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Stone in architecture and sculpture – source material for reconstruction

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ABSTRACT

Stone is the oldest, natural material, which was (and still is) used as both building and sculptural material. The most commonly used for these purposes are: granites, marbles, limestones and sandstones, representing the three main genetic groups of igneous, metamorphic and sedimentary rocks. All of them are permanently being destroyed in result as well of natural weathering as microbiological activity and anthropogenic pollution of atmosphere, known as deterioration. The speed of such decay depends on both environmental conditions and mineral composition of the stone and it can lead to such intensive destruction that conservation may require partial replacement. Smaller damages are refilled with appropriate mineral masses, whereas in case of bigger damages refilling with natural stone is necessary. Professional conservation practice demands the selection and use of the same rock or the rock that is, in so far as is possible, identical to that originally used. It can be done only after previous detailed petrographical studies of the original material. Only then the stone material used for reconstruction will be appropriate and stonework performed properly will not (or almost not) leave marks. In many cases the ancient quarries do not exist and original source material is not available. Then petrographical studies of numerous rock-samples, which are recently available from other existing and/or working quarries, will allow the indication the most similar material. In many cases, unfortunately, the stone used for replacement is not identical to the original but only macroscopically similar. In such a case results might be visible sooner or later. These will be differences in colour, differences in structure and in some cases even crystallization of secondary minerals in the newly inserted fragments.

Keywords: stone, architecture, sculpture, deterioration, petrography, reconstruction.

INTRODUCTION

Stone is a natural material accompanying a man since the dawn of time. In different climatic zones, people lived in caves which are natural karst formations developing in some types of rocks; and where there were no caves, people hid under great rock masses or overhangs. Later on, they collected loose rock debris and used it as a building material for different walls and simple habitable structures. What is more, appropriately processed fragments of some types of stone were materials used to produce simple tools and weapons. And this has not changed in many places all around the world. Apart from its protective and utility applications, stone was also used for decorative purposes which is best proven by not only various design elements but also, and most of all, numerous sculptures originating from different periods of the history.

Although stone in general is relatively durable material, its different types are characterised with different reactions to weather conditions, undergoing more or less advanced destruction over time. The most often, sharp edges become blunt and all tiny details fade away so that artistic expression is gradually dying away. Stone features located within great urban and industrial areas are especially exposed to destructive conditions, where natural weathering processes are intensified with the impact of deterioration related to anthropogenic pollution of atmosphere and poor ventilation of urban areas. The modern conservation techniques enable one to stop further destructive processes; however, in some cases, visible destructions require refilling in order to restore a sculpture or architectural structure to its original state (this also concerns mechanical damages). In this case one should aim at obtaining such a stone material which will not differ from the original material of the reconstructed feature, and the close petrographical analysis proves to be very useful here.

TYPE OF STONE

With regard to its durability and weather resistance, the best stone material is a vast group of crystalline rocks, commonly known as "granites" when, in fact, it includes igneous rocks of different mineral compositions, starting with gabbro and diorite, through tonalite, monzodiorite and syenite, and ending with proper granite. All these are hard rocks with a wide range of colours, from black to white, through all shades of brown, red, yellow and even green and blue. Their mineral composition is various and their chemical structure is dependent on proportional content of such major minerals as quartz (SiO_2), potassium-feldspar ($KAlSi_3O_8$) and plagioclase (a continuous series of minerals from sodium albite $NaAlSi_3O_8$ to calcium anorthite $CaAl_2Si_2O_8$). Furthermore, in relation to technical and chemical parameters, of considerable significance is the percentage of other rock-forming minerals as pyroxenes, amphibole and micas which are chemically complex iron and magnesium alluminumsilicate. The universal character of this vast group stems from their crystal structure and relatively high hardness (Lorenc, 2004; Lorenc & Mazurek, 2007).

The group with the commercial name of "granites" often includes equally nice, hard and crystalline rocks of totally different origin. The most often, these are different types of gneiss and some quartzites which are metamorphic rocks formed as the result of mineral, structure and texture transformations of, among others, sandstone and granite.

A second group of rocks widely applied in architecture and arts are sandstones which occur in equally wide range of colours as in the case of the above-mentioned "granites". These are rocks of sedimentary origin, composed of single grains of sand joined with mineral binding material which composition determines the basic physical qualities of these rocks. If the binding material is silica (SiO_2), these types of sandstones are the most durable and weather resistant. There are also sandstones of calcite ($CaCO_3$) or clay matrix which have relatively low chemical resistance; thus, rarely used in the stone industry. Apart from quartz sandstones of silica matrix, other types are quite susceptible to weathering and deterioration. The details concerning a type of sandstones' grain framework and binding material may be determined only during petrographical analysis. It should be emphasised that all sandstones are porous rocks which makes them absorbents of water and moisture - the major factors facilitating decomposition and/or disintegration of a stone.

Commonly used stone materials are carbonate rocks which, with regard to their genetics, represent two completely different groups. One of them are limestones which are sedimentary rocks of organic or chemical origin, almost entirely composed of calcium carbonate ($CaCO_3$). Here, this mineral does not have a crystal structure. The other group includes marbles of metamorphic origin, coming from limestones transformed in high pressure and temperature conditions. Here, calcium carbonate takes a crystal form and this causes that a stone has slightly different physical properties than a limestone. A disadvantage of all carbonate rocks is the fact that, as practically monomineralic rocks (composed almost exclusively of calcite), they are much softer in comparison with granites and sandstones.

DETERIORATION

Airborne aggressive dusts and gases cause considerable damages to stone features, especially, in a poorly ventilated compact urban development. Sulphur dioxide (SO_2) and nitric oxides (NO_x), mostly anthropogenic, are especially dangerous in this scope, which, when joined with water vapour, transform into very aggressive acids. Reaction with some rock minerals, especially those of porous nature, results in the acids causing crystallization of new salts changing the chemical composition, technical parameters and appearance of a stone to a great extent. In the case of some salts, a significant role is played by their force of crystallization having a mechanical impact on the rocks, that is, similarly to water in the process of freezing, causing bursting and crumbling of a stone while growing in volume. One should also bear in mind that porous and cracked surfaces of rocks are much more susceptible to destructive forces than smooth surfaces.

External indications of aggressive substances' influence on stone products are various. In the case of dark types of limestones, these are, the most often, discolorations, and in the case of multicoloured types – changes in colour contrast. In all rocks containing calcium carbonate, one may observe a quite common crystallization of gypsum efflorescence. This process has influence not only on the appearance but also internal structure of a rock due to rinsing calcium carbonate ($CaCO_3$) out from a binding agent and replacing it with insoluble gypsum ($CaSO_4$ x $2H_2O$).

What is more, rock materials undergo destruction because of bacteria, algae, lichens and fungi, that is the process of biodeterioration. One of the metabolism products of these microorganisms are organic acids which, in reaction with some minerals, cause precipitation of new salts, depending on the rock porosity, even 2-3 cm deep under an external surface. Other indications of stone destruction as the result of the influence of microorganisms are changes in original colouring, and new colourful stain and discoloration. Another indications of biodeterioration is stone spalling and dilapidating due to fungous activity (Lorenc, 2003; Lorenc & Mazurek, 2007). Methods of stone conservation in order to protect it against further destruction have long been applied and the details concerning these activities may be found in many reference books (among others, Haber et al., 1988; Domasłowski, 2011; Wilczyńska-Michalik & Michalik, 1995; Pavia & Bolton, 2000; 2001; Rembiś & Smoleńska, 2008).

STONE SELECTION

Degradation, weathering and deterioration often cause such considerable stone cavities that conservation requires application of proper refilling. Similar requirements concern features damaged mechanically for different reasons. Small cavities are refilled with relevant mineral pulps, while in the case of bigger damages, natural stone replacement is the only solution. Scrutinising the stone historic monuments, both architectural structures and sculptures, enables one to notice that, in some cases, the former renovation works were limited to refilling the cavity with cement or well-fitted fragment of a stone but only resembling the original. After a while, this kind of action results in different colouring and structure of the fillers which obviously reduces aesthetic value of the feature (Fig. 1). In some cases, if the fragments were stones of only similar colour but different mineral composition, less weather-resistant than the original stone, after several years they will differ in, for instance, the presence of secondary mineral crystallization (Fig. 2).

Fig. 1 The application of improper kind of sandstone

Fig. 2 The application of improper kind of sandstone

Undoubtedly, the best solution is selection of such a stone which will be as similar to the original as possible; and when there is such a possibility, using exactly the same stone (Figs. 3, 4). Although it is often impossible for different reasons, the possibility is always worth verifying (Lorenc, 2005; 2014).

In all above-mentioned groups of stones, there are macroscopically similar types; however, the hidden catch is that these are often very different rocks with regard to their genetics. In this case, visual similarity is very delusive - mineral (chemical) compositions of these rocks are so different that a possible refilling with the use of this material will come into play after a while with a clear distinction. In order to rule out such a mistake, first of all, one should conduct detailed analysis. Selecting a proper stone is only possible following the close petrographical analysis - both macro- and microscopic - enabling one to unequivocally determine a type of stone used to refill the cavity. In this case, the general determination of type of rock is insufficient as granites, marbles, limestones or sandstones may have extremely diverse mineral composition (Figs. 5-8). Their structures and colours may also differ. Many sandstones are similar to each other with regard to their macroscopic features, have similar grain size distribution and, especially, colours. Only the thorough petrographic analysis, apart from the type of a rock, enables one to determine the kind and type of grain framework and a nature of binding material. These are the factors determining crucial qualities of a stone as: hardness, abrasiveness, porosity, absorbability etc. that is resistance to aggressive chemical factors.

Fig. 3 The application of a proper kind of limestone

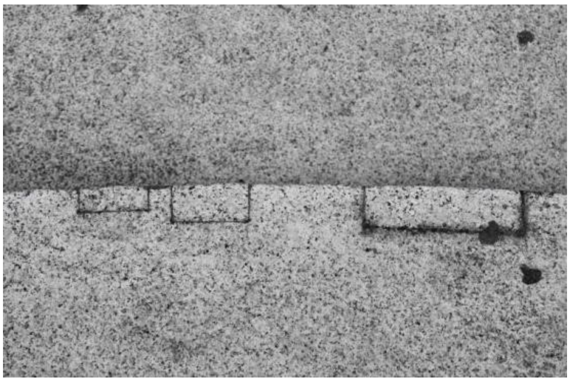

Fig. 4 The application of proper kind of granite

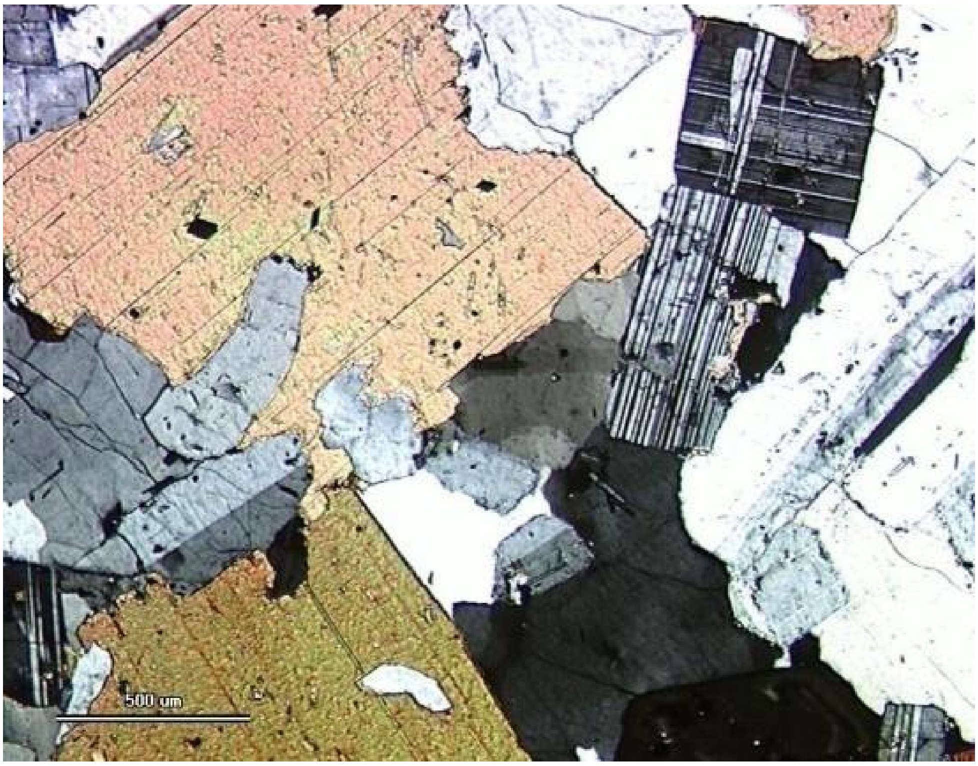

Fig. 5 The structure of granite. Polarized light, bar. 0.1 mm

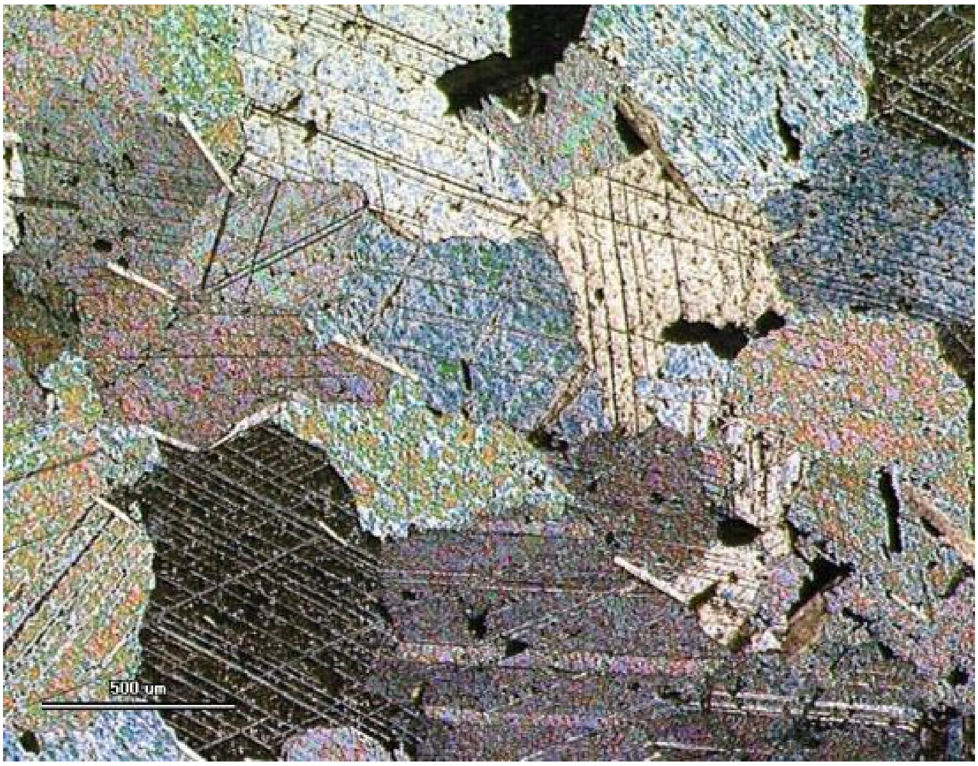

Fig. 6 The structure of marble. Polarized light, bar. 0.1 mm

The mineral composition of the particular types of rocks constitutes their distinctive feature, often specific for a particular type of mineral extracted in a specific place. In some cases, a detailed petrographical study enables one to show a deposit or even

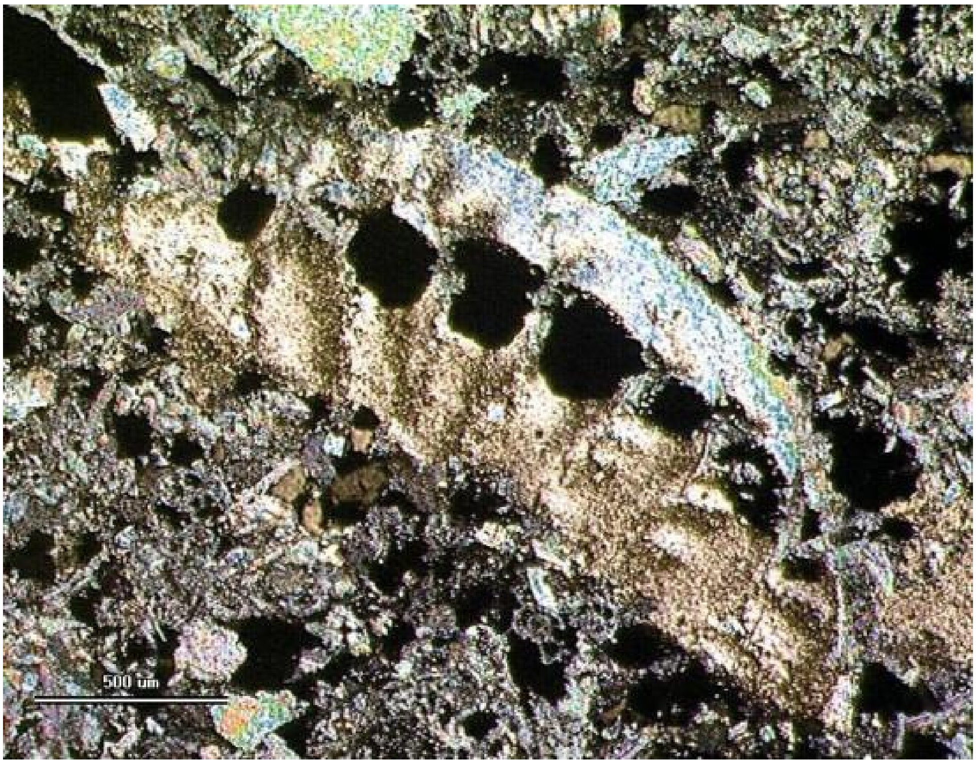

Fig. 7 The structure of limestone. Polarized light, bar. 0.1 mm

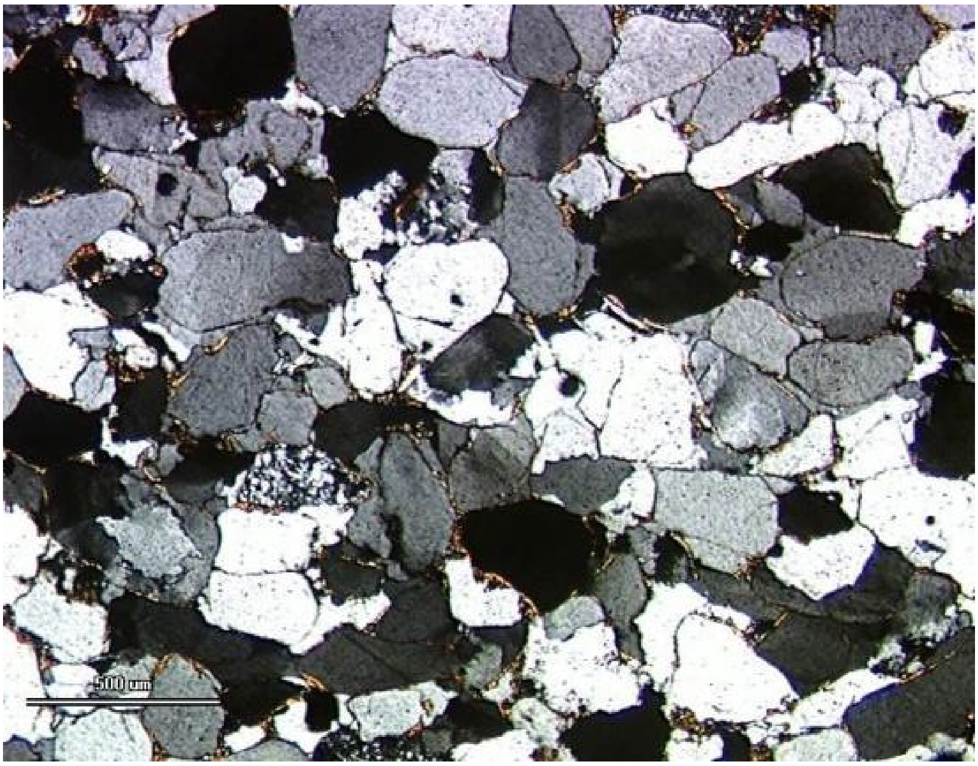

Fig. 8 The structure of sandstone. Polarized light, bar. 0.1 mm

quarry from which the material for a reconstructed feature originated. If the material is properly and unequivocally identified than the access to the "source" is conditioned only by its physical existence. In this case, stone material extracted for refilling or reconstructing will be the best possible. In the case of impossibility of finding the original, historic quarry, one should match a type of stone which would be the most similar to the original with regard to qualitative and quantitative mineral composition as well as structure and colour. Only then, the proper stonework will not leave a visible trace or this trace will be inconsiderable and doing no harm to the feature.

The procedure should be as follows: if there is documentation of the feature unequivocally indicating its material than the petrographical analysis is not necessary; the material for refilling is extracted from the place mentioned in the documentation. However, if there is no documentation or no mention of the source material, in order to identify the material used to make a historic monument requiring reconstruction, one should take a sample from the feature and prepare a microscopic thin-section which would be the basis for the above-mentioned petrographical analysis. The remaining part of the sample will be used for macroscopic structural descriptions. The result of such analysis enable one to correlate the stone material used to build a certain feature with a proper comparative source material existing in the database or extracted in the field. If necessary, scanning is done with the use of an electron microscope to reveal and determine changes in the structure of the analysed stones, the existence of neogenic phases as well as qualitative and quantitative changes in their chemical composition. These analyses enable one to determine the state of preservation of stone sample extracted from the feature and the possible existence of secondary products occurring as the result of the reaction of rock's original mineral substance with aggressive components of polluted atmosphere or organic components. Synthesis of data obtained at the particular stages of petrographical analyses of the sample taken from the investigated historic monument will enable one to determine its condition as well as intensity and level of its damage (Lorenc, 2005; 2009).

CONCLUSIONS

While it is true that the above-mentioned procedure of analysis is quite arduous, it may lead one to finding and obtaining the original material used to create a reconstructed stone historic monument. The alternative here is selection of material at least the most similar to the original. Incomplete satisfaction, even in the case of identifying the historic quarry from which the original stone material has been derived, most often results from the fact that qualitative changes in stone occurring over time are different in a historic monument most often located in a city, compared to a monolithic wall of a quarry located in the natural environment, often away from a specific urban atmosphere. A material properly selected for reconstruction remains unnoticed in the reconstructed feature with regard to quality, only with a shape of used filler visible. In the case of selecting the material only on the basis of colour, with no petrographical study, the negative effects will appear over time resulting, among others, from different level of weather resistance of the original and the filler. In the case of reconstructing features made of porous stones, one has to clean a monument before refilling and apply proper protection of moisture (hydrofobization) after the required reconstructions. Only then, the colour of the monument and refilled fragments will remain similar for a long time and the reconstruction will be discrete.

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