MICROCLIMATE AND TAFONI WEATHERING. RESULTS OF A FIELD STUDY ON THE ISLAND OF NAXOS (CYCLADES, GREECE)

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ABSTRACT

The question of the geographical extension, origin und development of cavernous weathering forms, usually addressed as "tafoni" has been a problem for geomorphologic research for decades. Within the Mediterranean tafoni are widespread and und mostly under active development. Therefore the question arises, which processes are responsible for the disintegration of the usual hard plutonic rocks. Many research papers point out that different forces and factors may influence the weathering process. The main factors called responsible for tafoni scaling are growing pressure from salts, different expansion coefficient of various minerals, hydration and hydrolysis. The climatic peculiarity within the tafoni is sometimes mentioned, but the importance of the special microclimate concerning tafoni development is still treated insufficiently. This paper intends to contribute to the role of microclimate on the question.

KEYWORDS: Tafone, weathering, microclimate, hydration, hydrolysis

1. INTRODUCTION

The problem of cavernous weathering – especially in plutonic rocks – displays a recurring question within geomorphology. Especially in the Mediterranean this kind of weathering is of remarkable importance. The islands Corse and Sardinia are often mentioned as exemplary areas (cf. Klaer 1956). The geographical extension of tafoni in the Eastern Mediterranean, for example in the Aegean, is less known. This fact seems surprising, as tafoni are widespread in the Aegean archipelago (cf. Riedl 1991) and frequently represent characteristic or even formative elements of the relief.

2. THE PROBLEM

Known as "tafoni" (sg. "tafone") these characteristic weathering forms are often described concerning there shape and regional distribution. The question of tafoni development is still a matter of debate. Wilhelmy (1981, 144) assumed a chemical inside rock weathering connected with case hardening. Other authors favour a weathering from outside giving special importance to the processes of hydration, the presence of salts or the specific microclimate (cf. Martini 1978; Kirchner 1996; Weingartner 1982). Several publications emphasize the role of salts in the weathering process, which changes its volume when absorbing humidity and thus is supposed to contribute by growth pressure to the disintegration of the bedrock (cf. Frenzel 1965, 320; Klaer and Waschbisch 1981, 74; Kirchner 1996, 83).

Some climatic measurements in the Aegean archipelago (Riedl 1978; Weingartner 1982 and 1989) indicated a promotion of microclimate for the development of tafoni. Based on these indications permanent climatic measurements were carried out, in order to verify the former short term measurements and to get a closer look to the specific "tafoni-climate".

3. AREA OF INVESTIGATION

The westernmost part of Naxos is almost completely built up by granodiorite of tertiary age (Jansen 1977). A part of this geological complex is represented by the Stelida peninsula. From the gemorphological point of view the peninsula is characterised by three W-E striking shield inselbergs, which bear boulders of

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different size, mainly rounded or even of spherical shape. The boulders are perforated by tafoni of very different form and size.

Measurements were performed at three different tafoni on the central inselberg.
At tafone 1 a permanent measuring was carried out. Air temperature, relative humidity (both inside and outside of the tafone) were determined every half hour. The measurements at tafone 2 and 3 were made during 3 different periods (3 days each).

3.1. REGIONAL CLIMATE

The climate of Naxos is characterised as Mediterranean type ("Csa" after Köppen and Geiger 1980). According to Theocharatou (1978, 31) the annual average temperature is 18,3°C. The warmest month is August (24,9°C), the coldest is January (12,1°C). The precipitation record reveals 397 mm (annually). A minimum is measured during August (0,4 mm) and July (0,7 mm). The greatest amount of rain can be observed during the winter months December (79 mm) and January (80.4 mm) (Theocharatou 1978, 127). The prevailing winds are from the northern sector, with seasonal differences - December 37,2 % and July 83,1% (Theocharatou 1978, 167). Thus, the summer dominance of the Etesian winds is clearly defined.

The dry period lasts from April until October with a total of 80 mm precipitation only.

4. THE MEASUREMENTS

According to the possible influence of climatic parameters on tafoni development, the following main questions arise:

- Which differences are between air temperatures and relative humidity inside and outside the tafoni?
- How are the relations between air temperature and relative humidity?
- Which differences do exist between day and night?
- And finally: Is there any evidence of microclimatic influence on tafoni development?

Fig. 1: Tafone 1, 30 m a.s.l. Helmet-shaped tafone, opening at the bottom of the boulder (north exposition). Maximum diameters of the opening: 190x140 cm. Maximum vertical incision: 52 cm.

Fig. 2: Tafone 3, 27 m a.s.l. SE-slope. The tafone has 2 openings (NW and SE). Maximum vertical extent of the cavity: 210 cm.

Fig 3: Tafone 2, 39 m a.s.l. Lateral honeycomb weathering. Mushroom-shaped boulder. Opening towards NE. Many alveols. Maximum size: 590x310 cm.

4.1. AIR TEMPERATURE

From the measuring period 2 days were selected to show the course of air temperatures inside and outside of the tafone.

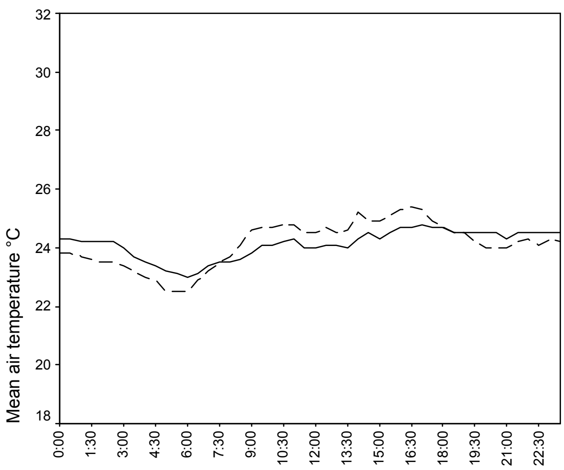

Fig.4: Course of air temperature, August 5th, 2000 (Tafone 1)

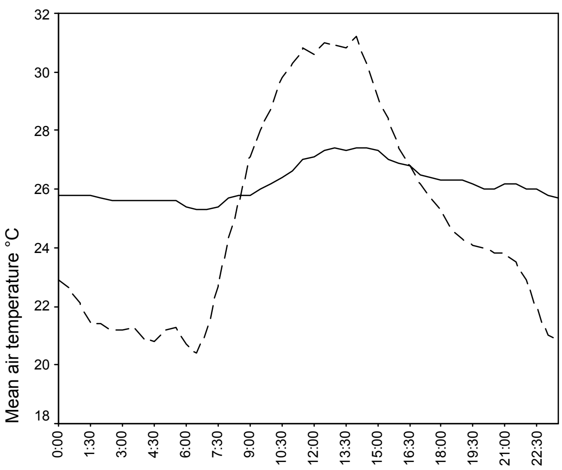

Fig.5: Course of air temperature, September 19th, 2000 (Tafone 1)

Legend for figures 4-7: ------ air temperature outside ——— air temperature inside

The diagrammes represent characteristic courses of temperature. It is obvious that during night the air temperature inside the tafone is higher than outside.

During September the temperature differences between day and night increase. The temperature level is influenced by the surrounding air masses. On September 19th warm air from the south is responsible for the high temperatures in- and outside the tafone. The maximum difference between inside and outside is at 07.30 in the morning (4,9°C).

The characteristic day-night contrast in the course of temperature is also visible in the average monthly course of the half-hour values.

The diagramme also reveals a delay in air warming up inside the tafone. The September diagramme is similar. Only the mean range of temperature outside increases from 9,8°C to 13,2°C and the temperature level is lower by about 1°C.

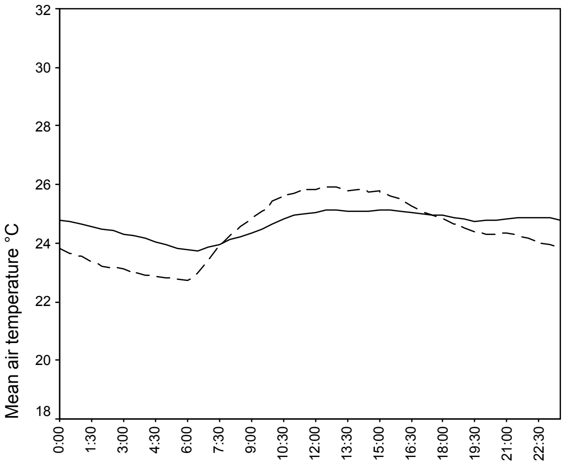

Fig.6: Course of air temperature, August 2000 (Tafone 1)

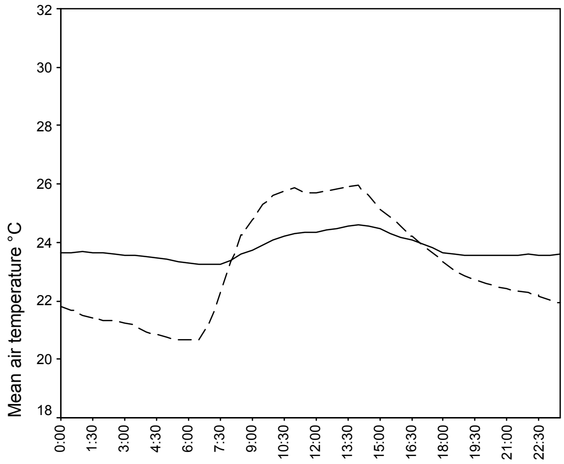

Fig.7: Course of air temperature, September 2000 (Tafone 1)

Concerning the whole measuring period, the temperature range inside is significantly lower than outside (14,5oC versus 21,1oC). This goes together with differences in minimum and maximum values:

Tafone 1	inside	outside
Minimum temperature °C	17,6	16,9
Maximum temperature °C	32,1	38

The daily courses of temperature within tafoni of different shape (compare fig.1-3) reveal significant differences. Tafone 3 is radiated in the morning and thus shows highest temperatures at this time period. The temperature of Tafone 2 starts to exceed these of Tafone 3 at noon. Due to its helmet form Tafoni 1 is least ventilated and the course of temperature is most levelled. Only during night the temperatures of tafone 1 are above those of the others.

4.2. RELATIVE HUMIDITY

According to the air temperature the course of relative humidity runs contrarily. The absolute maximum outside value is 92 %, inside 80 %. Mean maximum: Outside 73,5 %; inside 68 %. Both values are measured in the early morning hours. The minimum values are recorded at different times: inside around midnight, outside in the early afternoon (during the period of the maximum temperature).

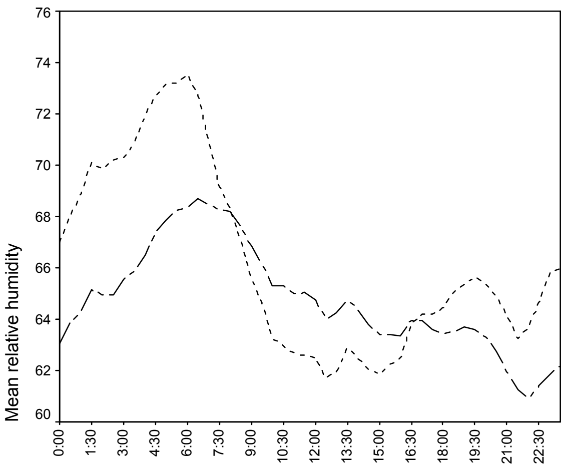

Fig. 8: Course of relative humidity, August 2000 (Tafone 1)

Legend:
……·…·· relative humidity outside
—·—·— relative humidity inside

The half hourly recording reveals a discontinuous course of the relative humidity. Oscillations of 10-15 % between consecutive registrations are common.

Within 2,5 hours up to 25 % difference is measured. Within a 24-hour cycle a maximum difference of 50 % (8 – 58 %) is registered.

5. WEATHERED MATERIAL

Weathered material (flakes) was taken off Tafone 1 and mineralogically analysed. It was clearly visible, that the macroscopic elements of the granodiorite are differently weathered. Feldspars reveal distinct signs of corrosion. At least their surfaces are covered with a thin layer of clay minerals indicating chemical weathering (hydrolysis). On the other hand, the quartz crystals are almost not weathered at all. Salt could not be found within the analysed sample.

6. MICROCLIMATE AND TAFONI DEVELOPMENT

Based on the 2-month climatic measurements, the microclimate can be characterised as follows:
The nocturnal air temperature inside the tafone is generally higher than outside. During daytime it is reciprocal. On the average the inside temperature (whole measuring period) is 0,43°C above the outside value. At the same time the inside range is 2,4°C less (14,5°C versus 16,9°C). The lower inside range is observed with the absolute minimum and maximum values too.

During the same observation period the relative humidity is 2,4 % lower inside. According to the average humidity and temperature values, the vapour pressure inside is 19,18 hPa (outside 19,40). During daytime the relative humidity inside the tafone exceeds the night values.

Apart from the average course the variability of relative humidity is high; daily differences up to 50 % and short time differences around 20 % are common.

As discussed in the introduction, the opinions concerning triggering and supporting tafoni development are controversial. With respect to the impact of microclimate little difference between inside and outside (Kirchner 1996, 80) and rather balanced, cooler and more humid conditions – due to the fact of shading - are supposed, thus supporting chemical weathering mechanisms (Cooke et al. 1993, 25; Mellor et al. 1997, 829). These assumptions cannot be supported by the available data from Naxos.

There is no doubt that the immediate influence of atmospheric processes (rain, wind,..) is responsible for the destruction of the tafoni. On the other hand screening from these processes is a premise for tafoni development. Many observations indicate, that break off of overhanging margins (visors) or a collapse of roofs cause a reduction or an end of tafoni growing (McBride et al. 2000, 875; Mellor et al. 1997, 830).

The most active areas of surface weathering (flaking, mineral disintegration) are ceilings. Inwardly curved walls are sometimes rather active too. These weathering characteristics are also reported from other investigations (cf. Kirchner 1996, 83; McBride et al. 2000, 872). If the geomorphology of tafoni is altered significantly, a change of microclimate is initiated and ventilation is enforced. Especially when the tafoni ceiling is perforated, the warm air inside the "helmet" can leak.

It is remarkable that within an "intact" tafone, the highest temperatures are always registered at the inside top of the opening (inside top of the closed helmet). Thus, the highest temperatures go together with the zone of most intensive flaking!

It seems likely that chemical and mechanical processes which are responsible for tafoni scaling can develop their intensive and sustainable impact only together with a specific microclimatic regime.

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