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Monitoring and Sampling of Gases and Fluids from Boreholes

Outline

Why investigating fluids/gases?

Discrete fluid sampling techniques

- Wellhead gas sampling (surface)
- Drill-core and cuttings gas/fluid extraction (surface)
- Downhole Fluidsampling and MDT (in situ sampling)

Continuous monitoring and sampling techniques (“online techniques“)

- Drilling mud gas monitoring
- Gas monitoring during pumping tests
- U-Tube technique
- Gas Membrane Sensor technique

Case studies (San Andreas Fault Observatory at Depth, NanTroSEIZE)

Why do we need information on gases/fluids from the subsurface?

SCIENTIFIC QUESTIONS

- origin and sources of gas?
- spatial distribution at depth?
- mechanisms of migration?
- temporal variation (earthquake/ vulcanic eruption forecast) ?

ECONOMIC POTENTIAL

- "classical" natural gas reservoirs
- unconventional gas (shale gas)
- CBM/ECBM
- gas hydrates

CLIMATE IMPACT/HAZARD POTENTIAL

- CO_2 capture and storage (CCS)
- sudden submarine gas release (landslides on continental slopes, hydrate-gun hypothesis)
- gas release in volcanic/geothermal areas
- drilling safety (blowout): hydrocarbons, H_2S

The Role of Fluids in Faulting

(see also Hickman et al., 1995: Mechanical involvement of Fluids in Faulting)

Ore- and mineral-bearing veins in faults

⇒ **Faults as conduit for fluids**

Natural gas accumulations below faults

⇒ **Faults as fluid barrier/trap**

Overpressurized fluids, fluctuation in fluid pressure, and link with earthquake cycles

⇒ **Fault valve behaviour, Kaiser-effect**

The role of fluids and minerals for reducing shear stress

⇒ **Fault weakening and failure**

Why Monitoring / Sampling of Fluids while drilling active Faults?

Anisotrope permeability structure of faults

in space and time

Based on

- geological observation on exhumed faults
- laboratory experiments on fault rocks
- modelling

but only little evidence from in situ measurements on active faults.

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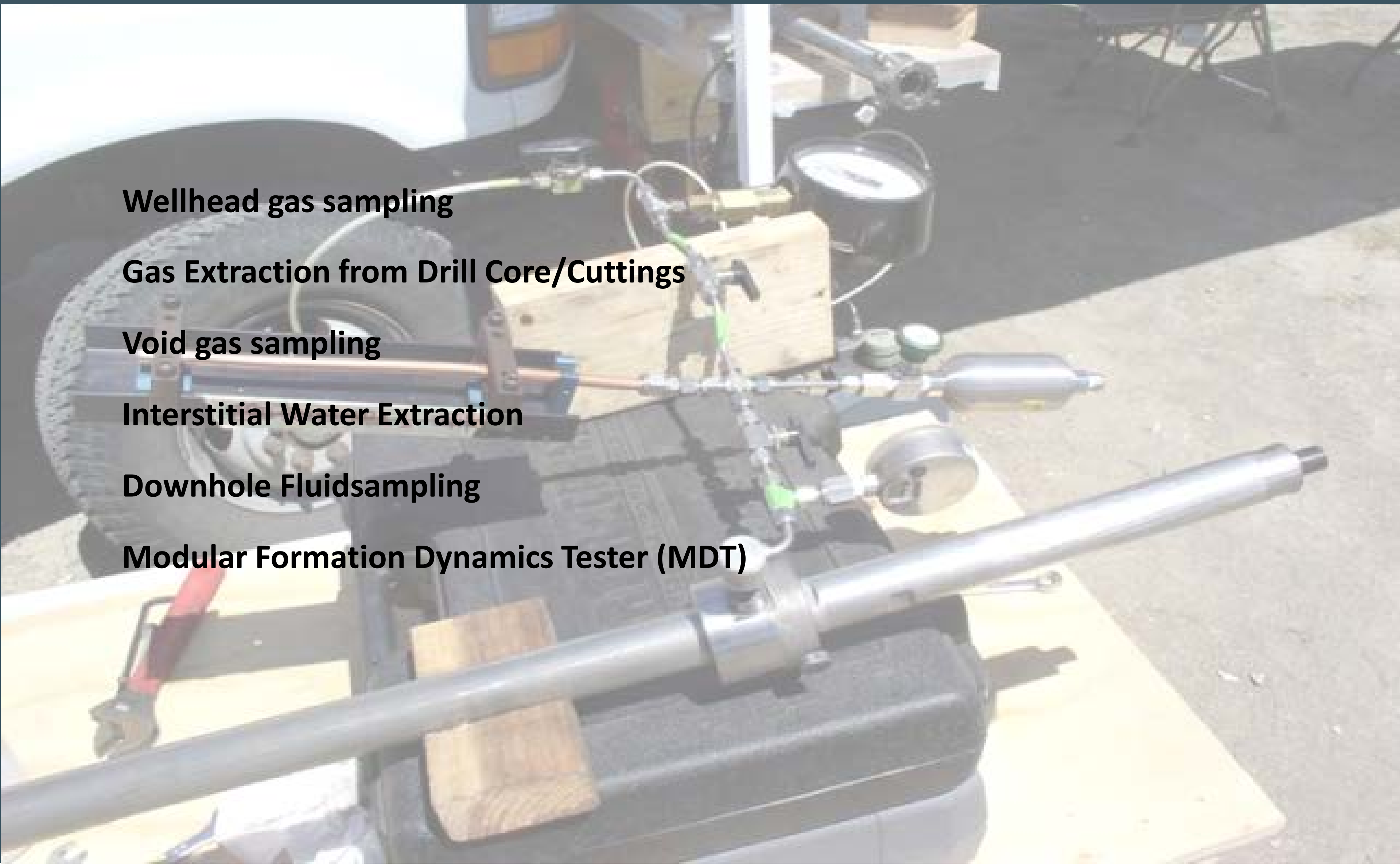
Discrete Sampling Techniques



Wellhead gas sampling

Gas Extraction from Drill Core/Cuttings

Void gas sampling

Interstitial Water Extraction

Downhole Fluidsampling

Modular Formation Dynamics Tester (MDT)

Discrete Fluid / Gas Sampling Techniques

Advantage
high-quality gas and fluid samples for laboratory analysis (e.g. isotopes)

Disadvantage
no real-time information and (almost) no continuous information in time or space

Wellhead gas sampling

- Sampling of fluid from the production line at the surface
- Separating into gas and water
- Sampling of gas with copper tubes and glask flasks

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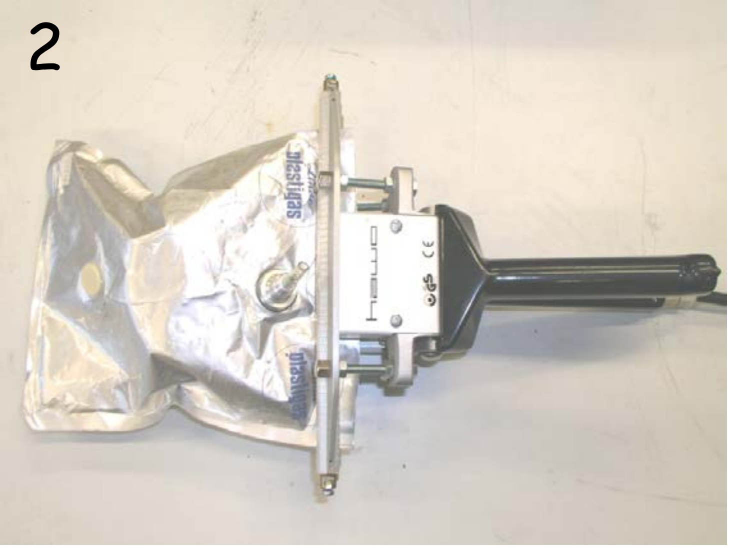
Gas Extraction from Drill Core / Cuttings

1

2



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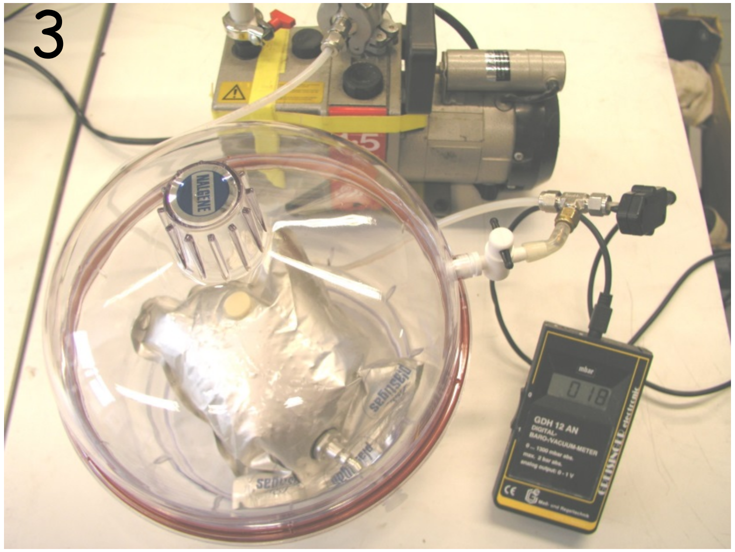

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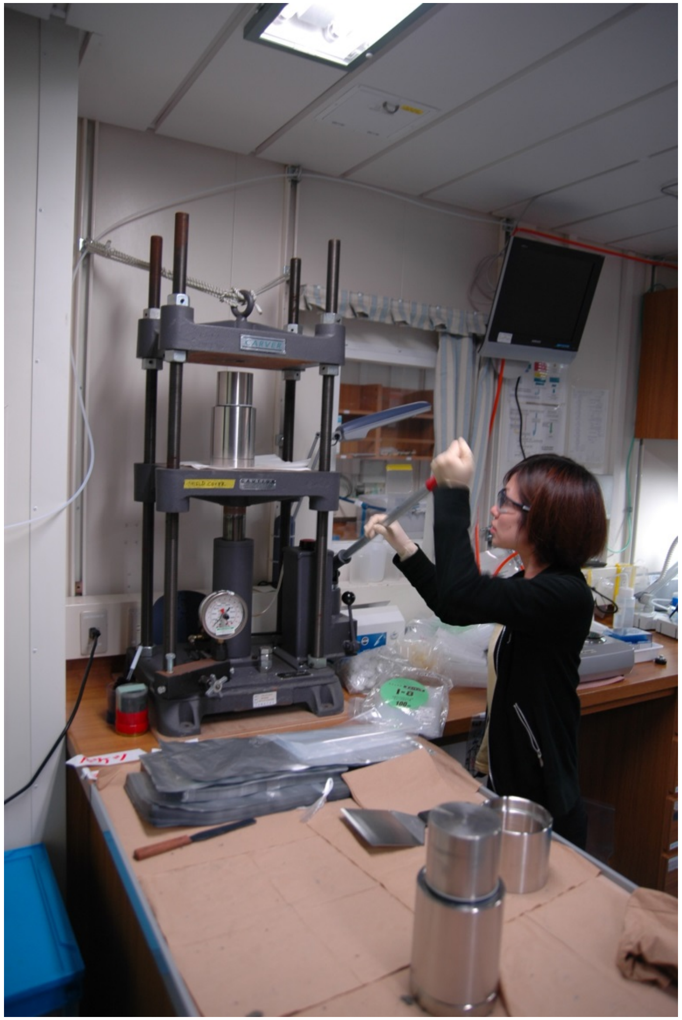
Void Gas Sampling

Sampling of gas bubbles after core arrival on deck
(drilling through the core liner)

Fluid Extraction from Drill Core



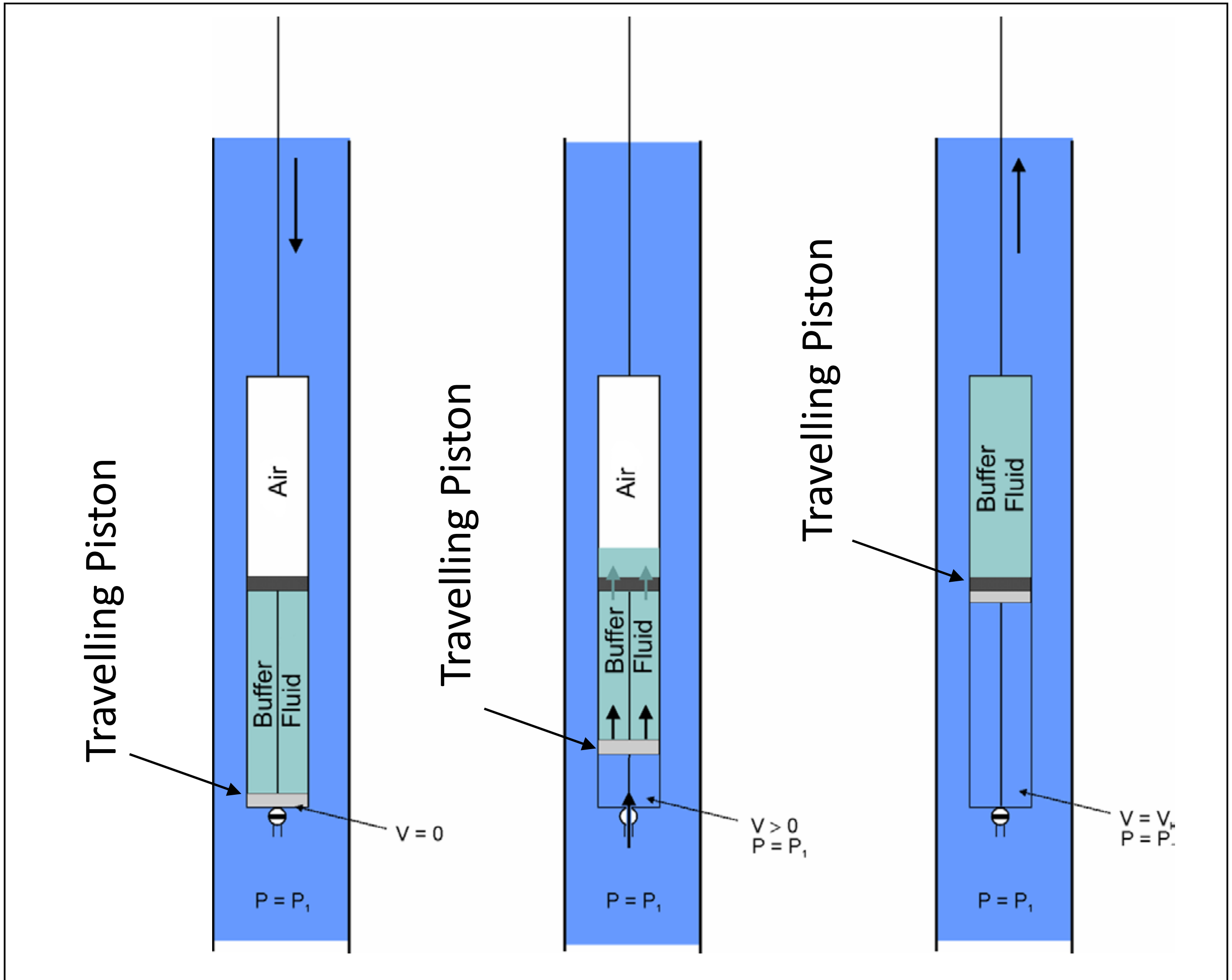
Drill Core Squeezing to extract interstitial water from unconsolidated rock

Downhole Fluidsampling

Positive Displacement Sampler

- Downhole sampling of formation fluids (600cc) at *in situ* conditions after formation testing/downtime
- Ability to operate in hostile well conditions (180° C/100 MPa)
- Little risk of sample fractionation or contamination prior to, during, or after sampling
- Sampler can be sterilized before operation

PDS Fluid Sampler: Working Principle



PDS Fluid Sampler in Operation

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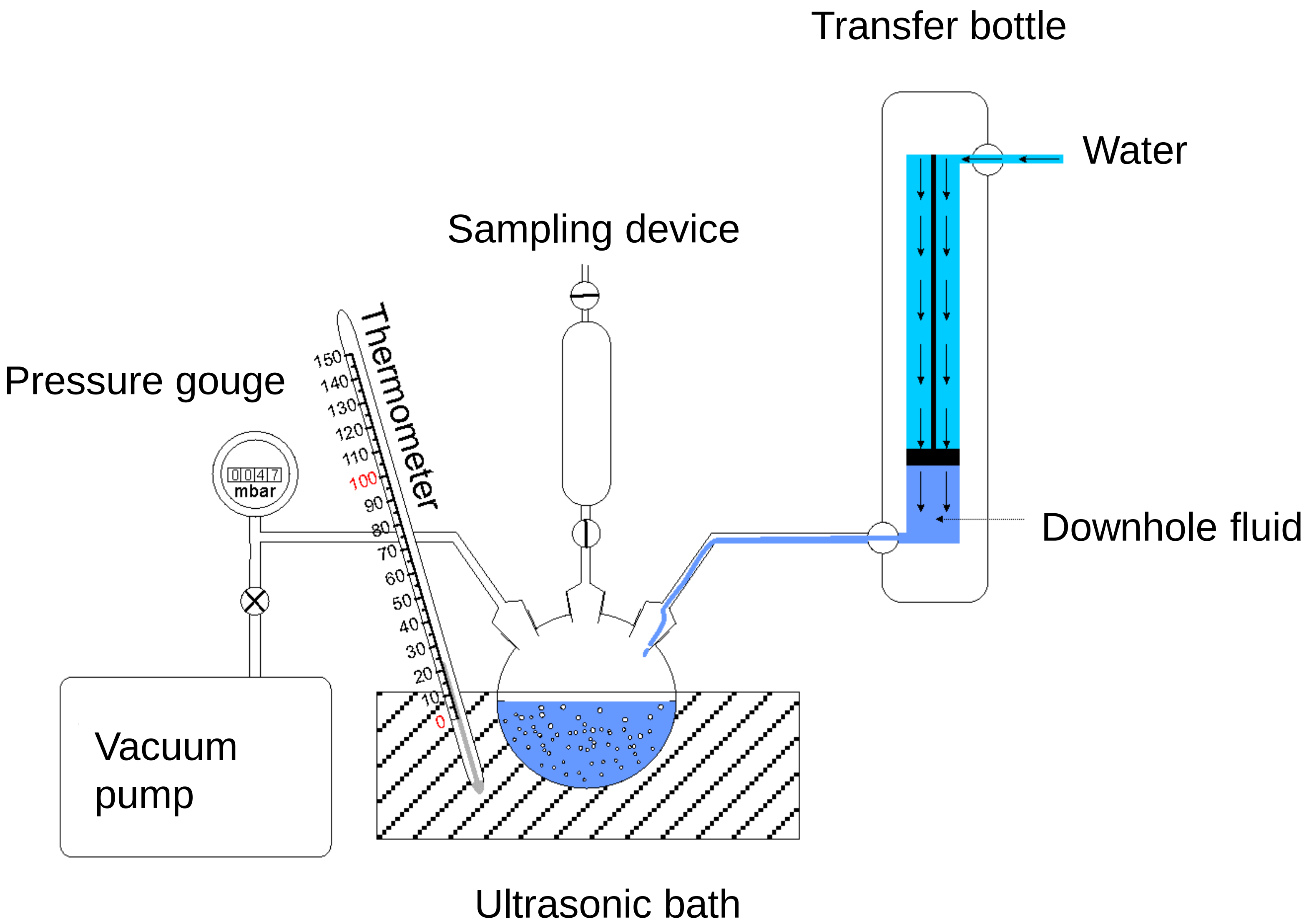
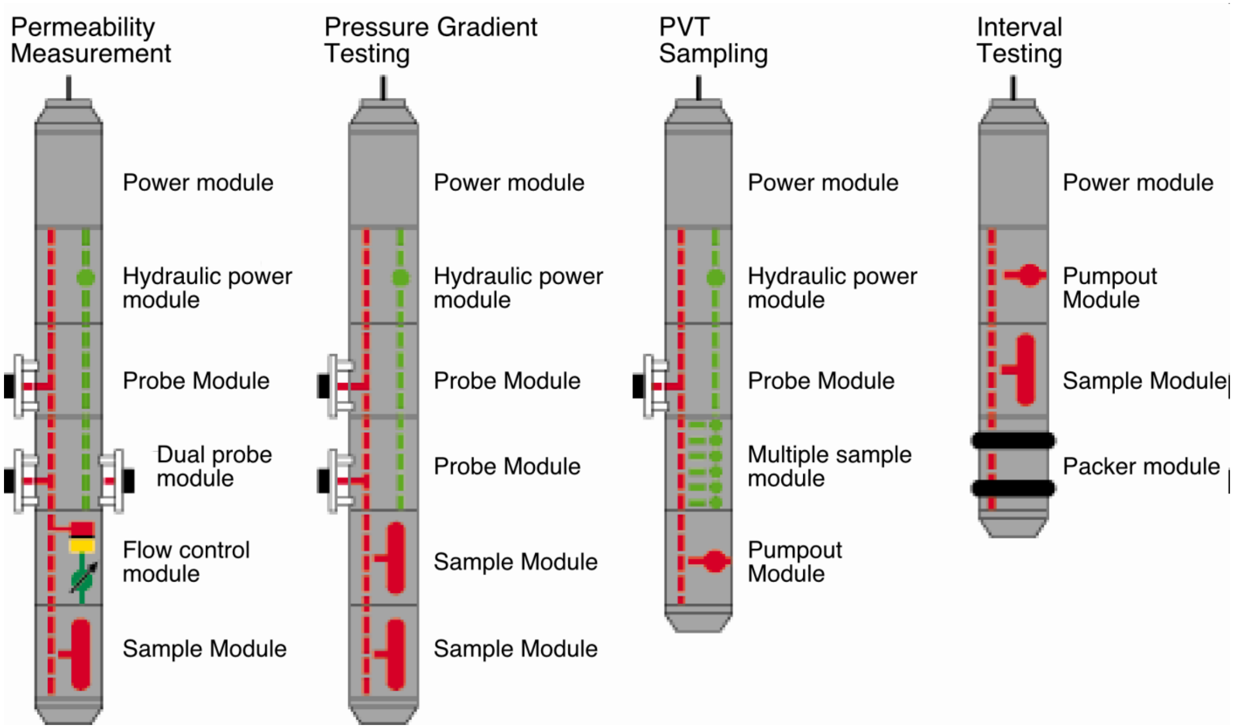
PDS Fluid Sampler: Gas / Water Separation



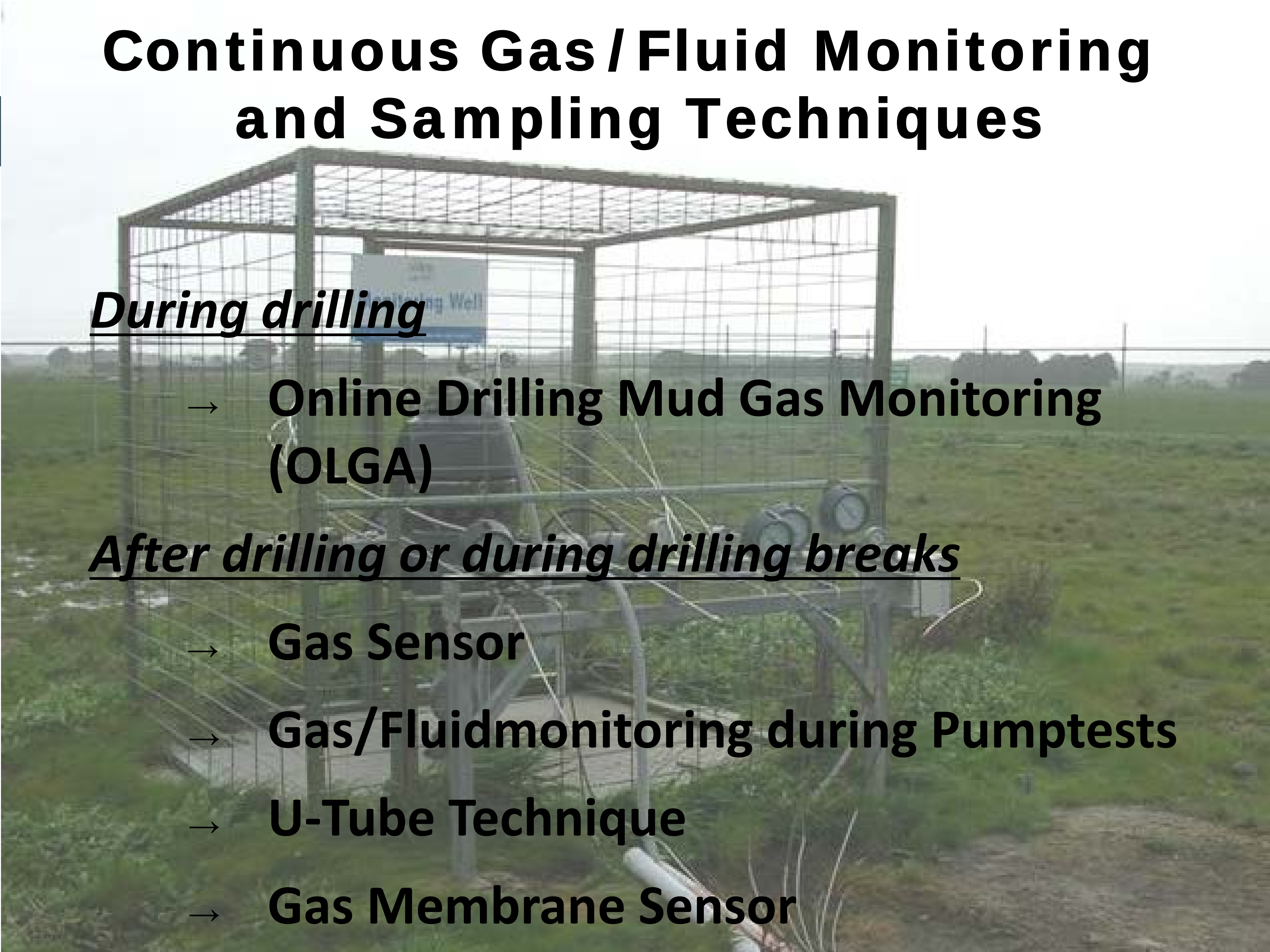
PDS Fluid Sampler: Gas / Water Separation

Modular Formation Dynamics Tester MDT

- modular downhole probe from SCHLUMBERGER for e.g. pressure and permeability that can also collect formation fluids
- tool diameter between 6 and 7 5/8 inch
- PVT: up to six 450cc-samples in one trip, standard sample: 2.8L



Continuous Gas/Fluid Monitoring and Sampling Techniques



During drilling

→ Online Drilling Mud Gas Monitoring (OLGA)

After drilling or during drilling breaks

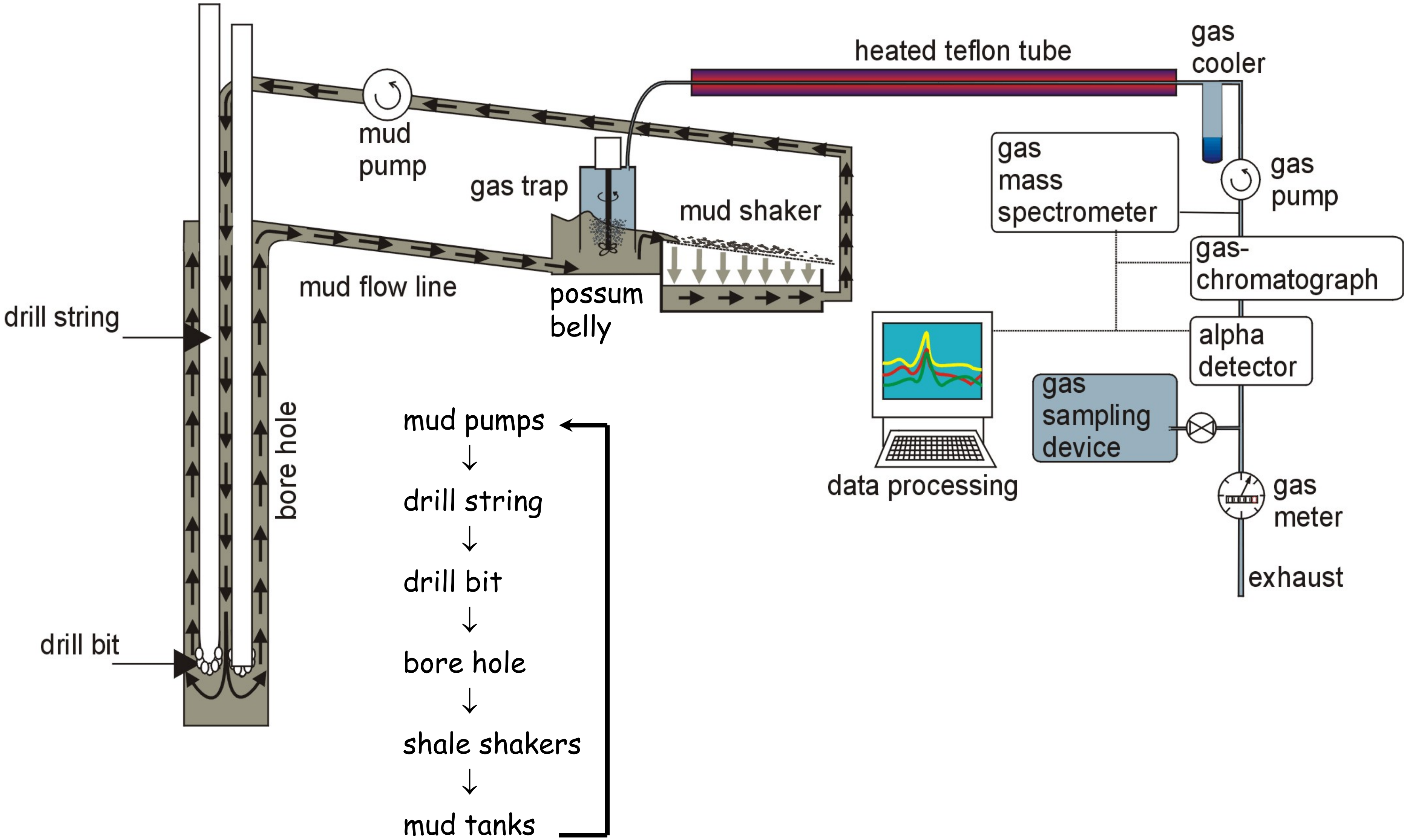
→ Gas Sensor

→ Gas/Fluidmonitoring during Pumptests

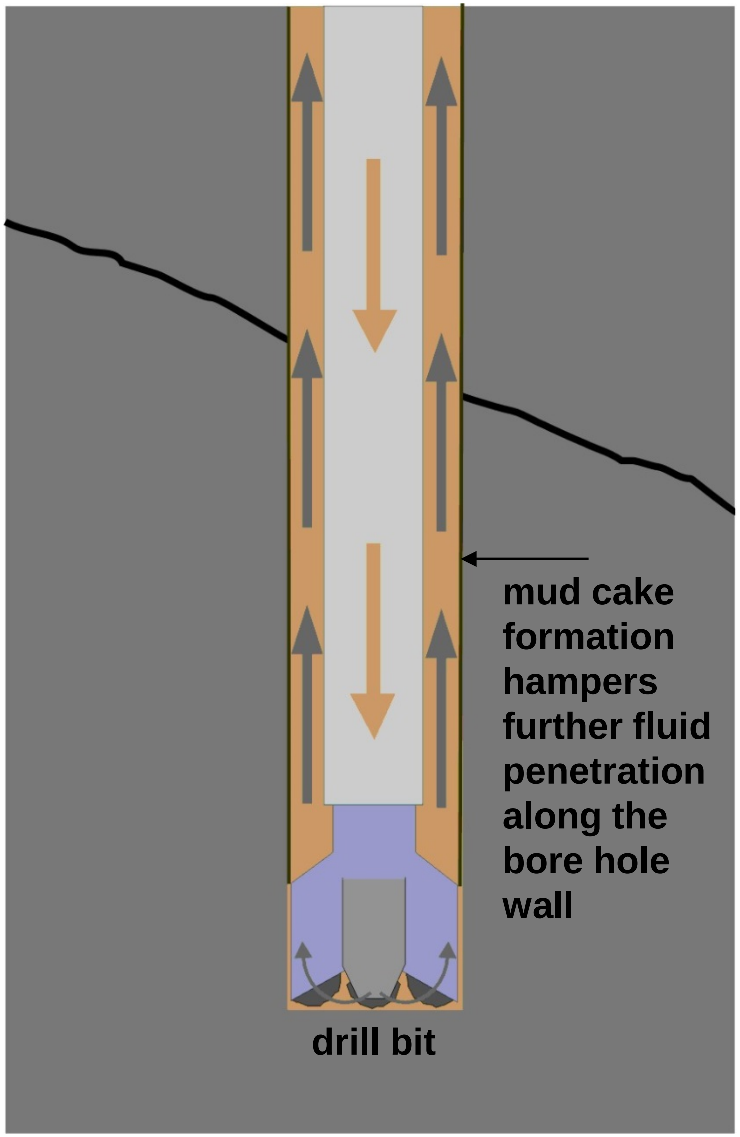
→ U-Tube Technique

→ Gas Membrane Sensor

Online Gas Monitoring of Drilling Mud (OLGA)



Gases in Drilling Mud



i. air (atmospheric gases can enter at the mud tanks and mud pumps): O_2, N_2, Ar

ii. gas accumulated in pore-space (released by rock crushing at the drill bit): in-situ produced HC, CO_2, H_2, He

iii. gas from permeable strata (when intersecting gas-rich fractures or faults): HC, CO_2, H_2, radon

Drilling mud gas extraction

Mud gas is extracted mechanically from returning drill mud in a separator under slight vacuum and continuosly piped into a nearby trailer

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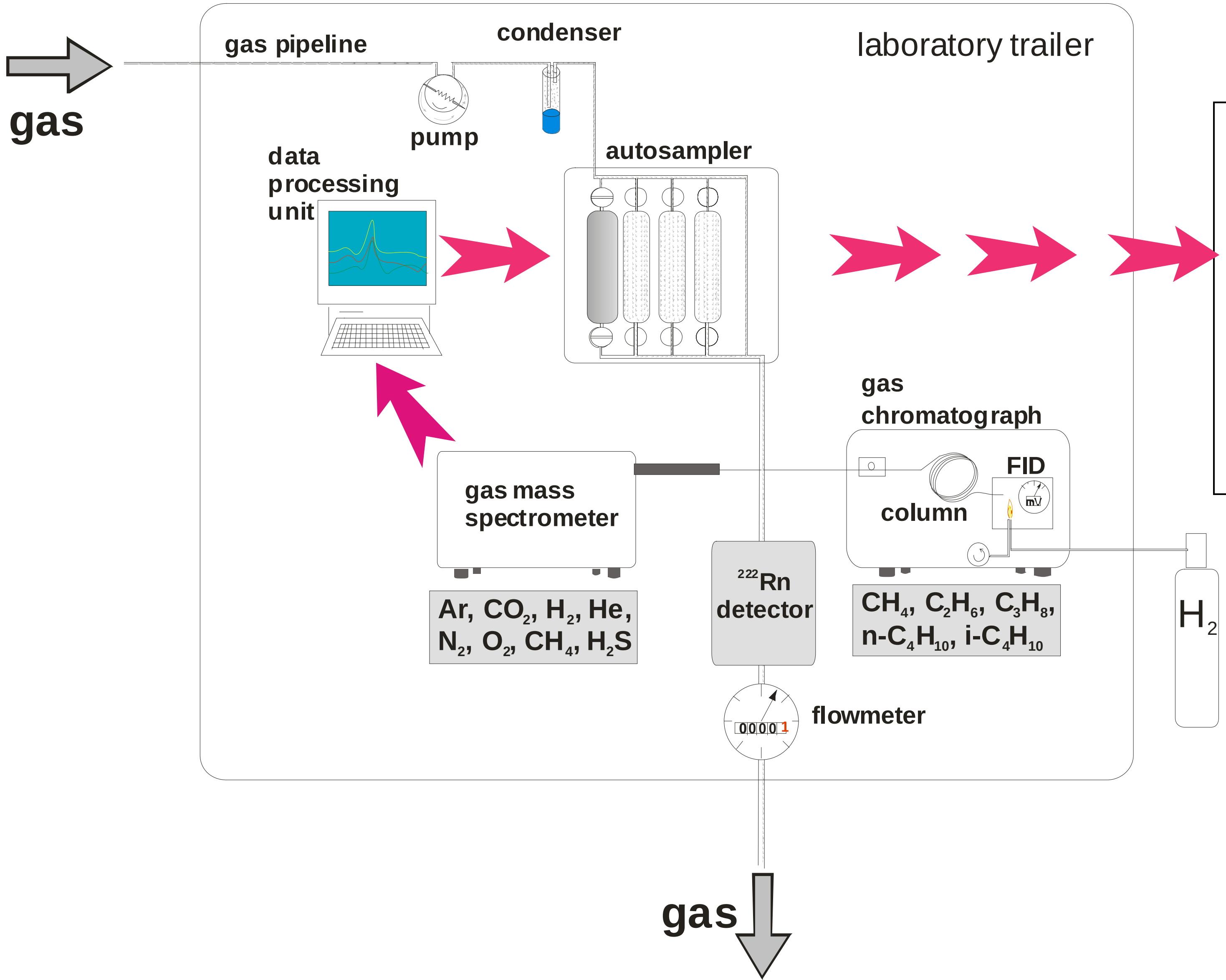
Online Gas Analysis



Off-line gas analysis (isotope studies on noble gases, hydrocarbons, CO_2)


GFZ
SRI 8610C
MS 3
GFZ
OmniStar

Online Gas Monitoring of Drilling Mud (OLGA)

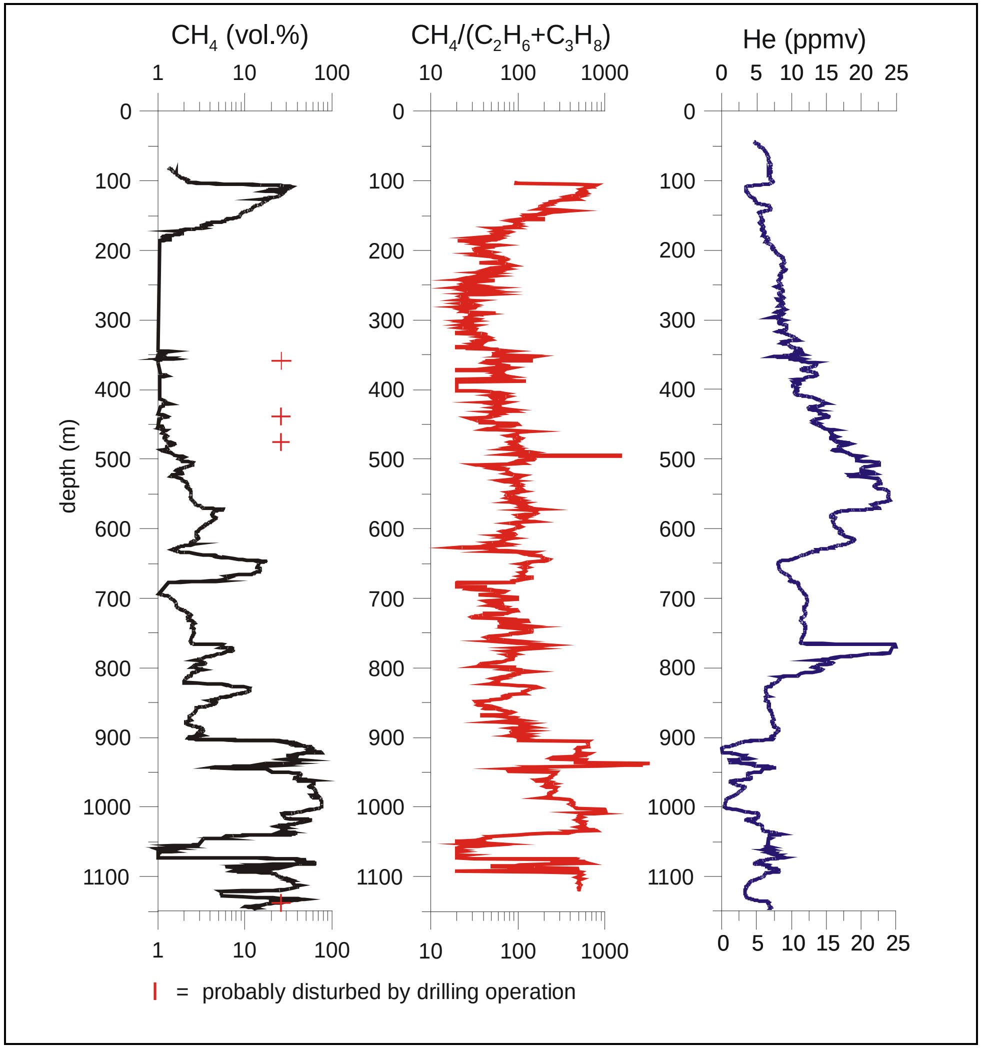
- On-line mud gas monitoring is useful for gases typically enriched in formation fluids (enriched relative to air), i.e.
    - hydrocarbons
    - CO_2
    - H_2
    - He
    - ^{222}Rn
    - H_2S

- Information on the gas compositon is avalaible within minutes, which helps aiding decisions on e.g., coring, fluid sampling etc.

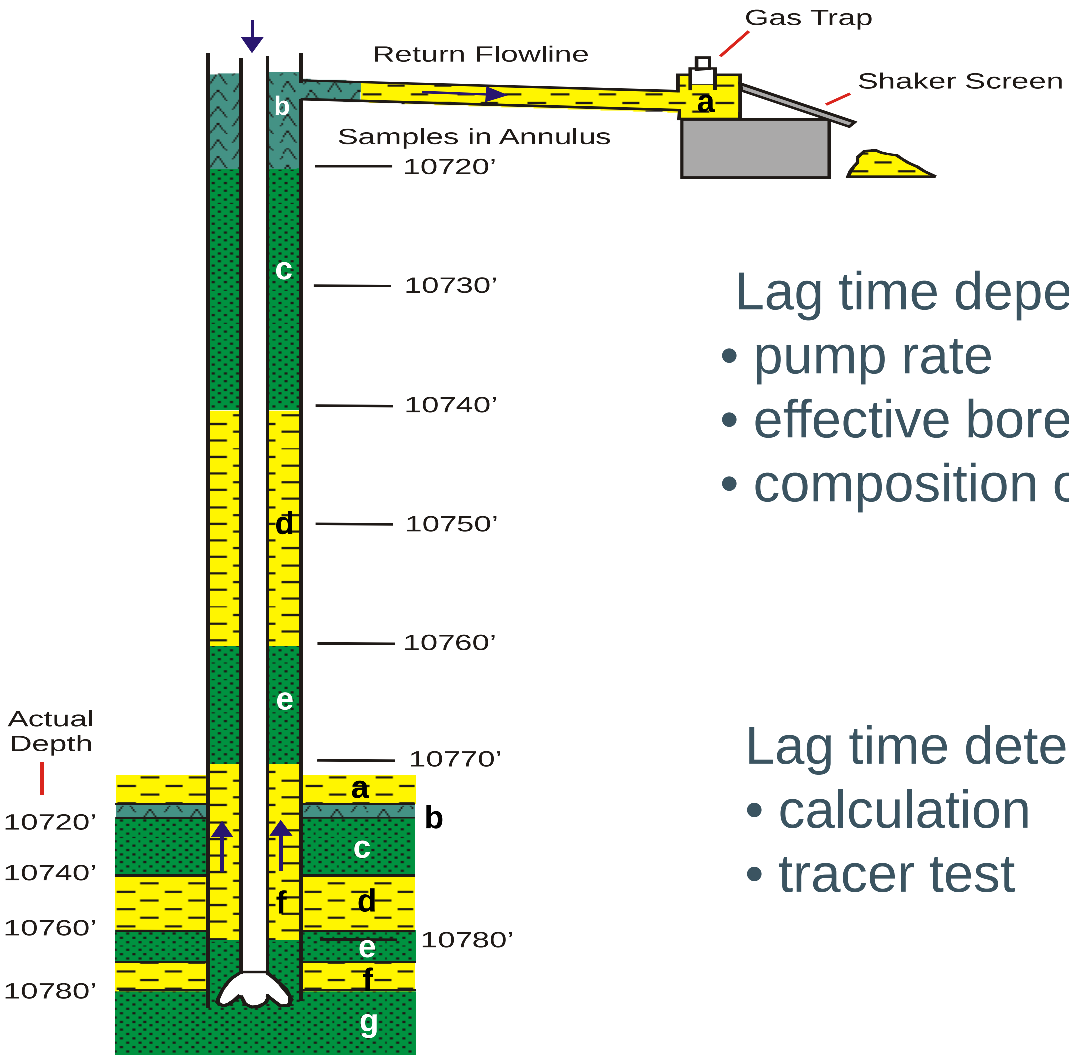
- Drill mud circulation is essential

On-line gas monitoring while drilling: data evaluation

- gas composition is analysed vs. time
- combiniation with data on the lag depth vs. time yields gas composition vs. depth



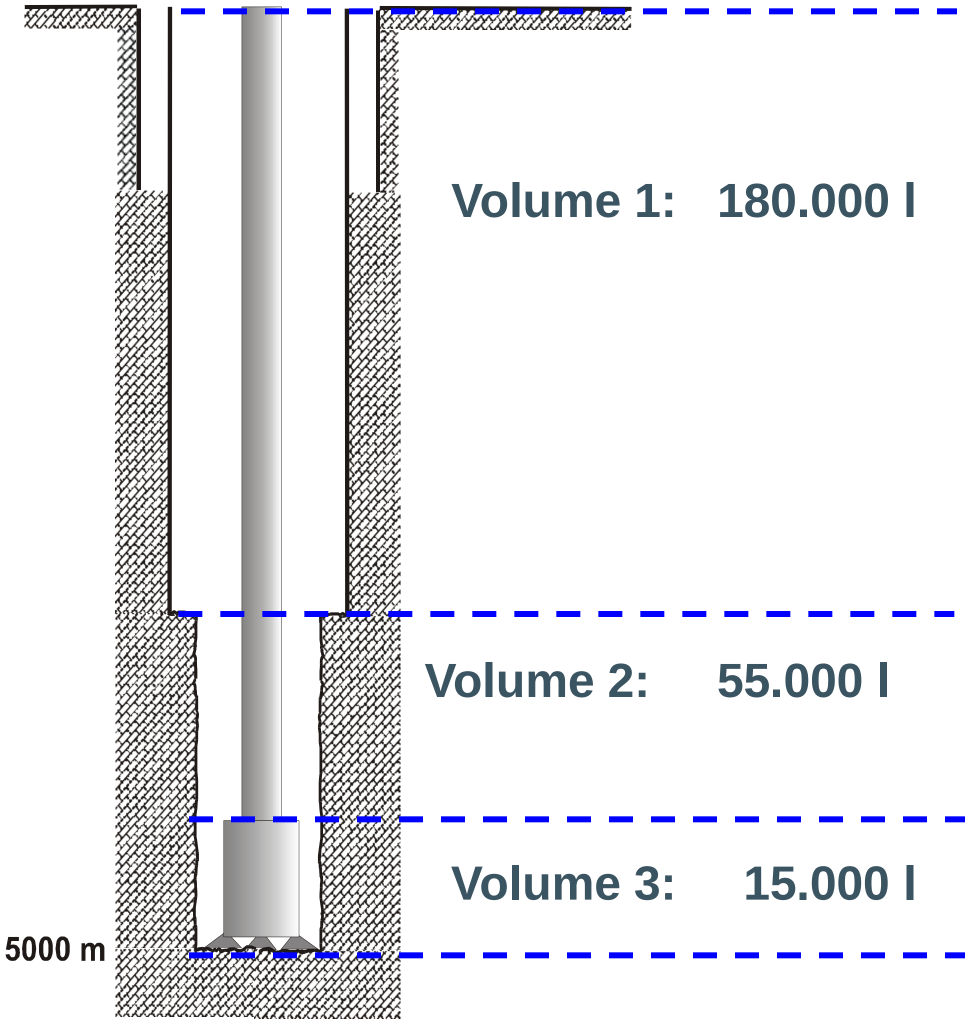
Lag time and lag depth



Lag time depends on
- pump rate
- effective bore hole volume
- composition of drilling mud

Lag time determination
- calculation
- tracer test

Lag time calculation



Pump rate = 100 strokes/min

1 stroke = 25 l

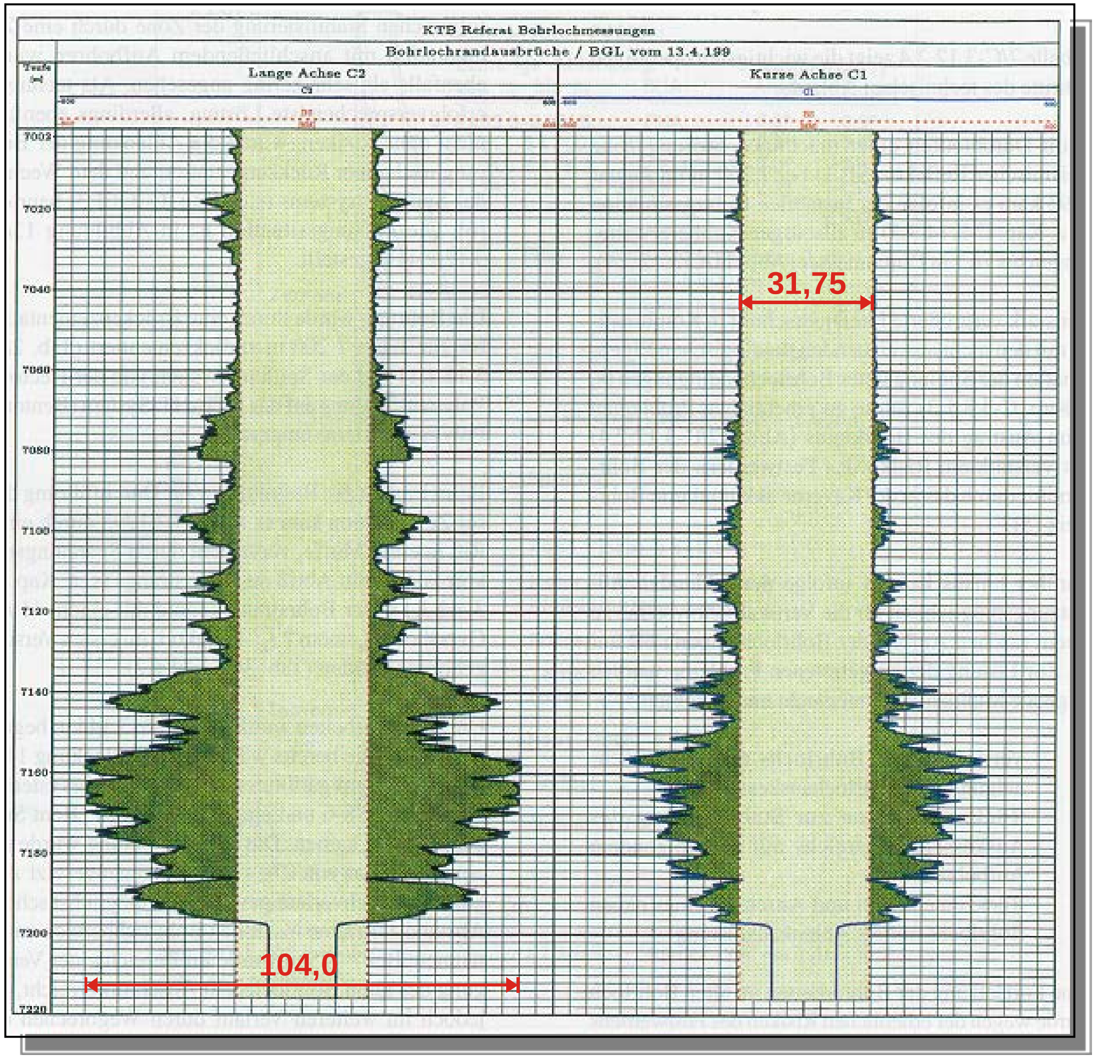
Rate of Penetration = 6 m/h

Pump rate = 2.500 l/min
Effective Volume = 250.000 l

Lag time = 100 min

Lag depth correction = 10 m

Borehole Enlargement

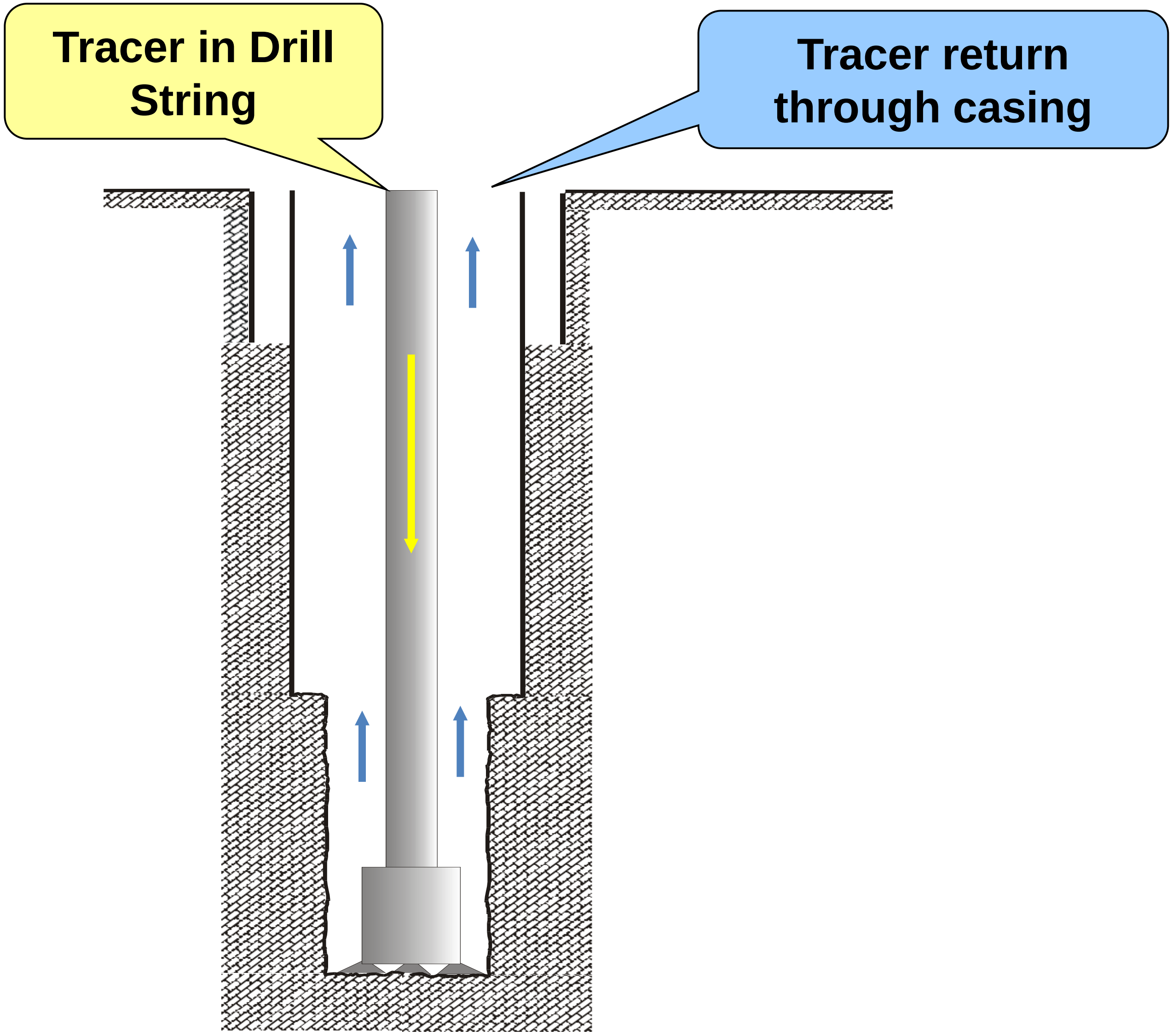


Increase of borehole volume

31,75 cm = 79,1 l/m
104,0 cm = 849,1 l/m

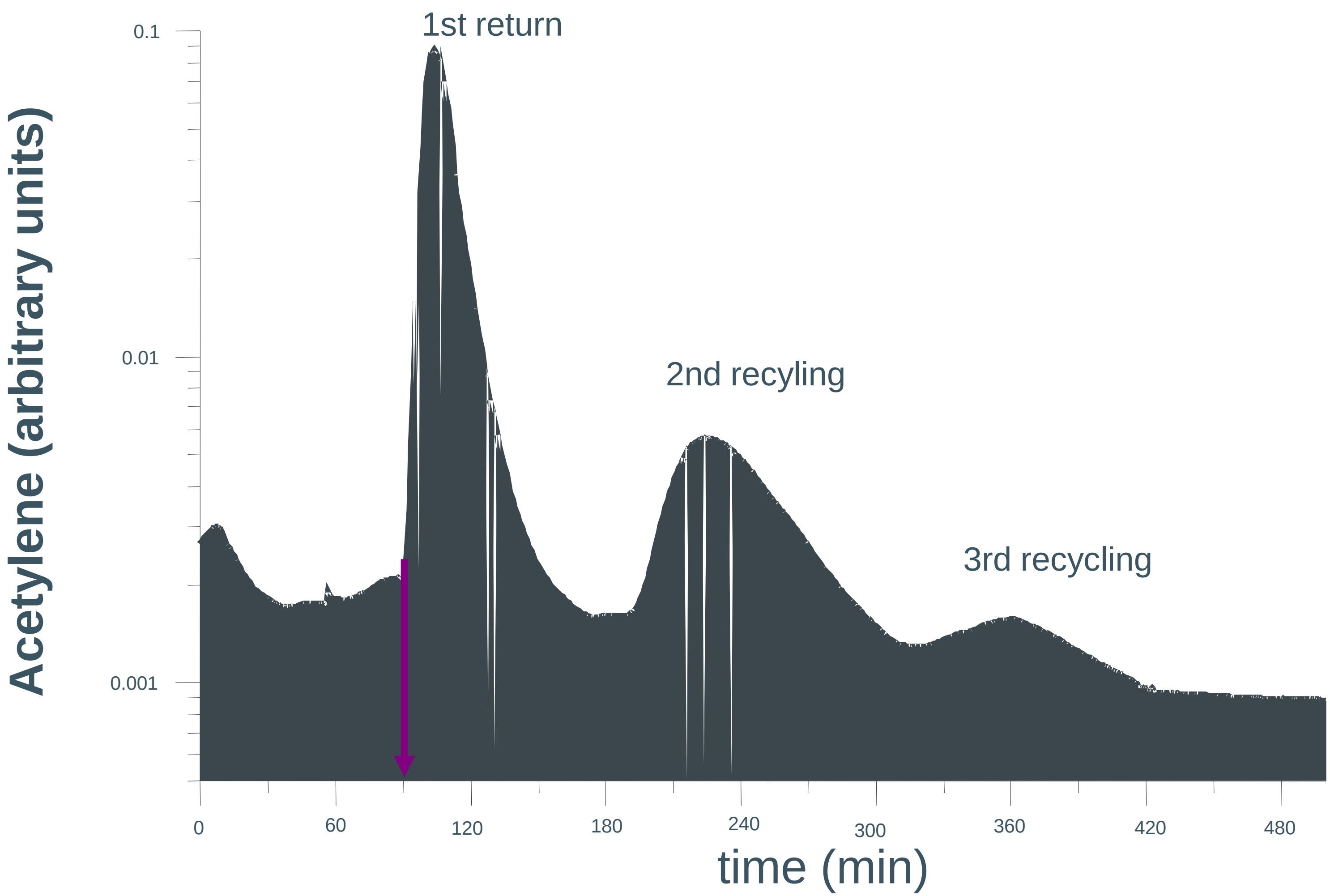
Tracertest!

Lag time determinaton through tracer

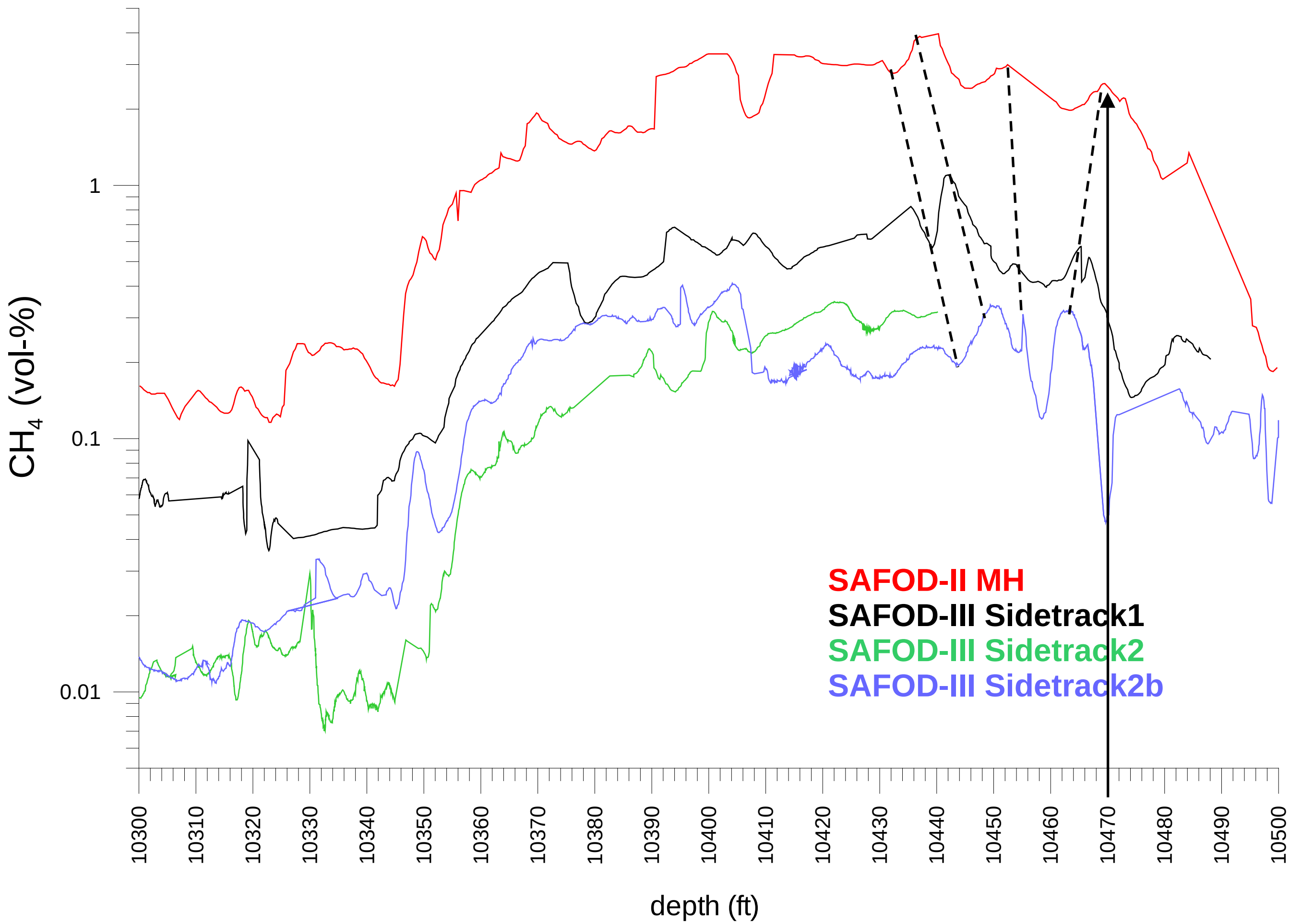


Tracer test (carbide)

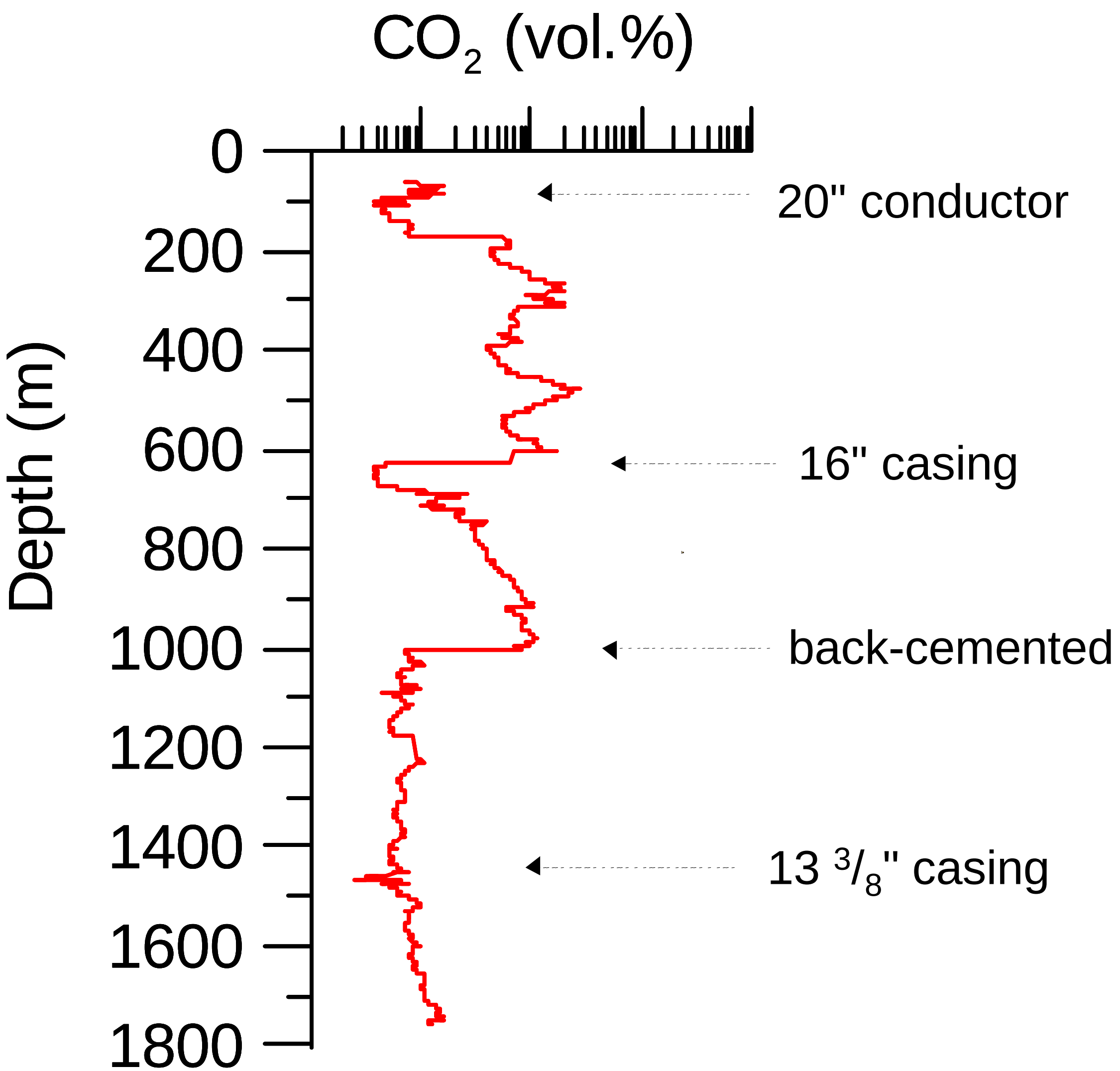
$$CaC_2 + 2H_2O \rightarrow Ca(OH)_2 + C_2H_2 \text{ (Acetylene)}$$



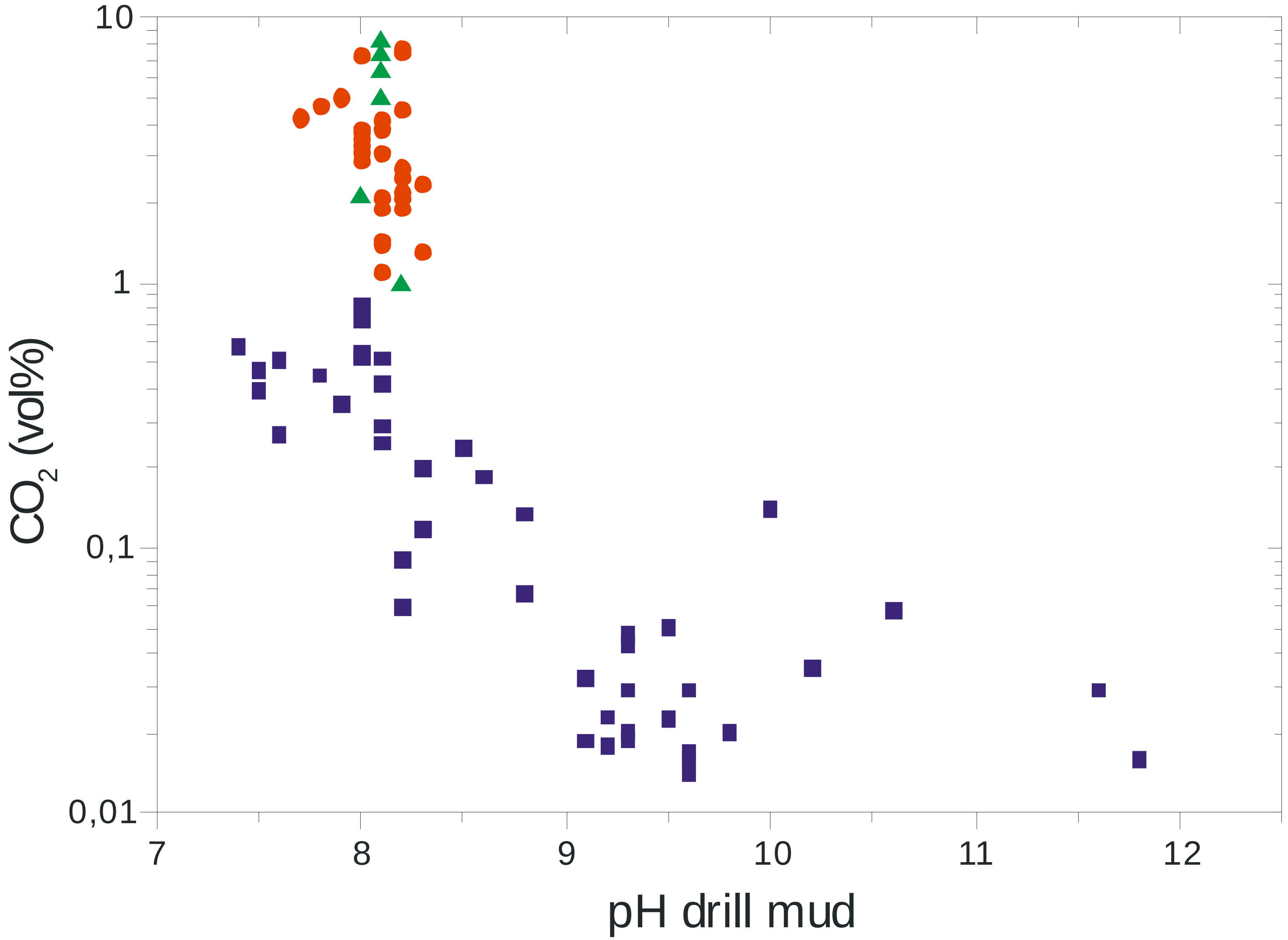
Using OLGA to determine strating depth for coring



What processes influence the mud gas composition?

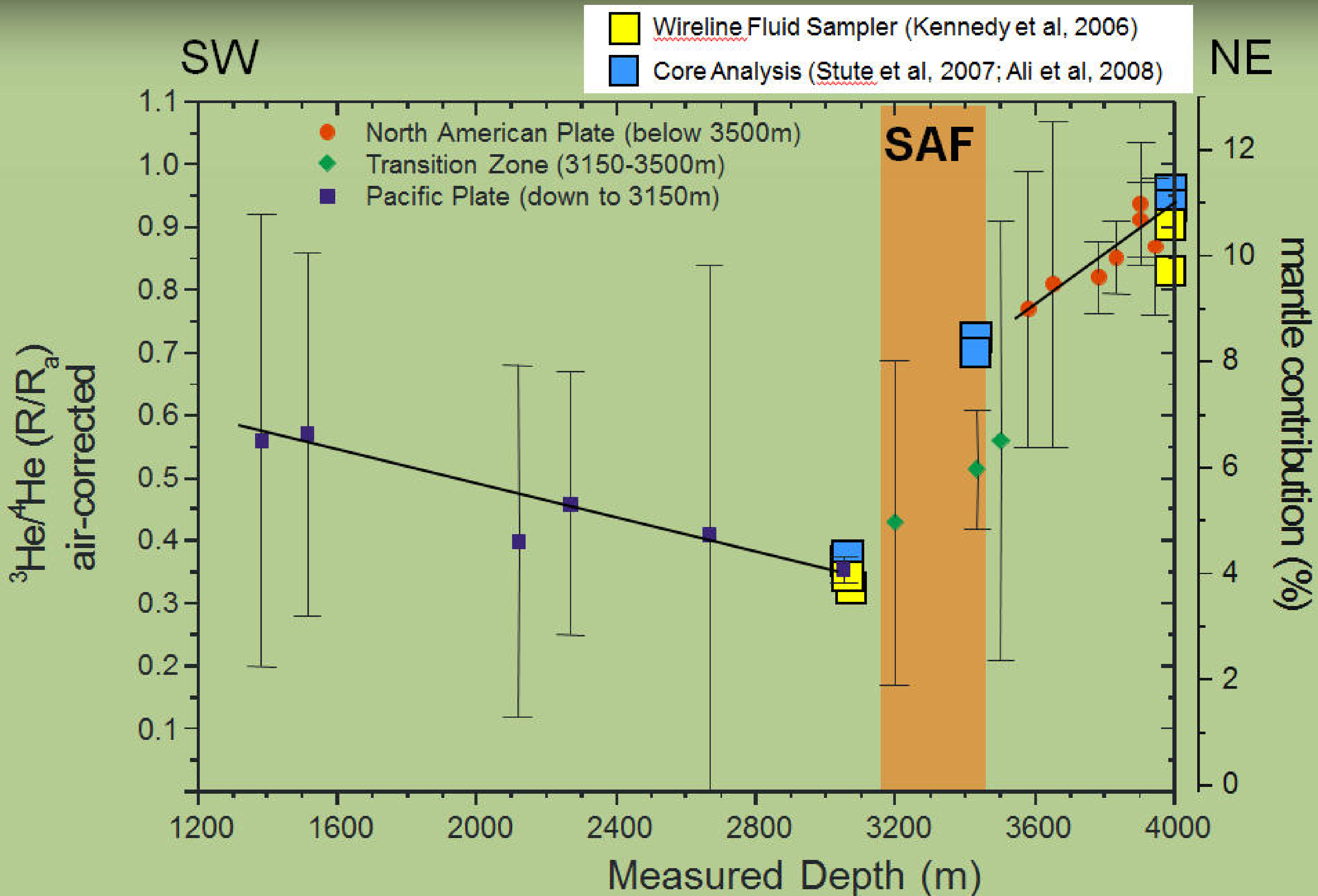


CO_2 vs. pH



Comparision Mudgas-Coregas-PDS

Mudgasdata from Wiersberg and Erzinger, 2007



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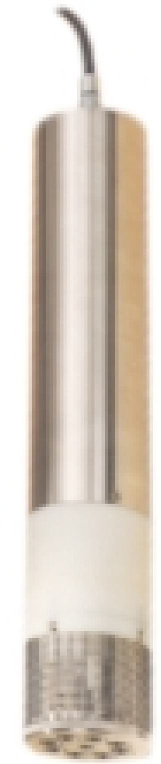
Gas and Fluid Sensors

Sea-sun-tech

- Multisensor tools with gas/fluid probes are limited for shallow depths (generally 100m, standard application: water wells)
- Gas/fluid probes are avaliable for H_2S, CO_2, H_2, HC and dissolved species (O^{2-}, NO_3^-, NH_4^+…)
- Other techniques (e.g. fiber-opictal IR) are under construction, but not ready yet



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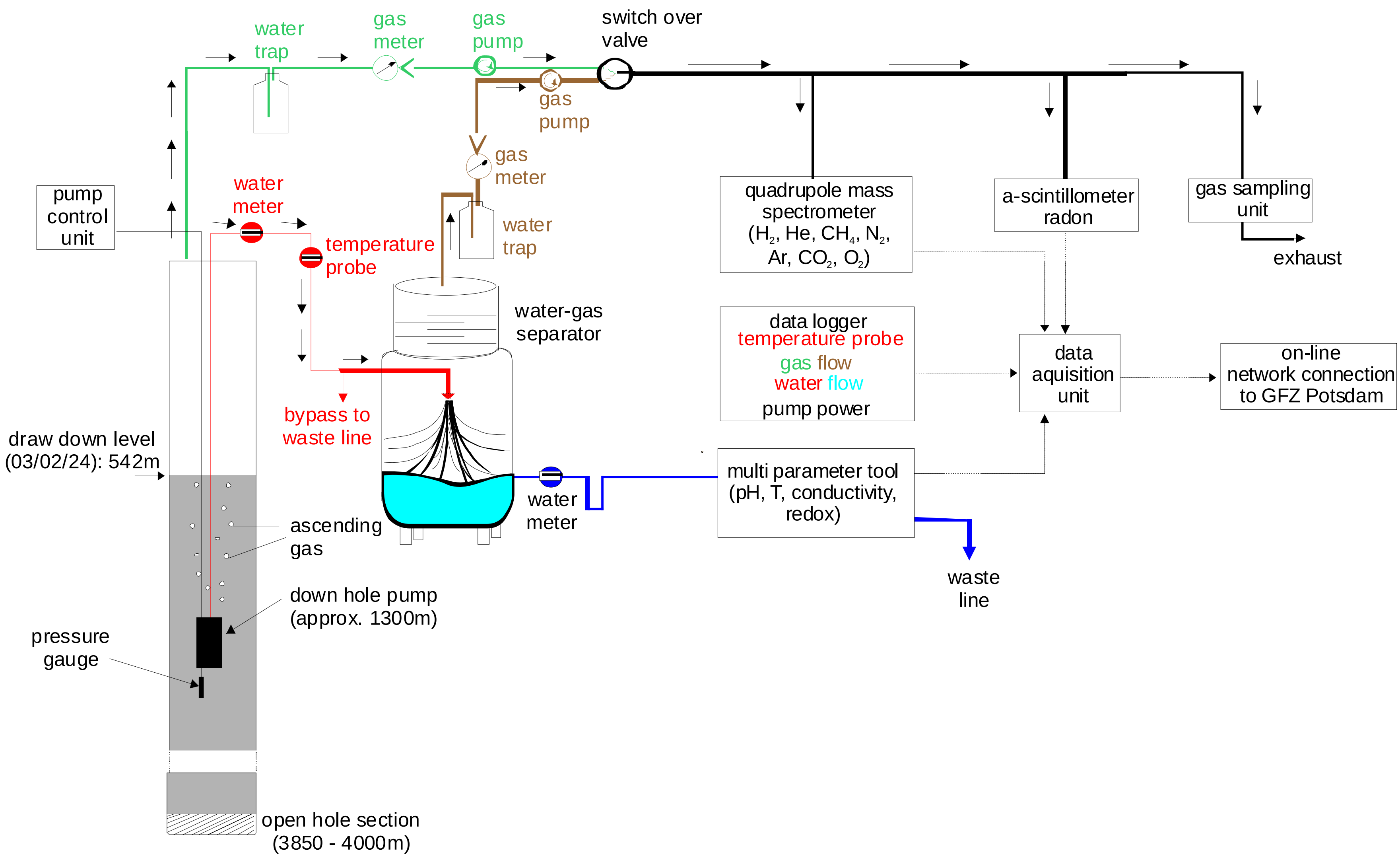
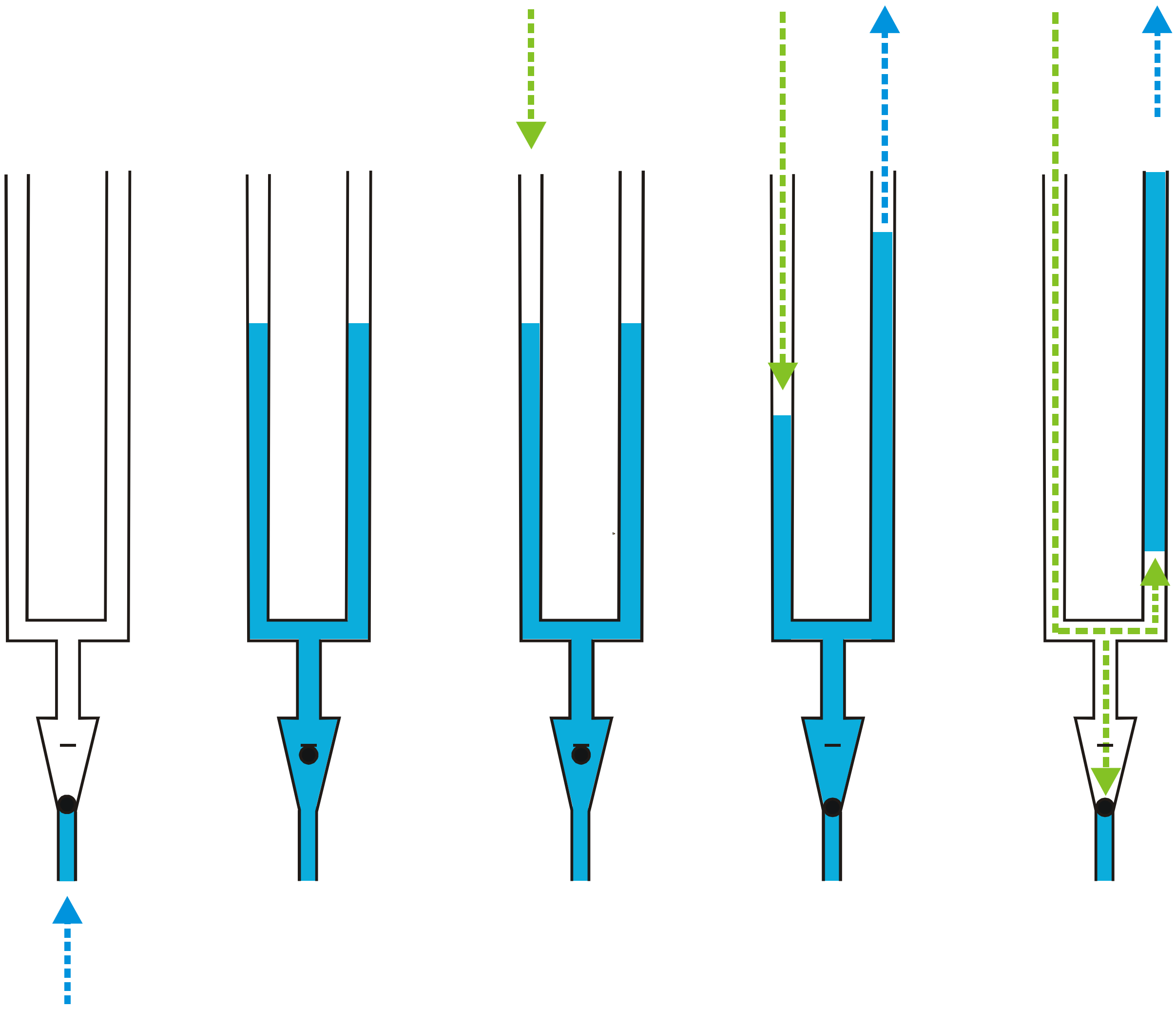
Gas monitoring during pumping tests



U-tube technique (Freifeld and Trautz, 2006)



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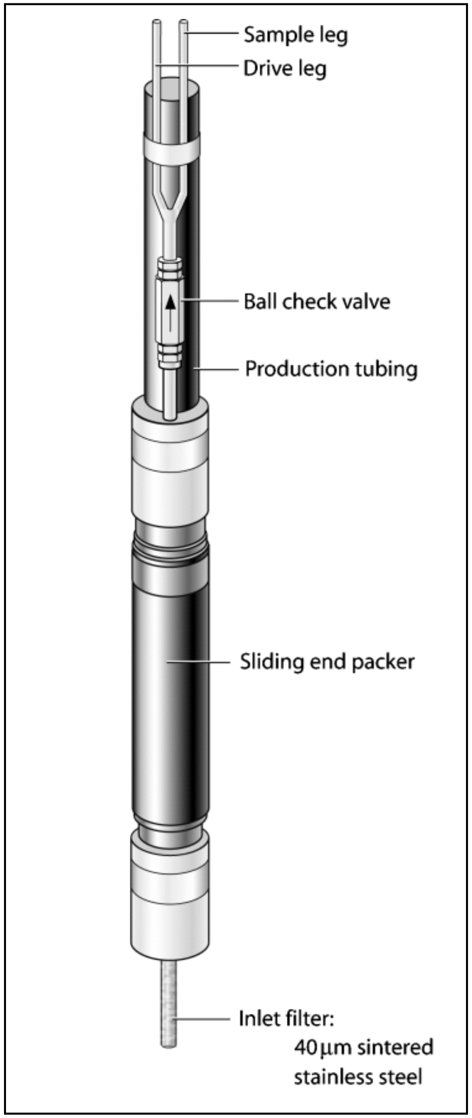
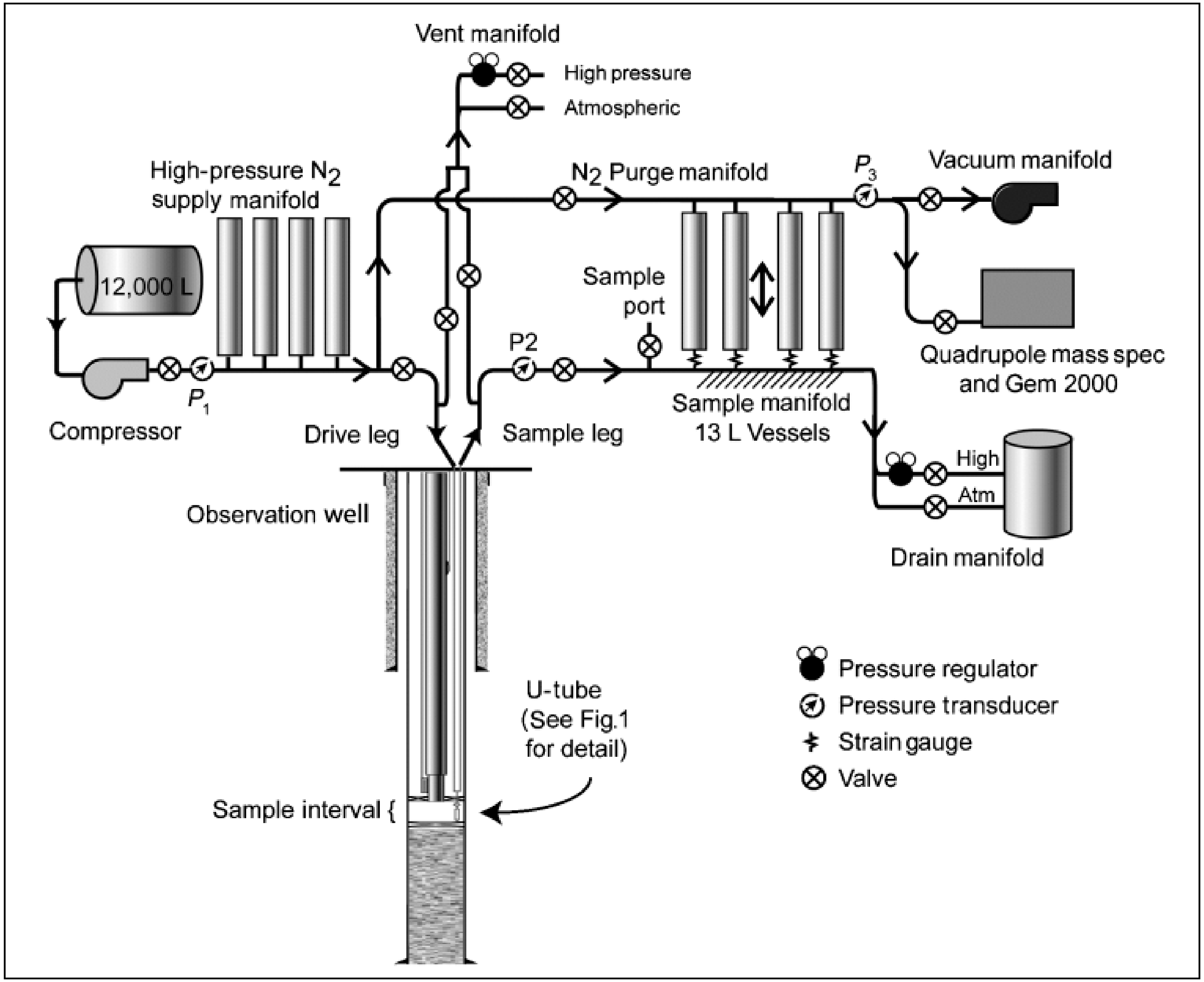
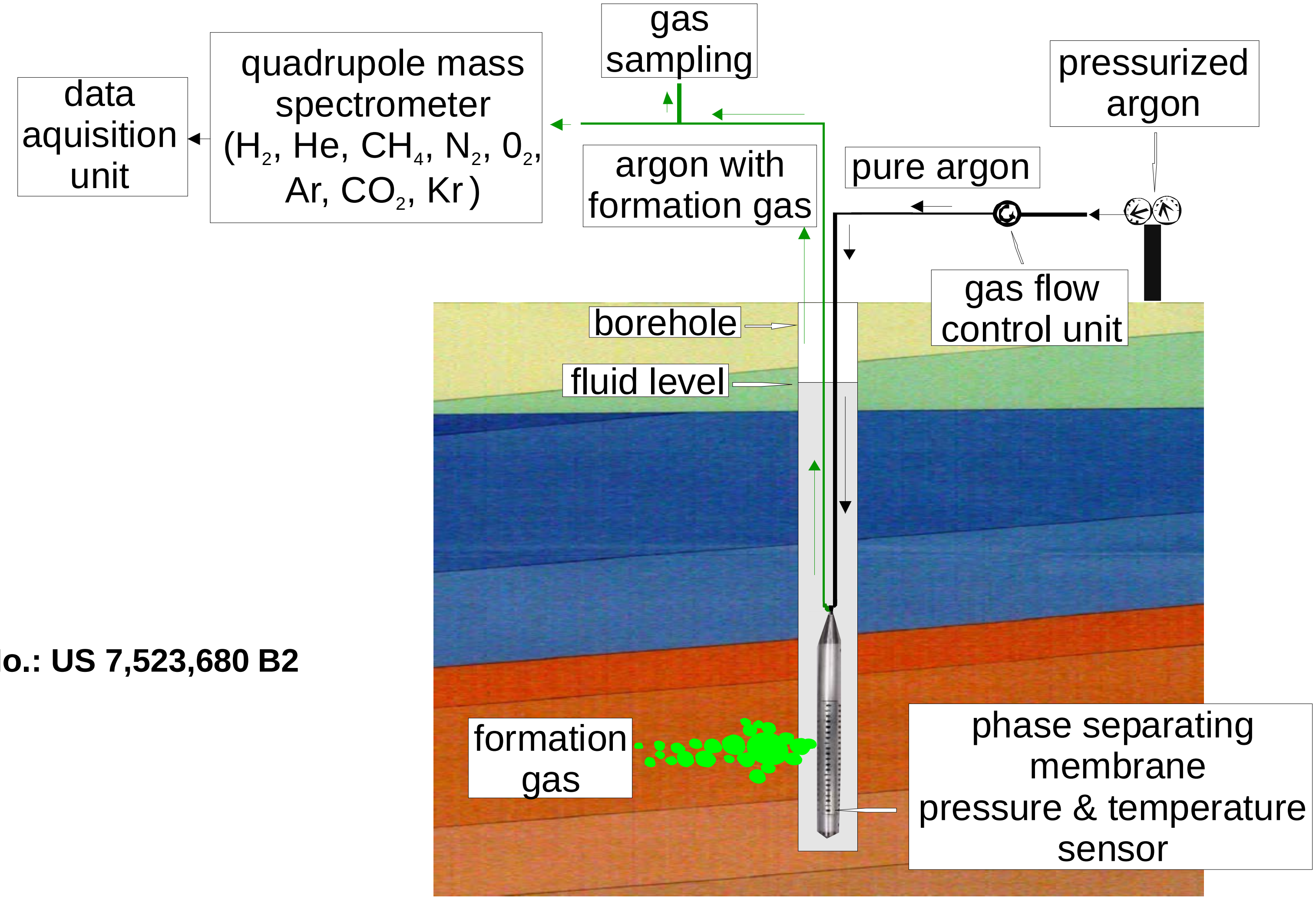




U-Tube gas monitoring during CO_2 sequestration in Otway (Victoria, Australia)

U-Tube gas monitoring during CO_2 sequestration in Otway (Victoria, Australia)

Gas membran sensor (Zimmer et al. 2008)



Patent No.: US 7,523,680 B2

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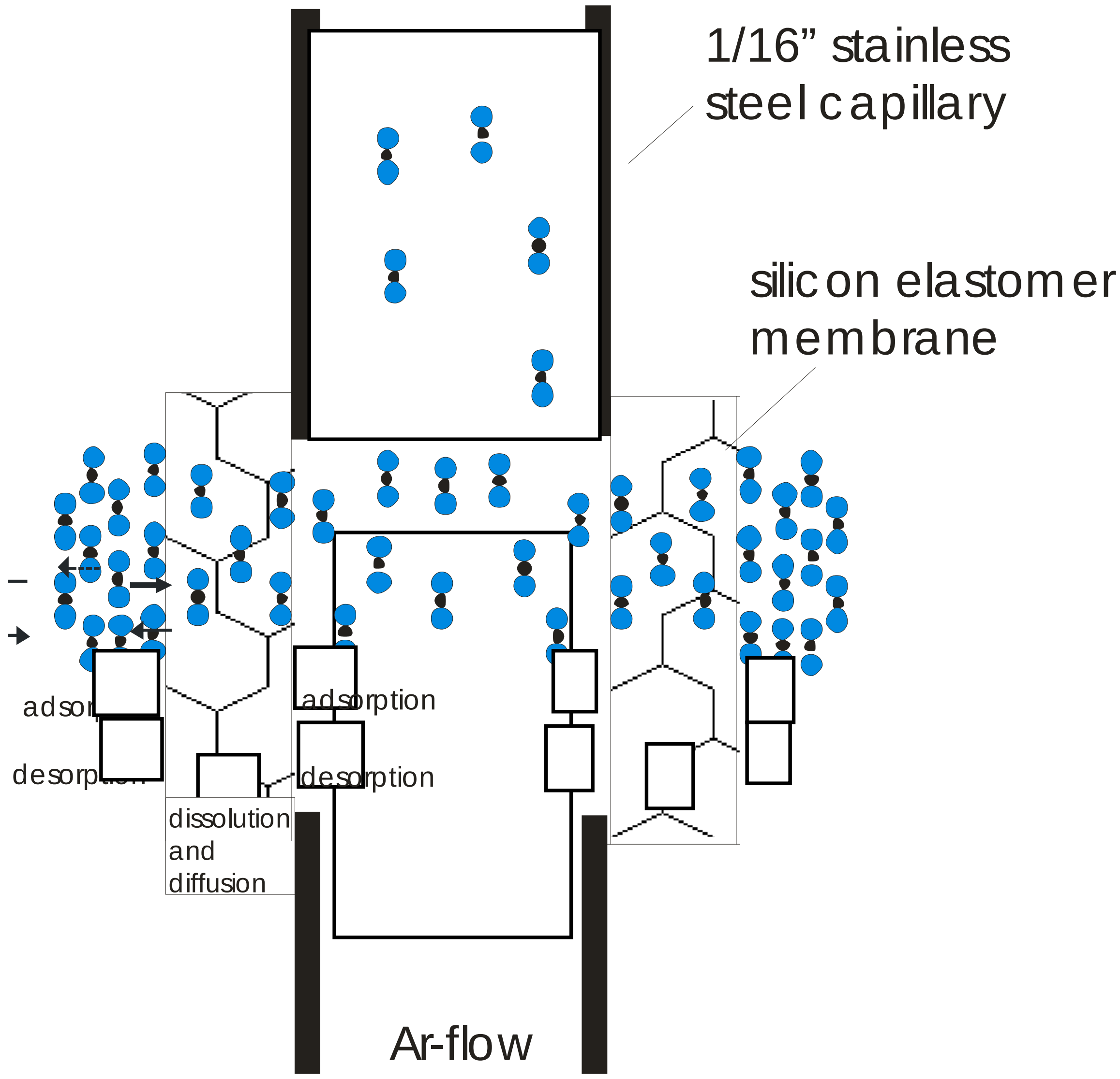
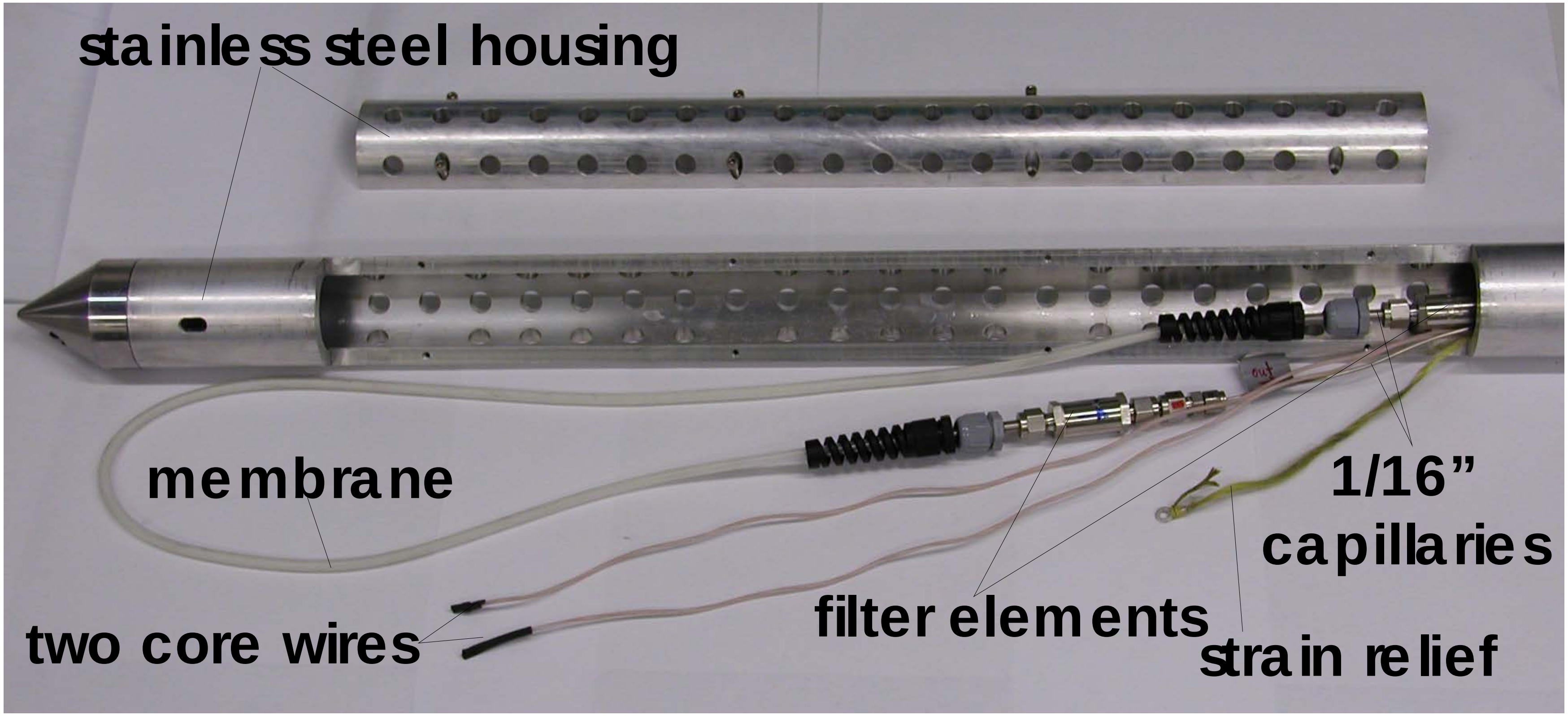
Diffusion-solution model



Gas Membran Sensor



Overview

METHOD	Sample quality	Information on temporal variation	Information on spatial distribution	Quantitative data[1)]
Wellhead fluid sampling	+++	++	+	++
Degassing of drill cuttings/core	+/++	-	++	+
Void gas sampling	+	-	++	-
Downhole fluid sampling	+++	+	++	+++
MDT	++	+	++	+
Downhole Gas Sensor	-	+++	+	-
U-Tube technique	++	++	+	++
Fluid monitoring during pumping	+++	+++	+	+++
Gas membrane sensor	+	+++	+	+
Drill-mud gas monitoring	+	-	+++	+

1) absolute gas concentrations and gas/water ratios

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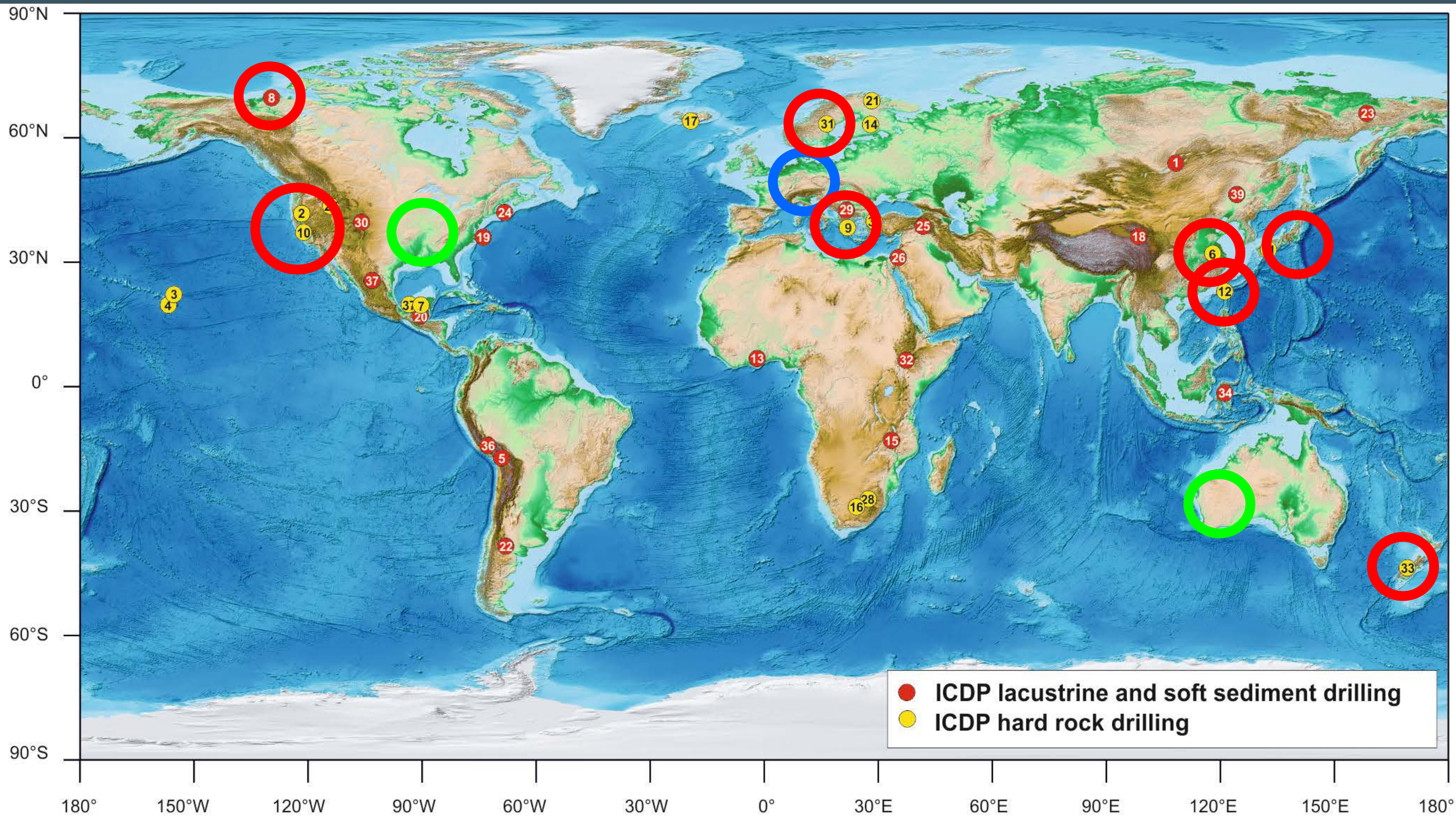
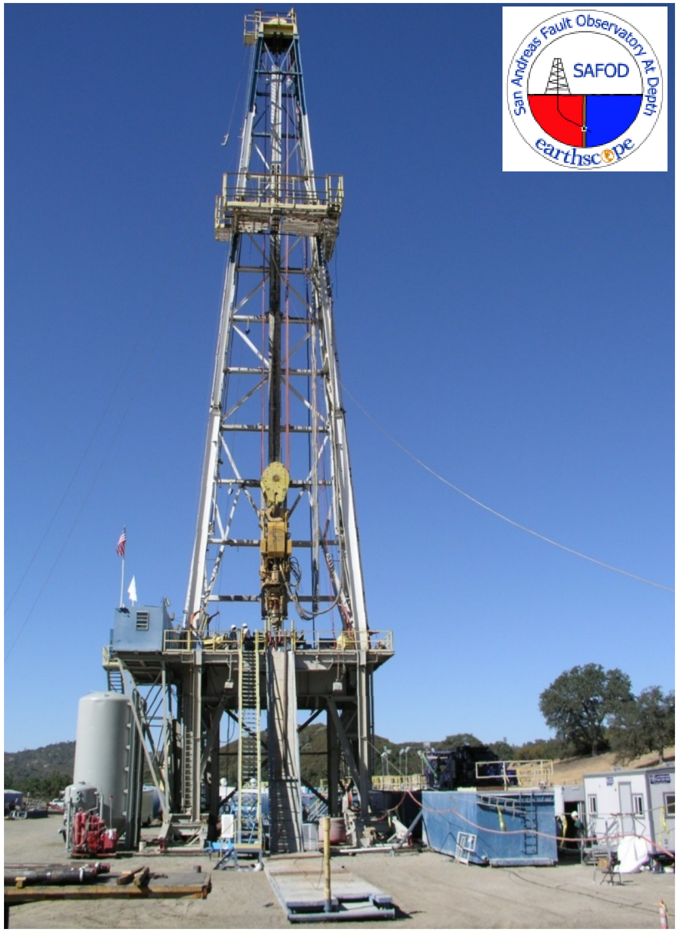


OLGA

U-Tube (non-ICDP)

Gas Membrane Sensor (non-ICDP)

Drilling mud gas monitoring while drilling through an active plate-bounding fault zone (SAFOD)

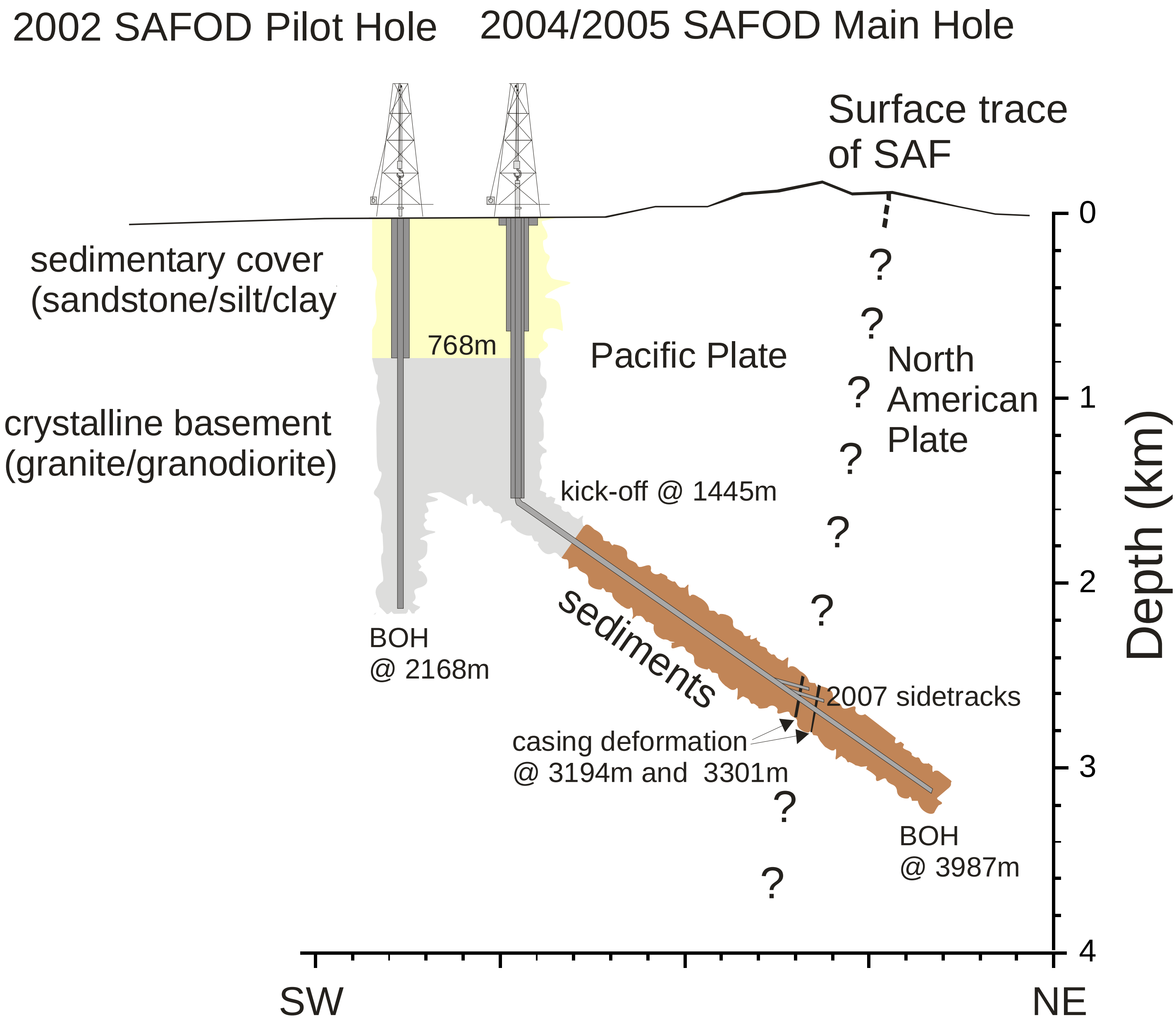


SAFOD earthscope

The central scientific objective of SAFOD is to study the physical and chemical processes that control deformation and earthquake generation within plate-bounding fault systems“

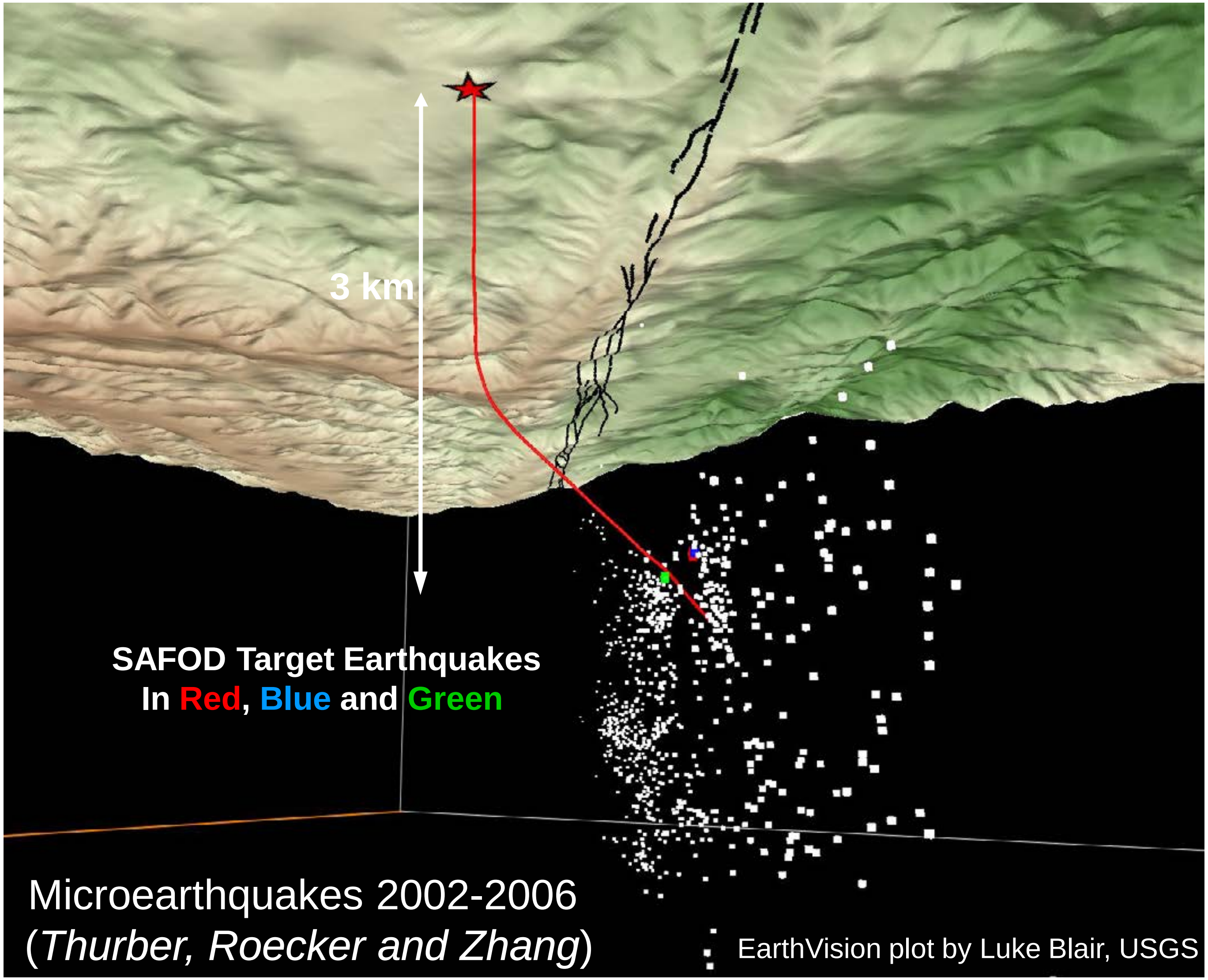
SAFOD aims to understand

- why major plate-bounding faults (like the SAF) are generally weak and how they loose their strength,
- why some segments of the SAF are creeping and others are locked,
- the role and origin of fluids linked with fault zone processes,
- the physics of earthquake nucleation and rupture propagation.

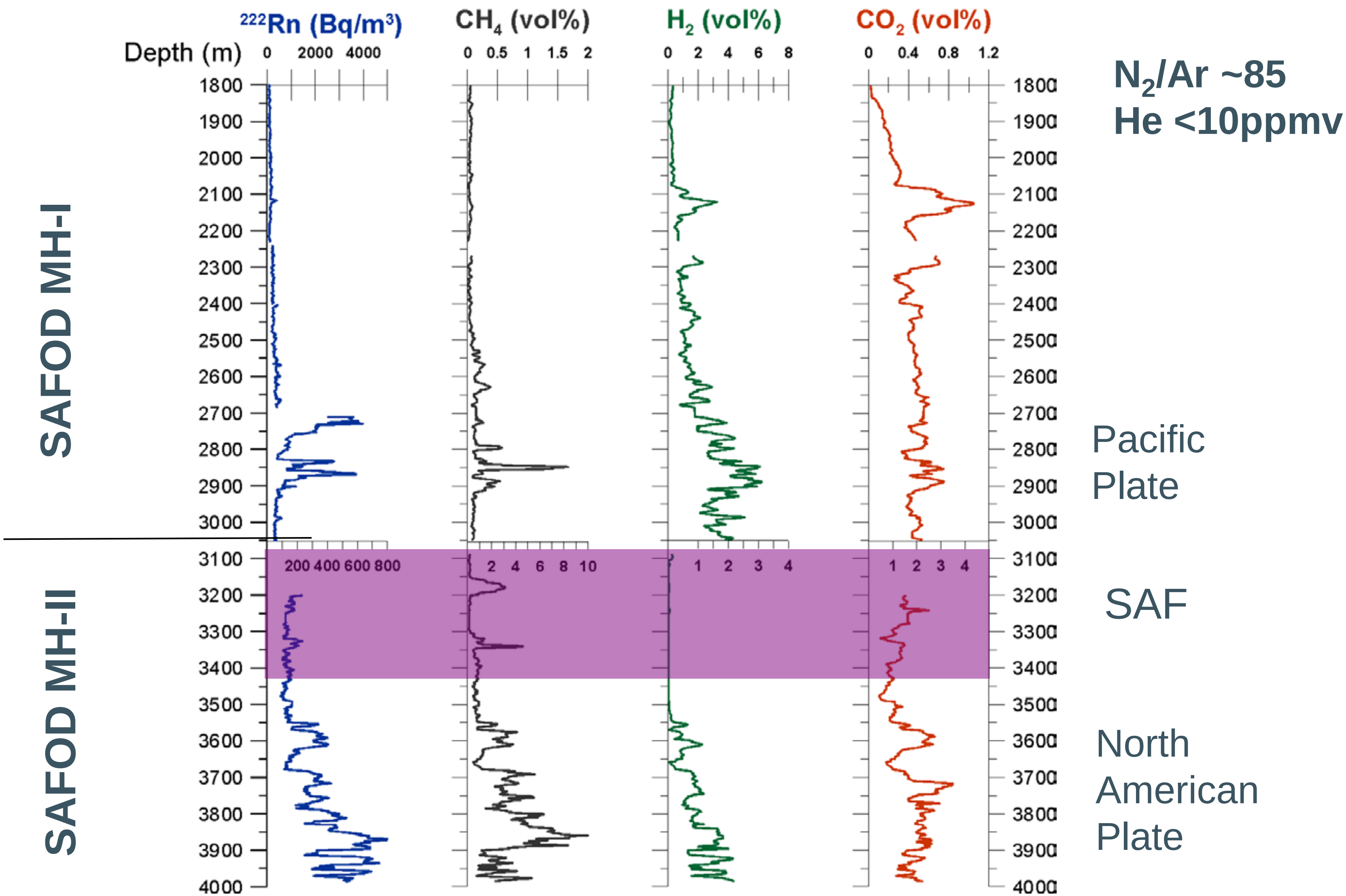


2002 SAFOD Pilot Hole
2004/2005 SAFOD Main Hole
Surface trace of SAF
sedimentary cover (sandstone/silt/clay
768m
Pacific Plate
North American Plate
crystalline basement (granite/granodiorite)
kick-off @ 1445m
sediments
BOH @ 2168m
2007 sidetracks
casing deformation @ 3194m and 3301m
BOH @ 3987m
0
1
2
3
4
Depth (km)
SW
NE

SAFOD location and drilling target

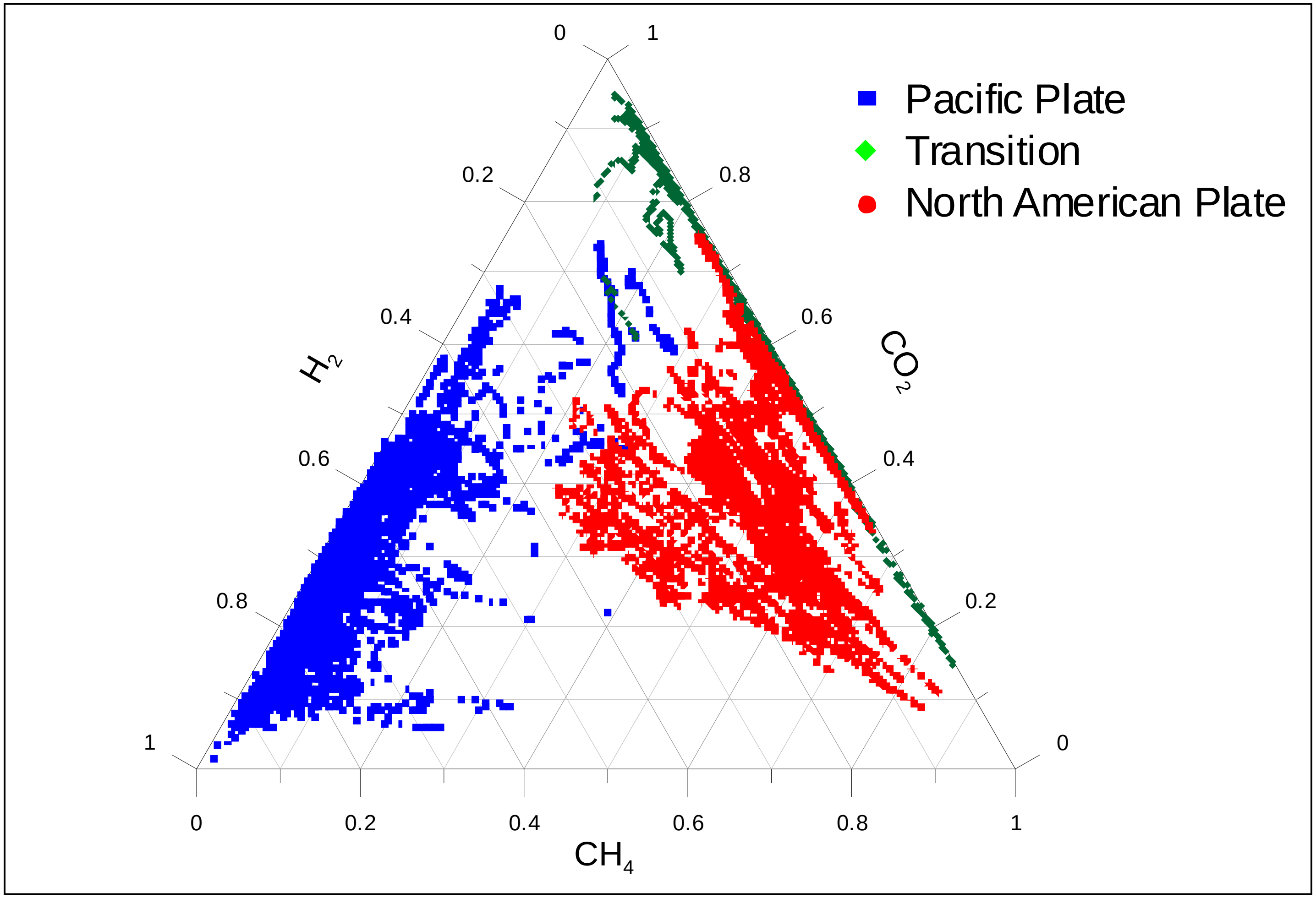


Depth distribution of gases at SAFOD



Wiersberg and Erzinger (2008), Appl. Geochem.

The composition of the main formation gases at SAFOD (CH_4-CO_2-H_2)



Wiersberg and Erzinger (2008), Appl. Geochem.

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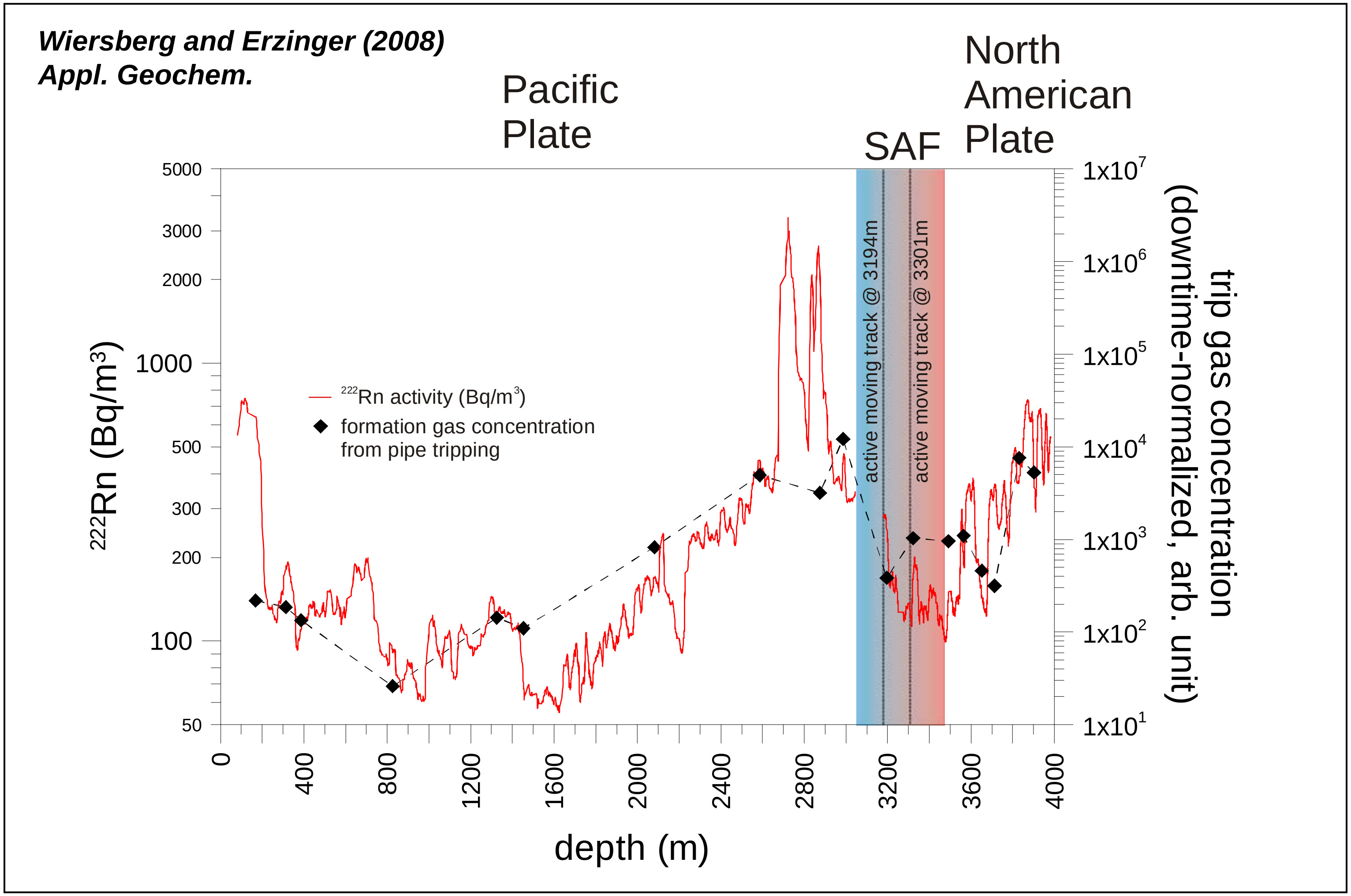
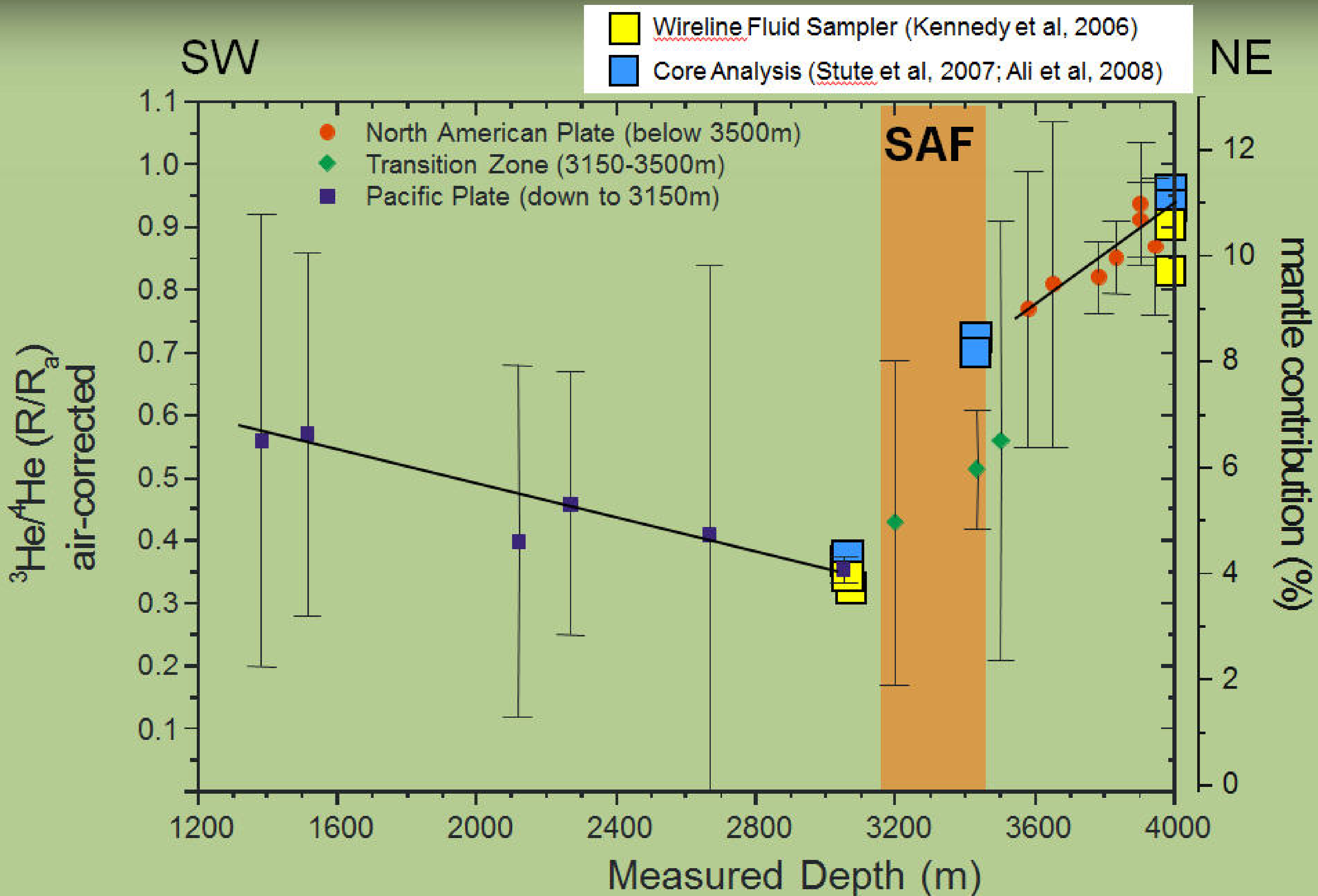
Relative permeability of the SAF from radon and tripgas studies

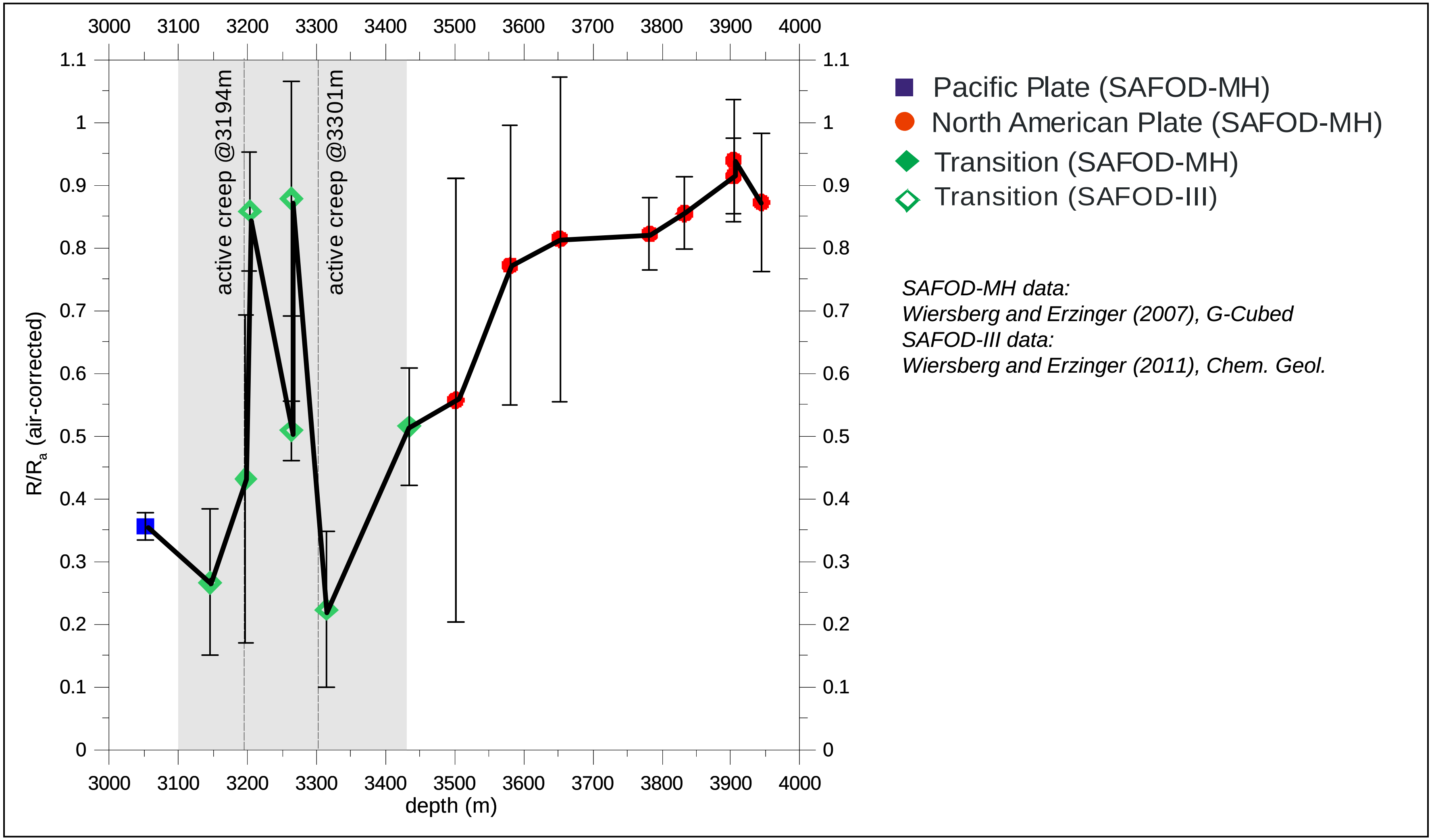


Comparision Mudgas-Coregas-PDS

Mudgasdata from Wiersberg and Erzinger, 2007



The role of mantle-derived fluids



Fluids @ SAFOD

- The most abundant formation gases in drill mud of the SAFOD wells are hydrocarbons, CO_2 (both organic) and H_2 (mechanochemical?)
- Distinct gas compositions on the Pacific Plate and the North American Plate, low trip-gas concentration and low radon activity imply low permeability transverse to the fault
- The overall contribution of mantle-derived fluids at the SAF is small, but higher in the centre of the SAF, indicating enhanced permeability parallel to the fault
- Nevertheless, most mantle-derived fluids migrate through permeable country rock on the North American Plate
- Both active moving branches of the SAF separate strata with different gas content and - composition

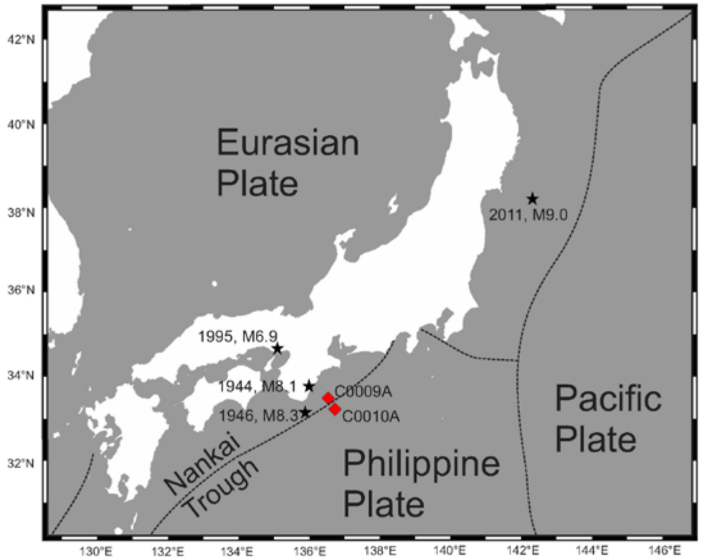
In situ gas concentrations in the Kumano forearc basin from IODP NanTroSEIZE Exp. 319 Site C0009A drilling mud gas monitoring and sonic velocity data

Thomas Wiersberg, Mai-Linh Doan,
Anja Schleicher, Keika Horiguchi,
Nobuhisa Eguchi, Jörg Erzinger

Exp 319 scientific targets

C0009A intersects the cover sediments of the Kumano Basin and penetrates into the accretionary prism below in order to

- retrieve and analyse drill core and drilling cuttings
- conduct downhole tests and measure *in situ* pore pressures and stress states
- install long-term borehole monitoring instrumentation
- gain information on formation gases by drilling mud gas monitoring



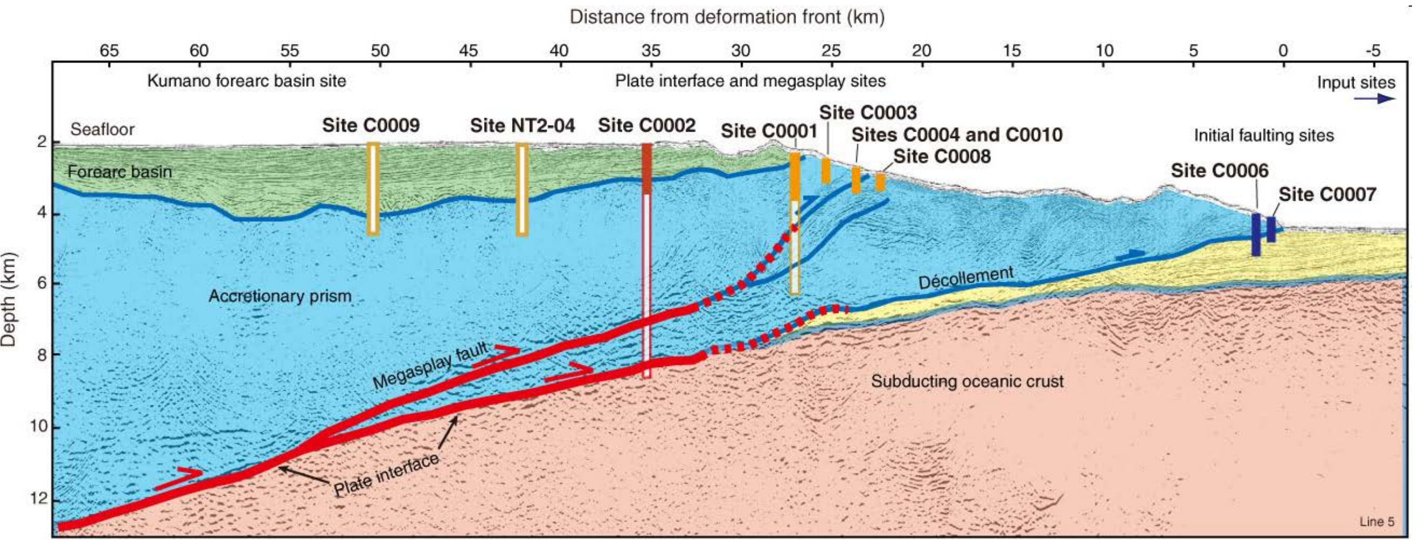
Exp 319 Site C0009A Drilling History
(water depth: 2082m)

0 - 704mbsf: non-riser drilling

704 - 1510mbsf: riser drilling (cuttings)

1510 - 1594mbsf: riser drilling (core & cuttings)

1604mbsf: final depth after reaming



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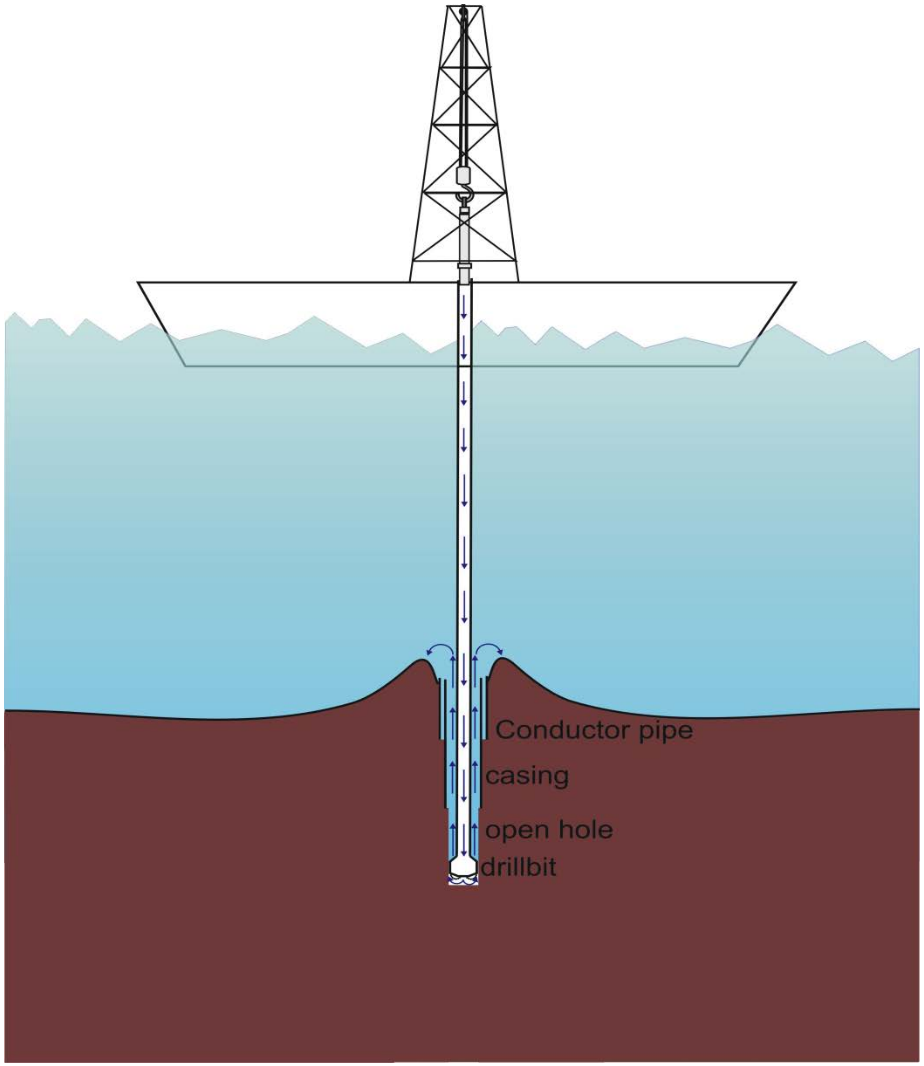
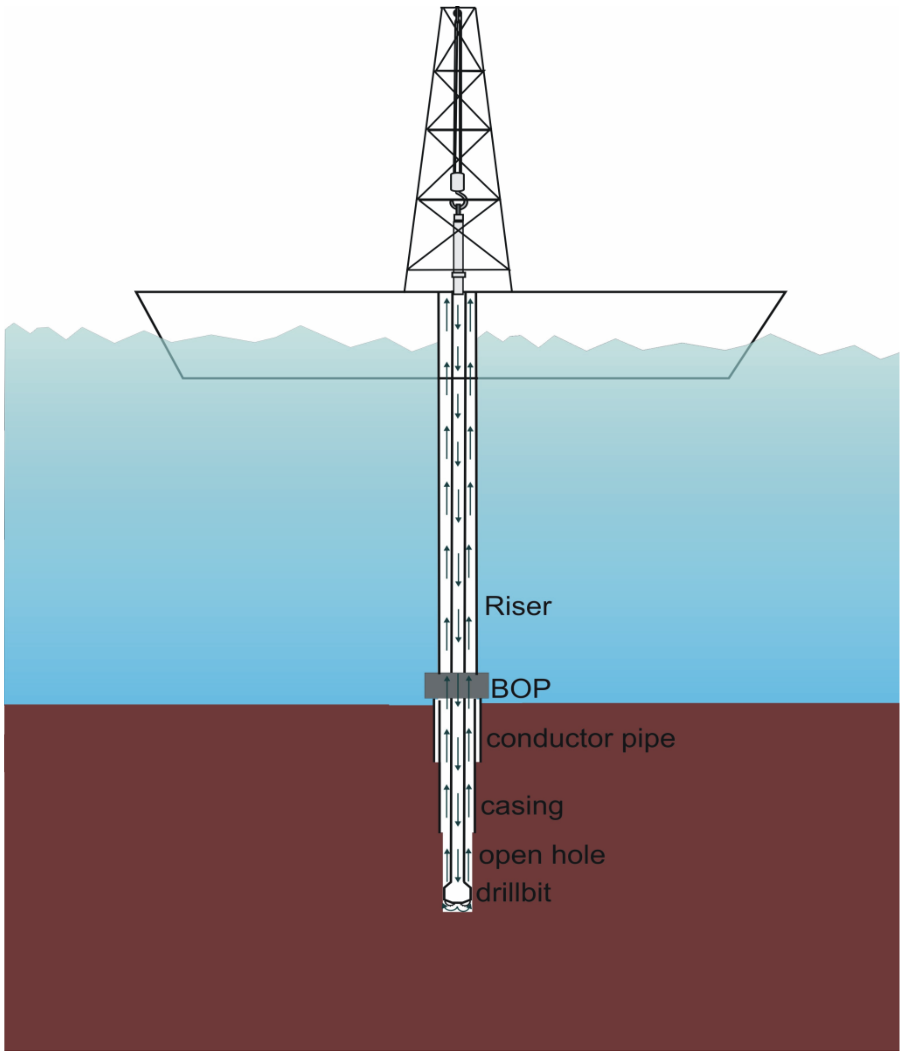
Conventional IODP Drilling	IODP Riser Drilling *(D/V Chikyu)*
Drilling fluid: seawater, no circulation	Drilling fluid: returning drilling mud





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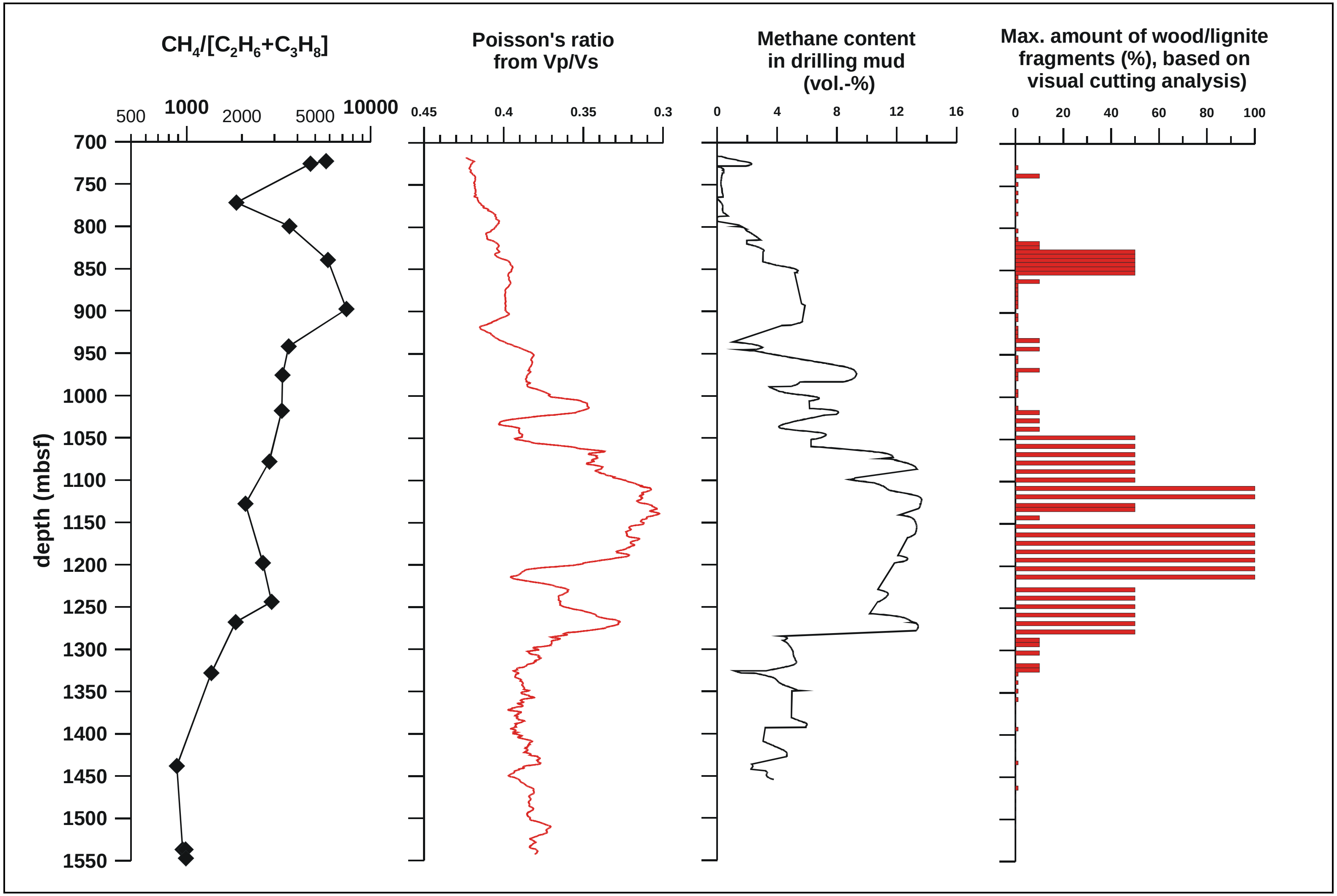
Provenance of formation gases from the Kumano forearc basin



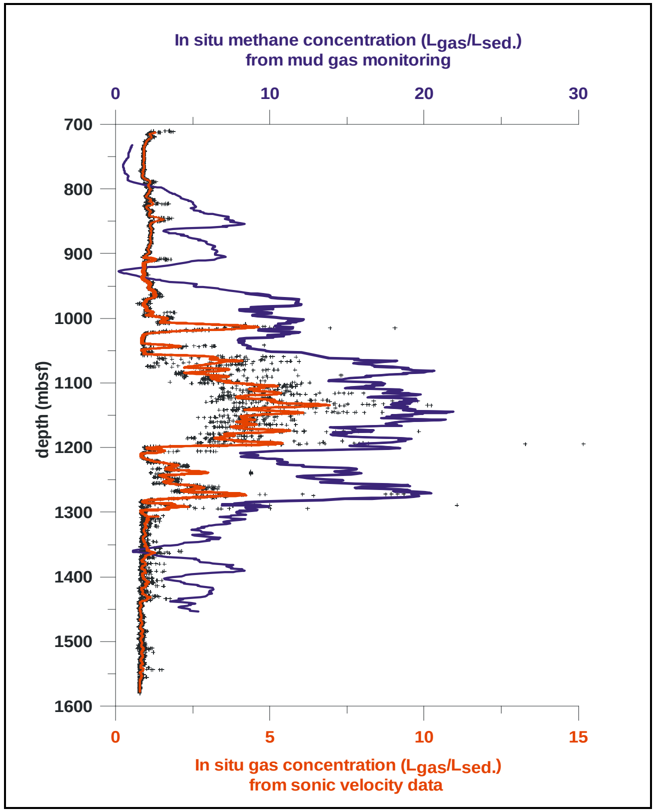
How to quantify *in situ* gas without drill core?

Approach A:
Quantification of drilling mud gas
+ gas in cuttings (needs drilling mud circulation)

Assumption
Formation gas from the drilled rock is either released in the drilling mud or remains in the core/cuttings

- For calibration of gas concentrations in drilling mud, a defined amount [175 L at STP] of a calibration gas (acetylene) was measured in the drilling mud vs. time
- Gas concentration vs. time can be transferred into Gas concentration per drilled rock volume via ROP
- Gas concentration in cuttings were two orders of magitude lower ⇒ cuttings degassing during ascent

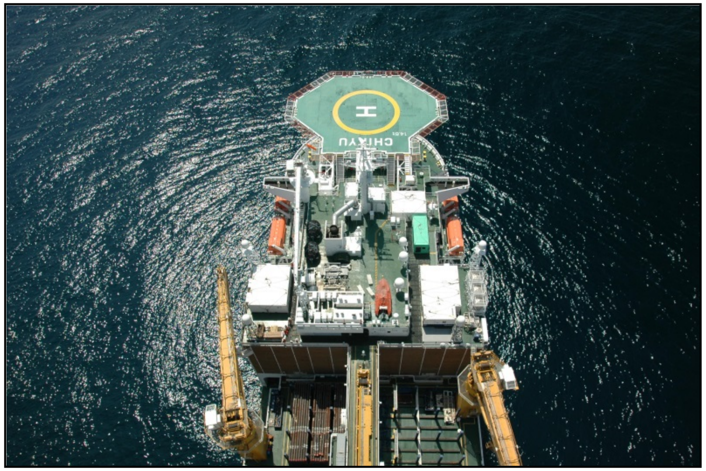
Approach B:
Estimate porosity, water content in intergranular pores and the gas saturation from sonic velocity wireline logging data (Doan et al., 2011)



In situ gas concentration determination: drilling mud gas monitoring vs. sonic velocity

In situ gas concentration from sonic data

⇒ Based on downhole logging (no real-time)
⇒ Very high spatial resolution
⇒ Determination of free gas only (no dissolved gas)
⇒ Knownledge of downhole pressure, temperature, and gas composition
⇒ Assumtion of ideal gas behaviour



In situ gas concentration from drill mud gas

⇒ Quasi-continuous dataset in real time while drilling
⇒ High spatial resolution
⇒ Returning drilling mud
⇒ Possible overestimation through

- Gas recycling
- Gas inflow through permeable strata
- Solubility behaviour of calibration gas

Summary and Conclusions (Exp 319 C0009A)

- **Hydrocarbons are the only formation gases detected in drilling mud**
- **Methane at depth correlates with occurrence of wood particles and with Poisson's ratio**
- **Chemical and isotope composition of hydrocarbons demonstrate a microbial gas source**
- **In situ gas concentrations from sonic velocity data and from drilling mud gas monitoring reveal similar depth profiles**
- **In situ gas concentrations reach 15 $l_{gas}/l_{sediment}$ (sonic velocitiy) and 24 $l_{gas}/l_{sediment}$ (drilling mud gas monitoring)**