TILING FAILURES THROUGH THE LENS OF A MICROSCOPE

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ABSTRACTS

Investigation of tiling failures always inexorably involves a systematic process from examination of documents to field inspection and testing and finally laboratory analysis of samples. Examination of documents provide information with regards to the design, materials used, method of construction as well as history of construction, maintenance and repair. Field inspection and testing on the other hand provides details on the extent and distribution of the problems. With a trained eye and experience, the mode of failure can be known and possible hypothesis can be derived. Samples of failed material as well as those that have not failed will always be required for laboratory examination. This includes samples of unused material. One method of examining such samples that almost often yields immensely useful information is through the microscope. Often, relics that reveal the type and quality of materials used, stress history, past environmental exposure and workmanship can be uncovered under the lens. It also allows the investigator to better understand the actual mechanism of failure which can at times not discerned macroscopically on site. The author has used a combination of polarizing fluorescent microscope, stereo microscope and scanning electron microscope to examine the composition, porosity, fractured pattern, cracks, secondary mineral alteration and structure of the tiling composite as part of the diagnostic tool. This paper discusses the methodology and some of the findings made.

1. INTRODUCTION

The use of microscopic techniques in the diagnosis of tiling or tiling system failures by the authors centres predominantly around the science and practice of petrographic examination, which had initially been developed for use in the field of mineralogical study of rocks. The word Petrography had in fact, originated from the Greek words of Petra for rock and Graphus which means writing or a record.

In the beginning, petrography had principally revolved around light optical microscopes with thin section analysis as the primary technique supplemented with microscopic study of polished specimens in incident light and stereo microscopic examination of broken surfaces. Over the years, the science of petrography had expanded to include new types of instrumentation and techniques from fluorescent microscopy and electron microscopy to subsidiary techniques such as X-ray diffraction, infrared absorption analysis and differential thermal analysis. Notwithstanding the wide array of advanced instrumentation and techniques, the basic tool, which is by no mean simple and very effective, continue to evolve around light optical microscopes. Polarizing and fluorescent microscope is probably one of the most versatile tools a petrographer can equip himself with in the diagnosis of tiling failures.

A number of literatures have been published describing and discussing petrographic examination but mainly on concrete[1-6]. Few documented literatures are found on diagnostic examination of mortar and tiling works and failures, however, the principle of the technique used for examination of hardened concrete similarly applies.

2. THE JOURNEY BEGINS

Though petrography is centred mainly on the light optical microscopy, it does not begin or end with a microscopic examination in diagnosis works. The petrographer should be consulted once failure is encountered so that an assessment can be made on the possible use of any of the various techniques for failure analysis. The petrographer will also need to understand the types of materials that were used in the tiling works, the method of installation and the overall construction of the building elements within which tiling failure has occurred. Historical records, time of discovery of failure with respect to the construction program and extent of failures like where have the tiles failed and not failed are all essential information which the petrographer will need to be fed with in formulating the diagnostic approach. Often, this process is much more difficult than it sounds as the information may not be so easily available for various reasons like poor documentation, biasness of the information, confidentiality and liability protection issues.

Once all the relevant information or whatever available information is collated, this should be reviewed and digested. Questionable data should be raised and highlighted. Further supporting documents and facts such as type of adhesive, quality of tiles, types of substrate etc. may need to be furnished or sought after. Due to the enormously huge amount of information and findings that can possibly be discovered from petrography, it is vital that the terms of reference of the investigation be clearly spelt out to be practical within the cost and time frame available. Some observable data may be irrelevant to the intent of the diagnosis which may cause more confusion than conclusion. The experience and skills of the petrographer thus becomes a critical parameter in the equation.

Upon completion of the documentation review, a site visit to inspect the tiling failures is the next necessary step. This will allow the petrographer to better understand the actual mechanism of failure to differentiate for instance between cracks and crazes, types of cracks like map or linear, mode of detachment whether between tile and adhesive or otherwise, extent of voidage between tile and bedding, environmental exposure condition, colour of the adhesive, method of application of the adhesive, substrate cracking and many more. Consistencies or inconsistencies of the various symptoms are important evidences to be recorded as each could well suggest different causations or mechanisms.

Petrographic examination is a systematic visual examination of a material from macro to micro level, sometimes even to sub-micro analysis. It is therefore of utmost importance that the petrographer personally carry out a field inspection to better appreciate the extent and nature of the problem. This will then allow the petrographer to design a proper sampling plan in terms of locations and number of samples. The sampling is extremely crucial as the specimens eventually extracted and subsequently analysed will be very small, usually significantly less than $1m^2$ with respect to the thousands of square meter of tiling works. The analysis of the extracted specimens is then supposed or expected to provide information as to the quality of materials, workmanship, composition of the bedding and substrate, fabric and composition of the tiling works to eventually allow a reasonable conclusion to be drawn as to the cause of the failure. Obviously therefore, reliable inputs such as background information from other parties in the tiling works from design to the installer and inspector cannot be underestimated.

In the sampling plan, often considerations need to be given to comparing locations where the tiling system has not failed, where different types of tiles or bedding has been used, of different substrates conditions, with different modes of failures and perhaps even also of different time of construction. The samples retrieved must always and unavoidably include the substrates. The procedure for extraction of the specimens should be selected with care so as not to further damage the tiles or obliterate the already delicate evidences particularly for instance staining, crazes and fine cracks. Very frequently, unlaid samples of tiles and bedding, at the very least, will also be required for comparative examination.

3. LOOKING THROUGH THE LENS

In the computer world, we are familiar with the phrase, "What you see is what you get or WYSIWYG. The same applies to petrography; however, the skill really is interpreting what is seen as reflected famously by Sherlock Holmes, "I see not more than you but I have trained myself to notice what I see." Through the myriad of techniques, even under the seemingly basic optical light microscopy, with the right skills and technique, abundant amount of information can be drawn.

Once the appropriate specimens have been extracted, they should be diligently examined with the naked eye and through the stereomicroscope to determine the nature of failures, cracks, compositional alteration, variations in colour and composition, voidage, mode of debonding, thicknesses and secondary deposits of the various layers in the tiling system. Such examination of the hand specimens is the first critical step as from here the petrographer will make selections on the sections on the specimens that need to be cut and prepared, for microscopic examination, which best represent the objective of the analysis, either to denote the quality of the materials or works or address the cause of the discerned failure. For each different purpose, chances are different sections of the hand specimens will be selected.

The petrographer then proceeds to develop initial hypotheses and diagnostic examination flow to ensure optimum transition from the macroscale to the microscale so that knowledge gained from each unit of effort, provides independent and complementary verification. Each step of the examination usually uses more than one method and care is needed to ensure that proper sampling is done at all levels of scale.

Macroscopic examination is very useful for coarse cracks as in a number of cases investigated, the cracks through the ceramic tiles had propagated into the bedding and coincided with large voids in the adhesive.

The microscopic analysis is performed on a ground section using a stereo and metallurgical microscope and on a thin section with a polarising and fluorescent microscope (PFM) under transmitted and reflected light. For preparation of the ground section, a small block of the sample is cut and ground to attain a smooth finish. For preparation of a thin section, a small block is sawn from the extracted sample, glued to an object glass and impregnated with an epoxy resin containing a fluorescent dye. After hardening of the epoxy, a thin section with a thickness of 20-30um is prepared for PFM analysis. For consistency in the fluorescence microscopy examination, the procedure in preparation of the thin section with fluorescent dyed epoxy is standardized[7 and 8].

Polished specimens which can be suitably etched, are prepared in order to identify the various cement mineral phases in unhydrated clinker particles contained in the bedding adhesive and substrate, typically plaster, screed and other cementitious finishes. The composition of the bedding such as type of cement and fillers like quartz or calcite can be identified through plane and polarized light microscopy which may be used to evaluate against the specified material. The type, amount and distribution of voids once identified can be used to check the mixing and compaction of the bedding and substrates.

Under transmitted light, the various components (type of minerals, cement and aggregates), voids/pores, cracks and damage phenomena in the samples are identified. Analysis of the cracks characteristics such as the pattern, distribution, extent, width, direction or orientation provides good indication on the likely cause and time of occurrence whether during installation, immediately after or at a much later stage. The cracks can also reveal possible causes such as shrinkage, movement or chemical reaction. In some cases, the age of the distress or even tiling works may be established though not entirely quantitatively but rather comparatively. There had been cases where the examination revealed that the tiles had been re-laid and not of the original installation based on evidences of artifacts from re-installation or hacking.

The actual mode or mechanism of failure in particularly in the case of debonding can often be better determined under the microscope. What was presumably detachment between the tile and adhesive to the naked eye may well be debonding between the adhesive and a film forming sealer in the case of a treated stone tile. Presence of shear cracks within the cohesively fractured bedding points to lateral movement of the tiling system.

Secondary reaction and chemical deterioration of the bedding and substrate can be distinguished by examining alteration in the composition of the material from the original. This can be seen for instance by secondary deposition of recrystallized ettringite, gypsum etc. and carbonation. Extensive volume of recrystallized ettringite and Portlandite infers severe leaching which can progressively weakens the adhesion strength of the adhesive.

By observing the fabric of the different layers, an experience petrographer can also deduce the likely method such as spreading or buttering of a mixture and quality of tile installation. The composition makeup of the bedding can be compared against the specified materials and the recommended mix proportion. Some of the samples analysed were palpably inconsistent with the recommendation of the supplier of the adhesive due to for instance lack of fillers or different types of cement has been used. For mixes with entrained air, over mixing for example can cause the entrained air to break and coalesce resulting in large compaction voids which in turn can adversely affect the performance of the bedding.

Under reflected light, the fluorescent microscopy makes it possible to study the homogeneity of the cement paste, capillary porosity, microcracks and other defects in the samples. The fluorescence microscopy is a very powerful technique that allows a petrographer to examine also the consistency in the capillary porosity. This can be used to compare against reference specimens prepared based on recommended mixture of the adhesive to check the water cement ratio.

Frequently in the course of a diagnostic work, comparative analysis will need to be employed. This can be made by comparing samples that had failed against those that had not, locations where there is failure against locations where there is not and in-situ samples against laboratory reference samples. Specimens and thin sections are commonly prepared from these different specimens for study.

For some cases, Scanning Electron Microscope (SEM) and Energy Dispersive X-ray (EDX) Analysis technique needs to be used to examine the topography and semi-quantitatively analyse the elemental composition of the tested sample. Infrared absorption analysis is also regularly used to check for the presence of polymer and identify the base polymer in the adhesive.

4. CASE STUDIES

In one case involving cracking of glazed wall tiles a few months after installation, removal of core samples across the cracks showed that some of the cracks on the tiles coincided with large voids within the bedding as seen on the hand sample in figure 1. This shows that the sharp triangular void in the bedding has played a significant role in causing cracking through the ceramic tile, probably due to shrinkage of the bedding. Such shrinkage of the bedding adhesive can be aggravated by the use of a rich mix resulting in stress concentration around the voids which may then be transmitted onto the tile layer. Under fluorescent microscopy, high capillary porosity of the bedding just below the interface with the ceramic tile was noted as depicted in figure 2. This is typically caused by an increased in water cement ratio, either due to bleeding of the bedding or contamination of water for instance from soaking of the tiles in water prior to installation. According to the method statement of installation in this case, the tiles were not supposed to have been soaked in water before laying.

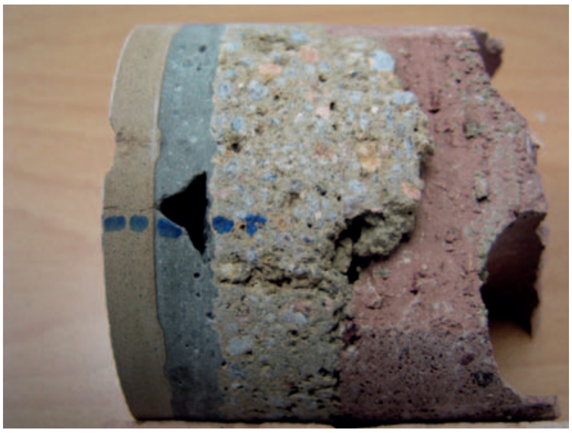


Figure 1.

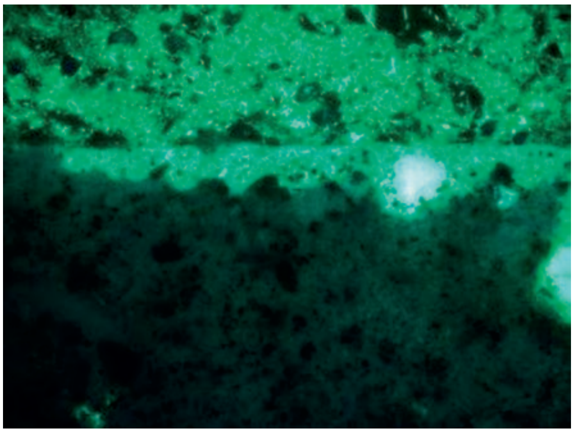


Figure 2.

One of the recent cases investigated involved buckling and debonding of homogeneous floor tiles as seen in figure 3. Examination of the mechanism of failure on site indicates detachment of the tiles from the bedding. Notch trowel marks could be seen on the exposed bedding with remnant strips of aluminium powder from the back of the tiles. The presence of the significant notch trowel marks infers that the tiles had not been pressed sufficiently onto the bedding during laying. It would also be naturally assumed that the aluminium powder has contributed to the debonding. See figure 4. Under the microscope however, as shown in figure 5, some of the debonding occurred within a thin layer of the bedding. The bedding appeared to be neat cement without any filler and characterized by massive shrinkage cracking as illustrated in figures 6 and 7. In figure 7 under fluorescent microscopy, there is also feature suggesting possible bleeding of water around the rectilinear crack; perhaps the cracks had occurred while the bedding was still fresh. Aside from the installation problem, the microscopic examination indicates that there could well be a problem with the adhesive used which was later discovered to be a formulation of latex and neat cement in proportion arbitrarily prepared by the tiler. In cases like this however, the cause of the compression stress induced onto the tiling layer should inevitably be checked as well.

Figure 3.

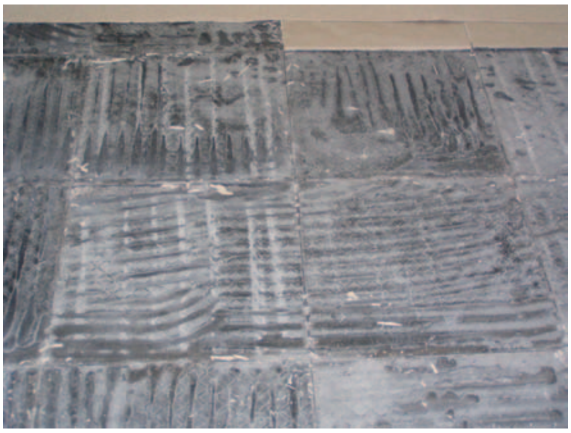
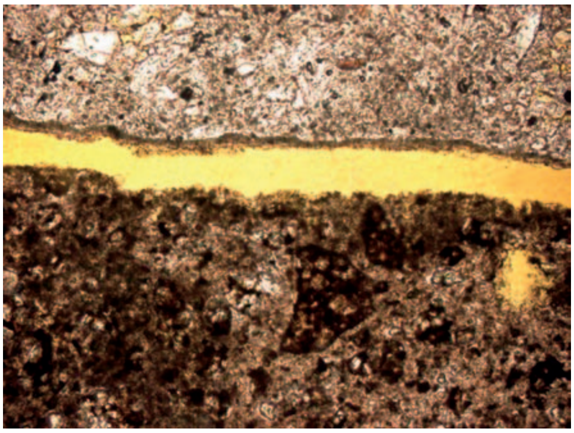
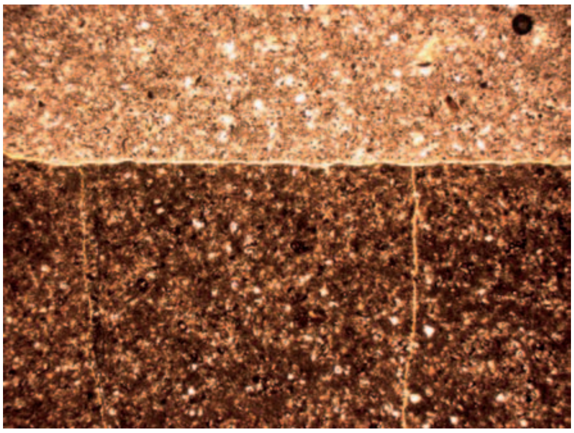
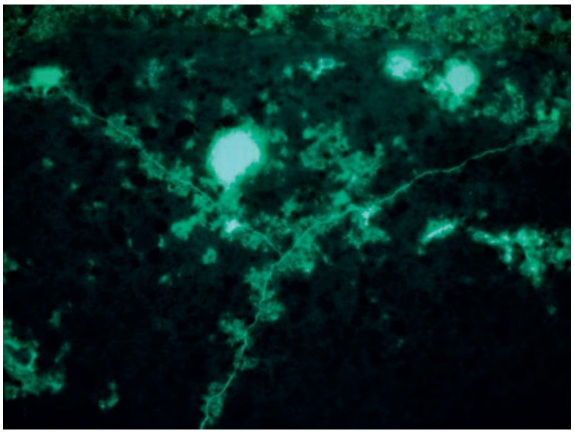


Figure 4.







From top clockwise, figures 5, 6 and 7.

Recalcitrant formation of efflorescence on the surface of natural stone tiles toilets in a hotel had been reported a few years ago. After cleaning off the whitish powdery surface deposits, within the next 1-2 days, the efflorescence reappeared as shown in figure 8. Under fluorescent microscopy, channels of very high capillary porosity were evident in the stone and this has caused uptake of water by the stone through capillary force. See figure 9. The capillary rise of the water from the cementitious substrate carried with it dissolved alkaline salt causing the formation of lime bloom on the surface of the stone.

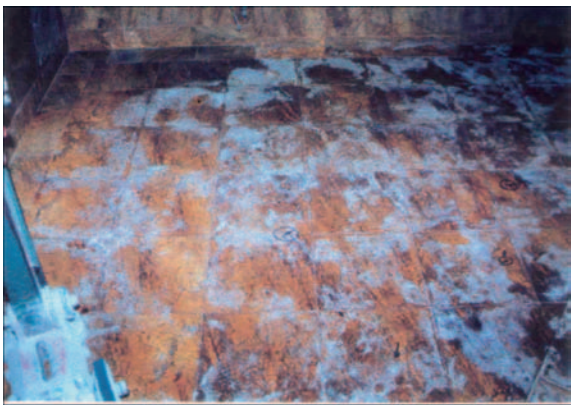


Figure 8.

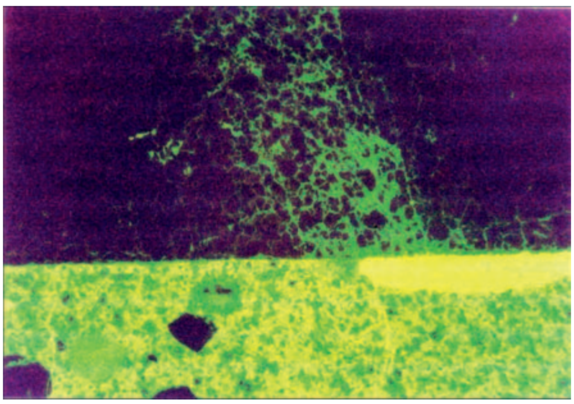


Figure 9.

In a hotel development, buckling and cracking of compressed marble tiles laid on the floor of a bathroom has been reported. Removal of the buckled tiles indicates that the tile had fractured horizontally within the thickness of the stone. See figure 10. There also appeared to be two bands of different shades of colour along the centre of the stone thickness, close to where the horizontal fracture has occurred as shown in figure 11. Such phenomenon was not observed on unlaid tiles. Under fluorescent light examination of impregnated samples, higher porosity at the bottom half of the tile thickness was discerned. See figure 12. It would appear in this case that the resin used in the compressed marble has been attacked by the alkali from the cementitious bedding resulting in increased porosity of the bottom of the tile that is in contact with the bedding. Subsequent simulation and alkali resistance test on the compressed marble confirmed the observations and hypothesis. Suitable and compatible adhesive will need to be selected for such application. Figure 13 shows recrystallised coarse grained Portlandite within the entrapped air void in the bedding, an indication of leaching or persistent dampness in the bedding.

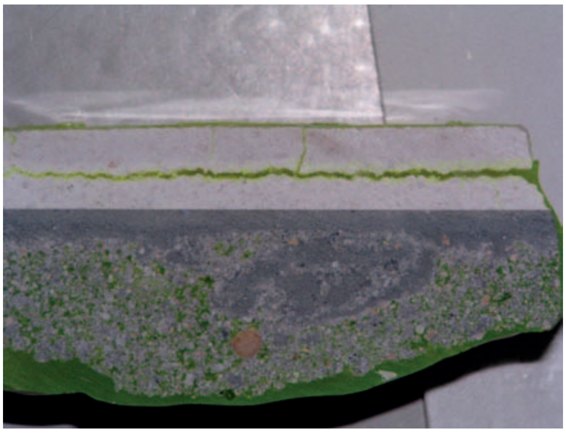


Figure 10.

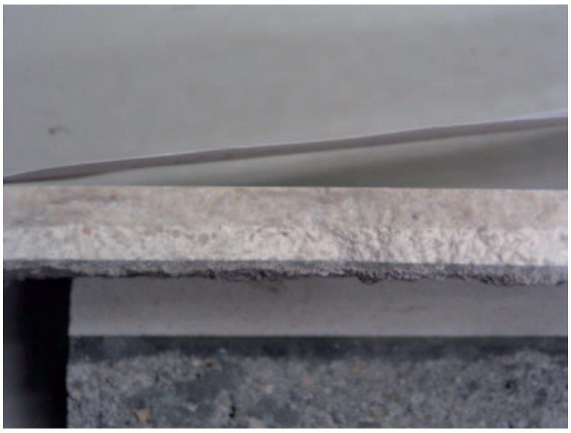


Figure 11.

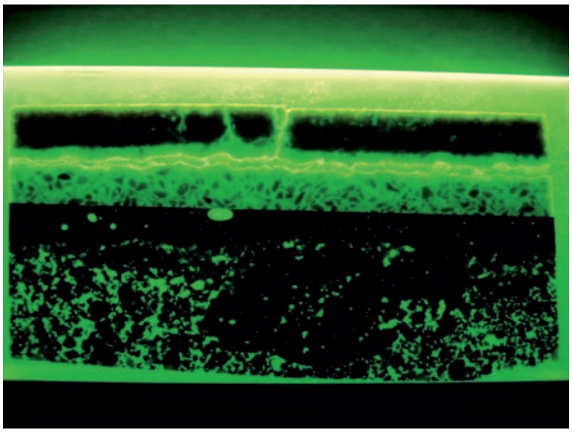


Figure 12.

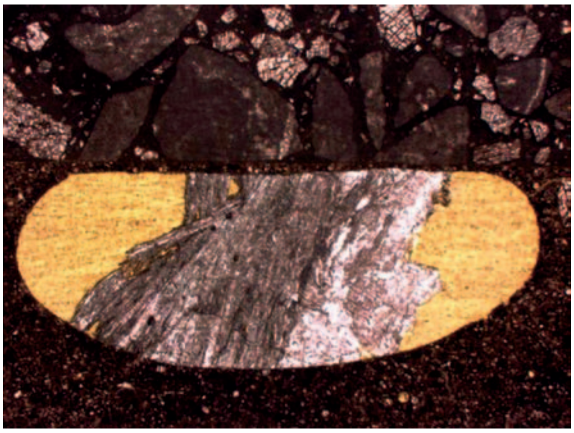


Figure 13.

5. THE FINAL LAP

The final stage of the diagnosis is the presentation of the findings and articulation of arguments into a report. Given the massive amount of information, it is understandable that a petrographer can be easily inundated resulting in a poorly prepared report despite all the excellent discoveries from the microscopic examination. The findings have to be managed to address the purposes of the examination that had been established at the onset of the investigation. Erlin[4] has succinctly put it that, "Doing petrography for the sake of solely providing information can be an exercise of futility whilst doing petrography for the purpose of providing links within activity within the concrete (tiling works) to its eventual behaviour or performance is indeed a fulfilment of the science." Sorting out the major cause or causes from the minor causes or secondary effects of deterioration requires the exercise of an experienced petrographer's best judgment. In order to be effective, the petrographer needs a good understanding of all the materials, installation of tiles and the influence of environmental exposure on its stability and performance. In the final analysis, the questions raised and the appropriate answers to them should be delivered. The actual mechanism of failure, quality of workmanship, type of materials and quality of materials used, environmental effect and future performance will need to be dealt with.

Through the lens of a microscope, a skilled petrographer is able to interpret the tiling system's past as it really was - the materials quality, installation workmanship and exposure condition. With experience, through the use of a sound examination approach and in the light of continued research only then a reasonably sound diagnosis can be arrived at.

Like concrete which is a man made rock, a tiling system perhaps in a way represents a sedimentary rock made up of different layers. Like rocks and minerals, a tiling system is a "mirror" with a memory. The artifacts of man's folly and wisdom from selection to installation and the sometimes uncompromising effect of mother-nature can be engraved within the finished products or works. By conscientious analysis using a systematic and yet creative approach, the evidences can be amazingly uncovered.

In conclusion, the following quote pretty much sums up both the intricacy and beauty of petrographic examination, though it may sound exaggerated:

From a drop of water, a logician could infer the possibility of an Atlantic of a Niagara without having seen or heard of one or the other. So all life is a great chain, the nature of which is known when we are shown a single link of it. – Sherlock Holmes.

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