# STONE MATERIALS AS SENSORS FOR ENVIRONMENTAL MONITORING – RESULTS OF A FIELD EXPOSURE STUDY

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## 1. Introduction

The need of protection and conservation of objects, such as buildings, technical constructions, historical monuments etc., has resulted in an increasing demand for monitoring environmental influences. So far metals and glasses have been proved to be useful short term sensors (VDI-Richtlinie 3955). In contrast to these dense products, porous materials, such as stone, offer considerably longer exposure durations (months to years) – provided a good property spectrum is given. The selection of appropriate stone materials may be achieved by field exposure experiments. Baumberg Calcareous Sandstone (BCS) which is known to be particularly susceptible for $SO_2$ and »dust components« as well as Obernkirchener Sandstone (OKS) which is of similar porosity and hygric behavior but chemically an almost inert material, seem possible candidates.

This note is concerned with an exposure study under »dry condition« to study the degradation processes of these two materials and to elucidate their possible use as sensor for environmental influences.

## 2. Experimental

Exposure experiments were conducted on four sites in Germany (Duisburg (D), Eifel (Ei), München (M), Kempten (Ke)) for five years and two in the Tyrolian Alps (Innsbruck (Ibk) and Obergurgl (Og)) for two years. All sites are characterized by different climate and anthropogene environment conditions. Contineously monitored meteorological parameters and pollution data were available for most sites. Stone slabs (50 x 50 x 5 mm) were mounted on Mank's carroussels for exposure.
Baumberg calcareous sandstone (BCS) is a biomicritic sandstone (Germany); porosity 19 vol%, spec. surface 10.5 $m^2/g$, w-value 2.5 $kg/m^2h^{0.5}$. Obernkirchener Sandstone (OKS) is a slightly quarcitic silt-sandstone; porosity 19 vol%, spec. surface 2,7 $m^2/g$, w-value 2.24 $kg/m^2h^{0.5}$.

## 3. Results and discussion

Fig. 1 to 3 give data of sample mass changes and corresponding sulfate contents. The BCS-samples exposed in Germany and Innsbruck exhibit all a typical tendency: the sulfate contents exceed the sample mass increases. An exception is Obergurgl where small sulfate contents contrast with dramatic mass losses to be attributed to severe frost/thaw events. Data on OKS are only available from the German sites so far (fig. 2). Similarly, the mass gains are exceeded by the mass of sulfates. However, in contrast to BCS the mass increases are continuous over the entire exposure duration. Despite the different exposure durations between the German and Tyrolian sites the results allow first principal conclusions:

• The inspection of mass change data shows that BCS is subjected to a higher deposition than OKS.

• Usually, sulfate found in stone is inferred to be a reaction product of $SO_2$-immission with carbonate components. In contrast to BCS, OKS is free of carbonate which leads to the conclusion this sulfate is from »exogenic sulfate sources«. This implies that sulfate of BCS is partially also exogenic.

• Data show that sulfate content exceeds mass changes. This indicates that the degradation process is accompanied by considerable grain losses of the stone material.

• On the basis of the available data it is possible to distinguish a number of partial processes characterizing the bulk process of stone degradation:

i) formation of autigenic sulfate (gypsum), ii) deposition of exogenic sulfate (gypsum?), iii) mechanically induced grain loss andiiii) dust deposition. Fig. 4 shows the partial processes for the dry exposed BCS. The only site of a really low pollution situation is Obergurgl/Tyrol; the so-called »clean air areas« of Kempten and Eifel have to be rather grouped among the medium polluted areas such as Munich and Innsbruck. The results of this study suggest that the two stones may be used as environmental sensor materials enabling to specify various environmental load sources at simultaneous exposure.

VDI-Richtlinie 3955, Part 1 and 2: Assessment of effects on materials. Part 1 (1996): Exposure of steel sheets (Mank's carroussel); Part 2 (1993): Exposure of glass sensors; Kommission Reinhaltung der Luft im VDI und DIN.

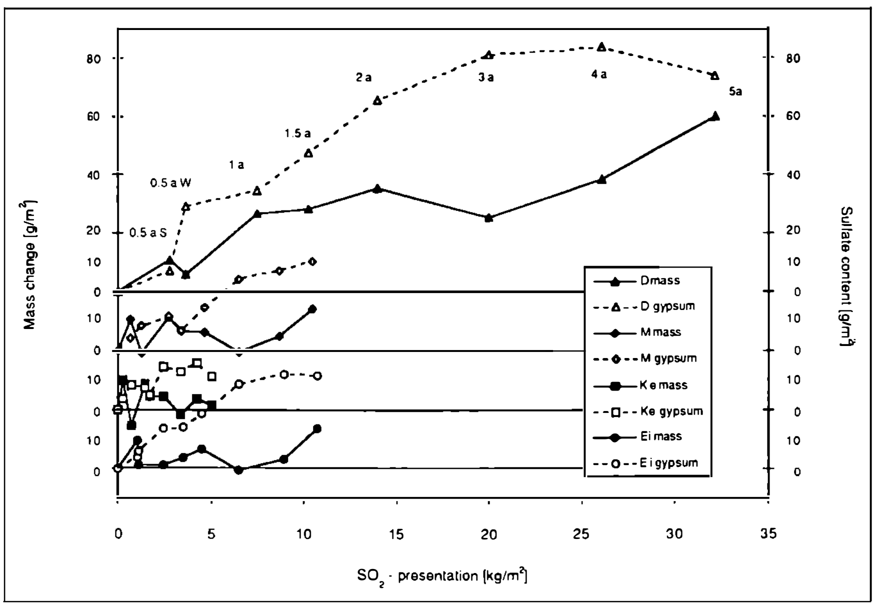


*Fig. 1:*
*Mass changes and sulfate content of »dry exposed« BCS slabs in a period of five years (Germany) versus $SO_2$-presentation. Abbrev. of site names: see text.*

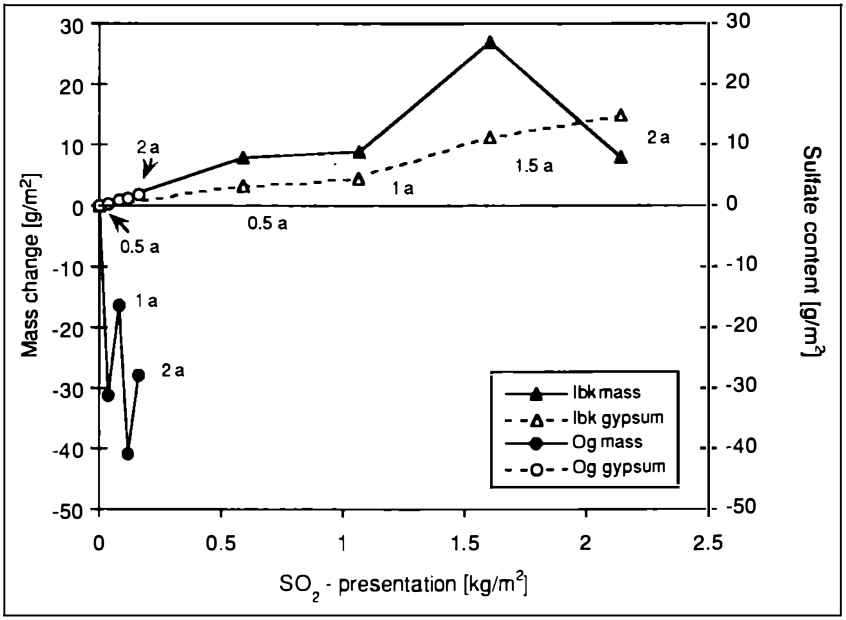


*Fig. 2:*
*Mass changes and sulfate content of »dry exposed« BCS slabs in a period of two years (Tyrol) versus $SO_2$-presentation. Abbrev. of site names: see text.*

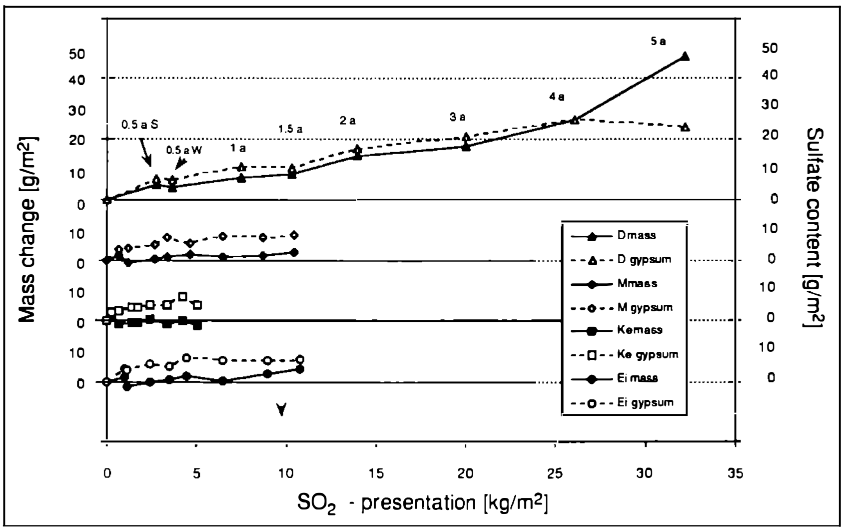


*Fig. 3:*
*Mass changes and sulfate content of »dry exposed« OKS slabs in a period of five years (Germany) versus $SO_2$-presentation. S = summer, W = winter. Abbrev. of site names: see text.*

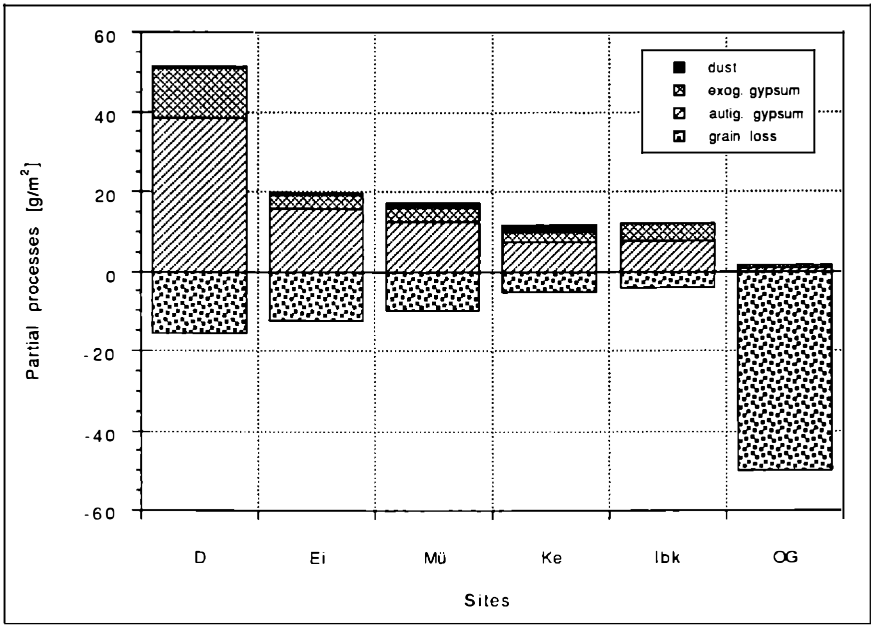


*Fig. 4:*
*Partial processes at »dry weathering« of BCS determined for six sites in Germany and Tyrol. Abbrev. of site names: see text.*