Geophysical Research Abstracts, Vol. 7, 03271, 2005
SRef-ID: 1607-7962/gra/EGU05-A-03271
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The weathering and weatherability of Basílica da Estrela stones, Lisbon, Portugal

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The study of Basílica da Estrela stones decay is presented. Basílica da Estrela is the most 18^{th} century famous monument in the city of Lisbon, Portugal. It was built with Jurassic and Cretacic limestones from the surroundings of Lisbon. Technological characterization of sound stone samples collected from presumable ancient quarries based on chemical, mineralogical and petrographical studies as well as on mechanical, physical and accelerated ageing laboratory tests was performed. At the monument itself detailed survey of stone decay phenomena, microclimate characterization and atmospheric pollutants sampling were carried out as well. In order to be able to establish the typology of the main monument stone weathering factors and forms, different approach were used involving several methodologies and technologies. Stereomicroscopy, X-ray diffraction and Fourier transform infrared spectroscopy techniques were used to study the weathering products (salt efflorescences and disintegrated stone material) found mainly inside the church. Based on photographic recording digital image processing and analysis techniques were used as non-destructive and contact-free methods for characterization of the weathering state of stone surfaces. These surfaces made of stone were megastructures not-easily manipulated and located inside Basílica da Estrela. Besides the historical and documental surveying of the monument made with particular insight into the repair works performed in the past, water-rock interaction studies based on the rain and seepage water collected at the terrace and inside of the church were also carried out. Statistical and graphical methods were applied to data analysis. The most deteriorated stone of Basílica da Estrela is the yellow variety of the Cretacic limestones used as lining material on panels located inside the church. This is also the most prone to weathering of all Basílica da Estrela limestones. Physical weathering forms (granular disintegration, flakes, scales and spalling) pre-

vail inside of Basílica da Estrela. Chemical weathering forms (salt efflorescences and calcitic concretion) are, however, also present due largely to calcite re-precipitation (large white zones) on the lining stones and soluble salts (trona and thenardite) precipitation in a very small and confined area. Basílica da Estrela is located in a moderately polluted area. As the environmental conditions for this soluble salt precipitation are the same all over the inside of Basílica da Estrela, it should be think of a local source and/or enrichment of salt solution that could promote the precipitation of these salts. This fact could be attributed to cleaning activity and repair (maintenance/restoration) works performed in the last few years. In addition, the evolution of seepage water composition under the environmental conditions found inside Basílica da Estrela shows that the stone decay induced by salt deposition cannot be attributed to trona and thenardite, given their small quantity and confined spatial distribution observed to occur. However, calcite dissolution and re-precipitation as it is confirmed for example by the existence of secondary calcite deposition as crusts, stalactites and stalagmites observed inside the church should be considered as one of the most important stone decay factor. The rather hydrochemical uniformity revealed by seepage waters suggests very similar conditions and mechanisms of water-rock interaction corresponding to the same type of percolating system through the building stone for all of the waters analysed. Although there is strong evidence of seawater contribution to rain water composition, there is no evidence of the influence of seepage water dissolved chlorides as likely causes of monument stone decay in the areas studied inside the church. Gypsum, a soluble salt commonly involved in the weathering process of carbonate stone monuments, was also practically non-existent. The interior microclimate of Basílica da Estrela combined with the presence of rainwater percolating the monument stone structures bring about changes mainly in the water composition due to dissolution of stone material, evaporation and precipitation of some water components. Wetting and drying cycles could also be pointed out as another major factor of Basílica da Estrela stone decay. The deterioration processes affecting Basílica da Estrela limestones seems to be simultaneous conditioned by stone structures (fracturing and disagregation along fossils, stilolytes, and so on) and architectural features (geometry, surface finish of the stones, etc.).