Foreword

Over the last century, Earth sciences have evolved from disciplines mostly based on naked eye observations of rocks and sediments to a scientific field employing the most sophisticated tools developed in analytical physics and chemistry. The introduction of quantitative instrumentation has thus played a major role in enabling advances in our knowledge of Earth history and processes. Because geological archives are so unique and complex, the geoanalytical refinements have often been pushed to their ultimate limits of resolution, precision and detection limits in order to extract crucial information from objects found in nature.

High-resolution core scanners incorporating X-ray fluorescence (XRF) spectrometry are arguably one of the most useful tools that have become available to the research community. Their impact is based on their ability to rapidly, non-destructively and automatically scan sediment cores. Not only do they rapidly provide important proxy data without damaging samples, but they can obtain environmental data at decadal, annual and even sub-annual scales. Micro-XRF core scanners can indeed be used at the limit of the inherent heterogeneity of sediments linked to the presence of grains of different nature, chemical composition and mineralogy. In addition to producing geochemical profiles along the core length, these scanners also allow study of spatial heterogeneities within the sediment through optical images, X-radiography or micro-XRF 2D images of elemental composition.

In a little over a decade, micro-XRF core scanners have made a substantive contribution to paleoenvironmental research as evidenced by the exponential rise in the peer-reviewed scientific literature. For the field of paleoclimatology, the use of sediment cores from lakes and oceans had always been limited by the resolution of discrete sampling, but the introduction of XRF-scanners truly revolutionized the field allowing the study of similar details in sediments as in polar ice cores from Greenland and Antarctica. The versatility of XRF-scanners allows their application to other types of paleoclimate archives from diverse locations such as massive corals from tropical reefs, speleothems from caves and subfossil woods.

The key initial strength of XRF core scanners was their ability to scan a meter of sediment core at high resolution in about 24 hours. Ongoing instrumental developments are already leading to further enhancements in sensitivity and speed and throughput. High-resolution XRF core scanners produce a high data output, with potentially several thousand spectra acquired per meter of core.

The increasing speed of analyses has allowed researchers to dare tackling projects based on large amounts of cored material, the XRF-scanner being often the first analytical tool used after opening and splitting the cores. The resulting elemental profiles, derived from the non-destructive analysis of cores and often involving several thousand XRF spectra, are thus used for reconnaissance studies and basic stratigraphic correlations. XRF core scanners can also be used for insightful geochemical studies, provided that proper calibration is performed by means of discrete geochemical measurements with accurate techniques such as conventional XRF or ICP. Whereas with these conventional techniques, data are acquired from dry homogenized fine-grained samples, wet natural sediment cores measured with scanners present very different sample conditions. Grain-size and water content variations, core surface imperfections, presence of organic matter and water pooling on the sample surface will all impact on data quality. Hence interpretation of core scanner data is not trivial and guidance is often needed to discriminate environmentally meaningful information from data artifacts.

As outlined above, the use of XRF core scanners is characterized by an inherent simplicity in acquiring useful elemental profiles, but making the best out of these sophisticated tools also requires experience and a deep knowledge in geochemistry and physical properties of sediments. XRF-scanner facilities are now used in about one hundred institutions spread throughout Europe, North America and Asia. This gave rise to a specific community of users with diverse technical expertise and scientific expectations.

As an illustration, I will say a few words about the specific example of the XRF-scanner installed in 2008 at CEREGE in Aix-en-Provence. We became interested in such analyses in the mid-2000s because of our tradition of working on deep-sea sediments, notably the basic quantification of major phases such as carbonates, detrital minerals and organic matter, but also several detailed studies of trace elements scavenged in the water column or trapped in the sediments because of specific redox conditions. These variables were quantified with various techniques of organic and inorganic geochemistry on discrete samples. Since then, micro-XRF scanner profiles have allowed us to better understand the relationships between these various profiles and integrate them into a coherent and high-resolution framework. This truly brought a new dimension to our research in paleoceanography.

The other main consequence of our XRF-scanner acquisition was that it fostered collaboration with specialists of other sedimentary archives, notably those taken from modern and ancient lakes. Our experience is obviously not unique and it can be stated with confidence that the rise of XRF core scanning contributed to bridging the gaps between scientific communities, which were working in parallel.

Scientists of this new community often have similar needs and expectations. By considering ratios of XRF profiles it has been possible to develop proxies for particle sizes, mineralogical composition and organic matter content of sediments. Hopefully, more direct evaluation of these parameters may come from future innovations in analytical core scanning based on other electromagnetic emissions and detecting systems.

This volume edited by Ian Croudace and Guy Rothwell, two pioneers and prominent contributors in the field, presents a broad ranging view of instrument capability and points to future developments that will combine higher precision elemental data coupled with faster core analysis. It also presents specific application papers reporting on the use of XRF core scanners in a variety of marine, lacustrine and pollution studies, together with papers examining practical aspects of core scanner usage and data calibration and interpretation. It is a welcome addition to the literature and the first volume of its kind to focus specifically on this important technology. Given the importance of XRF core scanning in modern paleoenvironmental research, this is a timely publication which environmental investigators will find useful. It contains essential reading for both experienced and new researchers using XRF core scanners.

Specific Publications from CEREGE that used XRF core scanning (by date)

Gasse F, Vidal L, Van Campo E, Demory F, Develle AL, Tachikawa K, Elias A, Bard E, Garcia M, Sonzogni C, Thouveny N. (2015) Hydroclimatic changes in northern Levant over the past 400,000 years. *Quaternary Science Reviews* 111, 1–8

Tachikawa K, Vidal L, Cornuault M, Garcia M, Pothin A, Sonzogni C, Bard E, Menot G, Revel M (2015) Eastern Mediterranean Sea circulation inferred from the conditions of S1 sapropel Deposition. *Climate of the Past* 11, 855–867

Cartapanis O, Tachikawa K, Romero OE, Bard E (2014) Persistent millennial-scale link between Greenland climate and northern Pacific Oxygen Minimum Zone under interglacial conditions. *Climate of the Past* 10, 405–418

Brisset E, Miramont C, Guiter F, Anthony EJ, Tachikawa K, Poulenard J, Arnaud F, Delhon C, Meunier J-D, Bard E, Suméra F (2013) Non-reversible geosystem destabilisation at 4200 cal. BP: Sedimentological, geochemical and botanical markers of soil erosion recorded in a Mediterranean alpine lake. *The Holocene* 23, 1863–1874

Simonneau A, Chapron E, Courp T, Tachikawa K, Le Roux G, Baron S, Galop D, Garcia M, Di Giovanni C, Motellica-Heino M, Mazier F, Foucher A, Houet T, Desmet M, Bard E (2013). Recent climatic and anthropogenic imprints on lacustrine systems in the Pyrenean Mountains inferred from minerogenic and organic clastic supply (Vicdessos valley, Pyrenees, France). *The Holocene* 23, 1764–1777

Jenny JP, Arnaud F, Dorioz JM, Giguet Covex C, Frossard V, Sabatier P, Millet L, Reyss JL, Tachikawa K, Bard E, Pignol C, P, Soufi F, Romeyer O, Perga ME (2013) A spatiotemporal sediment investigation highlights the dynamics of hypolimnetic hypoxia in a large hard-water lake over the last 150 years. *Limnology & Oceanography* 58, 1395–1408

Soulet G, Ménot G, Bayon G, Rostek F, Ponzevera, Toucanne S, Lericolais G, Bard E (2013) Abrupt drainage cycles of the Fennoscandian Ice Sheet. *Proceedings of the National Academy of Science* 110 (17), 6682–6687

Doyen E, Vannière B, Berger JF, Arnaud F, Tachikawa K, Bard E (2013) Land-use changes and environmental dynamics in the upper Rhone valley since Neolithic times inferred from sediments in Lac Moras. *The Holocene* 23, 961–973

Wilhelm B, Arnaud F, Sabatier P, Magand O, Chapron E, Courp T, Tachikawa K, Fanget B, Malet E, Pignol C, Bard E, Delannoy J-J. (2013) Paleoflood activity and climate change over the last 1400 years recorded by lake sediments in the North-West European Alps. *Journal of Quaternary Science* 28, 189–199

Simonneau A, Doyen E, Chapron E, Millet L, Vannière B, Di Giovanni C, Bossard N, Tachikawa K, Bard E, Albéric P, Desmet M, Roux G, Lajeunesse P, Berger J-F, Arnaud F (2013) Holocene land-use evolution and associated soil erosion in the French Prealps inferred from Lake Paladru sediments and archaeological evidences. *Journal of Archaeological Science* 40, 1636–1645

Cartapanis O, Tachikawa K, Bard E (2012) Latitudinal variations in intermediate depth ventilation and biological production over northeastern Pacific Oxygen Minimum Zones during the last glacial period. *Quaternary Science Reviews* 53, 24–38

Wilhelm B, Arnaud F, Sabatier P, Crouzet C, Brisset E, Chaumillon E, Disnar JR, Guiter F, Malet E, Reyss JL, Tachikawa K, Bard E, Delannoy J-J (2012) 1400yr of extreme precipitation patterns over the Mediterranean French Alps and possible forcing mechanisms. *Quaternary Research* 78, 1–12

Tachikawa K, Cartapanis O, Vidal L, Beaufort L, Bard E (2011) The precession phase of hydrological variability in the Western Pacific Warm Pool during the past 400 ka. *Quaternary Science Reviews* 30, 3716–3727

Cartapanis O, Tachikawa K, Bard E (2011) North-Eastern Pacific oxygen minimum zone variability over the past 70 kyr: Impact of primary production and oceanic circulation. *Paleoceanography* 26, PA4208, 1–17

Soulet G, Ménot G, Garreta V, Rostek F, Lericolais G, Zaragosi S, Bard E (2011) Black Sea “Lake” reservoir age evolution since the Late Glacial-hydrologic and climatic implications. *Earth and Planetary Science Letters* 308, 245–258

Böning P, Bard E, Rose E (2007) Towards direct micron-scale XRF elemental maps and quantitative profiles of wet marine sediments. *Geochemistry Geophysics Geosystems (G-cubed)* 8 (5), 1–14

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http://www.springer.com/978-94-017-9848-8

Micro-XRF Studies of Sediment Cores
Applications of a non-destructive tool for the environmental sciences
Croudace, I.W.; Rothwell, R.G. (Eds.)
2015, XXIX, 656 p. 239 illus., 152 illus. in color., Hardcover
ISBN: 978-94-017-9848-8