Poster

Degradation processes of colored papyri from Ancient Egypt

C. Montembault[1,2], C. Dejoie[1], M. Cotte[1], M. Burghammer[1], C. Dugand[3], M. Gervason[3], E. Simonnet[1], P. Bordet[2], P. Martinetto[2]

[1]European Synchrotron Radiation Facility, 71 avenue des martyrs, 38000 Grenoble, France, [2]Institut NEEL CNRS/UGA, 25 avenue des martyrs, 38042 Grenoble Cedex 9, France, [3]Musée Champollion, département de l'Isère, 38450 Vif, France

clement.montembault@esrf.fr

A large number of written and illustrated papyruses from Ancient Egypt have survived through the ages, providing numerous details about stories, practices, and everyday life in Egypt several millennia ago. We investigated a series of fragments of illustrated papyruses from the collection of the Champollion museum (Vif, département de l'Isère, France), showing scenes from the Book of the Dead, a document essential to prepare for the afterlife (Fig. 1a). To do so, optical microscopy and synchrotron X-ray powder diffraction, absorption and fluorescence techniques were used. The X-ray diffraction data proved to be very challenging, reflecting the high heterogeneity of the different colored regions where a mix of organic and inorganic compounds of variable microstructure and crystallinity co-exist. Despite this, we show that through mixed Rietveld and Pawley refinement procedures (Fig. 1b), we can access part of the quantitative and microstructural information contained in the diffraction data, thus allowing deeper understanding on preparation and degradation process [1].

The colors still visible today come from the well-known Egyptian palette: red hematite, blue cuprorivaite (also known as Egyptian blue), green malachite, yellow orpiment, white gypsum and lead white, and black carbon. These colors are believed to be still vivid today because of the inorganic nature of most of the pigments. Nevertheless , X-ray diffraction data proved the existence of degradation phases, unveiling a global degradation process affecting most of them. Indeed, in addition to the main pigments, we also identified several sulfate-, chloride-, and oxalate-based phases. As an example, malachite ($Cu_2CO_3(OH)_2$), which was used as a green pigment, transformed into atacamite ($Cu_2Cl(OH)_3$), and moolooite ($Cu(C_2O_4),nH_2O$). Furthermore, in regions where green and yellow were superposed, complex cross-degradation products appeared, like lavendulan $NaCaCu_5(AsO_4)_4Cl\cdot 5H_2O$ or $Na_2Cu_3(AsO_3OH)_4\cdot 4H_2O$ (referenced as *copper-arsenate_1*) (Fig. 1b).

Part of the degradation observed on the ancient papyri from the Champollion collection was investigated further in laboratory. In particular, we reproduced malachite and atacamite transformation into moolooite, and found that atacamite was not an essential intermediate between malachite and moolooite. Most probably, atacamite results from a degradation of malachite in the presence of chloride ions, later on also transformed into moolooite. A better comprehension of the chemical reactions leading to the current degradation state should help to gain insights into the long-term behavior of such materials and find appropriate conservation measures to transmit this unique Heritage from Ancient Egypt to future generations.

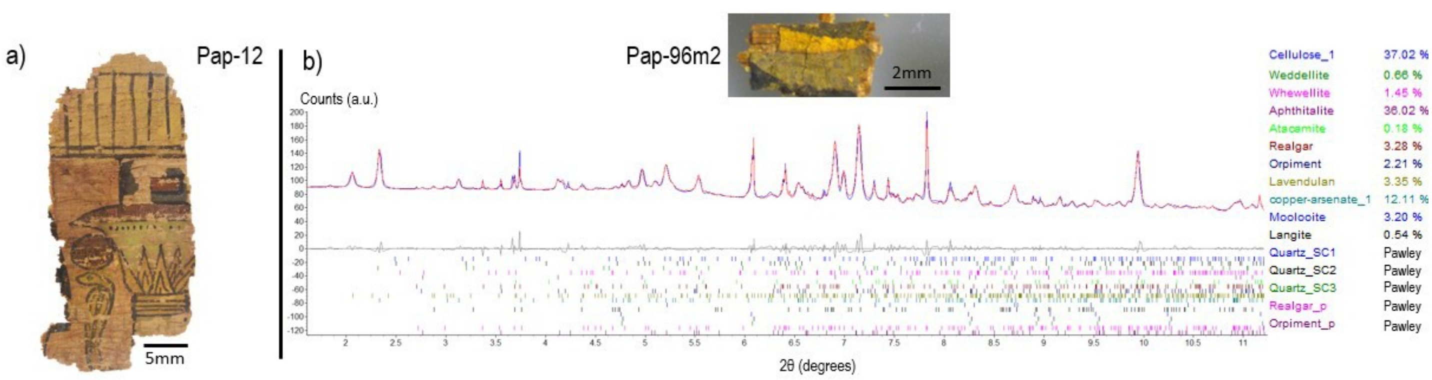

Figure 1. a) A fragment (PAP-12) from the Champollion collection represents a cobra with a solar disk on his head standing in front of a papyriform column. Lower part of the column contains a superposition of yellow and green pigments. b) Mixed Rietveld and Pawley (indicated by the *Pawley* mention) refinements against an X-ray diffraction pattern collected at the ESRF-ID22 beamline in the lower green region of a papyrus fragment (PAP 96-m2) (R_{wp}: 5.19 %, R_{exp}: 0.052 %, : 0.354304 Å).

[1] Autran *et al*., *Scientific Reports*, 13, 524, 2023.