Seismic oceanography as a tool to monitor climate change

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1. Introduction

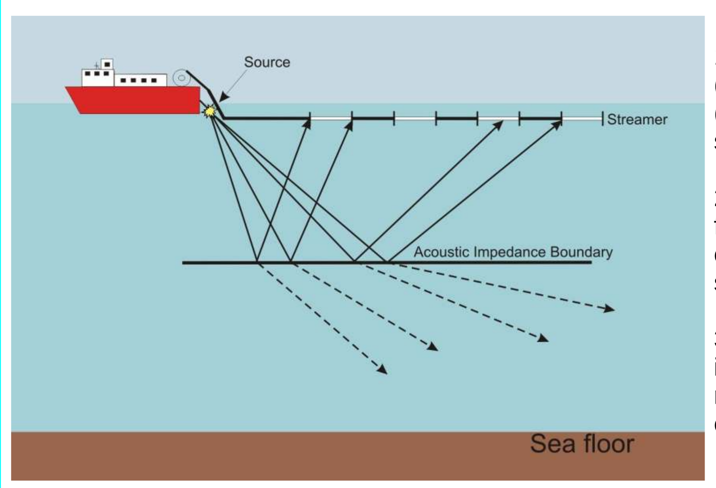
The danger of rapid climate change is real and serious. Humanity is challenged by this and its potential catastrophic outcomes because a rapidly changing climate will significantly modify the circumstances under which we inhabit the planet.

Since the ocean and atmosphere are coupled, ocean circulation plays a very important role. The ocean, though much less in volume than the atmosphere, carries an equivalent amount of heat due to its high heat capacity. Ocean circulation is driven mainly by the wind and secondarily by tidal forcing. The wind is driven by uneven solar heating of the Earth as it rotates between day and night. The wind in turn, along with density differences, drive ocean circulation.

While the basic mechanisms of ocean circulation are known, the details of how mixing of water masses and large-scale circulation occur and to what degree, could be further explored and better understood by analyzing the plethora of existing archived seismic data in conjunction with corresponding oceanographic data.

The combination of multi-channel seismics (MCS) and traditional oceanographic probes (normally XBTs and XCTDs) is Seismic Oceanography.

2. The multi-channel seismic reflection method



1) Towed impulsive source (air-gun) and streamer (cable filled with pressure sensing hydrophones).

2) Streamer records reflections from acoustic impedance contrasts (thermohaline stratification in the ocean).)

3) Redundancy of source incidents and multiplicity of receivers allow ‘stacking-out’ of noise.

4) Data are sorted by traces from a common midpoint (mid-way between source and receiver)

5) Data are corrected for normal offset (increasing time lag for more distant (offset) channels).

6) Various filtering and migration techniques to improve signal-to-noise ratio and interpreability of data.

7) Seismic data are acquired jointly with high-density of XBT (eXpendable BathyThermograph) coverage for independent verification.

3. Who says the ocean is a ‘nuisance’?

- The majority of marine seismic surveys depict the ocean as an inconvenient nuisance, blurring the imagery of the solid earth analgous to bad “seeing” to ground-based astronomy.
- The speed of sound only varies between about 1470 m/s and 1530 m/s in the ocean but remarkably, the seismic method is sensitive to these small changes, making detection of internal structures possible.
- An overabundance of marine seismic surveys exist having incidentally recorded the comparably faint reflections of oceanic structure.
- This thermohaline finestructure detectable on seismic records contains valuable information about the past, present and future state of the ocean, and by extension, the climate.

4. The discovery of seismic oceanography

- First known report of seismic reflections interior to the ocean were by Gonella and Michon [1988] and Phillips and Dean [1991].
- Holbrook et al. [2003] made the first detailed study of such thermohaline fine structure observed in seismic data.
- High international exposure to the physical oceanography community occurred in the intervening years lifting Seismic Oceanography to the level of a new and viable tool to study the oceans (see Buffett, 2011 for detailed bibliography).

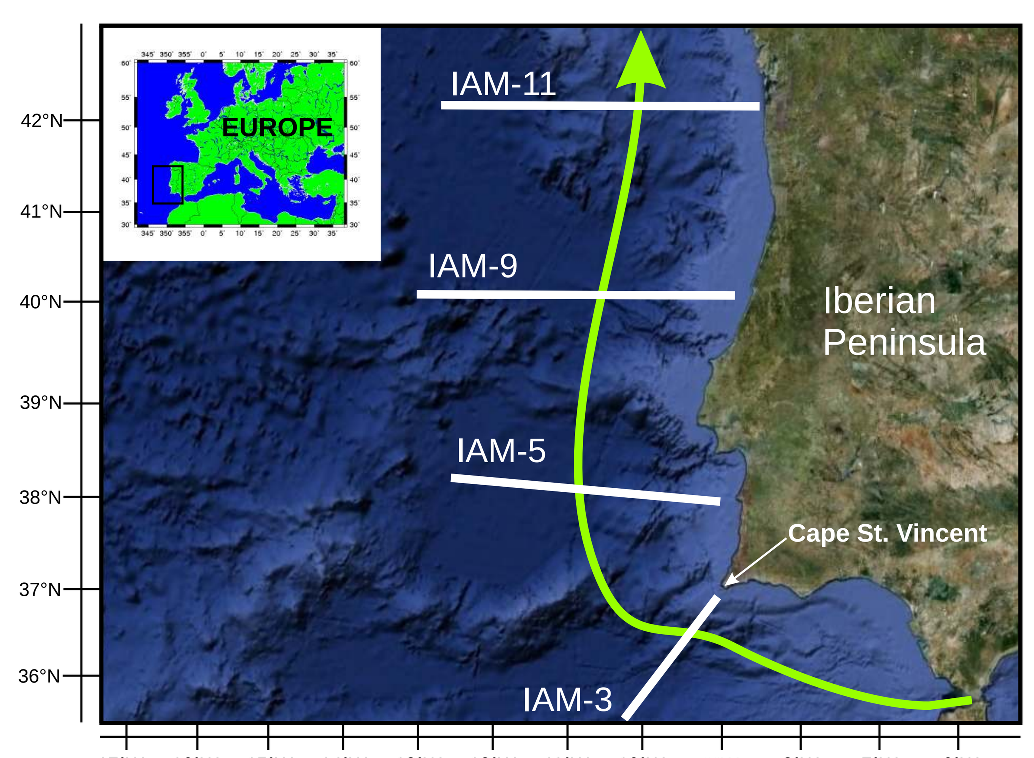
5. So, what is seismic oceanography anyway?

- It is in essence, a form of large-scale flow visualization, delineating oceanic finestructure with a horizontal resolution some 100 times higher than what is feasible with in situ probes.
- Where satellite data can show dynamics of the sea-surface, seismic oceanography can reveal dynamics to full ocean depths and horizontal scales on the order of hundreds of km.
- Recent and ongoing research is revealing more than just flow-visualization, but addressing dynamics, turbulent dissipation parameters, mixing, imaging tides and internal waves and interaction with topography.

6. Seismology as a tool to monitor climate change

- What were ocean currents like 10, 20, 30, 40 or 50 years ago?
- Have circulation patterns changed due to anthropogenic global warming ?
- What might future circulation patterns be?
- These questions and more can be addressed with seismic oceanography.
- Millions of km of seismic data of the ocean sits, collecting digital dust when it could be presenting Earth scientists with new ‘free’ data with incredibly valuable information about the past state of the oceans.
- Might the oil industry and academia alike be inclined to donate their ‘nuisance’ to seismic oceanographers?
- A suitable forum for the distribution and dissemination of this data would be online repositories such as: **The Virtual Seismic Atlas ((http://see-atlas.leeds.ac.uk:8080/home.jsp)**, which now hosts a special category for seismic oceanography data.
- Paradoxically, the tool that has arguably been the most effective in locating the oil that has contributed substantially to anthropogenic global warming may be used to learn about ocean circulation such that we can then mitigate it.

7. Some seismic profiles



Map showing regional location, position of seismic lines and approximate path of the Mediterranean Undercurrent emanating from the Strait of Gibraltar.

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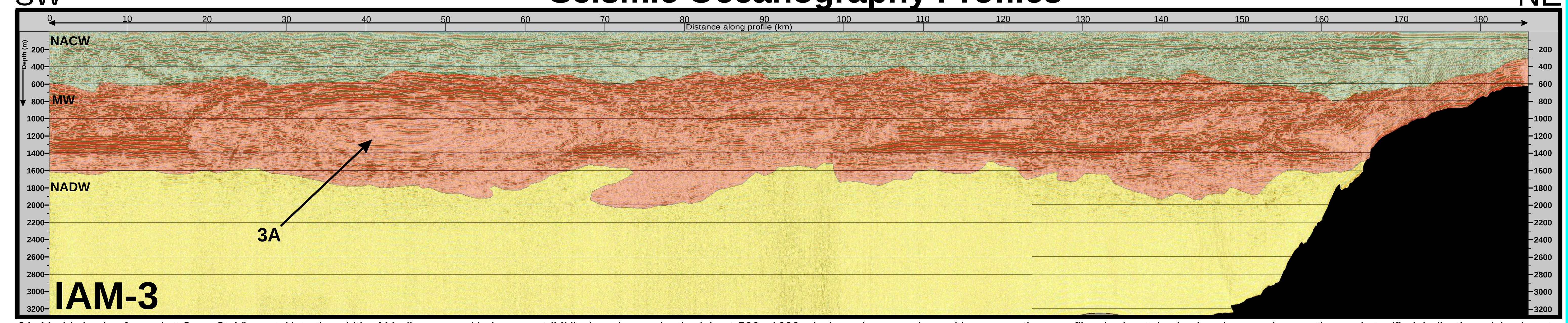
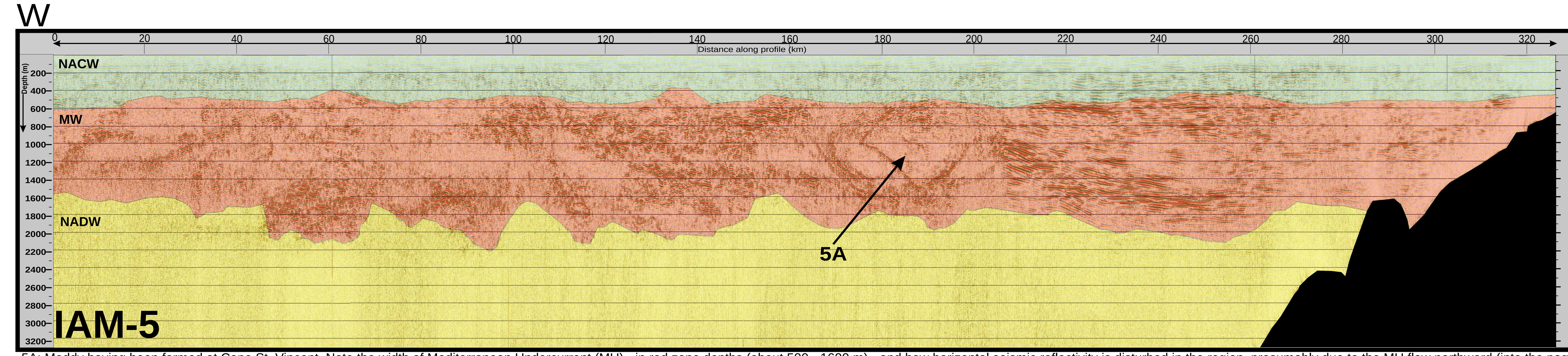
Seismic Oceanography Profiles

SW NE



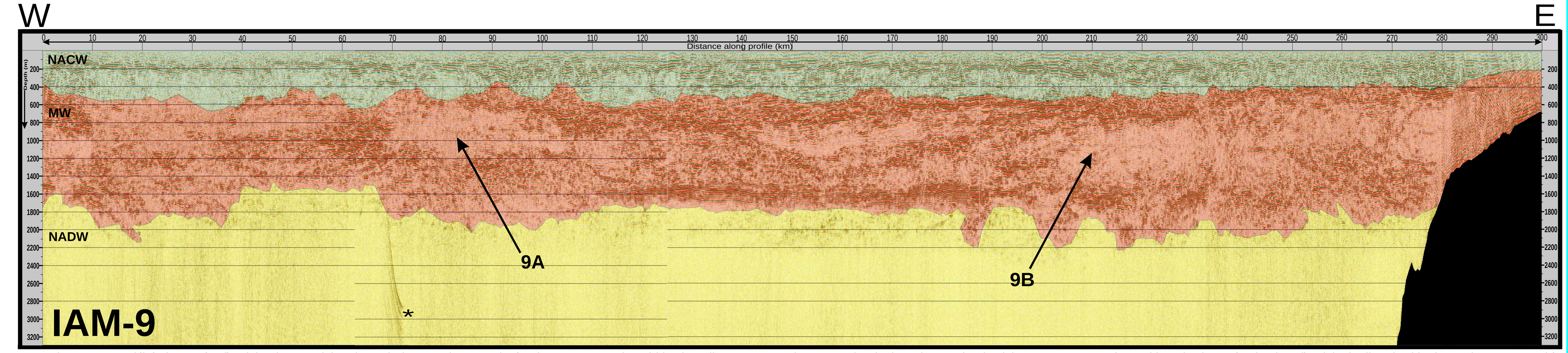
3A: Meddy having formed at Cape St. Vincent. Note the width of Mediterranean Undercurrent (MU) - in red zone depths (about 500 - 1600 m) - here, in comparison with more northern profiles, horizontal seismic coherency is smoother and stratified, indicating mixing is not thorough. Three water masses are labeled: NACW - North Atlantic Central Water (green); MW - Mediterranean Water (red); NADW - North Atlantic Deep Water (yellow).

W



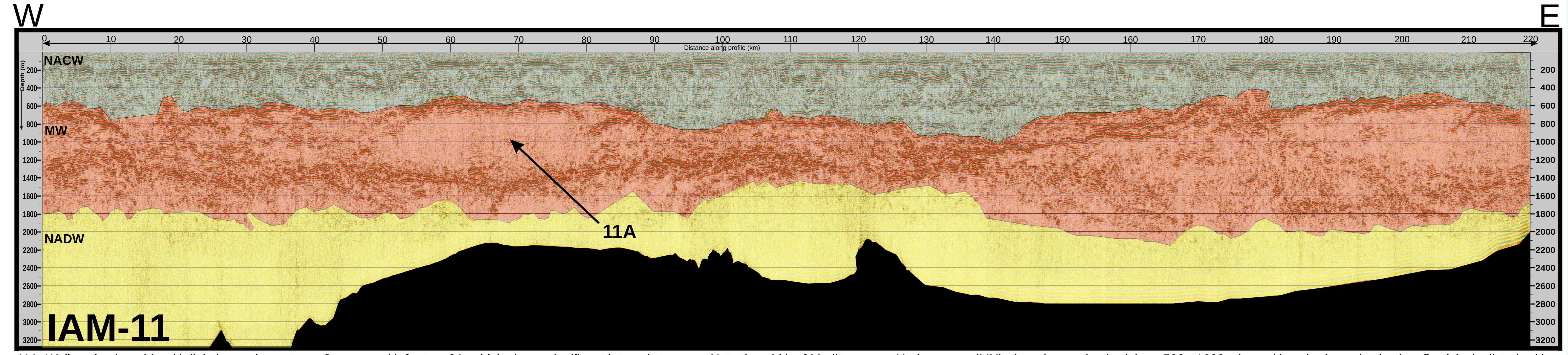
5A: Meddy having been formed at Cape St. Vincent. Note the width of Mediterranean Undercurrent (MU) - in red zone depths (about 500 - 1600 m) - and how horizontal seismic reflectivity is disturbed in the region, presumably due to the MU flow northward (into the page) resulting in increasing mixing. Three water masses are labeled: NACW - North Atlantic Central Water (green); MW - Mediterranean Water (red); NADW - North Atlantic Deep Water (yellow).

W E



9A and 9B: Zones of little internal reflectivity due to mixing through the entrainment of Atlantic water. Note the width of Mediterranean Undercurrent (MU) - in red zone depths (about 500 - 1600 m) - and how horizontal seismic reflectivity is disturbed in the region, presumably due to the MU flow northward (into the page) resulting in increased mixing. Three water masses are labeled: NACW - North Atlantic Central Water (green); MW - Mediterranean Water (red); NADW - North Atlantic Deep Water (yellow). * Seismic processing artifact

W E



11A: Well evolved meddy with little internal structure. Compare with feature 3A, which shows significant internal structure. Note the width of Mediterranean Undercurrent (MU) - in red zone depths (about 500 - 1600 m) - and how horizontal seismic reflectivity is disturbed in the region, presumably due to the MU flow northward (into the page) ergo increased mixing. Three water masses are labeled: NACW - North Atlantic Central Water (green); MW - Mediterranean Water (red); NADW - North Atlantic Deep Water (yellow).