Ecord Summer School 2013 - “Deep-Sea Sediment: From Stratigraphy to Age Models”

Karen Gariboldi’s Scientific Report

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1. AIM OF THE SUMMER SCHOOL AND PURPOSE OF THE VISIT

The aim of the 2013 Ecord Summer School was to make students conscious of the importance of stratigraphy in Earth Sciences. Indeed, stratigraphy represents the pre-requisite for correlation, which is the action of linking events registered in different sections on a local or regional scale. Therefore, stratigraphy is the discipline needed to interpret the succession of events in Earth History.

The most useful stratigraphic data used by the scientific community come from deep-sea sediments cores; that’s why, the school has offered not only lectures but also practical exercises, which aimed to make students confident with the methods adopted to analyse cores on research vessels. Those exercises have been conducted at the MARUM laboratories. Although the summer school was focused on sediments recovered by means of drilling, both the theory and practice learned at the summer school can be applied also on terrestrial outcrops.

I decided to take part to this summer school for two reasons:

- I wanted to increase my knowledge as a marine geologist (indeed, I got my master degree as a marine geologist at the University of Milano-Bicocca, Italy, in March 2012);
- I wanted to learn new methods and work strategies that I can potentially apply to my PhD thesis. Actually, I am working on a Peruvian Mio/Pliocene formation (Pisco Formation) and my first aim is to carry out a paleoecological reconstruction by means of fossil diatom association, but I would also like to correlate my data to some known reference cores.

2. SUM UP OF LECTURES AND PRACTICALS

Stratigraphy takes advantages of different objects that can be analysed. Therefore, it can be divided into many branches: biostratigraphy investigates the appearance and disappearence of taxa within the fossil record; magnetostratigraphy deals with the reversal of the Earth’s magnetic field; chemostratigraphy correlates the chemistry changes within the sediment record; tephrostratigraphy correlates ash layers originated by the same volcanic event; cyclostratigraphy identify Milankovitch’s cycles within a sedimentary sequence. Each of this branches has been fully analysed during the summer school throughout theoretical lectures. These lectures have been supported by exercises such as microscopy analyses and data analyses by means of specific softwares.

2.1.1 Biostratigraphy – Theory

Evolution is univocal, unidirectional and unrepeatable: this statement represents the basis on which biostratigraphy is founded. It merely means that evolution follows a unique path that leads to the appearance and disappearance of different taxa throughout the Earth history; once that a taxon becomes extinct, it cannot appear again.

Biostratigraphers identify “bioevents” such as FO (First Occurrence: the first evidence of the presence of a taxon in a given sedimentary sequence) or LO (Last Occurrence: the last evidence of the presence of a taxon in a given sedimentary sequence). Biostratigraphers establish biozones through the identification and combination of FO and LO of different taxa; biozones are the fundamental unit of biostratigraphy (taxon range zone, concurrent range zone, lowest occurrence zone, highest occurrence zone, partial range zone). Normally biozones have a range of few kyr, and are therefore very useful. Not all the fossils are useful biostratigraphic indicators. Good index fossil must: 1) have a short stratigraphic range; 2) be cosmopolitan in distribution; 3) have a distinct morphology; 4) be abundant.

Due to the characteristic of evolution (univocal, unidirectional and unrepeatable) biostratigraphy is often used in couple with other branches of stratigraphy in order to strictly tight events to time. Chemostratigaphy and magnetostratigraphy, for example, allow global correlations: isotopes variations in seawater and magnetic reversals of the Earth’s magnetic field are worldwide phenomena. Unfortunately, these events are not univocally recognisable: magnetic reversal occurred many time troughout the Earth history, and the ratio of a given isotope is not necessarily monotonic through time. On the other hand biozones are tightly related to the biogeographic distribution of fossils (there are different biostratigraphic schemes for the same period of time in different geographic regions), but every bioevent is univocally recognised. Therefore, coupling biostratigraphy with other stratigraphic tools represents the most effective way to apply stratigraphy to a sedimentary sequence.

Software such as Conop and Past were presented: these are useful tools to elaborate big sets of biostratigraphic data.

2.1.2 Magnetostratigraphy – Theory

Earth has its own magnetic field generated by motion of fluid in the outer core. The polarity of this field represent the direction of the field lines. When the field lines point northward the polarity is by convention normal; when the field lines point southward the polarity is reversed. Indeed, Earth's magnetic field polarity undergoes random reversals with a frequency of 2-3 myr. These reversals are recorded at the same time all over the world.

The total magnetic field vector describes the Earth's magnetic field and it is made of two components: declination (azimuthal angle between horizontal component of total magnetic field vector and geographic North) and inclination (vertical angle between horizontal component and total magnetic field vector). When the polarity is normal, inclination deeps downward (to the Earth's centre) in the northern hemisphere and upwards (to the sky) in the southern emisphere; when polarity is reversed, inclination is reversed too.

The inclination (and therefore polarity) of the magnetic field is recorded both by:

- grains in igneous rock when these are cooled;
- iron-bearing grains deposited in sediments.

Therefore, the polarity of magnetic field can be measured along a core or a section and magnetic reversal can be identified. Periods characterized by the same polarity are called *chrons*. Given that every magnetic reversal is identical to another (and that only the reversal boundary is recorded), a magnetostratigraphic division alone could not give any information on the age of the investigated sediment. Therefore, to construct a geomagnetic polarity time scale, polarity zones must be place aside a detailed biostratigraphic zones. Still magnetic correlation is the best method available for global correlation.

2.1.3 Chemostratigraphy - Theory

The isotope ratio of some elements varies in the atmosphere and in seawaters through time. These changes are due to processes such as climatic and volcanic ones; these processes influence the cycle of elements. Isotope ratios are recorded in marine sediments, ice caps etc., thus allowing the measurement of isotope ratios through time and the construction of reference curves. These curves are needed to apply chemostratigraphy.

The most important isotope ratios used for chemostratigraphy are:

- Strontium isotope ratios (^{87}Sr/^{86}Sr);
- Oxygen isotope ratios (^{18}O/^{16}O);
- Carbon isotope ratios (^{13}C/^{12}C).

2.1.3.1 Chemostratigraphy – Theory – Strontium Isotope Stratigraphy

Residence time of Strontium in sea water is ~10^6 years, while the oceanic mixing time is ~10^3 years. This observation implies that the ^{87}Sr/^{86}Sr in seawaters is identical in all oceans at a given time; furthermore this ratio is not constant through time, but varies due to mechanism such as weathering of old continental crust and hydrothermal activity. Marine organisms incorporate Sr in their skeleton without fractionation (that is to say, they do not incorporate more easily ^{87}Sr rather than ^{86}Sr in their skeleton or viceversa), therefore the ratio in their skeleton reflect the ^{87}Sr/^{86}Sr in seawater where they lived.

Isotope curves alone do not give information on the absolute age of the investigated sediment, therefore they must be always supported by radiomentric ages. However, calibrated lookup tables have been published for the ^{87}Sr/^{86}Sr ratio (Howarth and McArthur, 1997), thus simplifying the application of strontium isotope stratigraphy.

Strontium chemostratigraphy is particularly well-applicable to marine successions (both carbonate platform and deep-oceanic succession) from the Jurassic to the Neogene.

2.1.3.2 Chemostratigraphy – Theory – Oxygen Isotope Stratigraphy

The principle on which oxygen isotope stratigraphy is based is quite simple: oxygen has three isotopes ^{16}O, ^{17}O and ^{18}O; ^{17}O represent only the 0,04% of the total oxygen on Earth, while ^{16}O and ^{18}O are present with a percentage of 99,76% and 0,2% respectively. When water evaporates from the ocean at low latitudes, vapour is depleted in ^{18}O: this isotope is heavier than ^{16}O. Therefore clouds are enriched with ^{16}O. Clouds move towards higher latitudes and at mid latitudes heavy water (enriched in ^{18}O) condenses; therefore clouds reach high latitudes increasingly depleted in ^{18}O. Precipitation at high latitudes are enriched in ^{16}O and during glacial periods ^{16}O is entrapped in ice caps, resulting in a depletion of ^{16}O in the oceans. On the other hand, during interglacial periods, ice caps melt and ^{16}O is rapidly redistributed to oceans.

This is basis that stands behind the possibility of measure oxygen isotopic ratio δ^{18}O in oceanic benthic organisms (such as foraminifera) to identify glacial and interglacial stages along a sedimentary sequence:

$$\delta^{18}\mathrm{O}\ (‰)=1000\ ((^{18}\mathrm{O}/^{16}\mathrm{O})_{\mathrm{sample}}/(^{18}\mathrm{O}/^{16}\mathrm{O})_{\mathrm{standard}} - 1);$$

the standard to which this equation refers is known as VSMOW (Vienna Standard Mean Ocean Water).

This method is one of the most important in paleoceanography and it is most applied to upper Pleistocene sediments to identified glacial/interglacial cycles (SPECMAC stack), but it has been successfully applied to sediments as old as 5.5my (LR04 benthic δ18O stack). Morover, Marine Isotopic Stages (MIS) highlighted by this method match to Milankovitch cycles of orbital forcing, therefore allowing an integrate stratigraphy between chemostratigraphy and cyclostratigraphy.

Unlikely what happens for Sr, oxygen fractionation is a phenomenon that is observed and must be taken into account. Indeed, the uptake of oxygen by marine organisms from sea-waters is influenced by some factors such as water temperature. Therefore, Epstein et al. (1953) developed an equation to calculate water paleotemperature:

$$T(°C) = 16.5 - 4.3\ (\delta^{18}O_{CaCO3} - \delta^{18}O_{w\text{-}AMW}) + 0.14\ (\delta^{18}O_{CaCO3} - \delta^{18}O_{w\text{-}AMW})^2$$

where
$\delta^{18}O_{CaCO3}$ = δ^{18}O of calcium carbonate relative to VPDB (VPDB = Vienna Pee Dee Belemnite, reference for ^{13}C/^{12}C but also for ^{18}O/^{16}O)
and
$\delta^{18}O_{w\text{-}AMW}$ = δ^{18}O of the ambient water (AMW = VSMOW - 0.27‰).

2.1.3.3 Chemostratigraphy – Theory – Carbon Isotope Stratigraphy

Carbon has three main isotopes: ^{12}C (98,9%), ^{13}C (1,1%) and ^{14}C, which is radioactive and has a half-life of 5730 ± 40 yrs.

The main reservoirs of carbon on Earth are atmosphere and oceans; the global carbon cycle influences the ratio of $^{13}C/^{12}C$ in those two reservoir. In general, oceans uptake ^{13}C rather than ^{12}C, which is kept in atmosphere as CO_2. The variations of $^{13}C/^{12}C$ ratio in seawater is reflected in the carbonate shells of foraminifera and can be measured.

These values are useful to reconstruct Earth's climatic changes: a decrease in $\delta^{13}C$ (a shift towards negative values) is a synonym of an increase of CO_2 in the ocean, reflecting an increase of CO_2 in the atmosphere. Normally this mean an increase in global temperature, because CO_2 is one of the main green-house gases. The increase of CO_2 in the ocean is detectable not only thanks to the negative shift of $\delta^{13}C$, but also because of the dissolution of carbonates: indeed, an increase of CO_2 in the oceans results in their acidification. Therefore, Carbon Isotope Stratigraphy can be used to correlate different events in the Earth's history and can help reconstruct major climatic changes. Indeed, Carbon Isotope Stratigraphy has been useful to recognise and correlate events such OAEs, revealing its importance for applications in the Jurassic and Cretaceous.

Moreover, carbon variations have been recently related to astronomical cycles, suggesting that a integrated stratigraphy between carbon cycles and astronomical forcing may be developed.

2.1.4 Cyclostratigraphy – Theory

Earth's orbital variations are known as Milankovitch's cycles. These variations affect the amount, distribution and timing of solar radiation that reaches the Earth, therefore affecting its fragile climatic system.

The most important Earth's orbital elements are precession (change in the orientation of the Earth's rotational axis), obliquity (angle between Earth's axis and Earth's orbital plane) and eccentricity (how close to the shape of an ellipse/how far to the shape of a circle is the Earth's orbital plane): these have cycles of 19, 22 and 24kyrs (precession) and 41kyrs with additional periods of 54kyrs and 29kyrs (obliquity); eccentricity cycles can be divided into long eccentricity cycle, with a period of 400kyrs and short eccentricity cycles with periods of approximately 96 and 127kyrs. The reason why orbital variations have different cycles is that they are influenced by the gravitational interactions between the sun, planets and satellites of the Solar System.

As orbital variations affect the amount of timing and distribution of solar radiation, these cycles can be registered in the sediment record as climatic changes. The imprint of these variations on the sediment record can be recognised with the help of spectral analysis, a method that allows to identify any periodicity in a random signal from a sequence of time samples of the signal itself. Spectral analysis does this by observing peaks at the frequencies corresponding to these periodicities (http://en.wikipedia.org/wiki/Spectral_estimation). Therefore, the signal left in the sediments by orbital variations must be analysed by means of computers in order to be recognised.

Although the response of the climate system to the orbital variation is non-linear (it is influenced also by other environmental factors), trying to improve the identification of the influence of Earth's orbital variations in the sediment record is really worth it. Indeed, once these signal have been identified, they can be used to date past geologic events: this is the base of cyclostratigraphy. Compare to others, the advantage of this method is that, if anchored to the present, it can give absolute ages of geological events. Absolute ages can be obtained also by radiometric dating, but astronomic dating has higher levels of confidence in the Neogene compared to absolute dating. Therefore cyclostratigraphy can be used to improve and calibrate radiometric standards.

Lectures on cyclostratigraphy have been supported by some practical exercises: we have been introduced to “Astro”, a package of the “R” software. “R” has been developed to run common statistical analyses on every kind of data and “Astro” is an additional package that allows to easily run spectral analysis on data.

2.2 Practical – Virtual Ship

Practical activities (“Virtual Ship”) were introduce by talks, during which the theoretical basis of the activity itself were explained.

We have had the chance to follow step by step the analyses of different core sections: first we have described them, identifying different beds within it, describing sediment structures within beds (lamination, water escape structure etc.), lithologies (mud, sand etc.), colours (by means of the Munsell colour chart), bioturbations (slight, heavy etc.), types of boundaries between different beds (sharp, gradational etc.) etc. Some smear slides were prepared in order to evaluate the abundance of the microfossilifeorous content versus the continental component.

Subsequently, we learned how to extract pore waters by mean of rhizon soil moisture samplers: we ran both an analysis to calculate the alkalinity of the pore water and an analysis to estimate the NH_4 content. NH_4 in pore water (measured in mM) has a characteristic increasing trend from the top to the bottom of the core; therefore the NH_4 content can be used to verify the accuracy of the composite depth scale (see later).

We have also measured physical properties of core sections such as magnetic susceptibility and acoustic properties of the sediments by means of a Multi Sensor Core Logger (MSCL). Acoustic properties were used to classify the sediment itself: different acoustic properties correspond to different porosities; different porosities correspond to different sediments. Magnetic susceptibility was used during the core splicing section to construct a composite depth scale from data obtain from three different core drilled at the same site. Such physical properties can be measure also downhole by means of measuring instruments connected to a wireline; these measurements are useful when the core recovery is low. To complete the non-distructive analyses on the core, we also ran a XRF analysis on the archive-half of to obtain the record of element intensities along the section.

During the biostratigraphic sessions three main micropaleontological group were investigated: diatom, calcareous nannofossils and radiolarians. During the I Biostratigraphy laboratory session we learned to describe the morphologies of Cenozoic diatoms and coccoliths. During the II Biostratigraphy session, we simulated the work of a biostratigrapher on a research vessel: our task was to monitor a drilling through Cenozoic pelagic sediments by means of radiolarian associations and to indicate when the target depth was reached. Our main responsibility was to decide when to stop drilling.

3. TAKEN HOME POINTS

During the summer I learned many different stratigraphic techniques that I did not know before. All the lectures and the work done during the “Virtual ship” have made me more conscious of the meaning of the data that are normally presented in the reports of scientific drilling cruises. Therefore, when I will try to compare and correlate my data to those available in literature, I will be more aware of what I should look at and why.

As a student of paleoecology working mostly on diatom assemblages, the most important thing for me was the chance to compare my approach to that of a biostratigrapher. Indeed, I understood how the two approaches differ: while the paleoecologist need to identify most of the species within a microscope slide and to quantify the abundance of every single species (in order to do a paleoecological reconstruction), the biostratigrapher just need to identify a few marker species, no matter if the others remain unidentified. The two approaches differ also in terms of time: due to the rapid need of stratigraphic information during a drilling, preliminary biostratigraphic investigation (i.e., that needed on a research vessel) must require just a few minutes for each sample. On the contrary a paleoecological study is a little bit more time-spending, due to the need to count a statistically significant number of specimen.

Leaving aside what was more important to me, the clue point of the lectures was not focused to one specific branch of stratigraphy, rather on how these branches can be related together to construct an “integrated stratigraphy”. Integrated stratigraphy is the first step that leads to an “age model”. Through both the lectures and the laboratories, we have been taught how to pursue this objective. This was the most important goal of the summer school.

4. TRAVEL TICKETS

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Operato da:	K L M	**Aircraft type:**	B 737 800
Classe:	Economy	**Pasto/i servito/i a bordo :**	Snack
Classe di reserva:	R	**bagagli autorizzati:**	1 bagagli
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Domenica 8 Settembre 2013
16:40 Amsterdam (Schiphol (AMS)) - 17:30Brema (Brema (BRE))

Numero di volo:	KL1757	**Durata del volo:**	00h50
Operato da:	K L M	**Aircraft type:**	FOKKER70
Classe:	Economy	**Pasto/i servito/i a bordo :**	Snack
Classe di reserva:	R	**bagagli autorizzati:**	1 bagagli
Scalo/i:	senza scalo	**Terminal:**	

Il suo volo

Domenica 22 Settembre 2013
15:15 Brema (Brema (BRE)) - 16:45Parigi (Paris Charles de Gaulle (CDG))

Numero di volo:	AF1425	**Durata del volo:**	01h30
Operato da:	Air France	**Aircraft type:**	Embraer 145
Classe:	Economy	**Pasto/i servito/i a bordo :**	Nessun pasto servito a bordo

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Domenica 22 Settembre 2013
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Numero di volo:	AF1312	**Durata del volo:**	01h30
Operato da:	Air France	**Aircraft type:**	Airbus A320
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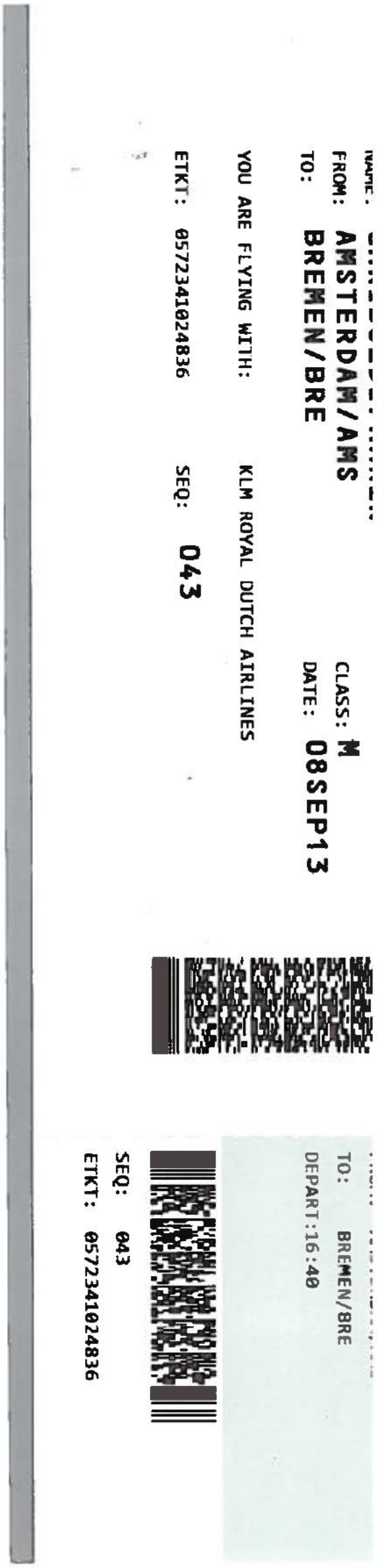

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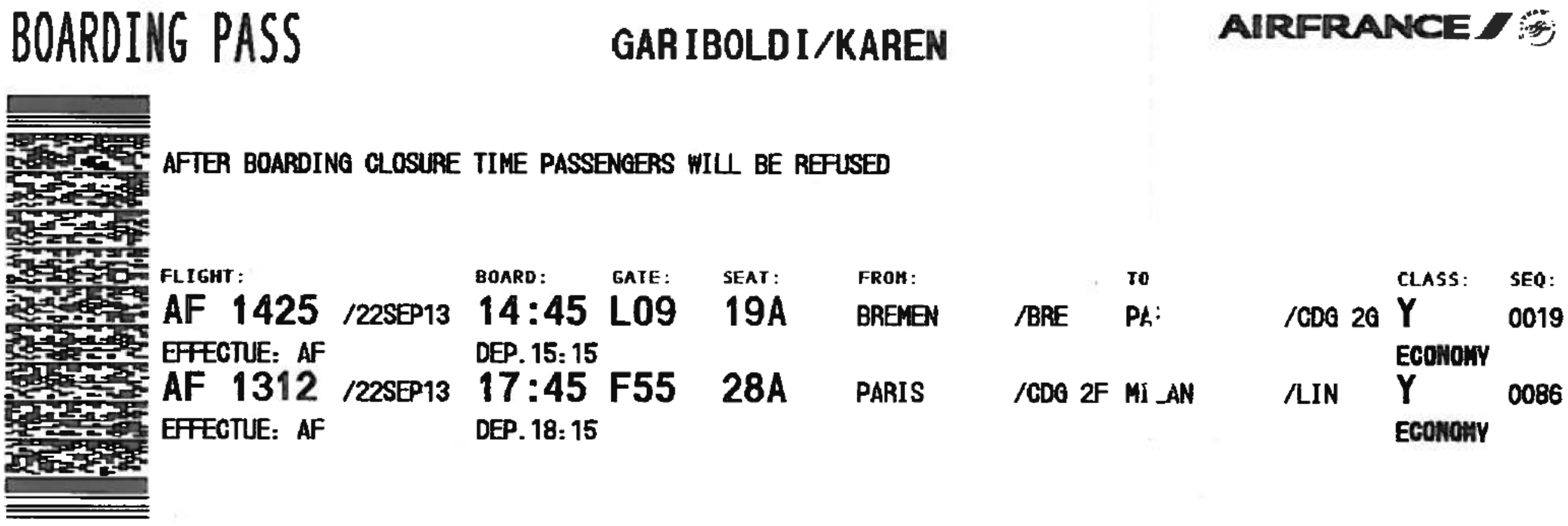

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