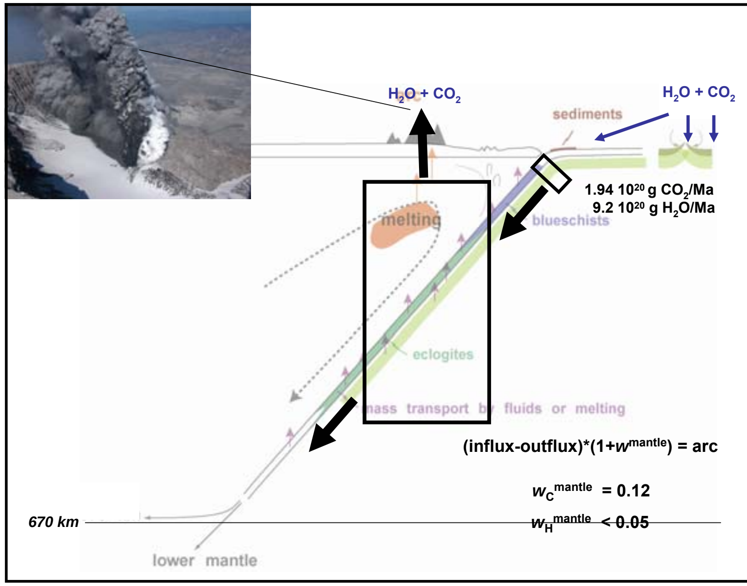
Some bits of mass balance related to UHP metamorphism in subduction zones



The deep, global, secular H_2O and CO_2 cycle

- H_2O
  - quantification
  - some principles *(you are spared the systematic approach)*
  - global deep mass balance

CO_2
  - fluid composition, subsolidus phase diagrams *(done)*
  - largely immobile *(done)*
  - global deep mass balance

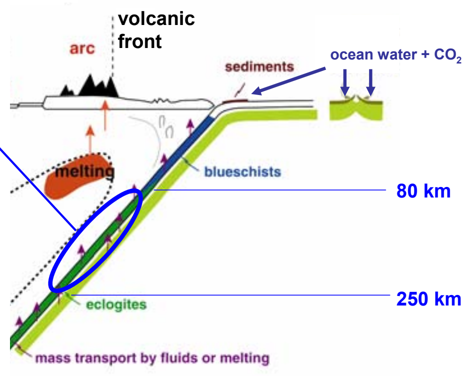
- quantification for subduction volcano output
- constrains on the H_2O and CO_2 cycles

Problem:

What transport capacities does the "mobile" phase have (e.g. how much Be is transferred under what conditions) ?

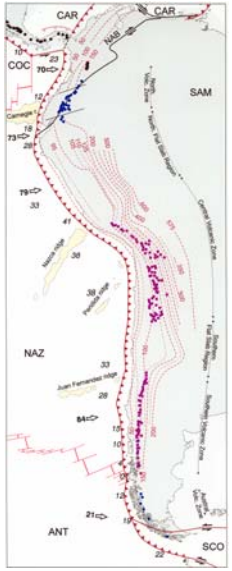
What do the observed trace Element (Be) concentrations in arcs allow to deduce about transfer conditions ?

→ Investigate experimentally element distribution minerals/mobile phase

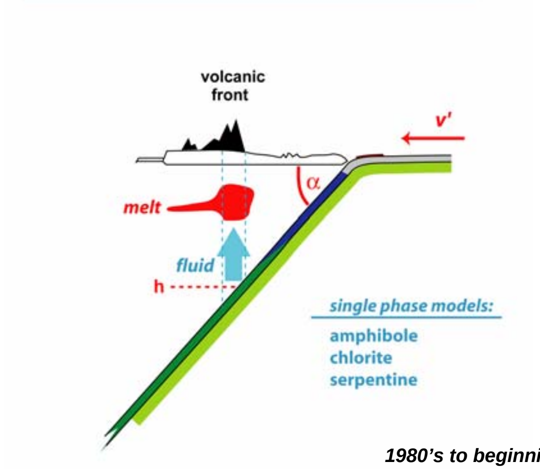


Plank and coworkers:
>50% Be are transfered to arc magmas, thus, slabs must melt,
thus temperatures of the subducted crust below the arcmust be >750 ºC

Why are volcanoes where they are ???

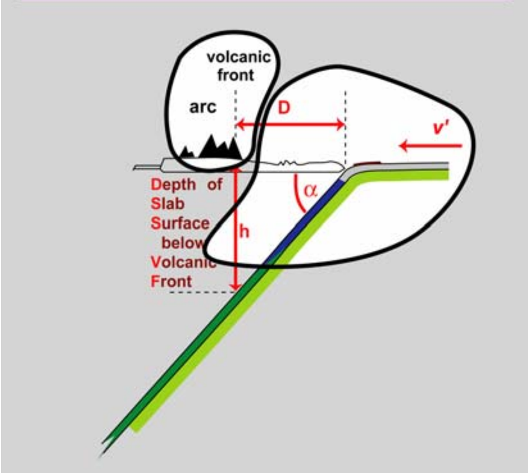


Pressure controlled single phase dehydration

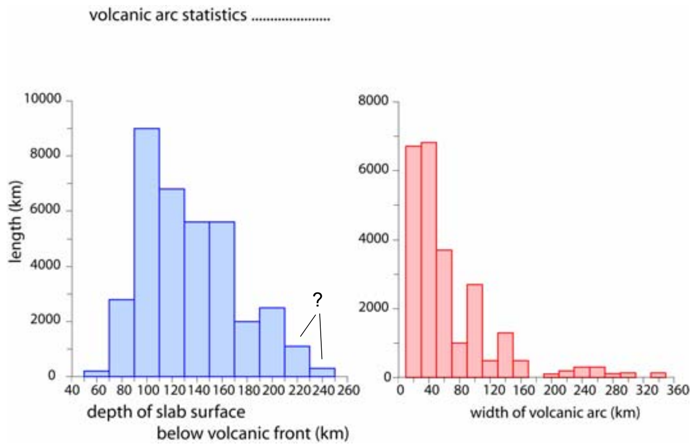


1980's to beginning 90's

Depth of slab surface below volcanic front (DSSVF)

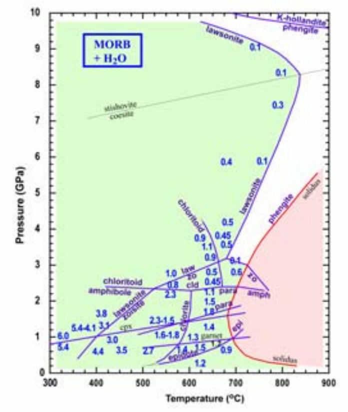


arc depth and width of all volcanic arcs

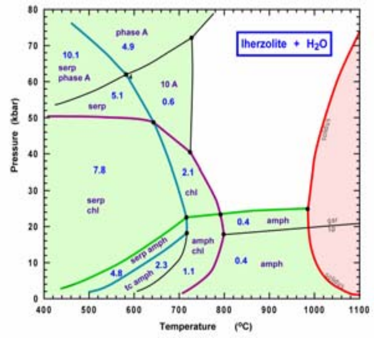


own compilation from 1999, unpublished

Hydrous phases in MORB and peridotite
and H_2O-contents stored in hydrous phases



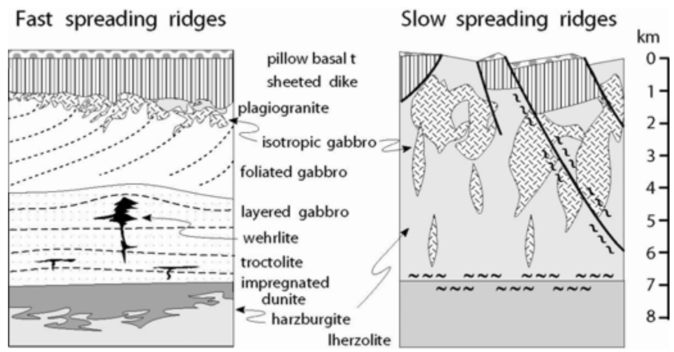
blue numbers are wt% H_2O stored in minerals

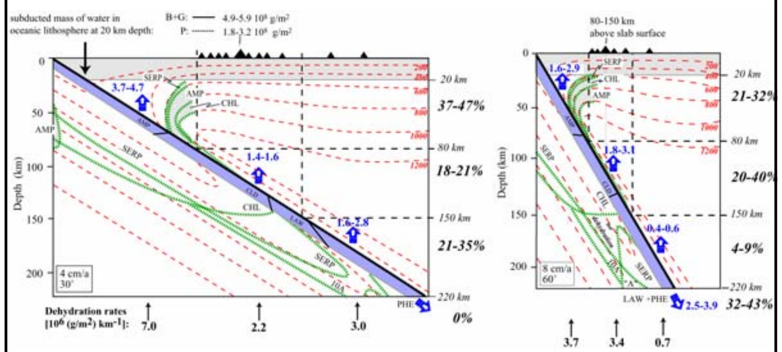


Schmidt+Poli 1998, modified after Fumagalli+Poli 2004

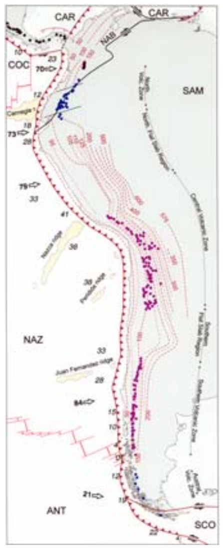
circumpacific:
> 80% present day subduction

atlantic:
- antilles
- south sandwich



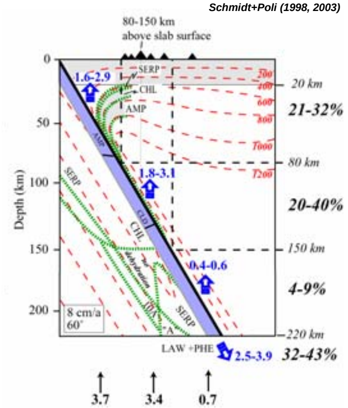


Schmidt+Poli 2003, Treatise of Geochemistry



own compilation, unpublished (forever)

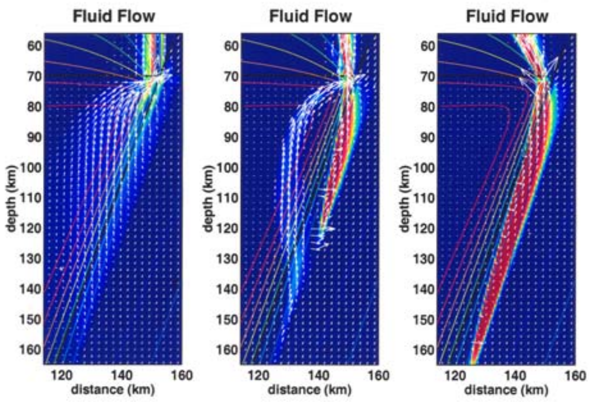
Schmidt+Poli (1998, 2003)



relatively cold subduction caused by:
- fast plate movement
- steep angle
- cold (old) oceanic lithosphere

~ 80% of modern subduction
(compiled as trench length)

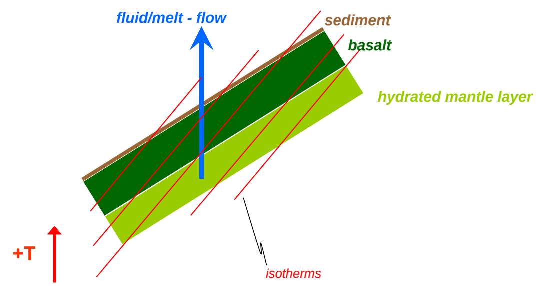
Coupled fluid/solid flow models



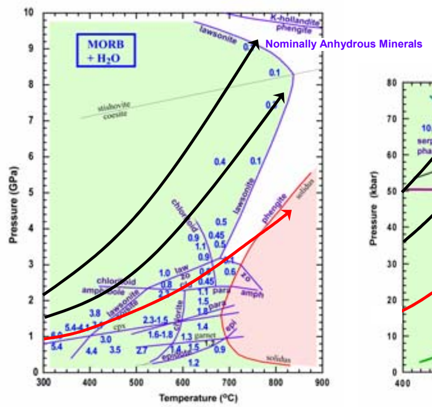
Spiegelmann et al.

Deep H_2O and CO_2 cycle: Major lithologies – coupled processes

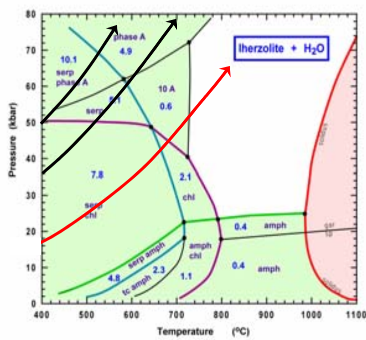
- H_2O-reservoirs are the ***basaltic oceanic crust*** and ***hydrated mantle layer***
- CO_2 reservoirs are ***sediments*** and ***basaltic oceanic crust***
- All in one stratigraphic column, not independent, H_2O-CO_2 in different minerals in the different lithologies, but in the same mobile phases (fluid, melt), temperature gradient is imposed



Hydrous phases in MOR basalt and mantle peridotite and H_2O-contents stored in hydrous phases



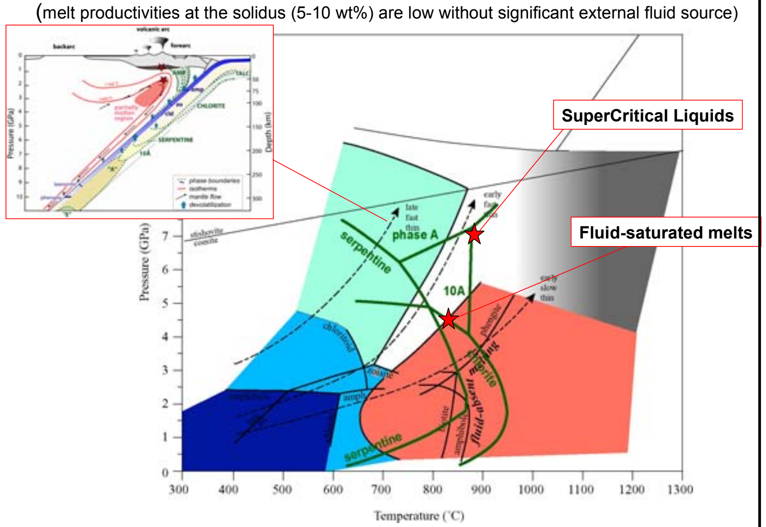
Schmidt + Poli 1998



Fumagalli and Poli 2004

mobilization regimes and flush melting

(melt productivities at the solidus (5-10 wt%) are low without significant external fluid source)



Intermediate Conclusions 1 – H_2O

H_2O

- **H_2O in *sediments* is negligable small → igneous crust and *hydrated mantle***
- **no argument for melting to be *necessary* in the subducting crust**

Two likely regimes

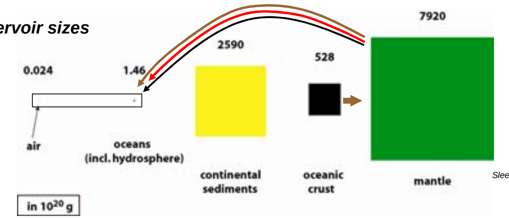
- **relatively cold subduction: 32-43 % of influx get subducted to >250 km depth**
- **relatively warm subduction: subducted lithospheric mantle gets hydrated and leads to flush melting of crust, no H_2O deeply subducted**

- **intermediate cases do almost not occur, because mantle dehydration and flush melting are coupled**

The deep **H**ydrogen and **C**arbon cycles

- Cycles: ***reservoir sizes***

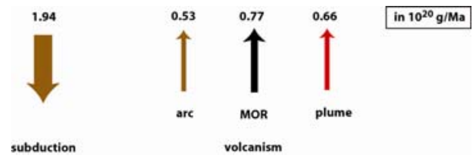
CO_2:



Sleep+Zahnle (2001)

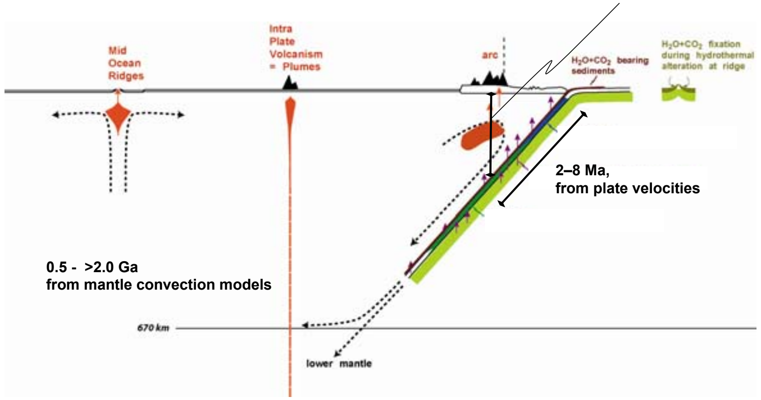
- ***and fluxes***
  - personal definition for "deep" → mantle
  - fluxes are from atmosphere+hydrosphere+crust to mantle: subduction
    mantle to atmosphere+hydrosphere+crust: volcanism

CO_2:



Sleep+Zahnle (2001), Marty+Tolstikhin (1998), own estimates

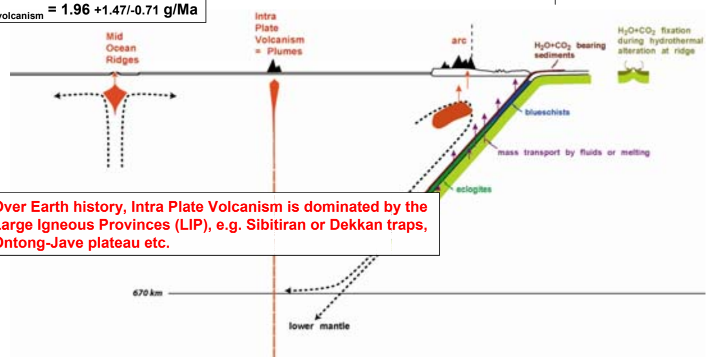
Time Scales of Reprocessing



How well do we know fluxes (CO_2) ?

reasonably well, from He/CO_2 ratios ± .33	*pretty bad, estimates from negligable to 1.5 ± .60*	*very biased, few data for many volcanos estimates are + 1.3 / - .18*	*reasonably well, from drill-holes in the oceanic crust ± .5*
0.77	**0.66**	**0.53**	**1.94 10^{20} g/Ma**

$\Sigma_{volcanism}$ = 1.96 +1.47/-0.71 g/Ma



Over Earth history, Intra Plate Volcanism is dominated by the Large Igneous Provinces (LIP), e.g. Sibitiran or Dekkan traps, Ontong-Jave plateau etc.

hydro+atmosphere reservoir: 1.46 10^{20} g, subduction flux → processing time for 1 ocean = 0.76 Ma

CO_2 –cycle during subduction

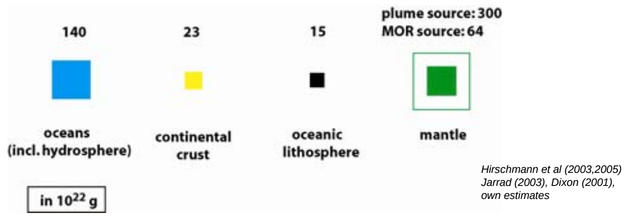
- **From phase petrology:**
  90-80% of carbonate survive subduction, dehydration, flush melting, and supercritical liquids, they are reintroduced into the deep mantle, unless temperatures of carbonate melting are reached (then, 0% survive).
- **From global tectonics/mass balance:**
  On modern Earth, only particular circumstances allow such temperatures (ridge subduction, edges of subducted plates), leading to <5% of the subducted crust reaching such temperatures

Thus:

SZ-Input flux:	**1.94 * 10^{20} g/Ma**
Loss from subducting crust: max.	**0.19-0.39 * 10^{20} g/Ma**
CO_2 addition from arc mantle melting = 12% of arc-CO_2	
Arc output:	**0.22-0.45 * 10^{20} g/Ma**

Agrees moderately well with global estimate of 0.53 *(+1.3/-0.18)* 10^{20} g/Ma derived from subduction zone volcano output

H_2O – reservoirs and subduction flux



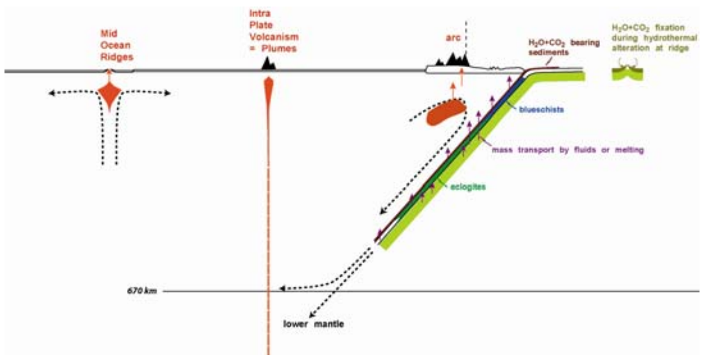
9.2 10^{20} g/Ma

Subduction flux:

Ocean processing time: 1.5 Ga

Hydrosphere CO_2 processing time: 0.76 Ma

CO_2 unbalanced:	**0.77**	**0.66**	**0.45**	**1.94 10^{20} g/Ma**
H_2O balance:	**1.62**	**0.66**	**6.9**	**9.2 10^{20} g/Ma**



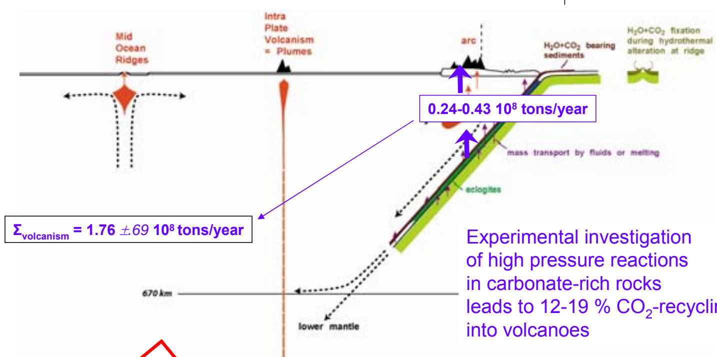
Deep global CO_2 cycle: arc flux from experimental petrology is more precise !

$\Sigma_{volcanism}$ = 1.96 *+1.47/-0.71* 10^8 tons/year

measured at the surface in a few volcanoes → global subduction estimate

INPUT

Estimates from volcanism: **0.77*±33*** **0.66*±60*** **0.53*+1.3-0.2*** **1.94*±.5* 10^8 tons/year**



$\Sigma_{volcanism}$ = 1.76 *±.69* 10^8 tons/year

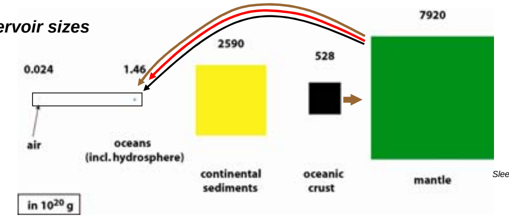
Experimental investigation of high pressure reactions in carbonate-rich rocks leads to 12-19 % CO_2-recycling into volcanoes

Carbonate cy[NO] unbalanced ? Subduction flux > volcanic flux ????

The deep **H**ydrogen and **C**arbon cycles

- Cycles: ***reservoir sizes***

CO_2:



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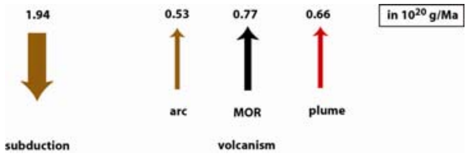
CO_2:



Sleep+Zahnle (2001), Marty+Tolstikhin (1998), own estimates

some conclusions

- There hasn't been a significant long term variation of ocean+hydrosphere mass during the phanerozoic, thus the surface H_2O mass is likely to be in secular equilibrium
- The H_2O recycling rate through subduction volcanoes (75-65 %) has to be complemented by ridge and plume volcanism, the higher recycling rate leads to reasonable concentrations in

  MORB (0.27 wt% H_2O, compare to 0.2-0.4 wt% from geochemistry) and plume basalts (1.1% H_2O, compare to 0.6-1.0 wt% from geochemistry)
- Whether surface+crust CO_2 is in secular equilibrium in the phanerozoic is yet unconstrained, in any case, CO_2 in the atmosphere, hydrosphere (and soils) is globally insignificant by mass and thus cannot be constrained by the fluxes between the large reservoirs.
- One could argue that continental carbonate build-up, produced by the biosphere, is almost completely phanerozoic, thus arguing for a volcanic output exceeding the subduction input.
- Whatsoever, >80% of the CO_2 input into subduction is recycled to the deep Earth.