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Geomechanical study of building materials of the Hawara pyramid (Fayoum, Egypt)

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The contemporary environment in which the monument stone element has managed to exist is essentially determined by climate, industry, geochemistry and sometimes by biospheric agents. In practice, their effects cannot be readily separated. They are a delicate and complex interplay of many factors in practically every case. Nevertheless, these weathering factors may be considered separately, and most important of them are insolation or solar radiation, causing failure through thermal expansion and contraction; moisture leading to fracturing, crumbling and discoloration, exfoliation and finally to deterioration.

Key words: geomechanics, microcracks, deterioration, mineral composition of limestone, X-ray diffraction analysis

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INTRODUCTION

The Hawara pyramid is situated 7 km southeast of Fayoum (Fig. 1). According to inscriptions, it was dated to III Amenemhat from the 12th dynasty. Samples of the building material (limestone and mortar), bees nests and salt from the Hawara pyramid were studied by X-ray diffraction (XRD), and polarizing microscopy (PL) to find their mineral composition and to determine the physical and mechanical properties of the limestones used in the entrance of the pyramid. The results of the study showed that the Hawara pyramid underwent different internal and external stresses due to the mineral composition of the building materials, climate factors and groundwater. Many types of destruction have been noted such as micro- and macrocracks, exfoliation fall of mortar, and wind corrosion, as well as destruction of walls by wasp nests and saliva.

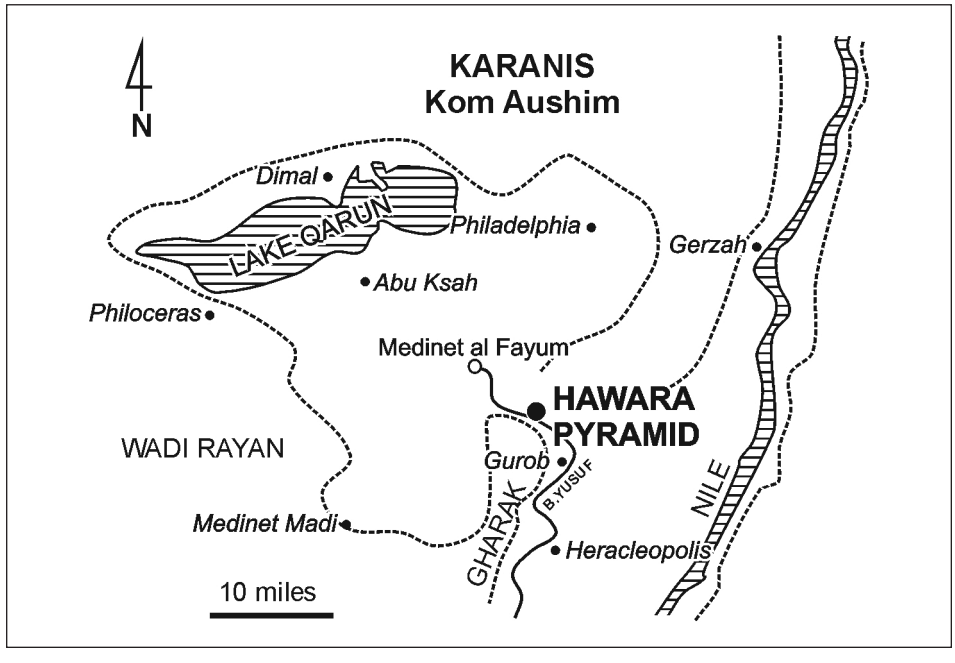

Fig. 1. Location of Hawara pyramid on Fayoum map (Hewisann, 1986)

MATERIALS AND METHODS

Samples of the building materials (limestone and mortar), wasp nests and salt from the Hawara pyramid were studied by X-ray diffraction (XRD) and polarizing microscopy (PL) to find their mineral composition and to determine the physical and mechanical properties of the limestones used in the entrance of the pyramid.

MACROSCOPIC OBSERVATIONS

Macroscopic observations showed that the mud bricks of the pyramid are mostly friable, and the limestones used in the entrance of the pyramid have a smooth texture of the white colour with some red and yellow spots and with the addition of some trace fossils which differ in shape, volume and number from sample to sample. The ancient mortar between mud bricks is clay, while mortar used between limestone blocks is gypsum, and both of them are very soft. The wasp nests on the walls have a grey colour and include some organic matter with sand grains as shown in Figs. 2–5.

MINERAL COMPOSITION

Thin sections

The thin sections of rock material were examined in the laboratory of Historical and Regional Geology, Warsaw University,

Fig. 2. Hawara pyramid

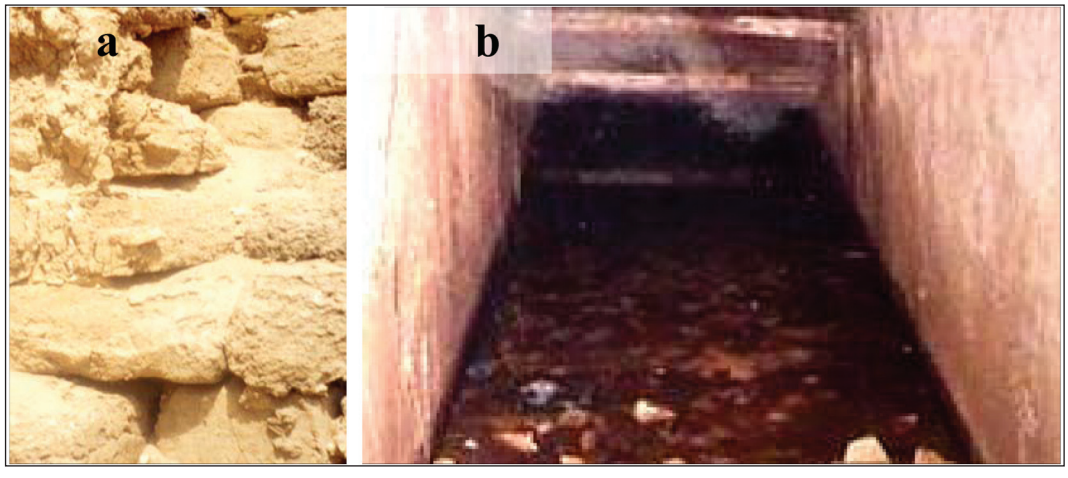

Fig. 3. Examples of destruction types: *a* – fall of clay plaster and mortar; *b* – salt crystallization in the entrance

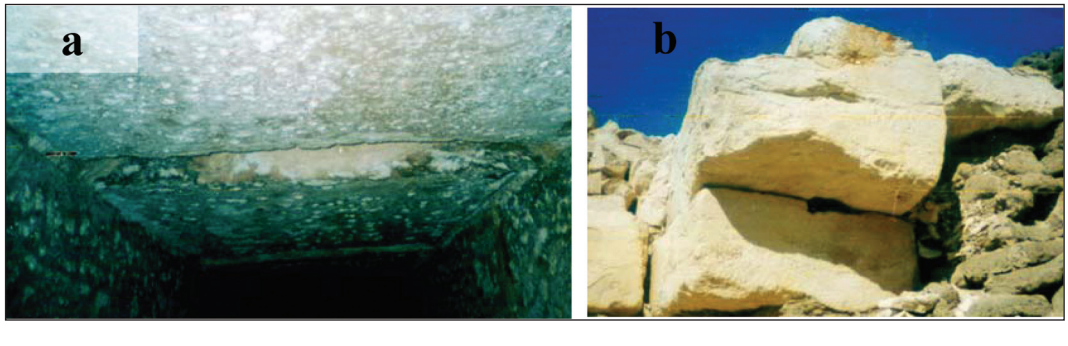

Fig. 4. Examples of destruction types: *a* – green and white spots on mortar; *b* – brown spots in limestone blocks

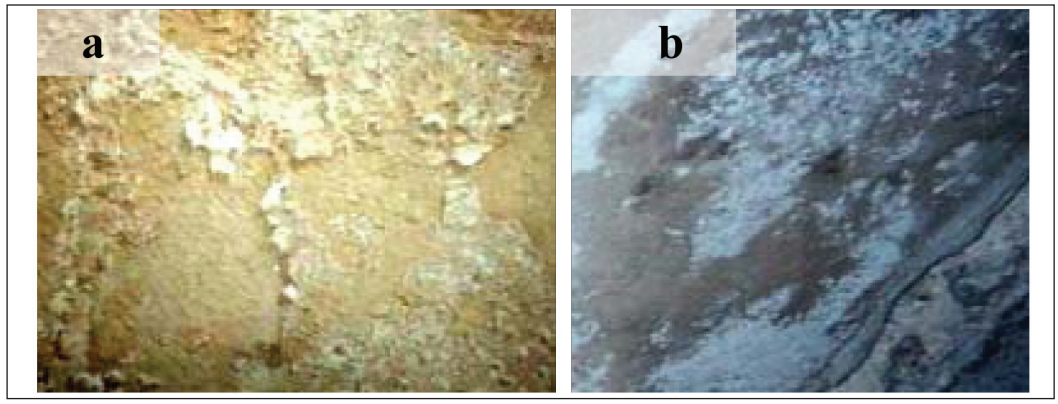

Fig. 5. Examples of destruction types: *a* – salt efflorescence and exfoliation; *b* – salt efflorescence

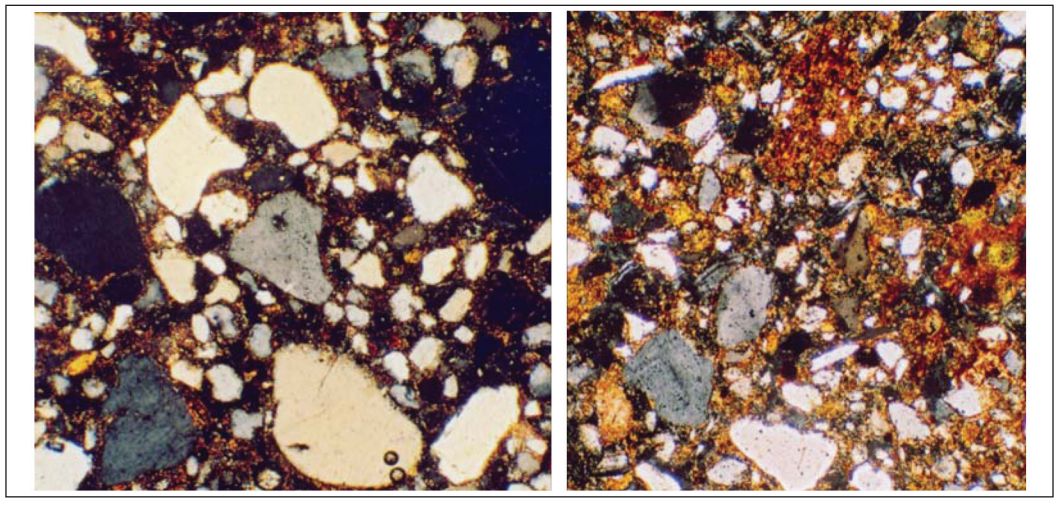

Fig. 6. Examples of thin section examinations of mud brick samples from Hawara pyramid

using Olympus Microscope. The examination of thin sections shown, the mud bricks of pyramid have a big amount of quartz in addition to some clay minerals as shown in Fig.6. The limestone samples are very similar: they are fine-grained biomicrite limestones according to Folk classification. All samples also contain a small amount of iron oxides, and a few quartz grains are also present within a view-field of the microscope (Figs. 6 and 7).

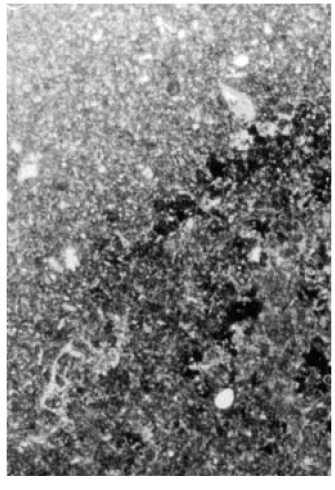

Fig. 7. Example of thin section examinations of limestone samples from the entrance of the pyramid

X-ray diffraction analysis

Ten samples from the Hawara pyramid were appropriately prepared and examined with a Philips X-ray diffractometer at the Department of Mineralogy, Petrology and Geochemistry of the Warsaw University.

The results of the study (Table 1) have shown that the mud bricks consist of quartz SiO_2, kaolinite $Al_2(OH)_4Si_2O_5$, calcite $CaCO_3$, montmorillonite $NaO \cdot 3(AlMg)_2Si_4O_{10}(OH)_2; 6H_2O$, microcline KSi_3O_8 and gypsum $CaSO_4 \cdot 2H_2O$ (Fig. 8a), while the limestone of the pyramid entrance consisted essentially of calcite $CaCO_3$ and a small amount of halite NaCl (Fig. 9a). The clay mortar consisted of quartz SiO_2, orthoclase $KaSi_3O_8$, calcite $CaCO_3$ and illite $K_2Si_3AlO_{10}(OH)_2$ (Fig. 8b). Gypsum mortar consisted of calcite $CaCO_3$ and traces of gypsum $CaSO_4 \cdot 2H_2O$ and quartz SiO_2.

XRD data of the wasp nests from the pyramid indicated that the nests consisted of fine grains of quartz SiO_2 and calcite $CaCO_3$ joined by wasp saliva (Fig. 10a), while the salts are gypsum $CaSO_4 \cdot 2H_2O$ and halite NaCl (Fig. 10b).

Table 1. **Results of X-ray diffraction analysis**

Material	Sample site	Composition
Mud bricks		Quartz, kaolinite, calcite, montmorillonite, microcline, gypsum
Limestone		Calcite, halite
Clay mortar		Quartz, orthoclase, calcite, illite
Gypsum mortar		Calcite, gypsum, quartz
Salts		Gypsum, halite
Wasp nests (recent)		Quartz, calcite

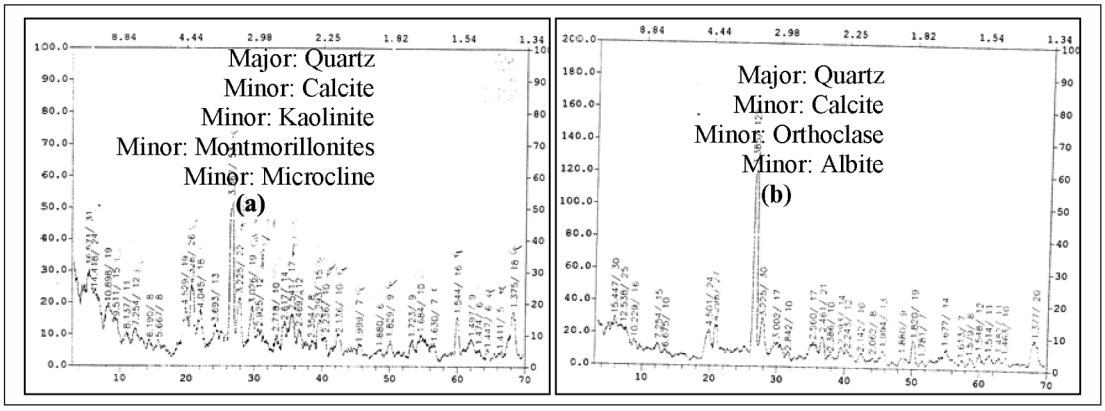

Fig. 8. XRD diagram: *a* – mud brick samples, *b* – clay mortar samples

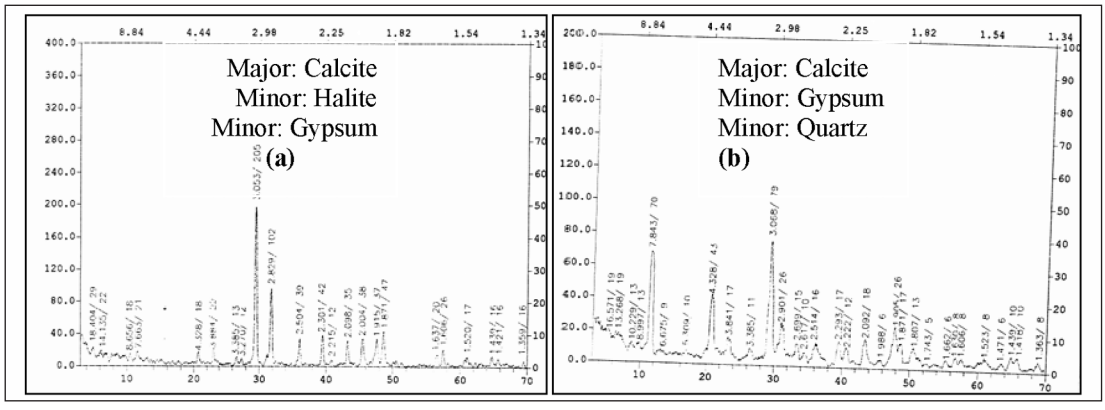

Fig. 9. XRD diagram of limestone and gypsum mortar samples

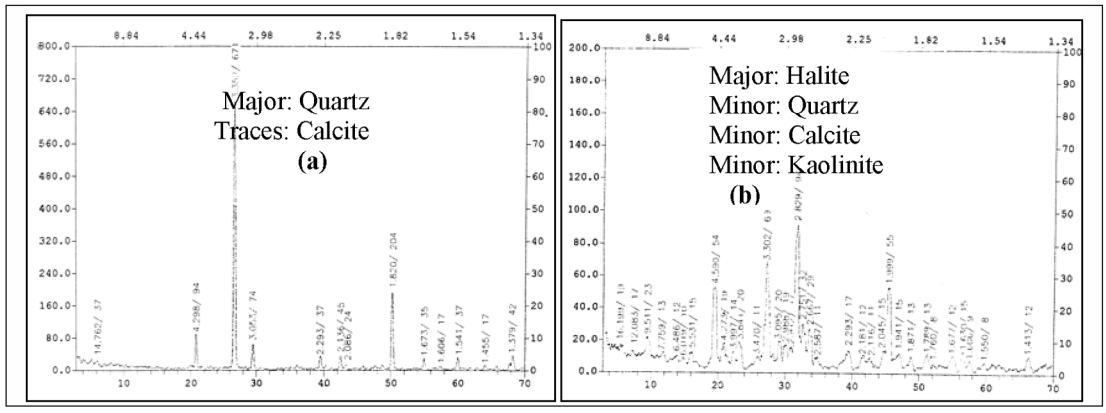

Fig. 10. XRD diagram: *a* – wasp nests, *b* – salts

PROPERTIES

The physical and mechanical properties of limestone samples from the entrance of the pyramid were determined by laboratory studies at the Department of Geomechanics, Warsaw University, using the MTS and ZD machines (Table 2).

Table 2. **Physical and mechanical properties of limestone samples from the entrance of the pyramid**

Physical properties			Mechanical properties	
Density, g/cm³	Porosity, %	Water absorption, %	Compressive strength (Rc), MPa	Tensile strength (Rt), MPa
2.11	15	5.4	36	3.7

CONCLUSIONS

• The Hawara pyramid is exposed to different deterioration processes (aging) caused by internal and external stresses due to the mineral composition of the building materials, climate factors and groundwater.

• All the existing elements of the pyramid are constructed from mud bricks which consist of quartz, kaolinite, calcite, montmorillonite, microcline and gypsum, in as well as Eocene limestone which consists essentially of calcite and small amounts of halite.

• There are two types of mortars: clay mortar consisting of quartz, orthoclase, calcite and illite, jointing the wall's structure of the pyramid and gypsum mortar consisting of calcite and traces of gypsum and quartz jointing the stones.

• Wasp nests from the pyramid consist of fine grains of quartz and calcite joined by wasp saliva, while the salts are halite and gypsum.

• The actual state of the building materials of the pyramid is poor; the mud bricks are more friable and the limestone is weakened and highly porous due to exposure to deteriorating factors.

• The deteriorating mechanism of salt solution depends on two sources of water: humidity from condensation and groundwater from capillary rise.

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HAWARA PIRAMIDĖS (EGIPTAS) GEOMECHANINIAI STATYBINIŲ MEDŽIAGŲ TYRINĖJIMAI

S a n t r a u k a

Hawara piramidė yra 7 km į pietryčius nuo Fayoum. Pagal esančius raižinius jos amžius siejamas su XII dinastijos Amenemhato viešpatavimu.

Lauko tyrimai rodo, kad piramidės statybines medžiagas pažeidė klimatas bei druskingas vanduo. Nustatyti mikro- ir makrosuaižėjimai, klinčių atsisluoksniavimas, skiedinio išbyrėjimas, korozija. Dėl vapsvų lizdų pradėjo irti mūro sienos. Klinties, skiedinio, druskingų dėmių ir vapsvų lizdų paveiktų vietų mėginiai buvo ištirti mineraloginiais metodais, rentgeno difrakcijos metodu (XRD), naudojant poliarizacinį mikroskopą. Tirtas klinčių ėminių, paimtų iš piramidės portalo, stiprumas juos gniuždant.

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BADANIA GEOMECHANICZNE MATERIAŁÓW KONSTRUKCYJNYCH Z PIRAMIDY HAWARA – FAYOUM, EGIPT

S t r e s z c z e n i e

Piramida Hawara jest zlokalizowana 7 km na południowy wschód od Fayoum. Zgodnie z inskrypcjami można jej przypisać wiek panowania Amenemhata z okresu XII-tej Dynastii. Badania terenowe wykazały, że piramida Hawara uległa wpływom czynników klimatycznych oraz wód zasolonych. Obserwowano mikro i makro spękania oraz eksfoliację w wapieniach budujących piramidę oraz wypadanie zaprawy, a także korozję wiatrową. Mury były także niszczone przez gniazda os. Próbki wapieni, zaprawy, wykwitów solnych oraz korozyjnego materiału gniazd os, poddano badaniom mineralogicznym stosując rentgenowską analizę dyfrakcyjną (XRD) oraz mikroskop polaryzacyjny. Próbki wapienne z portalu piramidy zostały zbadane również wytrzymałościowo. Na tej podstawie oceniono procesy deterioracji obiektu.

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ГЕОМЕХАНИЧЕСКИЕ ИССЛЕДОВАНИЯ СТРОИТЕЛЬНЫХ МАТЕРИАЛОВ ПИРАМИДЫ ХАВАРА (ФАЙОУМ, ЕГИПЕТ)

Р е з ю м е

Пирамида Хавара находится в 7 км юго-восточнее от Файоума. На основании имеющейся резьбы ее возраст относят ко времени господства династии Амнтехота XII. Полевые исследования показали, что повреждения строительных материалов пирамиды связаны с воздействием климата и соленой воды. Установлены микро- и макрорастрескивания, отслоение в известняках, выпадение осадка в растворе, коррозия, отмечены разрушения из-за осиных гнезд. Образцы известняка, раствора, засоленых пятен и мест осиных гнезд исследованы минералогическим методом с помощью рентгеновой дифракции (XRD) и поляризационного микроскопа. Образцы известняка, взятые из портала пирамиды, испытывались одноосным сжатием.