Fig 4a

Fig 4b

Attack of the Stylolites...!

Stylolite *n*. M19 [f. Gk. *stylos* column + -LITE.] Geol. A surface or a seam within limestone or (occas.) sandstone, characterized by irregular interlocking pegs or sockets around 1 cm in depth and a concentration of insoluble substances.

Stylolites (stylos + lithos) are irregular surfaces that commonly appear as dark, jagged lines on exposed surfaces of carbonate rocks (and rarely on other sedimentary rock types). Their origin is usually attributed to solution that occurs *after* the host rock was formed. The dark layers are insoluble residues.

In the annals of Post-Modern carbonaceous and dolomitic geology and geochemistry, few subjects have provoked more acrimonious debate, incomprehensibly complex three-dimensional diagrams and pedantic letters to editors of obscure academic journals than the nature, origin, diagenesis and idiosyncratic Weltanschauung of stylolites (pronounced *style-o-lights*). The only current rival in the fields of misdirected scientific enquiry and multi-lingual vituperation may be the splenetic debate over the whereabouts of *The Higgs'* bosun said to be buried somewhere under the Franco-Swiss border. This writer has definite and demonstrably sound views on all such matters and on the intellectual and personal shortcomings of opposing parties to these debates, in particular the flaccid and fatuous Dr. Manfredo Tartutti-Frutti of the University of Genoa, but *Discovering Stone*, alas, is not the most appropriate journal in which to explore and elaborate on those subjects.

Instead, I will concentrate on certain sub-parallel phenomena that, were they better understood, might cause roughly equal amounts of terror, confusion and delight among stone suppliers, architects, interior designers and consumers. I write, of course, of the relative strengths and weaknesses, stability, permeability and porosity of stylolites in limestone wall and floor finishes.

Efforts to describe the appearance of stylolites have sorely taxed the lexicon of academic geology. Most commonly compared to *sutures*, stylolites have also been described as *dark jagged lines, subplanar wavy features, tooth-like projections on one side of the surface [that] fit into cavities of similar shape of the other side* (this translated from the Dutch), *serrated interfaces between two rock masses that have a sutured appearance in section normal to the plane of the stylolite, stress-corrosion anticracks,* contact surfaces …*marked by an irregular interlocking penetration of two sides whereby the columns, pits and tooth-like projections on one side fit into their counterparts on the other, near-parallel squiggle-like lines* and as resembling pen traces on seismographs and electrocardiographs. You get the picture.

One stylolite enthusiast styling himself *The Lost Geologist* goes so far as to attribute to stylolites bad manners, writing that …*they will cut across any rock fabric without discrimination!* (see: http://lostgeologist.blogspot.-com/2009/02/stylolites-.hmtl). After years of patiently observing and analyzing various stratigraphic horizons in carbonate rocks, another aficionado has distinguished and classified six basic geometric configurations of stylolites: (1) seismogram types, (2) simple wavelike types, (3) sutured types, (4 & 5) Up-peak and Down-peak types, and (6) sharp-peak (tapered and pointed) types. This terminology is said to be essential for the purposes of scientific description according to the new Euronorm EN12407 - *Petrographic Examination*, and possibly useful in determining the quality of stone subjected to dynamic loading, as in floors and paving.

Once one becomes aware of stylolites and their significance in the performance of architectural stonework, it is difficult to overlook their ubiquity. It is said that a picture is worth a thousand words and the editor of *Discovering Stone* often remarks, evidently in homage to my well-honed photographic skills, that in my case a picture is worth several thousand words. I correspondingly draw attention to **Figure 1** that shows a series of approximately parallel orange/brown and black

Fig 1a

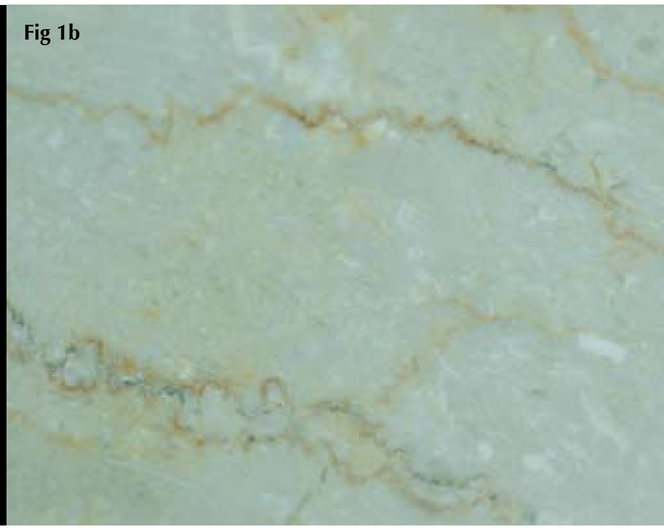

Fig 1b

Fig 4c

Fig 4d

stylolites in polished beige limestone of the floor of the lobby of the Crowne Plaza Hotel in Canberra.

With specific regard to the analogy often drawn between stylolites and sutures, I am compelled to observe that any surgeon whose suturing resembles these fairly typical stylolites should seek re-assignment to the post-mortem pathology department or even employment in a field remote from medicine. But I digress! **Figure 2** is a broader view of the hotel's lobby. **Figure 3** is a photograph taken with an on-camera flash to accentuate shallow irregular recesses along outcropping stylolites in an area subjected to heavy pedestrian and luggage trolley wear. These stylolites extend into the stone almost exactly perpendicular to its polished surface. Even here, however, the so-called *open* stylolites (below) enhance the natural appearance of the floor and are not detrimental to its performance. In technical terms, they are classified as *Good Stylolites*. After many years of heavy traffic and proper maintenance, the limestone floor remains resplendent, sound, serviceable and well worth a visit, as does the Binara cocktail lounge in the distant background.

Figures 4 to 6 are close views of fractures in 30 mm thick slabs of a beige French limestone used as veneer cladding on luxury apartment buildings at The Peak in Hong Kong. Within a year of completion, hundreds of limestone panels displayed full-depth cracks along open stylolites, breakages where stylolites intersected finished surfaces at shallow angles and spalls where stylolites coincided with or passed close to holes drilled for stainless steel dowel pin-fixings. After seven days of immersion in water, some samples of pristine limestone slabs from the same source could be forced apart by hand. During a protracted law suit instigated by the owner and developer of the apartments, the judge concluded that the limestone selected and recommended by the architect and project manager was not fit for its intended purpose; these weak brown seams were rightfully classified as examples of *Bad Stylolites*. Curiously, the small samples of stone, submitted for testing soon after stone selection was approved, were described by the testing agency as *grey limestone* containing no features that resembled stylolites.[NOTE 1]

An editorial in a European stone industry magazine recently observed that:

> *A great deal, if not most, of litigation and complaints in the [building] stone sector concerns floor coverings containing problematic stylolites cut with-the-bed,* >

NOTE 1 An excellent but dauntingly long account of this matter, entitled 'The effects of alkaline solutions on limestone', written by Peter McKenzie of Jackson Teece Architects and his obsequious sidekick Peter Hartog of Building Diagnostics Asia Pacific, was published in issue 6 of *Discovering Stone*. One reported highlight of expert evidence in the hearing was the stone importer's claim that the limestone's supposed age of 5 billion years demonstrated its durability. By current theories of geochronology, that stone would predate the formation of the planet by about half a billion years. Another was that limestone from the same French quarry remained intact in castles and walls built by ancient Roman invaders. That overlooked differences in the rates and effects of weathering on massive rusticated masonry blocks and on 30 mm thick honed slabs. The project managers pleaded that they knew nothing about stone and had not recommended any particular limestone. They were unable to explain why they had accepted the stone supplier's offer of first class return air fares to visit the quarry, warehouse and famed limestone buildings in France if not to enable them to assess and ultimately to approve the selected limestone. Ironically, floors in pubic areas of the high-rise court building in Queensway, Hong Kong, where these hearings took place, are finished in limestone with distinct, dense and very sound closed stylolites. Unfortunately photography in that precinct is prohibited.

Figures 4a-d (above) : *Close-up of brown stylolite seams exposed at edges of slabs of 30mm thick French limstone used for cladding of apartments in Hong Kong.*

Figure 5 ***(next page)*** *A stylolite, roughly parallel to the bedding plane of the same French limestone, outcropping at a honed surface.*

Figure 6. ***(next page)*** *A similar but more cunning stylolite made less visible by the bush-hammered finish.*

Figures 1–3 (below): *Close-up of typical stylolites in polished limestone of the lobby floor; general view of the lobby; close-up emphasising depth, not a defect unless extending to depth of slab. Crowne Plaza Hotel*

Fig 2

Fig 3

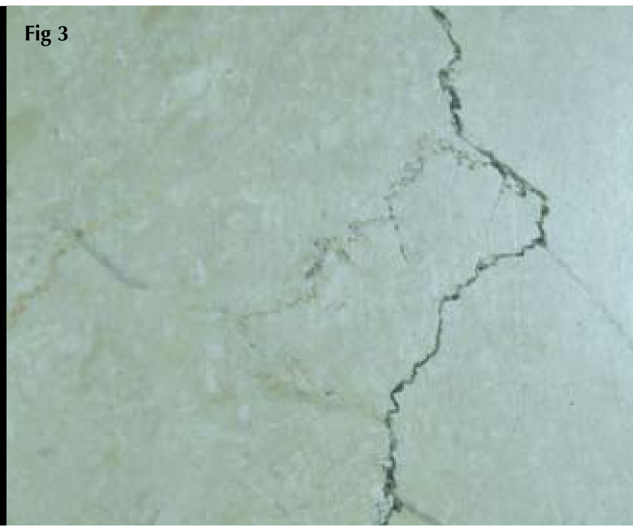

Figure 5. *A stylolite, roughly parallel to the bedding plane of the same French limestone, outcropping at a honed surface.*

Figure 6. *A similar but more cunning stylolite made less visible by the bush-hammered finish.*

in addition to slipping, tripping and stumbling accidents. …Environmental uses or conditions play an important part. For example, the same stone performing perfectly in cladding cut on-bed may have unsightly open seams when used in flooring water action, by continuous dampness, ponding, residual water or toxic cleaning may slowly dissolve the clayey or marly stylolite infillings. Surface spalling is another result from using stylolitic limestones cut on-bed.

Anecdotal information from local (Australian) consultants suggests that the incidence of disputation over unsatisfactory performance of limestone is rising. The European magazine lists some locally (in Europe) and internationally popular varieties of limestone containing stylolites:

Perlato Sicilia (Italy)	Botticino Classico (Italy)
Asagio Perlatino (Italy)	Topazio (Portugal)
Rose de Brignoles (France)	Comblanchien (France)
Rhodos Beige (Greece)	Serpeggiante (Italy)
Rocheret Gris (France)	Jaune Imperial (France)
Siklos (Hunagary)	Florida Rose (Spain)
Troizina (Greece)	Orquidea Sierra (Cuba)
Bayamo Orquidea (Cuba)	Basso Profundo (Arun Amarin)
Rosso Colemandina (Italy)	Saalburg Rot (Germany)
Portoro (Italy)	CH234 (China)
CH056 (China)	Tuhar (Czech Republic)

So, what are stylolites and what distinguishes the good from the bad and the ugly? For a start, **they are not veins or cracks** that occurred in limestone (and in marbles, travertines, dolomites, sandstones and bedded siderites) during lithification, that is, in the process in which loose sediments changed into solid rock. Although debate continues (see above), most credible geologists and Dr. Pingo Dripstone consider that stylolites are secondary structures produced by differential *pressure dissolution* (paradoxically also known as *pressure solution*) of materials along partings and fractures in already consolidated rock. In simple terms, crystalline solids under non-hydrostatic pressure are more soluble than identical solids under less pressure. They may therefore dissolve around points of local contact between mineral grains in zones of increased local pressure caused by vertical movements (from overburden pressure) and oblique or even horizontal movements (from tectonic forces). High compressive forces cause materials in solid layers of stone to dissolve, to be carried away through pore fluids between grains and to precipitate and consolidate in zones of relatively lower stress elsewhere. Carbonates are more soluble than quartz, so pressure dissolution from overburden loading tends to start at very shallow depths in high carbonate limestones and dolomites, whereas in quartzites it occurs at depths of 1000 metres or more.

In even simpler terms, the very fine-grained and solid but readily soluble stuff is dissolved and squeezed out. What remains are thin compressed seams of relatively insoluble materials, such as clays, silt, mica, oxides of iron and manganese and organic carbonaceous residues, that were from the outset and remain minor constituents of the consolidated rock. Comparison of concentrations of accessory minerals in marble (metamorphosed limestone) and stylolites has shown that 40% or more of the volume of a limestone bed may be dissolved and dispersed in the process of forming stylolites. This phenomenon of pore solution migration can be demonstrated at home with finely graded sand, refractory and metakaolin cements, common food dyes, everyday household tools and a slightly modified car panel stamping press of at least 45 tonnes capacity.

An important feature of stylolites is that most stylolitic structures caused by overburden pressures on limestone are oriented more or less parallel to bedding planes. In all cases, stylolites occur only in relatively “pure”, clay-poor and homogenous rocks. It follows that the presence of many stylolites probably indicates a relatively pure limestone, architectonically-speaking. According to Pettijohn’s magisterial *Sedimentary Rocks* (2nd edition, 1957, 718 pp, 2.85 kg.) stylolites have never been found in shales, an oddity that may puzzle anyone who has seen stylolites in calcite veins of carbonaceous shales at Arkaroola, South Australia and perplex those who dabble in hydrocarbon exploration.

If the materials within stylolitic seams of a limestone are acid-insoluble relative to the rock proper and are insensitive to moisture generally, the rock will be tend to be durable where used for architectural purposes in outdoor environments. Kaolinite (a white or grey aluminium silicate) and illite (a hydrated silicate of potassium and aluminium) are among the non-expansive or less-expansive clay minerals that are known to occur in stylolites.

If materials within stylolites are rich in clay minerals that swell (but do not necessarily dissolve) when damp, absorption of water during cycles of wetting and drying can cause the rock to weaken and even to disintegrate, as occurred in the French limestone cladding of the Hong Kong apartments. Swelling clay minerals in stylolites include montmorillonite (another aluminium silicate) and hectorite (a rare hydrous silicate containing aluminium, magnesium, calcium and lithium, mined and used commercially as a thickener in ‘organic’ cosmetics and roll-on deodorants).

Stylolites in finished limestone can be *closed* or *open*. Closed stylolites cause no visible disruption at the surface other than in the colour of the stone. Open stylolites occur where some of the insoluble minerals have been disturbed, during cutting and finishing, so as to leave shallow recesses. The distinction between good and bad stylolites may then depend on whether such irregular crevices (a) deepen in service enough to cause their edges to break or shear, and/or (b) admit and concentrate dust, dirt spilled liquids and cleaning fluids and in turn, cause staining.

>

Excessive wetting by damp mopping can also cause expansion and rapid decay of minerals within stylolites in high carbonate stone of interior floors. For example, two of the many varieties of limestone proposed in 2006 for flooring at a casino in Macau were rejected because the rate of spillage of drinks by gamblers at poker machines and of almost immediate mopping-up was estimated to be equivalent to as many as 3600 cycles of wetting and drying during the minimum tolerable service life of the floors.[NOTE 2] Early tests indicated that shallow open stylolites were likely to cavitate and accumulate soilants under such condiditons.

Some densely-compacted minerals in stylolites act as impermeable barriers to moisture movement through the stone, whereas pores and columnar capillary structures within other stylolites may have the opposite effect, i.e., they may provide conduits for migration of fluids and concentration of extraneous solutes, such as sodium and potassium salts from Portland cement in concrete backing and mortar bedding. If stylolites are immediate or potential planes of weakness in carbonate rocks, it follows that for stone to be used for flooring and paving, slabbing perpendicular to the bedding plane is to be preferred over slabbing parallel to the bedding plane for stone to be used for flooring and paving.

The strength, structure, constituents and likely effects of stylolites on performance of stone cannot be determined merely by examining pristine samples. Limestones (and in other types of stone; see above) with stylolites may appear to the naked eye to be dense, strong, homogenous and impermeable, but at the micro-scale may incorporate permeable, porous and moisture-sensitive materials that adversely affect durability and appearance in service. The best way to confirm the suitability of a stone for specific purposes is to examine a precedent that has stood the test of time in genuinely comparable conditions. Unfortunately, the marketing of new and untried stone products, sometimes by comparison to or as equivalent to familiar but unrelated varieties, as well as efforts by distant exporters to conceal ultimate sources of stone, can make this approach occasionally problematic.

If reliable information is not available, the durability, mineral constituents, structure and related properties of a stone can be evaluated with thin-section analysis by polarizing and fluorescent microscopy, by energy dispersive X-ray spectroscopy analysis, by methylene-blue absorption testing (to detect swelling clay minerals) and by other laboratory techniques. Two instructive case studies, one on limestone facing of precast concrete cladding panels and another on travertine floor tiles, have been published by J A Larbi of TNO Building and Construction Research of The Netherlands (HERON, Vol. 48, No.3 (2003), Special Issue). A paper titled *Microstructures and Evolution of Limestone Slabs Used in Building Façade Cladding*, by Potherat P *et al.,* was published in the proceedings of the *Symposium on Industrial Minerals and Building Stones* held in Istanbul in 2003. Attempts to obtain a copy have so far been futile, but the title is certainly intriguing. See also *Rolling Stone's* favourable review of *The Stylolites* 1998 album *Crenellated Cleavage*.

It is evident that some in the supply chain from quarry to stone-fixer do not appreciate the importance of stylolites and of confirming their soundness in all relevant service conditions. Ideally, product-specific information should be provided by stone sources and made available to exporters, importers and distributors. The cost of acquiring it independently is unlikely to be acceptable to prospective consumers other than on large commercial or institutional projects. Nonetheless, several members of the Australian Stone Advisory Association are equipped to perform and interpret the results of appropriate tests to help consumers avoid unanticipated and belated attack of the *stylolites*. Only excessive vibration under the base of our recent refurbished scanning electron microscope (due to nearby roadworks) and the lack of a reliable 3-phase electricity supply currently prevent Atelier Dripstone Bar & Grill offering this service. Meanwhile, for those visiting Baltimore, the Maryland State Geological Survey in the USA has prepared a *Geologic Walking Tour* of the downtown city, the highlight of which must surely be stylolites in light grey and pink Ordovician limestone from Tennessee in a powerfully oblate street sculpture on East Lombard Street just short of Commerce Street. This rates 4 out of 5 Oolites of the logarythmic Dripstone Scale.

An unrelated matter…
Figures 7 show examples of progressively worsening brown staining of polished and honed granite on walls at the base of a four-storey electronics factory and attached offices in Singapore. The staining was first noticed within a year of completion of the building in 2002; these photographs were taken in 2009. Stains occur wherever an unidentified epoxy resin has been used (1) around stainless steel angle fixings that engage slots cut into the rear faces of stone panels, and (2) as flattened pads between stone and the underlying concrete blockwork wall. **Figure 8** is a close view of two of these stains. Their colour and spread change with exposure to rain and sunlight; where completely sheltered under the porte cochere (**Figure 9**), the stains are almost black and much smaller and display distinct edges. The most remarkable aspect of this daunting detail is the explanation initially offered by an expert witness acting of behalf of the building contractor; the stains were, he declared, a natural and unavoidable feature of the stone. Dr. Dripstone is interested in feedback – via the ever-obliging editor of *Discovering Stone* - from those who have seen and can explain similar staining.

Dr. Pingo Dripstone is an inveterate contributor to Discovering Stone *and self-published author of* Dive Site Atlas of Tibet, Asphalting for Beginners *and the frequently anthologized screenplay* Revenge of the Microlithons. *His interest in stylolites commenced in the early 1980s when, in search of dissertation subjects for a mail-order doctorate, he embarked on a decade-long quest to demonstrate that stylolites contain hastily scribbled messages from ancient prelithic but proto-literate civilizations. He now regretfully characterizes that part of his career as a futile obsession brought on by routine overindulgence in botrytis-affected wines of the Yarra Valley and chemically incompatible prescription drugs.*

NOTE 2 Two members of the staff of Atelier Dripstone Bar & Grill are proud to have been closely involved as beverage-mixing, spillage and fluid removal consultants during this extensive program of off-site real-time full-scale prototype testing. As a public service, we take this opportunity to record that the most powerful common staining agents identified in the experiments were Tabasco sauce, squashed pimentos and various purple liqueurs. Red wine of any quality and lime juice were found to remove the polish from reconstituted marble tiles within 10 minutes.


Fig 7

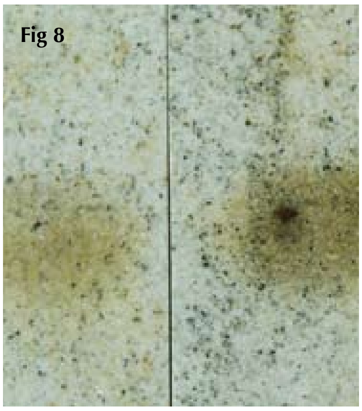
Fig 8

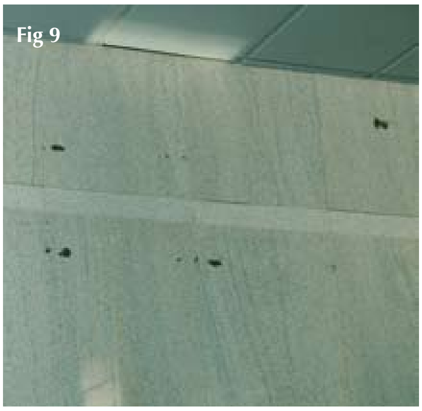
Fig 9