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Lesvos Petrified Forest: the fascinating colours of the silicified trunks

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The Lesvos Petrified Forest was formed by silicification process of plants during the Lower Miocene era, when intense volcanic activity occurred in that region. It is situated in the western part of Lesvos island (NE Greece) and consists of hundreds of standing and lying fossilized tree trunks, covering an area of 150 km^2. It is one of the most important natural heritage monuments in the world and in 2004 the area was included in the Global Geoparks Network (Zouros, 2010). The Natural History Museum of the Lesvos Petrified Forest is the management body of Lesvos Geopark.

The numerous visitors of this geopark are impressed by the fascinating colours of the fossilized trunks. A palette of vivid colours is often evident in the silicified stems (Figure 1). Variable colours are noticed not only in fossil plants from the same locality, but within a sole fossil plant itself.

Several factors affect the distribution of different colours within the fossilized plants: the nature of pyroclastic rocks and the hydrothermal solutions produced during the volcanic activity; the silicification process itself (replacement of cell-wall structure or void filling, i.e. permineralization process); the possibility of a multi-stage petrification and the subsequent mobility of chemical elements therein; the palaeoenvironmetal conditions (hydrology, pH, Eh etc.); the type of species and the variability of plant tissues within the same species.

The aim of the present study is the investigation of the origin of these natural colourants by determining the chemical and mineral abundance of fossil plant samples.

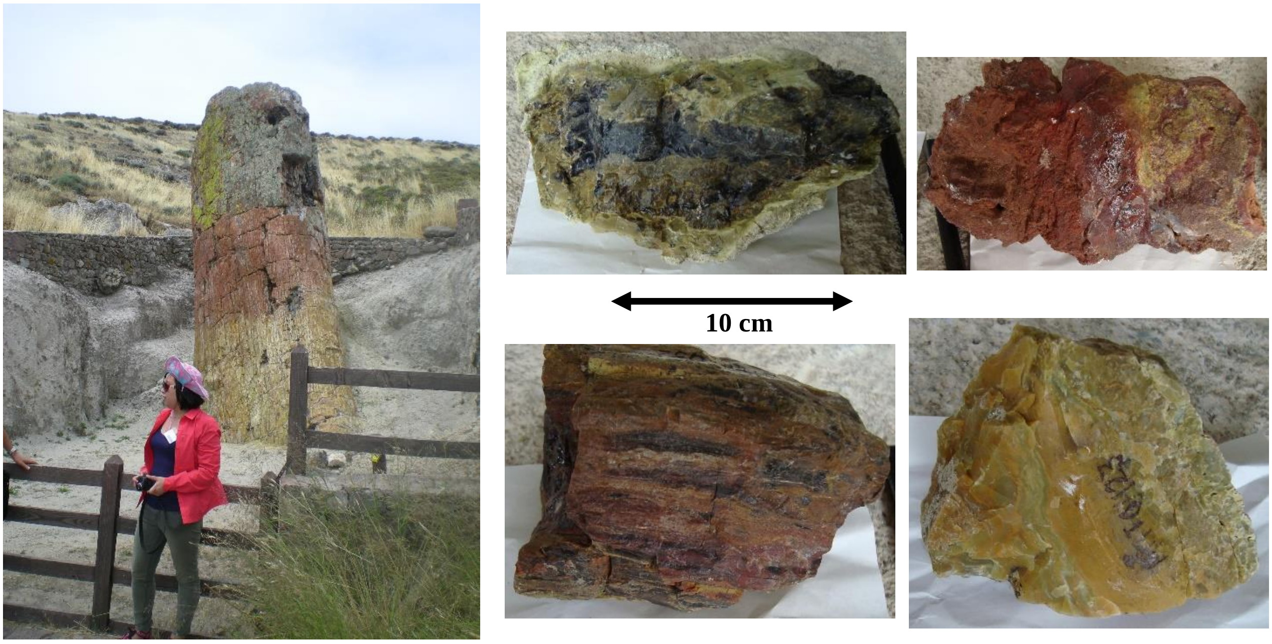

Figure 1. The famous, longest –world record awarded- standing fossilized tree from Lesvos geopark, showing three characteristic chromatic zones [left] and macroscopic images of four representative silicified plant samples [right].

Seventeen fossil plant samples were collected from the Sigri pyroclastic formation within the Lesvos Petrified Forest. Polished block sections of each sample were prepared for analytical purposes. A Philips QUANTA 200 Environmental Scanning Electron Microscope (ESEM), coupled with an Oxford INCA Energy 200 Energy Dispersive System (EDS) was used for imaging and chemical (both in area and spot) analyses. For the Raman spectroscopy, a Thermo Scientific DXR Raman Microscope with a 780 nm laser beam was employed. The power value of the sample irradiation was ranging from 6 mW to 12 mW. The average spectral resolution in the Raman shift range of 100-3000 cm^{-1} was 5cm^{-1} (grating 400 lines/mm, spot size 2μm).

The main colours determined are black, milky white, transparent white, green, red, orange, brown and yellow. The presence of black carbon was clearly estimated in the black zones by the characteristic Raman spectra bands at 1378 and 1536 cm^{-1} (Figure 2). However, pure silica was only detected by EDS in the black colour of some samples. Thus, black colour is attributed either to the relicts of organic matter in the silicified sample or may simply be related to the low reflectance of translucent silica oxides (Musteo & Acosta, 2016).

Raman spectroscopy confirmed the presence of opal in milky white and quartz in transparent white colours. Quartz was revealed with its intensive band at 465 cm^{-1} and the secondary bands at 123, 203 and 497 cm^{-1}, while opal showed a characteristic hump between 200 and 500 cm^{-1}, with distinct strong peaks at 350, 784 and 1590 cm^{-1} (Iordanidis et al., 2014). The EDS analysis of green, yellow, orange, brown and red colours revealed that iron (Fe) is the primary colourant, with the intensity of colour proportional to the abundance of that element. Consequently, lower concentrations of Fe were found in the green colour, while higher contents of iron were determined in the red colour and intermediate contents for orange, brown and yellow tints (Sileo, 1979). Similarly, the presence of iron oxides and hydroxides was determined in the red/orange/brown/yellow and green colours by Raman spectroscopy (Figure 2) and particularly hematite (Fe_2O_3) for the red hue, lepidocrocite [γ-FeO(OH] for the green colour and goethite [α-FeO(OH)] or mixtures of the aforementioned iron oxides/hydroxides for the brown/orange/yellow tints (Musteo & Acosta, 2016). Hematite showed characteristic bands at 223, 296, 402, 658 and 1315 cm^{-1}, goethite presented peaks at 243, 298, 389, 550, 681 and 1298 cm^{-1} and lepidocrocite displayed characteristic bands at 170, 256, 285, 440, 525 and 694 cm^{-1}.

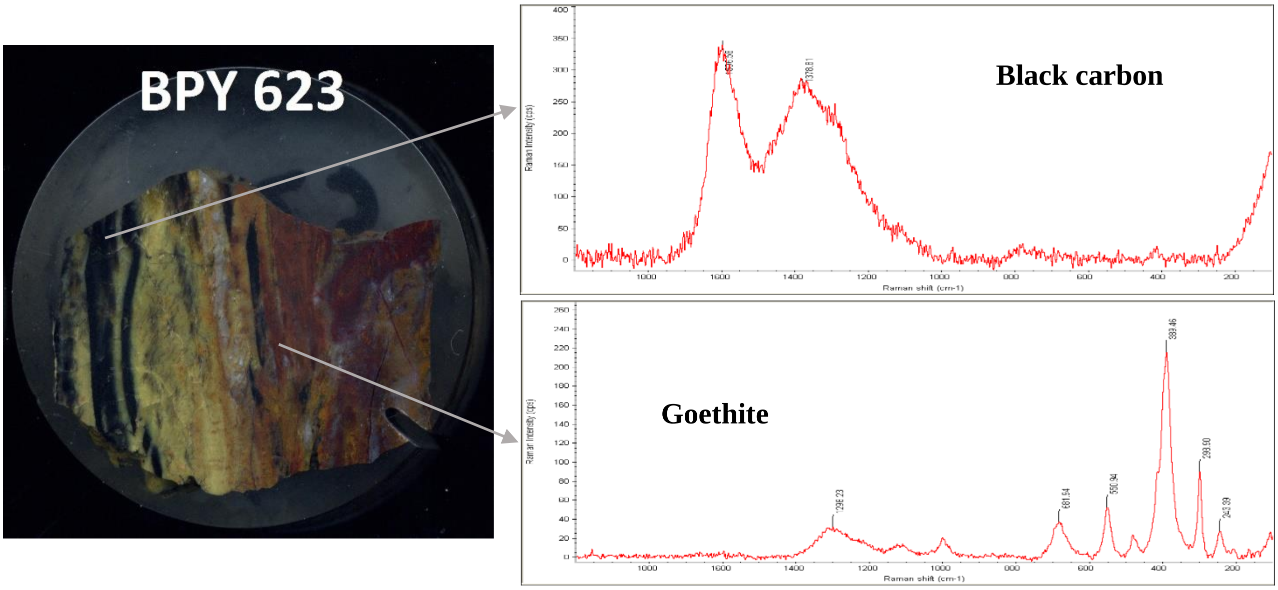

Figure 2. Polished block section of the BPY 623 fossil plant sample, showing characteristic black, white, green, yellow, brown, orange and red colours [left] and the Raman spectra of black carbon and goethite determined in the black and brown areas respectively [right].

Trace amounts of the chemical elements Mn, Ti, V, Hg, Ba, REE were also detected by EDS. Some of these trace elements, such as Mn and Ti are known as natural colourants (Sileo, 1979). However, they were determined in all colour hues and therefore could not be consider as colour creators. It should also be noted that the chemical analysis of this study refers to a spot or area (up to some hundreds of μm^2) EDS analysis and not to a bulk sample analysis.

In conclusion, the complementary use of ESEM-EDS and Raman microscopy techniques provided significant information on the natural colourants, accountable for the fascinating colours of the fossilized stems from Lesvos petrified forest.

Acknowledgements

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