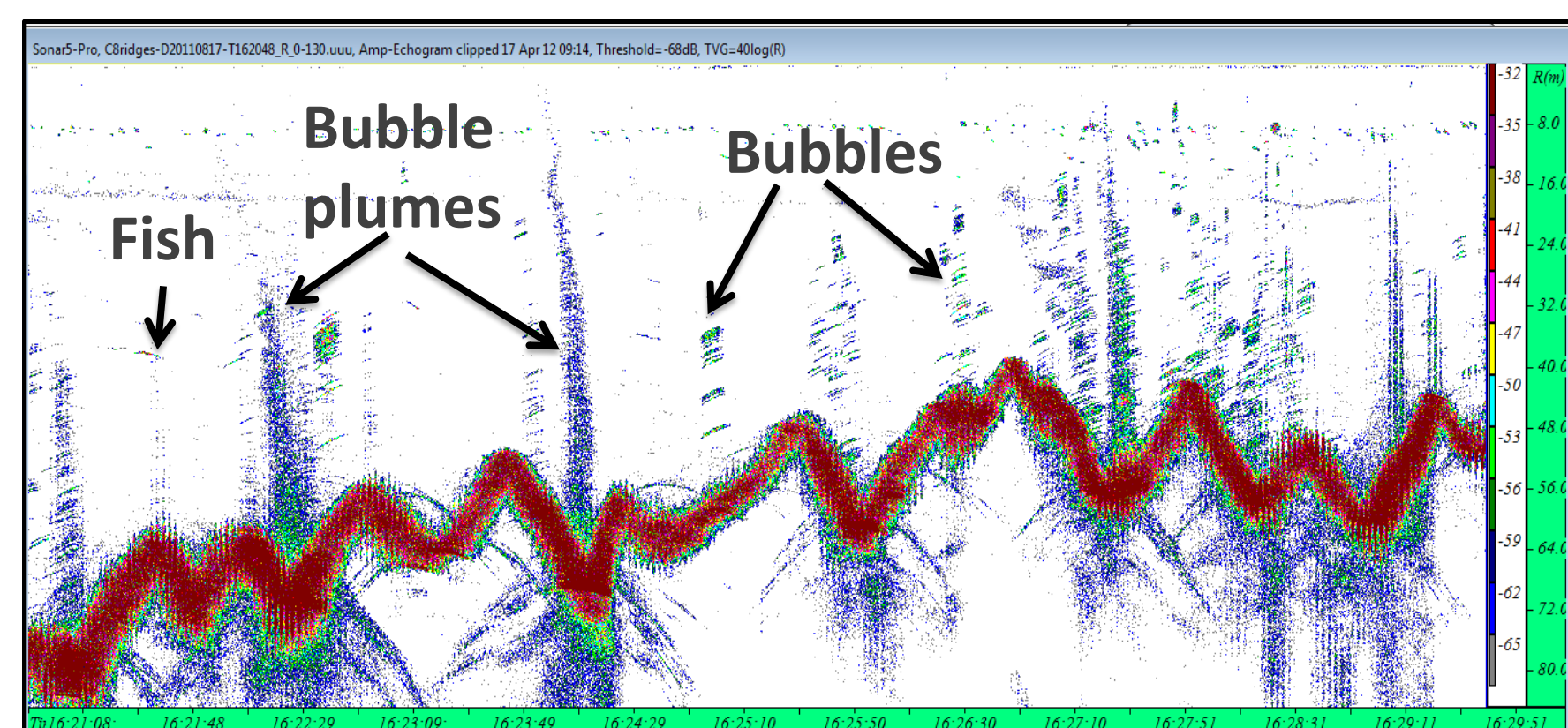


Figure 5. Example echogram from Rhone delta showing bubbles, bubble plumes, and fish

II. With the best bubble echoes, find the bubble size distribution (TS, Fig. 6)

$$TS [dB] = 10 * \log(\sigma_{bs}) [m^2]$$

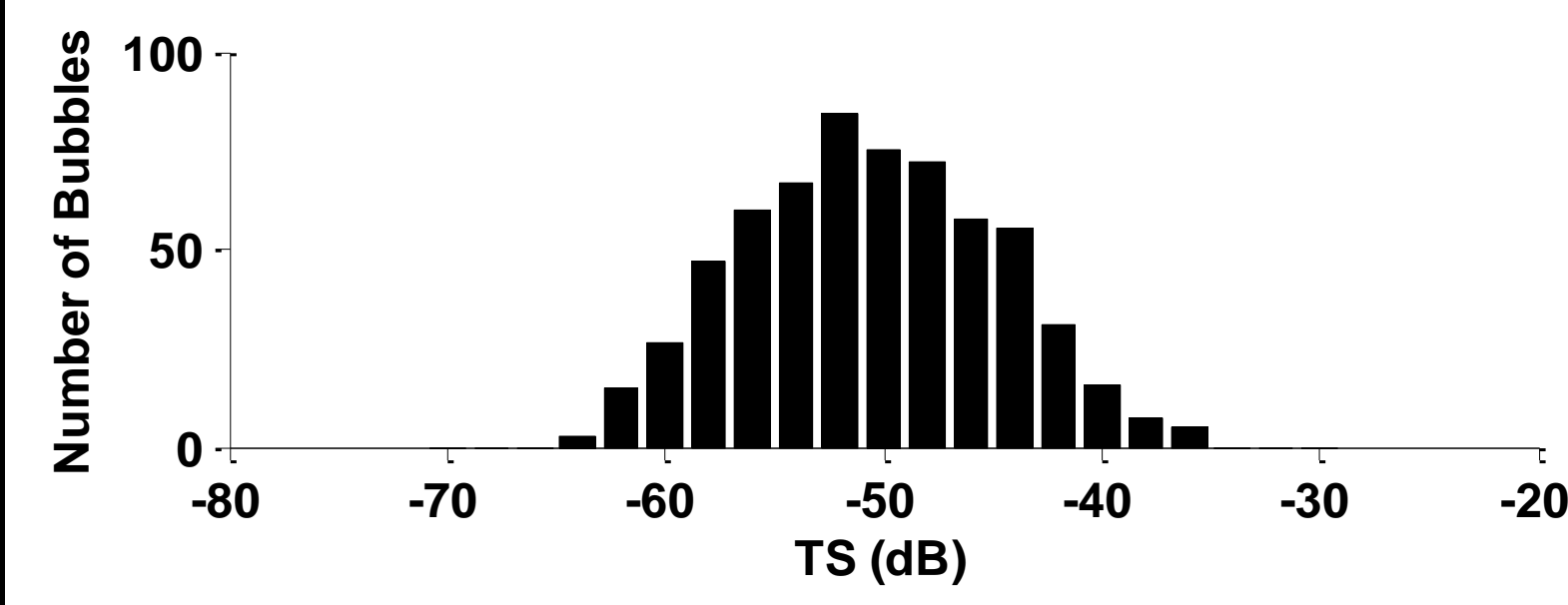


Figure 6. Bubble size distribution expressed as TS (target strength) distribution

III. Scale the acoustic energy in water (sv) by TS (Fig. 7) to get bubble density (N)

$$N [\#/m^3] = sv/TS [m^{-1}/m^2]$$

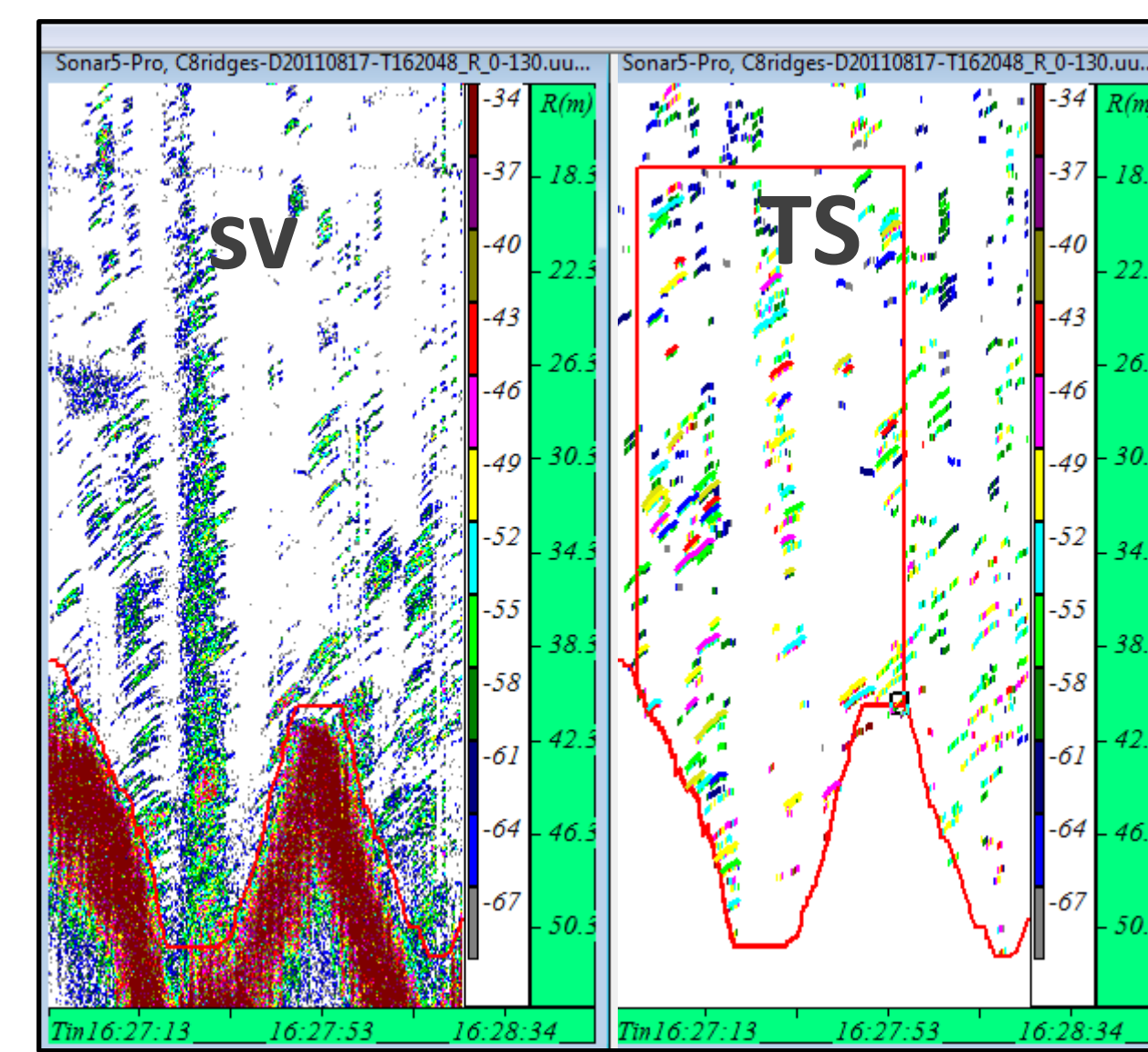


Figure 7. The full acoustic energy (sv) in the left echogram has many reliable bubble echoes in the right echogram for the TS distribution

IV. Calculate volumetric bubble density (N_b) using TS converted to volume (TS_{vol}) via Fig. 4

$$N_b [ml/m^3] = N [\#/m^3] * TS_{vol} [ml]$$

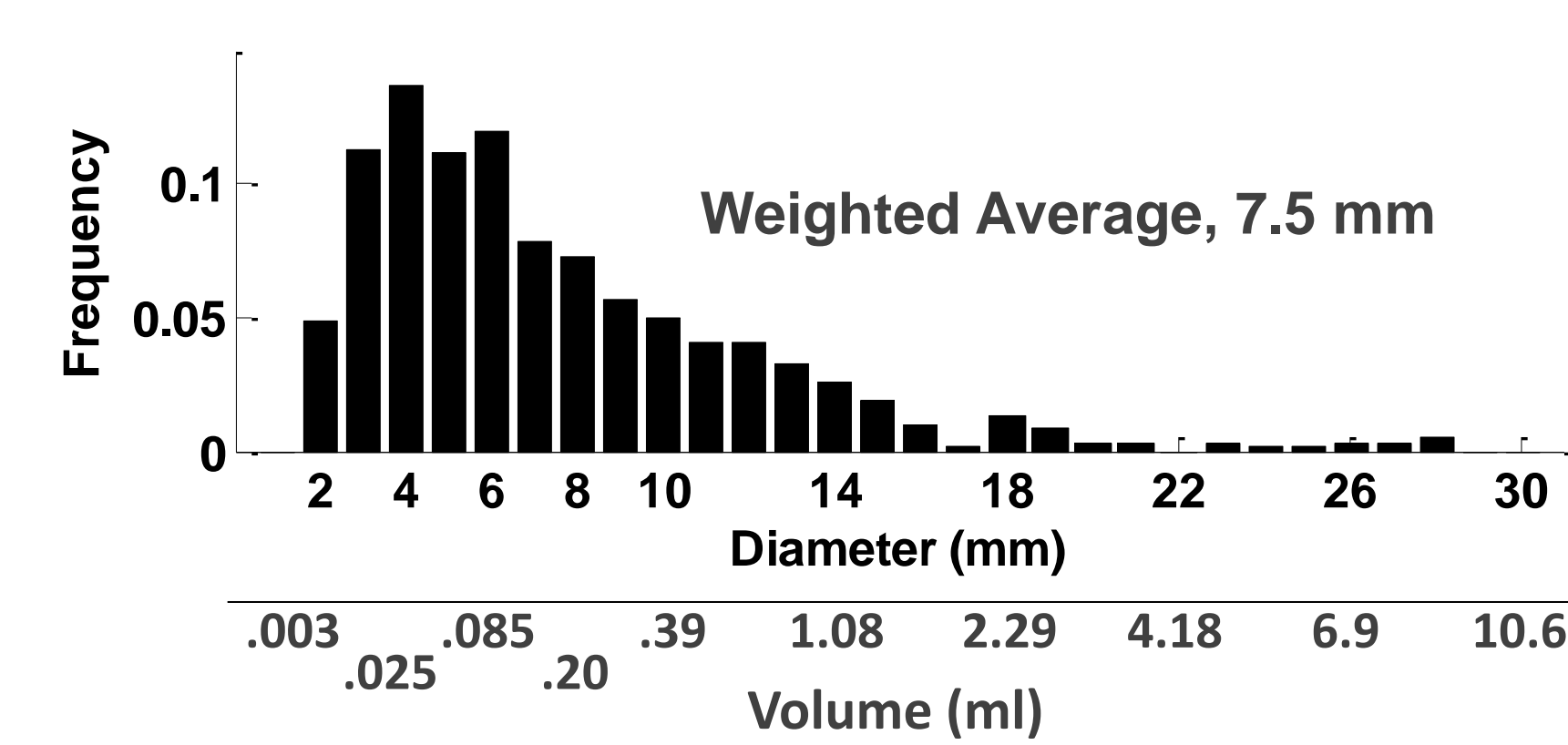


Figure 8. Bubble size distribution expressed as bubble diameter and volume.

V. Use bubble rise velocity (V_z) and fraction of CH₄ in bubble (F) to find CH₄ bubble flux (J)

$$J [mg m^{-2} d^{-1}] = N_b [ml/m^3] * V_z [m/s] * F (\%)$$

Avg. Rise Velocity (V_z)	0.24 m/s
Avg. CH ₄ Fraction (F)	84%

Table 1. Sediment Ebullition Flux in Rhone delta

Rhone Delta Region (Fig. 9)	Ebullition Flux, J (mg m ⁻² d ⁻¹)
Delta	400
Northeast	300
Southwest	230
Average	310

Spatial heterogeneity of ebullition

- Ebullition was more prominent directly in front of the river inflow than to the NE and SW (Fig. 9a)
- Concentration of bubbles to north could be due to the Coriolis force acting on Lake Geneva (Fig. 9a)
- Bathymetric highs produced more ebullition, particularly at deeper depths (>50 m, Fig. 9b)
- Deeper than 100 m ebullition focused on canyon levees/shoulders

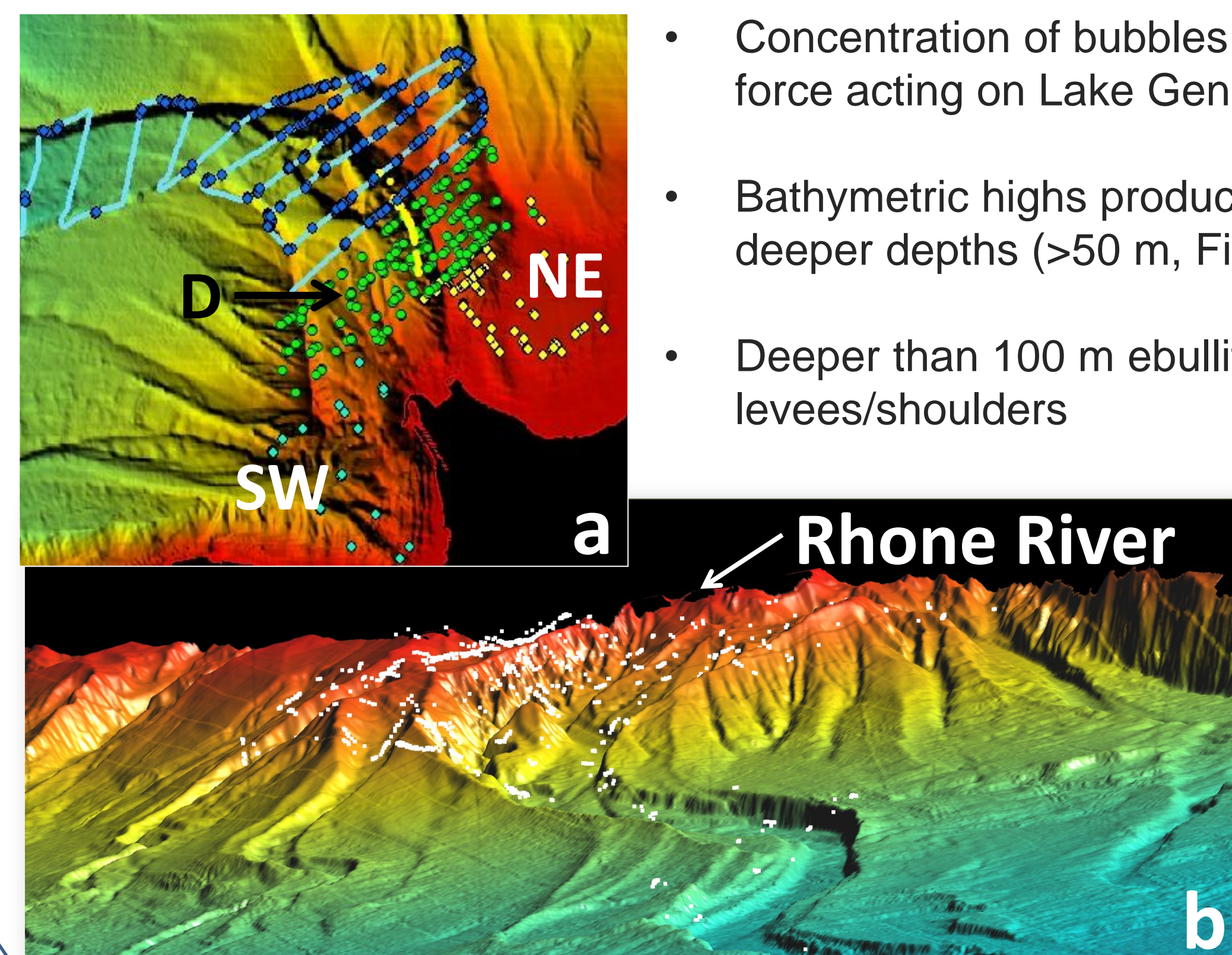
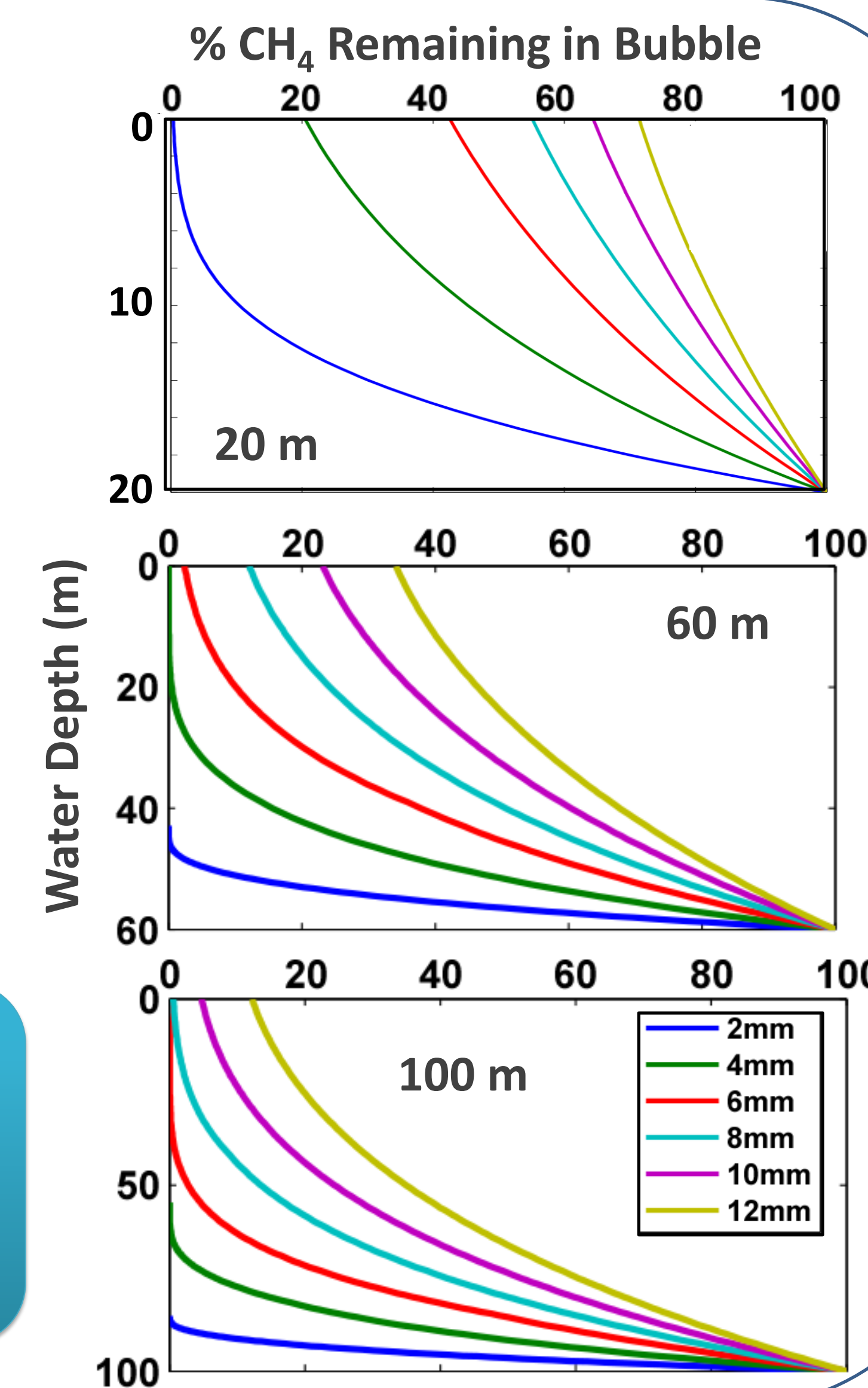


Figure 9. (a) Locations of bubbles found in proximal delta (D), northeast (NE) and southwest (SW) of Rhone inflow. (b) 3D view of active canyon (C8) with bubble locations shown in above where they were observed

Fate of CH₄ bubbles

- A bubble of average size (7.5 mm) will release 50% of its CH₄ to the atmosphere if released from 20 m, but only 10% from 60 m and 0 from 100 m (Fig. 10)
- From the average depth of the delta region (30 m) and using the average estimated flux (Table 1), the 1.7 km² delta emits ~0.2 t CH₄ per day in summer
- Therefore, the Rhone River delta emits up to 70 t CH₄ per year, a small but non-negligible amount

Figure 10. Amount of CH₄ released to atmosphere depends on initial bubble size (colored lines show diameter), release depth, gas concentrations in bubble and in ambient water



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