What are thermohaline staircases?

Thermohaline staircases are stepped, stratified structures that may vary in thickness from centimeters to several meters. They occur where variations in vertical temperature and salinity gradients share the same sign, increase with depth and nearly compensate with density (Kelley, 1984).

The Tyrrhenian Sea

The Tyrrhenian Sea is a deep, closed basin in the larger Mediterranean Sea. It is located between the Apennine Peninsula and the islands of Corsica, Sardinia and Sicily. Three water masses are identified:

- 0-200 m: Modified Atlantic Water (MAW - water which originates at the Straits of Gibraltar);
- 200-700 m: Levantine Intermediate Water (LIW - originating in the Eastern Mediterranean);
- and from 700-seafloor: Tyrrhenian Deep Water (TDW; Astraldi and Gasparini, 1994).

The current definition of thermohaline staircases is based on the work of Fer et al. (2010). They occur where variations in vertical temperature and salinity gradients lead to the formation of thermohaline staircases in the center of the basin but the precise mechanisms are not well-known.

The Tyrrhenian Sea

MAW and LIW enter the Tyrrhenian Sea between Sardinia and Sicily and begin to circulate anti-cyclonically, bound by bathymetry at their respective depths.

There is some lateral exchange of water masses between the circumferential current of MAW and LIW into the deep water in the center of the basin but the precise mechanisms are not well-known.

Formation of staircases in the deep basin

The presence time of water on the deepest parts of the basin is quite high (approx. 30 years) compared to 2-3 years for the LIW (Zuddas and Gasparini, 1994). This dynamic stability provides favorable conditions for the formation of thermohaline staircases.

Their detection using seismic oceanography

Thermohaline staircases have been observed seismically before by Far et al. (2010), among others. In seismic data they appear as sub-horizontal stratigraphy, unlike their namesakes which come from their appearance on CTD profiles. The staircases in this study are rather weak on seismic data, having only small differences in salinity and/or temperature (large acoustic impedance contrasts), making their detection rather elusive.

A summary of this study

In this research we use a combination of dense seismic (MCS) reflection profiling alongside the deployment of an autonomous BathymThermograph (XBT) probes as well as the first use of an autonomous underwater glider in seismic oceanography. Careful seismic processing clearly shows thin, well-defined sub-horizontal reflectivity corresponding to staircase steps. XBT and glider data both correspond to regions of seismic reflectivity.

Oceanographic Setting

Multi-Channel Seismic (MCS)

Data were acquired in April and May, 2010 as part of the MEDOC (I) Seismic database seismic survey (Ranero et al., 2010).

MCS data acquisition is a two-step procedure: a source and a streamer is laid on cable (laid with hydrophones) to measure the intensity of reflections from both seismic horizons and the solid Earth.

Optical geometry information is applied to the seismic data using a back-projection algorithm.

- Attenuation of the direct wave (energy that travels directly from source to receiver after a reflection) is not important for the large wavelengths in these steep seismic contrasts.
- Some source harmonics are also present in the data but their effects are small.

- Data were filtered to control receiver noise using FFT derived sound speeds.

XBT deployment

XBT data were acquired in concert with seismic acquisition. Probes were launched from an XBT deployment and retrieved (see map for location). They measure in situ temperature as a function of depth.

- Data were acquired in April and May, 2010 as part of the MEDOC (I) Seismic database seismic survey (Ranero et al., 2010).

- XBT data were acquired in unison with seismic acquisition. Probes were launched from an XBT deployment and retrieved.

- Autonomous Underwater Glider

An autonomous glider was deployed between 2 April and 15 May, 2010 (see map for location).

- Data were acquired in April and May, 2010 as part of the MEDOC (I) Seismic database seismic survey (Ranero et al., 2010).

Acquisition

Multi-channel seismic acquisition

The streamer and the source.

Air bubble shortly follows

XBT Launch

Oceanographic Data

Glider salinity map overlaid on grayscale seismic reflectivity data. Seismic data clearly show thermohaline staircases as sub-horizontal reflectivity patterns.<br />

References


Ranero, C. and the MEDOC team (2010), El MEDiterráneo Occidental (MEDOC), The Western Mediterranean basins: A natural laboratory to study the processes of formation of rifted continental margins. Elsevier, 950 pages.

1) The seismic (acoustic reflectivity), XBT (temperature) and glider data (salinity) each clearly show the three main water masses.

2) The glider was only able to dive as far as the shallowest staircases, but data show a strong correlation with seismic reflectivity.

3) XBT data also show a strong correspondence with the boundaries of seismic reflectivity.

4) EF-1: Strong bowl-shaped reflectivity in LIW which seems to correspond to bathymetry. Temperature inversion in upper 300 meters.

5) EF-2: Weak, undulating staircases.

6) U1: Strong bowl-shaped reflectivity in LIW which seems to correspond to bathymetry. Temperature inversion in upper 450 meters.

7) U2: Strong undulating staircases.

8) GH-1: Strongest undulating staircases; staircases are ‘uplifted’ by seamount. Could this be evidence of buoyancy caused by increased seafloor heat flow?

9) GH-2: Dipping thermohaline filaments in LIW, possibly indicating the intrusion of LIW into centre of basin.