Technical Paper TP003
Tiles made from Natural Rock Types
Identification, Issues and Considerations

Monday, March 16, 2009—Wednesday, October 11, 2017

Introduction and Scope

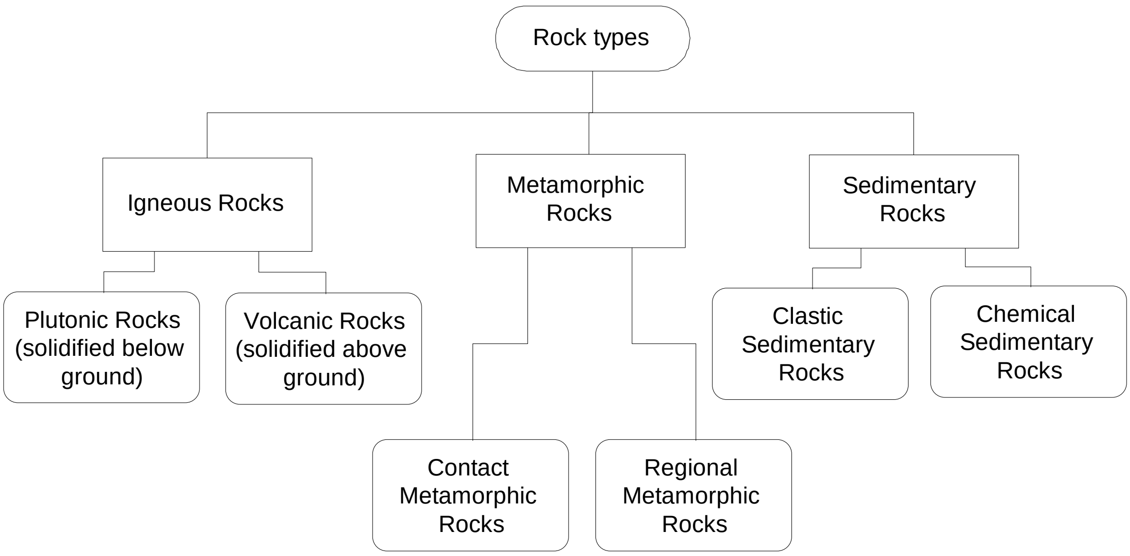
It is a long standing quirk of the tile and masonry industry that tiles made from natural rocks (called 'stone' or 'stones' by the trade) commonly have names that do not reflect what the rocks are really made from. Whilst it might be a marketing thing to give the tiles glamorous or mysterious names, it also creates some issues for selection of adhesives to fix these tiles. A lot of stone tiles have come through Ardex Technical Services, and in quite a number of cases, the name has no bearing on what the rock really is.

Compounding the problems of naming, are peculiarities of the rocks themselves and particularly the properties of cheap stone tiles brought in from places outside Australia. We at Ardex have seen of late, a number of stone tiles that ostensibly should be stable based on their nominal rock type, but have turned out not to be when installed. Closer examination has shown the presence or unstable minerals or other issues.
In this paper we will look at the different types of rocks used to make 'stone' tiles, and also the properties and any 'show stoppers' that might occur with them.

Types of Rocks

There are three basic types of rocks that are quarried for the manufacture of tiles and they are further subdivided into two classes for each basic sub-type. The classifications are genetic and mineralogy based divisions. Genetic means how the rock formed, and mineralogy means what mineral types make the rock up.

The classification scheme is shown above, and the principle types of rocks used for the wide range of 'stone' tiles are the Igneous and Sedimentary rocks. Metamorphic rocks are lesser used with a handful of specific types the major representatives.



This paper is divided into three parts for simplicity, Part 1 covers Igneous rocks, Part 2 covers Sedimentary rocks and Part 3 covers Metamorphic rocks.

Glossary of Terms

Amphibole—A rock forming mineral found in Igneous and Metamorphic rocks. These are usually dark colours in shades of brown, green and black, and are composed of Silica with metal cations Iron, Magnesium and Calcium. They commonly have needle to columnar crystals with 60-120^0 edge angles.

Acidic—An older term used to describe Igneous rocks containing high levels of Quartz. Granitic rocks were commonly called acidic.

Alkaline—An older term used to describe Igneous rocks containing raised levels of Sodic and Potassic Feldspar.

Arkose—A type of sandstone where the major mineral grains are composed of detrital Feldspars.

Ashlar—Finely dressed (cut, worked) masonry, either an individual stone that has been worked until squared or the masonry built of such stone.

Basic—An older term used to describe Igneous rocks with high level of iron-magnesium minerals. Pseudo synonym for Mafic, and applied to Basalts and Gabbros.

Calcite—Rock forming mineral composed of Calcium Carbonate. The mineral forming Limestone and Marble, and common cement for Sandstone.

Chrysotile—One of the three polymorphs of Serpentine that can be found in Serpentinite. This is one of the three common forms of asbestos and is usually called white asbestos. It is a well documented cause of fatal lung disease and cancer and is a banned import.

Contact metamorphic– These rocks are formed from pre-existing country rocks by heating and solution effects caused by contact or close proximity with underground molten igneous rocks (usually Granitic rocks).

Feldspar-Common rock forming mineral composed of Silica and metal cations such as Calcium, Potassium and Sodium. Colours are light and range from clear to white, cream, beige, and pink to red. The crystals are commonly tabular or blade like, and many be visibly twinned.

Leucocratic– Light coloured igneous rocks with high contents of minerals such Quartz, Feldspar or Feldspathoids.

Mafic—Dark coloured igneous rocks which contain high contents of iron-magnesium minerals and low or nil free silica as Quartz.

Melanocratic—The term refers to the dark colouration of igneous rocks because of high dark mineral content. Mafic rocks tend to be melanocratic, but Granitic rocks with higher than normal amounts of Pyroxene, Mica or Amphibole can be called melanocratic.

Mica—Common platy structure rock forming mineral in Igneous and Metamorphic rocks. The common types varies in colour from clear through shades of brown to black. Slate is composed of Mica and Quartz.

Olivine—A rock forming mineral in basic igneous and some metamorphic rocks, composed of iron and magnesium silicate. It usually forms green, yellow green to green brown crystals which are easily recognisable.

Pyroxene—A rock forming mineral found in Igneous and Metamorphic rocks. These are usually dark colours in shades of brown, green and black, and are composed of Silica with metal cations Iron, Magnesium and Calcium. They commonly have stubby prismatic shaped crystals with 87^0 edge angles.

Regional metamorphic– These are rocks are formed from pre-existing country rocks by compression and heating caused by mountain building or continental collisions and movements.

Silica cement / Siliceous cement—Dissolved silica (effectively dissolved Quartz) that forms the cement of Sandstone, especially Quartz Sandstone like those found in the Sydney region.

Quartz-Rock forming mineral that composed of Silicon and Oxygen, and has the general formula SiO_2. This is very common, and is the familiar water-white glassy mineral that makes up common beach sand in Australia.

Vesicles (n), Vesilcular (adj)—A small cavity in a volcanic rock that was formed by the expansion of a bubble of gas that was trapped inside the lava.

Part 1—Igneous Rocks

Igneous Rocks

The two basic types of Igneous rocks are Plutonic and Volcanic which solidify from the molten state— magma (genetic). Their basic compositions are the same (mineralogy), but the appearances are completely different.

Plutonic Rocks

These solidify below the ground and are coarsely crystalline to look at, with crystals sizes from around 2mm upwards. These rocks are typically hard and strong, but may also contain some minerals that are not long term stable at the earth's surface and so weather easily. The faster the rock cools, the smaller the crystal size, and so shallower rocks tend to have smaller crystals.

Volcanic Rocks

These rocks come of out the ground from volcanoes (liquid lava or falling ash), or harden below the surface at very shallow depths. The rapid cooling results in the rocks either being fine grained with no visible crystals, or being porphyritic which means they are a mixture of fine matrix with coarser crystals embedded. The hardness and strength of volcanic rocks is dependent on whether the rock hardened from flowing lava (hard-strong) or formed from compacted ash fall out (usually not as strong).

Colour	**Fine Grained Volcanic Rock/ Coarse Grained Plutonic Rock Equivalents**			Tradenames
Very light coloured creams, greys, pinks, beige, red-brown	Rhyolite/Granite (light to very light colours)	Rhyodacite/ Adamellite (light colours)	Dacite/Granodiorite (light greys)	True Granites
Intermediate greys, greenish or brownish tinged rocks	Alkaline Rhyolite/ Monzonite-Syenite (shades of grey)	Trachyte/ Monzonite (mid grey)	Andesite/Diorite (Black and dark to mid grey)	So called 'Blue Stones' are on this side of the table
	Trachyte/Syenite (shades of grey)	Alkaline Basalts/ MonzoGabbros (Black to shades of grey)	Basalt/ Dolerite_Gabbros (Blacks, blue blacks, dark greys, green blacks)	
Black or shades of black. Unusual colours due to specific mineralogy.	Trachytes/Syenites		Basalts/Gabbros-Anorthosites (blacks, bluish blacks, banded, whitish blues, greenish blacks)	Coarse grained are so called 'Black Granites'

Light vs Dark—Mineralogy

The composition of the rock controls its properties, but the most immediate difference is the colour scheme, and colour is usually the first indicator that the rock name doesn't match what the rock really is. Light coloured (leucocratic) unweathered igneous rocks are full of very stable Quartz and reasonably stable Feldspars. Dark coloured (melanocratic) rocks contain less stable feldspars and dark minerals such as Pyroxene, Amphibole and Mica.

The above table immediately gives rise to an obvious naming problem, and a commonly encountered commercial name is 'black granite'. Examination of any commercial catalogue which show a range of dark rocks named as 'black granite'. The reality is that there is no such thing as 'black granite', and that coarse grained black rocks live in the bottom right hand corner. As such they would be correctly Gabbros, Dolerites, Diorites and other specialized rock types of rarer distribution.

By contrast, petrographically correct granites live in the top left hand corner and are pale colours. The reality is that Granite-Adamellite-Granodiorite and many Syenites are all considered 'granitic rocks' and have similar properties. This is more than an pedantic academic argument though, since the black rocks often contain minerals that are less stable and weather more easily than the 'granitic' rocks. Granitic rocks are also usually harder because they contain more quartz. A further important feature of the dark rocks is that are more likely to contain unstable sulphides and oxide mineral grains that weather or rust out.

Another problem commercial name is 'blue stone' which could any of the fine to medium grain rocks on the lower right quadrant ranging from Trachyte, Andesite to Basalts. The indescriminate naming means the mineralogy is not certain but worse, neither is the texture which could be anything from hard dense basalt to fragmental ash deposits composed from Andesite and crystals—really almost a sedimentary rock, and often weak and porous. Traditional 'blue stone' from Victoria is normally a hard and durable Alkaline Basalt, but cheaper imports are usually something else with highly variable properties.

Basalt

The most commonly used volcanic rock is Basalt which is a fine grained, dark blue-gray to black and hard. Basalt does not show a crystalline texture but has a fine grained ground mass, though individual crystals may be present in the rock. It can also be full of voids and holes which are called vesicles or scoriaceous texture. As a tile, fine grained Basalt is normally stable, hard and long wearing. The dark colour however can have thermal implications for external installations.
As already noted, a lot of rocks that are not Basalt are being called it, or 'Blue Stone' so an examination of the tile may be required to determine what it really is.

An example of a black fine grained Basalt tile

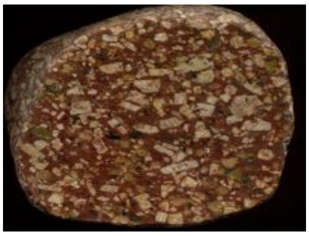
Scoriaceous Basalt time

Basalt hand specimen

Ignimbrite

These are a particular type of volcanic rock, usually a Dacite-Rhyolite which was formed by welding together of hot ash fall material. They are sometimes called 'welded tuffs' and can be either very hard and dense, or conversely soft and porous. The ones used for tiles are the hard glassy ones which can be a bit like a porcelain tile to bond. They are usually stable, unless severely altered by weathering and long lasting but the darker coloured ones also suffer from thermal heating effects when exposed in the sun.

Purple-brown ignimbrite tiles

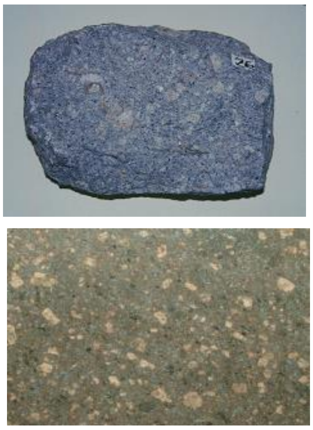


Hand specimen showing distinctive welded appearance with flattened glass shards

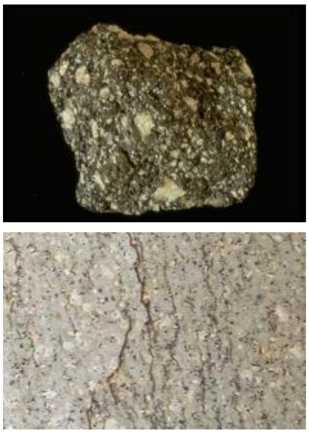
Light coloured volcanics

Some light coloured volcanic rocks are quarried for tiles, usually Trachytes, Rhyolites or Dacites. They are typically creams, pales brown or pale gray in colour, and are usually hard and non-porous. However, some rocks have been weathered and contain clay minerals and pores. The hard dense ones are normally stable and have similar bonding requirements to porcelain. The weathered and porous ones however can displayed moisture dimensional instability and also marking.

Rhyolite rock hand specimen and tile. Note layering in rock called flow banding and glass shards



Dacite rock hand specimen and tile. The large crystals are Feldspar.



Trachyte rock hand specimen and tile. These rocks often show Feldspar or Feldspathoid crystals.

Gabbroid Rocks

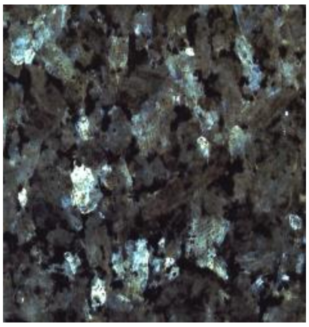
The term Gabbroid refers to the range of medium to dark grey-green, blue-black to black coarse grained plutonic rocks used for tiles. They are hard, non-porous and relatively heavy. The properties of these rocks are reasonably similar and they display large and obvious crystals sometimes with unusual colours or iridescence (Labradoresence from a particular type of Feldspar) . As we have noted these rocks carry the common misname 'Black Granite'.

Stability was not usually considered a problem with these rocks until recently when very high Olivine content cheap greenish Gabbros and Microgabbros (Picrites) appeared on the market. Some examples of this rock tile Ardex has seen display severe thermal warping problems. Moisture stability has not historically been a problem but high proportions of metastable minerals can lead to premature weathering. Some Gabbroid rocks carry sulphides which weather out and stain over time and produce rust stains.

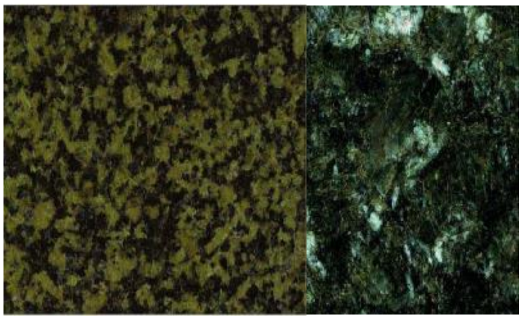
As the grain size reduces, the rocks grade into Dolerite, and with increasing quartz content to Diorites (sometimes called Quartz-Porphry). The increased quartz content makes the rocks harder and more weathering resistant. Visually Diorites are lighter with a more grey speckled appearance than Dolerite.

With an alteration in the feldspar type the rocks grade into Syenite and finer grain Microsyenite. There is a continuum of feldspar compositions with resultant changes in the rock type. Increasing the quartz alters the rock type to Monzogabbro and Monzonite. Syenites can be a wide

Examples of Gabbro. The rock at left is a hand specimen and below three examples of Gabbro tiles. These are the rocks erroneously called 'Black Granite'.



Special Gabbroid rocks called Anorthosites are common as tiles called Blue Pearl and similar names. The iridescence (Labradoresence) comes from the bluish coloured Feldspar.



Another unusual Gabbroid rock sometimes called 'Green Granite' is Charnockite. It contains a green Pyroxene called Hypersthene.

Examples of Dolerite as hand specimen and tile

Examples of Diorite as hand specimen and tile

Example of Syenite as handspecimen and tile

range of colours from grey, greenish to browns and also vary in grain size from medium to very coarse.

Granitic Rocks

The term granite is severely misused, but in its correct sense refers to light coloured coarse grained plutonic rocks that contain high contents of feldspar and quartz.

They usually carry a small percentage of dark coloured minerals which gives them their speckled appearance. The high quartz content makes them normally hard and stable, but feldspar and dark minerals can affect the long term weathering stability. Of all the igneous dimension stone, granitic rocks are the most used and have the highest performance.

We have noted that some examples display moisture sensitivity to colour changes and shading.

An example of a moisture sensitive granite tile effected by adhesive. At left the original tile and at right bonded to concrete with a standard C Class cement based adhesive.

The colour and texture range for granitoids is vast and they are very common rocks overall leading to a very wide range of suppliers and sources. The primary considerations with granitic rocks in relation to stability are whether they contain unstable sulphide minerals, have badly weathered dark minerals or Feldspar, and if they have open pores and sheared structures. Moisture stability and staining are not normally associated with granitic rocks, but occasionally have been observed from some source areas and in thinner examples. Reputable suppliers would source fresh material rather than weathered surface types.

An example of true Granite above, and at right some of the many granitic dimension stones used as tiles.

An example of Adamellite which is intermediate between Granite and Granodiorite based on Feldspar types. This sample has large crystals of pink Orthoclase Feldspar, and is called porphyritic.

An example of Granodiorite. These are commonly more melanocratic than true Granite, and contain Plagioclase as the main Feldspar.

Common usages and other considerations.

Coarse Grained Rocks

The Granitic and also Mafic plutonic rocks have been used for ashlars and construction of buildings and monuments since pre-historic times, for example ancient Granite standing stone Menirs in Europe, and Stonehenge in the UK is constructed mainly from Dolerite. Parts of the Great Pyramid near Cairo are constructed from Granite block. More recently these rocks have been used in many major and historic buildings in the worlds cities; the piers of the Sydney Harbour Bridge are Granodiorite from the NSW south coast. Syenites have also been commonly used, but are not usually recognised by non-specialists for what they are.

Typically Granitic rocks are very stable and weather well, and their high strength and stability makes them suitable for heavy construction. They also make good tiles for internal and external applications (noting some issues with marking recently), on walls and floors.

The Gabbroic rocks are also stable, however the minerals they are composed from are less environmentally stable than the lighter coloured rocks. They have been used less commonly for construction stone that the leucocratic equivalents. In particular the green mineral Olivine which is present in greenish coloured mafic rocks weathers relatively rapid. To this end, high Olivine content rocks (for example Picrite or Olivine Dolerites/Gabbros) are unstable and not ideal for external applications. Dark coloured rocks also tend to heat up much more in solar exposed situations than paler coloured rocks.

Both light and dark coloured types commonly carry sulphide mineral grains and the darker rocks metallic oxides which tend to 'rust' and corrode out leaving pits and rust stains down the rock face. When installed on walls weight is a consideration, and more so for the Gabbroic rocks as they have greater physical density.

Fine Grained Rocks

The most commonly used fine grained dark volcanic rocks are the loosely named Basalts (because commercially it commonly also includes fine grained Dolerites, Andesites and Trachytes). These have been used for various construction purposes, and since ancient times have been used for packed dry wall type constructions. They are generally stable and weather well. 'Blue stone' has been commonly used for building in Victoria and South Australia because of the ready availability of good Alkaline Basalts. As tiles these rocks are normally sound and can be used for internal and external tiles. Where they are vesicular, they can be more prone to showing moisture penetration since it find its way through the voids in the rock structure.

The lighter volcanic rocks are less commonly used for tiles. The compact and solid ones are usually Quartz rich, hard, dense and difficult to cut. Slabs have been used for block construction. Generally these rocks weather well and are durable. Since they commonly dense they are normally stable to moisture.

The tephra (ash) types like Pumice and some Ignimbrites are usually too weak and poorly compacted to use for construction. Moderately welded or lithified ash though can be cut into blocks and used for construction such as NZ Hinuera stone.

Granite headstone

Hinuera stone wall

Blue stone dry wall

Syenite statue

SEDIMENTARY ROCKS

The second major class of rocks used for dimension stone and tiles are the Sedimentary Rocks. These are formed from the erosion products of other rocks, fossil deposits, or from chemical processes that set down particular minerals. Like Igneous rocks there are two major types—Clastic sedimentary rocks which are formed from erosion particles (clasts or grains) bonded together with a cement (matrix), and Chemical Sedimentary rocks which are composed of minerals which precipitate from solution, often containing particles or fossils and a matrix which holds them together.

From the perspective of 'stone' tiles, the most common types come from the Limestone and Sandstone families. The general groupings encountered are shown in the table below.

Family	**Clastic Sediments**		**Chemical Sediments**	
Common Types	Quartz Sandstone	Feldspathic Sandstones (Arkoses)	Fine grained Limestone	Onyx/Cherts/ Sards
	Rock fragment Sandstones	Volcanic Sandstones (ash falls and erosion products)	Alabaster and Gypsum like minerals	Travertine, Caliche
	Conglomerates and Breccias	Fossiliferous and Grain Containing Limestones		Crystalline Limestone
	Clay—Mudstone		Lime Mudstone	

CLASTIC SEDIMENTS

The most commonly encountered clastic rocks used for tiles are sandstones, which are formed from eroded sand sized grains bonded together with a cement.

Sand is actually a textural term and refers to particles with a size between 0.06 and 2mm in diameter. As can be seen from the table above, sand can made up from a large variety of minerals or fragments (e.g. small rock fragments or even volcanic ash) so the term does not necessarily refer to rocks like the familiar Australian Quartz Sandstones used for building stones. In the case of some rocks, such as grainy volcanic types it can be diificult to determine if the rock is actually a primary volcanic rock, or a secondary sedimentary rock made up from volcanic debris. This can have some implications for dimensional stability.

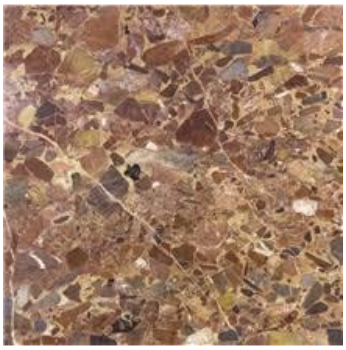
The mineral types can have an effect on the properties of the sandstone, as unstable minerals can lead to dimensional and durability problems. For example sandstone containing high feldspar, mica and volcanic mineral content are more likely to weather or deform than sandstone made of quartz sand.

Typical sandstone tiles and hand speciment

There are three common types of cement which hold the clasts together, and to be called a sandstone, the matrix cement has to be less than 50% of the rock mass. The three most common cements are re-dissolved silica, Calcium Carbonate (spar or lime mud) and clay. Each cement has its own properties and it is the clay and lime mud types which can lead to instability problems and marking.

The size next scale up is Conglomerate which comprises rocks grains from <2mm up to cobbles 30cm in size. The composition of the grains can be any type of other rock, and reflect typically whatever the mountains nearby were made from. When the clasts are rounded the rocks are Conglomerate, and when angular are usually Breccia. Paraconglomerates are less than 20% clasts and Orthoconglomerates less than 15% matrix.
These strong and usually hard rocks are made into spectacular tiles at times, but also have the man made analogue of terrazzo tiles (cement or resin, and usually limestone chips).

https://mineralseducationcoalition.org/



Conglomerates

These clastic colour of these rocks can vary widely with grey, almost black, all shades of brown, whitish, creams, orange, shade of red and grey greens all being possible.

Chemical Sediments

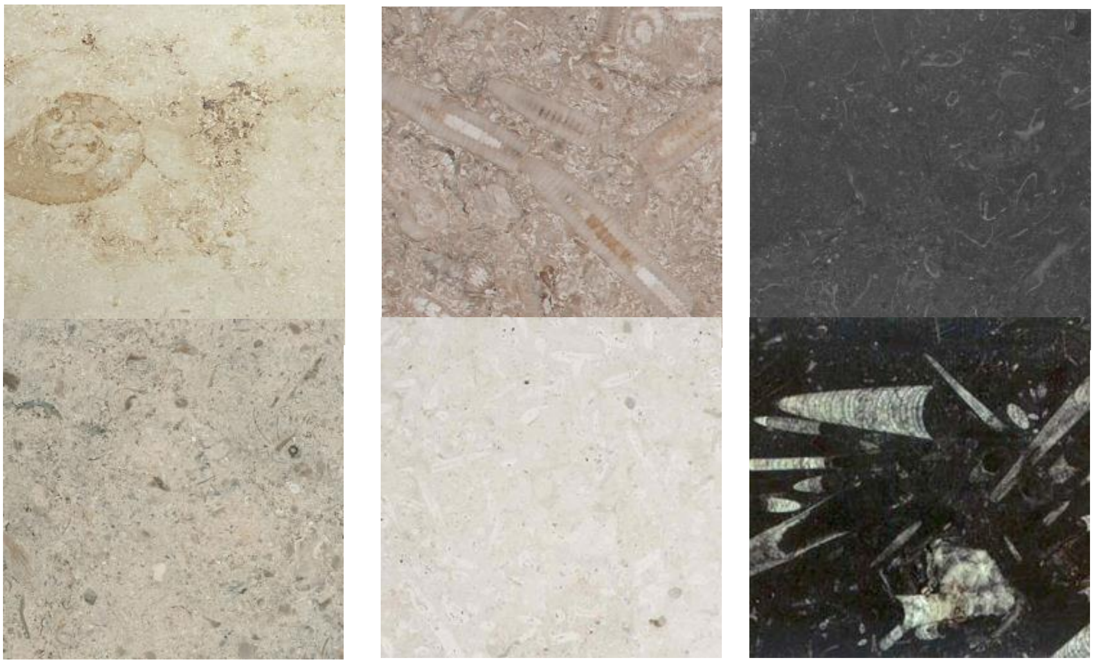
These are rocks made up from minerals that have precipitated from solution usually in seawater, but also salt lakes and hot springs.
There are several varieties that are commonly found as tiles including Limestone, Dolomite and occasionally Onyx and Alabaster.

Limestone

The most common type of chemical sediment is limestone which is made up from Calcium Carbonate cement which has come out of solution, and frequently marine **fossils** or other calcareous grains or sands. The related Magnesian rock is called Dolomite (or Dolostone) which is usually a mix Magnesium Carbonate and Calcium Carbonate.
The primary issues with Limestone are to do with the way the cement holds the rock together. Where the carbonate matrix is lime mud the fine particles can absorb water and swell or distort, or selectively retain components of the adhesive and discolour. The thinner the tiles the more likely this is to happen. Sparry Limestone and recrystallised Limestones are more stable.
A secondary issue with limestone is that they frequently carry mechanical defects which can render them weak or susceptible to unusual moisture movements.
The most unstable, porous and mechanically weak types of limestone are Travertine and Caliche which are usually formed from hot water solutions or carbonate rich brines.
Hard and compact limestone is normally shades of grey, blue grey to black due to mud and iron mineral content. The highly porous limestones such as Travertine are typically greys, creams and brown.

Rill weathered limestone at Wee Jasper NSW.
http://www.geomaps.com.au/scripts/weejaspercaves.php

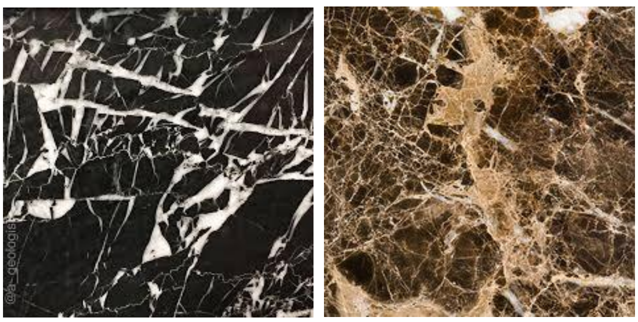
Laminated or varved limestone tiles—typically display moisture marking in thinner slabs



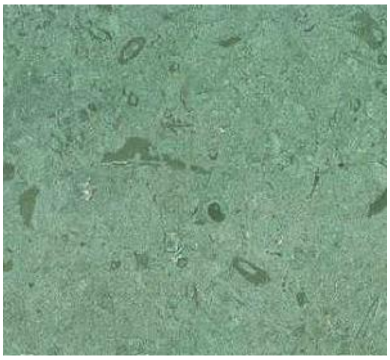
Fossiliferous limestone tiles—Matrix rich tiles can show marking. Denser darker tiles tend not show any marking.

Travertine limestone tiles—These tiles often show marking which starts at the voids in the rock structure. They can be filled with grout to fill the voids.

L Grey limestone
R Two examples of veined and cataclastic limestone (often called 'Marble')



It is important to note that Limestone is not Marble and visa-versa. They might have the same composition, but have formed in different situations and do not have the same properties. Limestone is commonly erroneously called Marble for commercial reasons.
Dark coloured limestone is known to carry sulphide minerals such as Pyrite which can result in rusty weathering stains on the rock when used externally.



Dolomite tile

Mudrocks ('shales')
Mudstones are not commonly encountered as they are relatively weak and weather poorly. However they are the precursor rocks for slates, and some of the commercial slates are so low grade they almost retrograde into mudstone or indurated siliceous mudstones called Argillites. They are relatively easy to recognise as they are normally finely layered (laminated) and soft to scratch. The colours are very varied from yellows to red-browns, greens, grey, black, bluish-grey and even creamish shades. The right picture is an Argillite formed into a 'slate' stackstone.

http://www.sandatlas.org/shale/

Alabaster and Onyx
Alabaster is in the strict sense Calcium Sulphate (Gypsum—as a sulphate, the mineral forms as an evaporite in salty lakes), but this is really too soft for tiles, and the industry has also used this name to cover a type of pseudo Alabaster that is really Calcium Carbonate (i.e. Limestone). In the latter case, the tiles behave like limestone tiles.
Onyx is a hard rock formed from microcrystalline silica and is related to Agates and Cherts. Tiles made from this rock are hard likely to stable.

Two examples of Alabaster tiles

An Onyx tile

Common usages and other considerations

The main types of sedimentary rocks used for construction purposes are Sandstone and Limestone.

Limestone

The use of Limestone goes back to ancient times and many grand buildings and monuments were constructed from Limestone or its sibling Marble as ashlars, columns, facings and other major building elements. In the majority of cases the rock used was Limestone, rather than true Marble, though it may have been called the latter. The Egyptian pyramids were clad in Limestone, and Roman and Greek buildings were constructed from it as well (with ornamental Marble as well). Limestone is still used for these purposes, for example the Australian War Memorial in Canberra. The weatherability of these rocks are reasonable though they are not as robust as igneous rocks and suffer chemical as well as physical weathering.

For tiles the major concern is moisture sensitivity in terms of marking and show through. The fine grained Limestone and materials such as Travertine commonly allow moisture through rapidly and can develop spotty appearances. They can also be marked by standard cure adhesives. For most types, the rocks can be used internally or externally, however the ones highly sensitive to marking will constantly show irregular appearances with changes in moisture content due to rainfall and drying. Certain limestones can also display efflorescence where they contain salts or free Calcium salts which can be leached.

Sandstone

This rock has also been used since ancient times for construction and the most conspicuous use was the Medieval cathedrals of Europe. In Sydney, many of the Colonial and Victorian era buildings were constructed from locally quarried white or honey coloured Sandstone. The usages are equivalent to Limestone with ashlars, massive blocks, columns, pediments and other detailing carved from the rock.

The weatherability, performance and strength are dependent on the mineral grains that form the rock skeleton, but also the cement matrix that holds the grains together. Dense Sandstone composed of Quartz grains and siliceous cement is harder and weathers better than Arkosic Sandstone with iron oxide or Calcite cement. For example, building constructed in Sydney in the 1800s are displaying varying degrees of erosion, with certain buildings having sections progressively replaced.

The susceptibility to warping appears to be low, but commonly Sandstone can mark and display moisture show through. The thinner the tile, the more porous the cement, and the less dense it is, the easier and more likely it is to display marking. The generally high porosity of Sandstone means that soluble materials (such as solutes from the adhesive) are more likely to penetrate and permanently mark the tile.

Most sandstone tiles can be used internally or externally, but it needs to be recognised that they are more likely to show moisture effects than other types of stone. The commonly pale colour of many freshly hewn Sandstones tends to darken and become more orange-brown over time due to oxidation of the iron content. The surface of sandstone on external floors and as flagging will tend to develop moss and algae, giving them a distinctive greenish colouration. Sandstone can also bleed iron oxides can develop red brown stains and streaking down the surface, and some can also contain efflorescent salts which can be leached out.

METAMORPHIC ROCKS

The third class of rocks used for cladding and tiles are metamorphic rocks. These rocks are derived from the altering of other the rock types due to heat and pressure. The degree of alteration is referred to as 'grade' and the higher the grade the more severely altered the original rock has been. The alteration process creates distinctive structures and fabrics in the rock which have implications for the properties of the rocks when used as tiles. There are two basic types of metamorphic rocks that result from the alteration process they have undergone.

The first type are called 'Regional Metamorphic' rocks which result from tectonic earth movements and are formed by predominantly high pressures and to a lesser extent high temperatures. Regional metamorphism results in the formation of fabrics in the rock, which as the degree of metamorphism increases become more pronounced. An example of such a fabric is the structure of slates, were the rock peels apart in layers.

The second type are 'Contact Metamorphic' rocks which have been altered by exposure to high temperatures and also heated fluids. These rocks are more likely to be crystalline and may not show any distinctive fabric unless coarser grained.

Some types of source rocks produce the same metamorphic rocks regardless of the type of metamorphism, for example limestone and quartz sandstones produce marble and quartzite in both cases.

The two tables show the continuums for metamorphic rocks from low to higher grades left to right across the table. The Regional Metamorphic rocks are easier to identify in hand specimen that the Contact Metamorphic rocks which usually require a more careful examination of the minerals present.

Regional Metamorphic Rocks

Source rock	Very Low Grade	Low Grade	Medium Grade	High Grade
Mudstone	Argillite-Slates	Phyliite	Greenschist-Schist	Light coloured Paragneiss
Limestone	Limestone	Marble	Marble	Marble
Sandstone	Indurated Sandstone	Quartzite	Quartzite	Quartzite
Mafic Volcanic (e.g. Basalt)	Meta-volcanic	Meta-volcanic	Schist - Amphibolite	Orthogneiss
Mafic Intrusives Olivine rich	Serpentinite	Serpentinite	Serpentinite – Blue Schist	
Silicic Volcanics (e.g. Rhyolite)	Meta-volcanic	Meta-volcanic	Feldspar-White Mica Schist	Orthogneiss to Migmatite
Silicic Plutonics ('Granites')	Meta-Granite	Meta-Granite (Foliated)	Meta-Granite to Schistose Granite	Orthogneiss to Migmatite

Contact Metamorphic Rocks

Source rock	Very Low Grade	Low Grade	Medium Grade	High Grade
Mudstone	Argillite	Spotted Mica Hornfels	Purple-brown Hornfels	Mid to purplish brown Hornfels
Limestone	Marble	Marble	Marble	Marble
Impure Limestone	Calc-Silicate rock	Calc-Silicate Hornfels	Calc-Silicate Hornfels	Grey-green Hornfels
Sandstone	Indurated Sandstone	Quartzite	Quartzite	Quartzite
Mafic Volcanic (e.g. Basalt)	Meta-volcanic	Meta-volcanic	Black-green Hornfels	Greenish-grey Hornfels
Silicic Volcanics (e.g. Rhyolite)	Meta-volcanic	Meta-volcanic	Pale coloured Hornfels	Pale coloured Hornfels

Increasing →

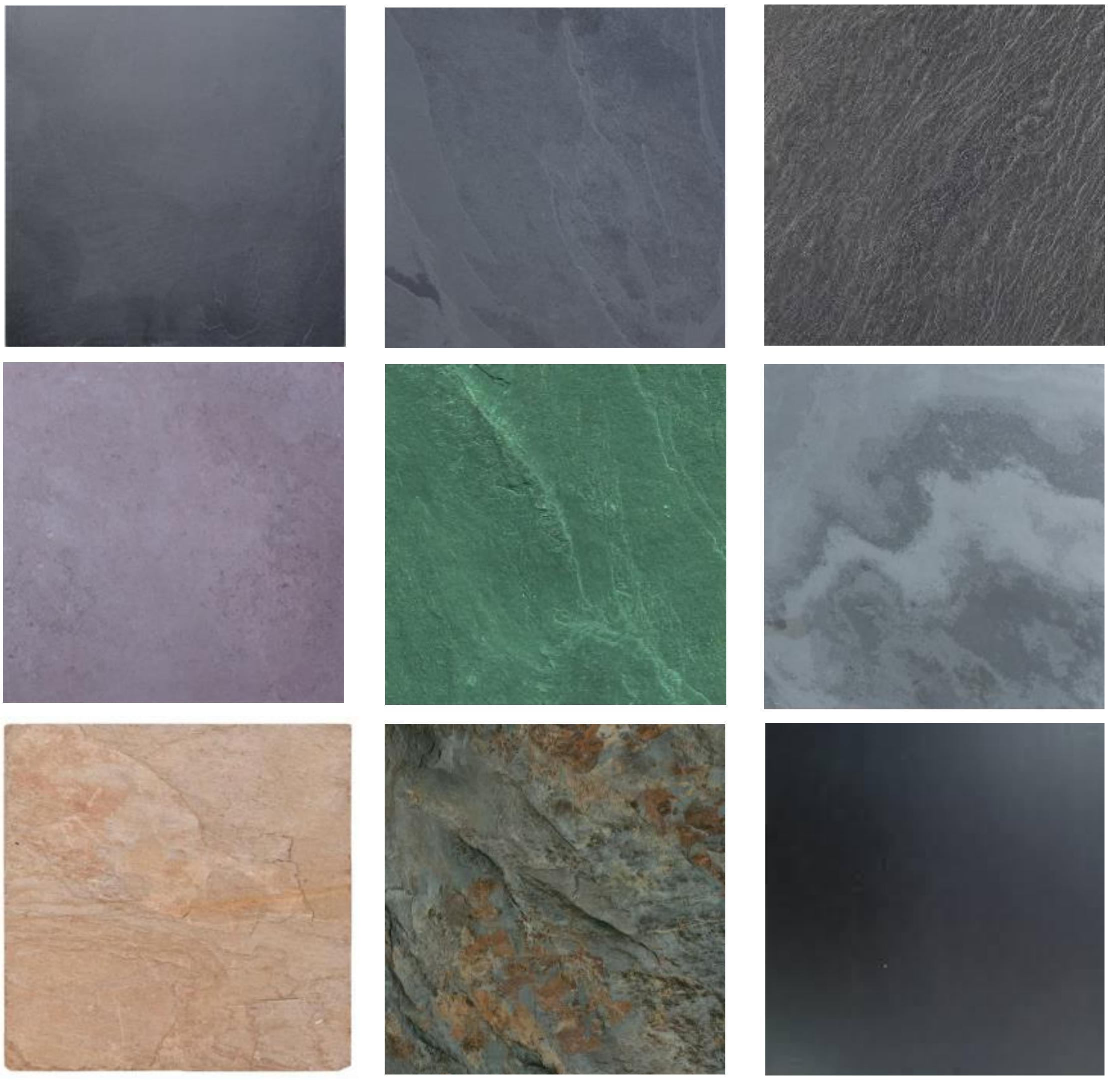
Slates

The most common metamorphic rock encountered as a tile is the ubiquitous Slate. These have the distinctive slatey cleavage which is the plane of weakness which they split along. Slates are composed of baked clay minerals and as the degree of metamorphism increases the flakey nature of the rock increases. Slates are also commonly slightly ‘greasy’ which is due to the presence of graphite, particularly black and dark grey shiny Slates.

The main things to recognise with Slate are that it can warp when wet, it is difficult to re-tile over, increasing graphite content makes it hard to bond, increasing flakiness makes it weaker and it often contains sulphide minerals which ‘rust’ and stain the rock. Poor examples tend to delaminate which is relatively commonly seen in stackstone versions.

The colours of slates are very wide ranging, but are mainly earthy colours such as shades of greys, grey-greens and browns. There are iridescent silvery and silvery-grey types that have high mica contents and more closely resemble Schists. Probably the most common colour is dark grey to black.

Typical piece of slate rock



Examples of ‘glittery finish’ Mica rich Slate, bordering on Phyllite to Schistose

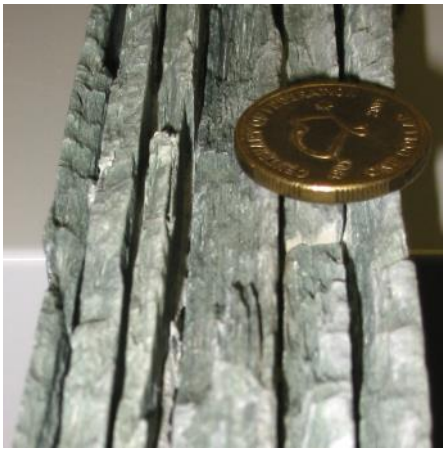
Phyllite

Intermediate between Slate and Schist is Phyllite which has properties of both rocks types. It has sheet like structure of slate, but the minerals are more obvious and the shiny surface shows the development of mica crystals.

The behaviour of the tiles is little different to Slate though it Graphite rich can be harder to adhere well. As the Mica content and crystal size increases, the tile rock durability starts to decrease.

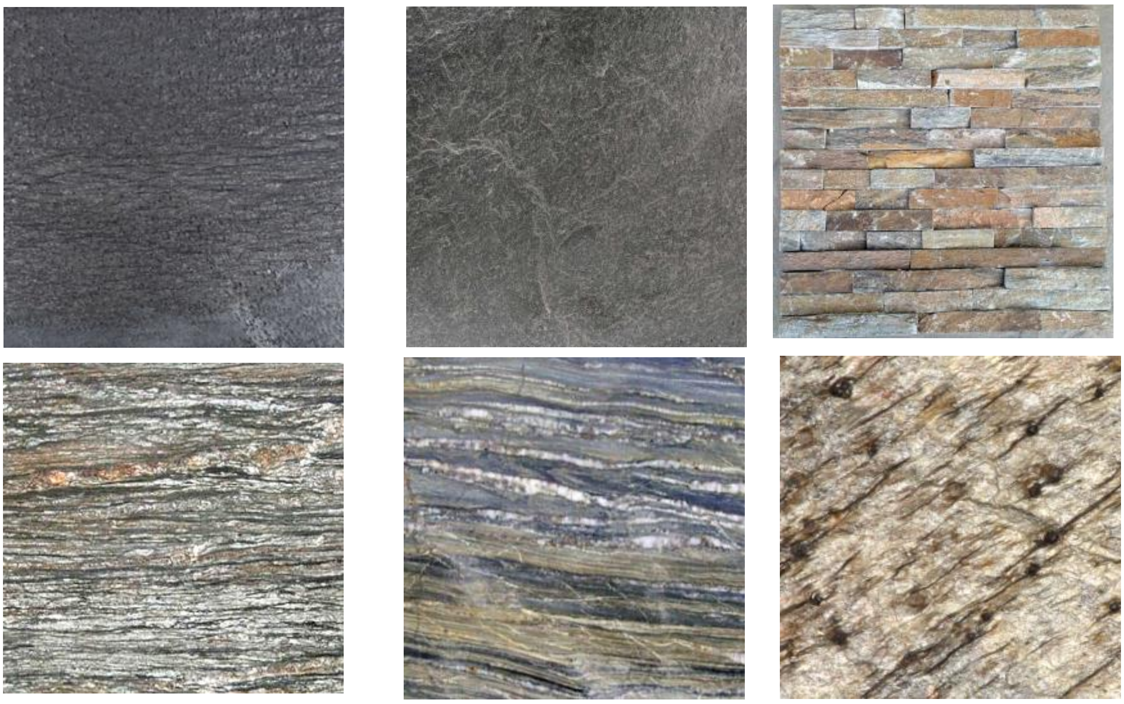
Schist

This is the next stage up from Slate and is easily distinguished by its shiny metallic and flakey appearance. Schists are weaker than Slate and are more rarely seen as whole tiles, but seem to appear more frequently in the market as ‘stack stone’. The increasing Mica content and development of foliation makes these rocks more easily fractured and weathered. Dimensional stability is usually acceptable.



Schistose stackstone tile

http://www.sandatlas.org/wp-content/uploads/1853-slate-phyllite-schist.jpg



A range of different Schistose tiles and an example of a stackstone

Quartzite

This is a hard type of rock composed of interlocking Quartz grains with a sugary appearance. They are hard to cut and long wearing in general. They can be a wide range of colours from off -white to black and all sorts of shades of brown, reddish, greenish and blue-grey. Purer examples are normally non-porous and quite stable. However, impure Sandstones lead to the presence of other minerals like Mica which can negatively alter the properties.
This rock type appears sometimes as full tiles but more commonly as stack stone or pavers.

A piece of Quartzite stackstone

Examples of Quartzite tiles

Marble

This is the metamorphic equivalent of Limestone, and its most distinctive feature is the sugary-grainy granoblastic texture. True Marbles are normally lighter coloured in shades of white, cream and grey because the impurities are forced out in the solid solution recrystallisation. They usually have striking colour patterns and may display cata-clastic structures, veining and stylolites.

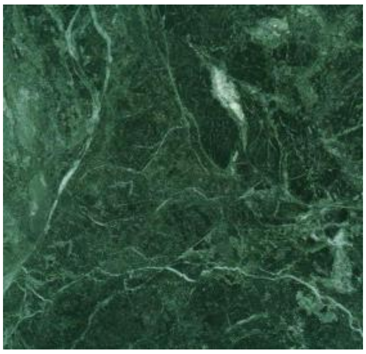
It is quite common for a range of Limestones to be described as Marble when they are not. True Marble is the classic stone used for sculptures, headstones and architecture since ancient times. Another rocks described as Marble is so called green Marble which is actually Serpentinite, a completely different material.

There are many quarries in southern Europe, but the best Marble is usually considered to come from the Carrera region in Italy, and in thinner sheets is often slightly translucent. As a consequence these tiles can displayed marked show through effects from the adhesive.

Marble is considered to be the 'flashiest' type of stone used for tiling and is found in grand buildings, mansions and bathrooms.

https://artislimited.wordpress.com/2012/12/09/turning-art-history-into-toothpaste-the-issues-involving-the-ongoing-environmental-disaster-in-carraras-marble-region-are-beginning-to-be-noticed/

Examples of true granular Marble tiles, some showing deformation structures consistent with regional rather than contact metamorphism.



Examples of other rock types commercial *called* Marble tiles. The three light coloured rocks are lime mud Limestone, the black tile deformed and compact Limestone and the green tile Serpentinite (discussed next).

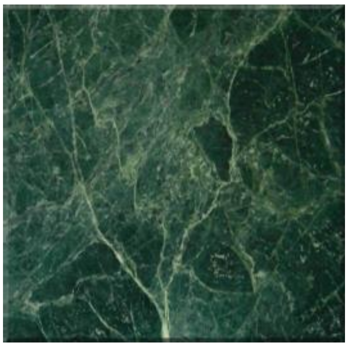
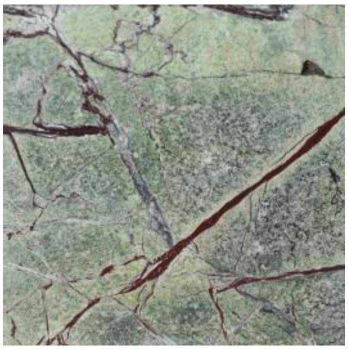
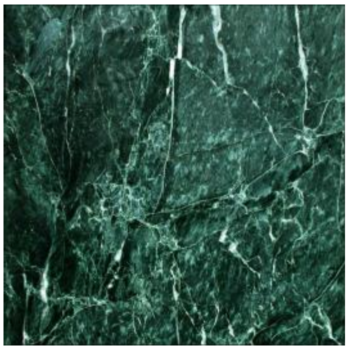
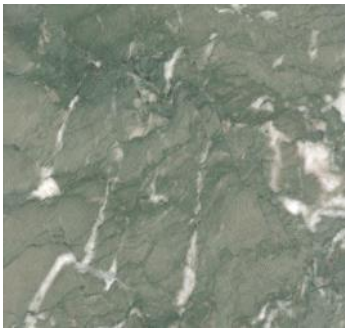
Serpentinite

The term used to describe Serpentinite in the tiling industry is green Marble because of its appearance, though Serpentinite is actually composed of hydrated ferro-magnesian minerals and is a form of metamorphic Basalt or Dolerite.

Serpentinite is predominantly formed of the polymorphs of the mineral Serpentine, which include the asbestos mineral Chrysotile. All samples of Serpentinite with white veining should be examined for the presence of asbestiform minerals as these are prohibited imports and pose a WH&S problem when the tiles are cut or broken. Colours vary from deep green, apple green to pale green and also shades of greenish tinged brown. Some rare types are red-purple.

The structure of Serpentinite is typically cataclastic to schistose though can be compact and massive. It commonly has veins of white Serpentine or Calcite and can carry grains of Chromite which is an Iron-Chromium oxide (which also ‘rusts’ out over time).

This rock weathers relatively rapidly and is well recognised to be dimensionally unstable to moisture. Because of the schistose structure it can also be mechanically weak. As a consequence non-cementitious adhesives should be used, and the installation in pools and water features is a questionable practice.



Serpentine—Green Marble tiles. The last two tiles are so called ‘forest patterns’.
Bottom row at far left a typical hand specimen and left an example with an asbestos vein

Gneiss

This is the end member, high grade metamorphic rock and is the next grade up from Schist. They can show a range of compositions and appearances from grainy banded rocks to granular rocks almost like granite. Gneissic rocks grade into Granulites and partially re-melted rocks called Migmatites. They can display a range of textures as well, from foliated, banded to swirlish appearances. Colours are usually light, or alternating light and dark banded depending on the mineral grown, and what the original source rock was. Gneissic rocks used as tiles can contain spectacular red or red-brown Garnet crystals.

The behaviour of these rocks varies from similar to schist to equivalent to true Granites.



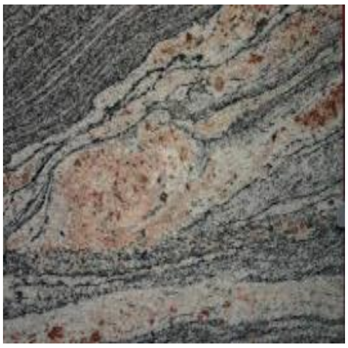
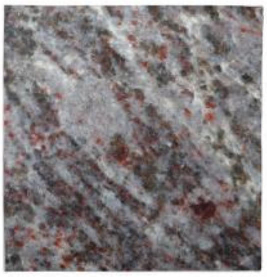

Examples of Gneissic, Granulitic and Migmatic rocks at top.
At bottom examples of Gneissic tiles in the first row and Granulites and Migmatites in the bottom two rows.









Garnet Gneiss tile

Hornfels

The final type of rock we will examine is the Hornfels family which are contact metamorphic rocks formed by heat from nearby underground molten rocks (i.e. granites). The composition depends entirely on whatever the original source rock was, but that have a distinctive sugary-grainy appearance under hand lens examination. Very fine grained types resemble Chert or Flint. Calc-silicate Hornfels can contain varieties of asbestos such as Tremolite.

It should be noted that Quarzite and Marble can also be described as Hornfelsic rocks. Varieties include Metabasalt Hornfels (usually greeny-black), Mica-Quartz Hornfels (purplish to purple brown) and also other types named after the minerals in them.

The properties depend on the source rock and minerals present, but they are typically hard to very hard and tend to glassy and tend to be stable. Hornfelsic rocks have commonly been used for stackstone tiles.



Examples of Hornfels, banded, meta-igneous and Quartzite


Hornfels tiles

Hornfels stackstone tile

Common usages and other considerations

The two most recognisable rocks in this group used for construction and tiles are Slate and Marble. Gneiss and Granulites-Migmatites may not be immediately recognised for what they are, and may be confused with Granitic rocks.

Marble

Marble is best known as the high class and quality stone used for monuments, statutory and facing stones, buildings and has been in use since ancient times. The height of use in this application were Greek and Roman building and art, Renaissance sculpture and major buildings in the 17th and 18th centuries. It is easy to form into architectural shapes (pediments), decorations, columns, ashlars, large blocks and facing slabs. Marble also has the morbid association with funeral monuments and mausoleums. True Marbles have tightly interlocking polygonal grains and are not normally considered to be permeable. However, such rocks with sparry Calcite can be translucent and hence can display show through of adhesive, which is consider a type of moisture sensitivity. As tiles they can be used internally and externally, though tiles subject to show through when damp would be best used for dry internal applications.

Geology.com

Slate

Slate was traditionally used as a roofing material (shingles and 'slates'), flag and paving stones, and in dry stone walls and construction of stone buildings (for example in Wales). In these situations it was found to be durable and gave long service, as shown by the hundreds of year old slate roofs and dry stone walls.

As a floor material it is necessary to recognise that its flakey structure (due to cleavage and the presence of platy minerals) means that if not dense and cohesive, it can flake and break away under the combined effects of traffic and weathering. It is not a good idea to bond new tiles over existing Slate because the general surface weakness, but also because they are commonly sealed (bond breaker).

Another feature with Slate is that because of its anisotropic structure, and the types of minerals it is composed from, the rock can display moisture instability and warping. Some also display thermal instability, which may be in part related to moisture changes, rather than pure expansion and contraction. The thinner the tile, the more likely this problem is to develop; on a roof curling is not really an issue, but clearly when bonded down to a floor, that is a different matter altogether.

Slates have been used externally and internally for tiles on walls and floors. We suggest that

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when used in any external application they be examined for moisture and thermal stability to avoid subsequent de-bonding issues. Slate (though often Argillte or even well lithified Mudstone has been passed off as Slate) has also become popular for stackstone cladding with variable quality and success.

Serpentinite

It is not helpful that the tile supply industry calls this rock a 'marble', because its properties are completely unlike the true carbonate rock. The properties of Serpentinite are generally well known, and it is recognised generally that tiles made from this rock require specialised adhesives. The major issue is moisture instability which can come from the environment, but also from the adhesive itself.

The major historic use of Serpentinite was carving of ornaments, though the use for stone tiles and pieces is more recent.

friendlytrading.co.uk

This rock was also quarried since ancient times as a source of the mineral fibre '*amiantos*' (ancient Greek) later Amianthus (abt 1607), with the modern name Asbestos from the Latin '*asbestinon*' which was coined by the Roman historian and naturalist Pliny the Elder. The uses of this fibre and its associated hazards are well documented.

When used for tiles, this material really should only be used in environments where it is not subject weather and wetting.

We note that stone from Indonesia has been used in pools, but our experience with this application in Australia with imported stone has unearthed a number of failures when bonded with C Class adhesives (image at left is an example).

Schists , Gneiss, Granulite and Migmatites

The usage of these rock types (Schists to Granulite) is not that common compared to their lower metamorphic grade sibling Slate or the higher grade Migmatites. The major concern with these types of rocks is the Mica content and how it is distributed through the rock matrix. High level of Mica plates make the rock weather more rapidly and also subject to mechanical wear and tear.

The use of these rocks is more directed towards tiles, or slabs used for bench tops and panels, and given their weatherability internal applications would be preferred. Historically Schist have been used in place of Slate for roofing tiles (below), and Gneiss has been used for ashlar blocks. In the case of Migmatite, (re-melted rocks) these are more closely related to Granitic rocks in their behavior and would be considered with them in applications.

iStock

Hornfels & Quartzite

The use of Hornfelsic rocks for this type of application is not that common, but Quartzite has been used for ashlars and construction in the past. These rocks are generally hard to very hard and long wearing as flag stones and for stone walls. Recently various types of rocks in this grouping have been extensively used in stackstone cladding. It would be expected that when used for tiles they would be durable (unless the stackstone lamination adhesive fails) and generally stable.

References for further consideration

ARDEX Australia Technical Paper TP005 (2009) Stability problems with natural stone tiles.

ARDEX Australia Technical Paper TP019 (2017) Further considerations on stone tile stability.

ARDEX Australia Technical Bulletin TB001 (2004) Installation of large format ceramic and heavy stone tiles.

ARDEX Australia Technical Bulletin TB010 (2000) Fixing of moisture and thermally sensitive natural stone and/or manufactured tiles.

ARDEX Australia Technical Bulletin TB144 (2006) Issues with fixing schistose and layered stackstone tiles.

ARDEX Australia Technical Bulletin TB148 (2006) Mechanical fixing of stackstone cladding tiles to wall substrates.

ARDEX Australia Technical Bulletin TB161 (2010) Issues with resin backed tiles.

ARDEX Australia Technical Bulletin TB223 (2012) Quick checks for natural stone tiles—dead load and environmental stability.

Hartog P. (2001) Is green marble marble? *Discovering Stone* Issue #2, Australian Tile Publications.

REASON FOR REVISION - ISSUE

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