SLATE ROOFS
AND THE CONSTRUCTION INDUSTRY
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1) Introduction

This report will examine the use of slate roofs in the construction industry. An ancient roofing system inherited from the mists of time, slate roofing is often seen as a relic from our days of polymeric roofing membranes and mass-produced asphalt shingles. However, slate still prospers in some segments of the construction industry (if only in the renovation sector) and it offers itself as an interesting option for the roof designer.

We will present the particularities of slate in terms of historical aspects, physical properties, installation, and performance. The goal here is to offer an effective insight into the opportunities and possible drawbacks of this material to anyone interested in analyzing the possible alternatives available to the roof designer today.

2) History

As we will explain in the next section, slate has been available as a construction material for a while. Humans have been using slate as a material for roofing probably since the day they found it outcropping on the sides of hills during the Stone Age.

For geological reasons, Britain’s subsoil possesses numerous slate deposits. Thus Britain has historically used slate intensively in its architecture, in remote villages as well as in large industrial cities. The English are extremely fond of their ancient slate roofs, which are omnipresent in many parts of the country:

"The extraordinary richness of England’s built heritage is a reminder of our ingenuity in response to our surroundings and their particular environmental and geographical characteristics. (...) Stone slate roofs are a fundamental part of the distinctive local character of vernacular buildings in many parts of the country. Their solid beauty achieves a visual harmony with the stone buildings and the drystone walls of the fields which makes areas such as the Cotswolds and the Pennines unique." [20]

('stone slate' is a type of foliated stone similar to slate except that it is not metamorphic and it is softer.) It is safe to say that most of the techniques and styles related to slate use in roofing were developed by English builders.

Here in North America slate has been around for a while too. In the United States quarrying became common only after 1850, but slate roofing is known to have been used as early as the 17th century:

"Slate roofs were introduced in Boston as early as 1654 and Philadelphia in 1699. Seventeenth century building ordinances of New York and Boston recommended the use of slate or tile roofs to ensure fireproof construction." [10]

The first commercial slate quarry in the United States was opened in 1785 in Peach Bottom Township, Pennsylvania [10]. Before that, slate was imported from North Wales in England. It seems that some of the first slates to have been used in the colonies were actually re-used stones that had been used as ballast inside the hold of merchant ships on their way to North America. (The opposite is true: some of the first slates quarried in the U.S. were used as ballast for ships on their way back). The immigration of Welsh quarrymen was a contributing factor to the development of a slate industry in the U.S. Welsh immigrants opened quarries in Pennsylvania, Vermont, Maine, Virginia, and New York in the 18th and 19th century. [14]

It seems the earliest uses of slate in North America were actually in Canada, in what was then New France. It was used in religious and in civil administration buildings:

"The 1666 Jesuit church built on the Place du Marche at Quebec, and designed in the form of a Latin cross with a bell tower at the transept crossing, had a French-slated hipped roof. (...) At
Quebec, the Jesuit College was slate covered and the second Ursuline Convent was partly roofed with slates. Accounts indicate that the nuns bought 38,000 slates in 1674. (…) In 1687, 36,000 slates, with 300 feet of lead and 60,000 nails were sent to Montreal from the port of La Rochelle in France to cover the Sulpician seminary then being built." [3]

As in the U.S., building code started recommending slate roofing to prevent fires in Canada as early as 1721. [3] However the first quarries took longer to appear in Canada than in the U.S.; efforts were made between 1728 and 1733 to open a quarry at Grand Etang on the south bank of the St. Lawrence River, but were abandoned after tests done on samples had shown that the slate was of inadequate quality. The Reciprocity Treaty of 1854 encouraged imports of slate from the U.S. quarries. In 1847 the Geological Survey of Canada identified suitable location for slate quarries in the Eastern Townships. The first commercial quarry in Canada, the Walton Slate Quarry, was opened in that region in 1861 in the township of Melbourne [3]. Slates from that quarry were used for the roof of the Parliament Buildings then being built in Ottawa. A second quarry, the New Rockland Slate Quarry, was opened nearby in 1868. Some quarries were also opened in Newfoundland where they had some success between 1902 and 1905, but the two Eastern Township quarries mentioned before "were always the principal source of roofing slate production in Canada and supplied most of the needs of the Canadian market until 1900." [3] After that date, the proportion of slates imported from the U.S. became larger and stayed that way until today.

Actually it seems the history of slate production in Canada was marred by unsound economic practices: between 1881 and 1900, the Canadian slate industry was artificially maintained by the federal government through tariffs imposed on slate importations from the U.S. The federal government was also one of the main clients of the Canadian quarries: it subsidized indirectly the industry by using slate for nearly all post offices and custom houses built in eastern Canada in the 1870s and 1880s. The New Rockland quarry acquired a monopoly over the market when its competitor closed; they kept prices artificially high by limiting their sales to only four or five firms in Toronto. These kinds of government-subsidized industries protected from the realities of the free-market economy rarely yields good results. The

Canadian slate industry never even approached the production quantities of the U.S. market

"Even at the height of the Canadian industry in 1888 United States production was 30 times the value of Canada’s, by 1906 the multiple had reached 180. In terms of quantities, during the first decade of the 20th century the American industry was producing about 250 times our domestic output." [3]

It must be noted that in Canada as well as in other countries like England or the United States, the expansion of slate use after 1850 was promoted by three factors: rapid increases in the populations of cities bringing a sudden need for new buildings, development of extensive railway networks allowing economical transportation from the quarries to the cities, and finally the advent of new architectural styles promoting the use of slate roofs.

Before rail networks became efficient, slate use was for a large part limited to the regions close to the slate quarries. Slate is heavy and the cost of transportation is significant in the retailing price. Also slate is relatively fragile and high losses will occur during transport if good quality transportation links are not available. Even today one will notice that in the areas close to operated quarries, slate is used much more liberally in buildings, even on utilitarian buildings such as barns, because of the proximity to the quarry. (Figure 1)

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At the same time that rail made slate more accessible, a switch to new architectural styles increased dramatically the demand for that material (note that this is maybe not just a coincidence: rail networks became possible
thanks to the Industrial revolution, but the apparition of new industrial sceneries with their austere factories and chimney stacks may have been the motive for the population to aspire for more romantic features in residential and institutional buildings). This phenomenon is well documented:

“The architectural styles prevalent during the latter half of the nineteenth and early twentieth centuries placed strong emphasis on prominent roof lines and greatly influenced the demand for slate. Slate, laid in multicolored decorative patterns, was particularly well suited to the Mansard roofs of the Second Empire style, the steeply pitch roofs of the Gothic Revival and High Victorian Gothic styles, and the many prominent planes and turrets associated with the Queen Ann style.” [10]

See Figures 2 to 5 for description of these styles.

In ‘The History of Slate’, Judith Selwin concurs:

“The later Victorian styles, such as Queen Anne and Stick, with their whimsical decoration executed on wood and brick buildings, extensively used the variations of slate for color and design. Slate remained popular in residential and small commercial construction as the Shingle, Romanesque, Arts and Crafts, and Colonial Revival designs progressed in popularity from the
1880s through World War 1. The Gothic style was popularized for use on churches in the 19th century. (...) Institutional buildings, including city halls, libraries, schools and universities, chose masonry construction with durable slate roof systems.” [14]

Here in Montreal, the extensive use of roofing slate that occurred in the years between 1906 and 1914 left an obvious mark, even today. Mansard roofs (see box) slated with French style patterns are omnipresent on many streets (Figure 6); the visual impact of these decorated roofs on the general look of the city is enormous, even if a lot of people are so used to seeing them that they don’t notice it anymore.

It is no coincidence that Heritage Montreal, an organization “dedicated to the preservation of Montreal’s urban, architectural, landscape and social heritage”, chose an illustration of a row of slated mansard roof buildings as a logo for its website. These mansard roof buildings occur in many Montreal neighborhoods, from working-class to wealthy areas.

Figure 6: Slate-Covered Mansards, corner Marie-Anne and Boyer in Montreal (Personal Coll.)

Figure 7: Heritage Montreal Logo [23]
The demand for slate roofs did not last forever. First, the fashions of the new Victorian, neo-Gothic and Queen Ann styles eventually came out of fashion. Second, new manufactured roofing materials such as asbestos shingles, asphalt shingles and built-up roofing began competing with slate. These materials were lighter, more homogeneous, had a more consistent quality, and could be installed faster by unskilled labor. Skilled labor was already becoming increasingly hard to recruit in this industrial age. These changes occurred at the same time in Canada and the U.S., around 1914.

“Roofing slate production statistics and import tables precisely identify 1889 as the high point of Canadian consumption. Slate continued in common use until the First World War, but from that period on appeared almost exclusively on architect-designed buildings and homes, eventually disappearing in the 1930s.” [3]

Today, the slate industry evolves in a context very different than the one that existed during the Industrial revolution and the early 1900s. Over the years, slate use in new buildings became a sort of anachronism and almost disappeared, unable to compete with the new roofing materials that were mass-produced, mass-transported, and easily installed. In its successful days, slate offered the best possible long-term reliability, and was recognized as superior to the other roofing materials such as tin or iron sheets, wood shingles, etc, while offering a very sought upon visual effect. Slate went from being seen as one of the prominent roofing materials with a reputation for quality, durability, and superiority, to an inconvenient relic from the past.

Thus from the 1920s onward, slate use in new buildings was limited to certain high-end residential projects of very high quality for wealthy individuals who desired to exploit the traditional look of slate in order to display affluence and a taste for traditional products of quality. Use of slate for governmental and religious buildings disappeared. However there remained a constant minimum market demand for the renovation of historical slate roofed buildings. Indeed, historical buildings are not very compatible with any of the new roofing materials; whenever slate roofs are replaced with modern materials, the visual effect is disastrous. Thus anyone who wants to renovate responsibly a historical building is compelled to find an adequate source of replacement slate.

There has recently been resurgence in the demand for slate in the sector of good-quality residential housing. This may be due at least in part to the current economic conditions that tend to increase the gap between wealthy and poorer groups. It seems also that a new contemporary architectural style has emerged, which exploits the high-quality, clean-cut look of well installed slate roofs. (Figure 9)

What is a Mansard?

Roofs with mansards evolved from the simple two-sided hip-roof. The straight inclined slopes were replaced with broken sides having two different slopes: a gentle slope near the ridge and a steep one over the façade. When flat roofs were introduced around 1885, this style evolved again into the false-mansard system: a very steep roof portion imitating the steep portion of mansard roofs is used to decorate the upper story of the new flat-roofed buildings. Slated false-mansard roofs were very commonly used in Montreal in the late 19th century and early 1900s.

Figure 8: Mansard Roofs [3] (and Personal Coll.)
In a 2003 article from the Professional Roofing Magazine (a publication by the U.S. National Roofing Contractors Association), Matt Millen reports that a survey by the National Slate association indicated that the amount of slate produced and used in North America has doubled during the past 10 years. Says he: “Slate roof-designs often are the systems of choice of architects and builders for new homes in the East Coast, Mid-Atlantic, Midwest and West Coast regions.” [13] According to an annual market survey by the National Roofing Contractors Association, only 3% of all roofing in North America uses slate. [14] In England, slate accounted for 5% of roofing material in 1990. [21]

In Canada, as already mentioned, old slated roofs on many urban buildings have endured the elements until today and now form an integral part of our inherited urban landscape:

“In Urban Canada today, the recycling of commercial and government buildings and the revitalization of housing in older neighborhoods have renewed interest in slate and other historic building materials. Many slate-roofed buildings endure from the 1870s to 1930s period.” [3]

In Canada today, the files of the Canadian Inventory of Historic Buildings (CIHB) identify approximately 3000 slate-roofed buildings. [3] Only about 60 of these are located west of Ontario. This later province has four times more slate-roof buildings than Quebec. In Ontario, half of the buildings are located in Toronto; in Quebec they are found only in Montreal and the Eastern Townships.

Note that because not all of the quarries that were exploited in the 1800s and 1900s are still in use today, some of the particular slate varieties that have been used on various historical buildings are not available any more. This complicates renovation work since it is preferable to match the existing slate with slates from the same quarry to obtain the same color effects. However it is usually possible to obtain similar slates from some of the quarries still in operation. In North America, slate is now quarried in the following states and provinces: [11]

In the U.S.:
- New York
- Pennsylvania
- Vermont
- Virginia

In Canada:
- Quebec
- Newfoundland

Imported slate is also available from Spain, Wales, China, Brazil, and South Africa.

The producing regions in the states of New York and Vermont actually share a common geological deposit at the south end of Lake Champlain, at the border between the two states. This producing region is 25 miles long and 5 miles wide only. It produces all the colored slate now found in the United States. Four hundred quarry sites have been used at some point or another in the 150 years since this region has been producing slate. About 35 quarries are now in production.

Among a variety of colors, this region produces the ‘Unfading Red’ variety (in Washington County, N.Y.) which is essential in roof designs with bright color patterns and which is more expensive to produce than others because it is more brittle.

Pennsylvania, another region having historically produced a lot of slate in the last 150 years, now produces blue-gray and blue-black slate. 160 companies have quarried this region over the years.

Virginia produces an unfading black slate.
Quebec now produces an unfading black slate which is exported to Europe and the rest of North America. Only one quarry is now being exploited, the Glendyne Quarry in St. Marc du Lac Long. Apparently this quarry is the largest roofing-slate producing facility in North America and one of the largest in the world. [11] Their slates are distributed in North America by North Country slate (a company based in Ontario), in the United Kingdom by Blunn Slate Inc., and in France by Axtel. The slates produced are smooth-textured and have a consistent black color with “subtle vertical shade markings”.

Newfoundland produces purple, deep purple, green, and variegated green slates at its deposit at Burgoynes Cove.

3) Mineralogy

Slate has unique physical properties that allow its use as a roofing material. It splits easily along smooth, flat planes, it is impervious to water (porosity of 0.25 to 0.45 %) and to air, resistant to acids, it is of medium hardness and is relatively strong.

In familiar terms, in English as well as in French, the word slate is used to denote both the mineral and the shingles or the black writing tablets (chalkboards) manufactured from it.

Technically, slate is a fine-grained foliated metamorphic stone. A “metamorphic” rock (from the Greek words meta, meaning succession, and morphe, meaning form) is a rock whose crystalline structure has been modified due to considerable pressure and temperature. “Foliated” means that this mineral contains layers, or cleavage planes, as opposed to rocks such as marble that isotropic are not distinctly layered. It is fine-grained, as opposed to sandstones which are made of larger, visible grains of sediments.

The creation of slate rocks goes back millions of years ago when sedimentary particles of clay (hydrated alumina silicate) and silt (fine deposits of mud, clay, etc.) were first washed down onto ocean floors. Over time, successive layers of those flat, flakey deposits accumulated and formed compact blocks of “mudstones” (from which limestones and sandstones also originate). Later, with movements of tectonic plates, these sedimentary rocks were eventually subjected to intense compression and high temperatures. Under that strain the grains of sediment were forced to align themselves in a direction perpendicular to the compressive force, like biscuits piled up on their faces. These deposits then turned into a harder material that we call shale (clayey schist). The high temperatures involved also chemically transformed the clay sediments into harder minerals such as chlorite, mica, and quartz, magnetite, graphite and others [1]; the shale thus turned into slate.

Slate owes its ability to split along smooth planes to this particular alignment of its grain along parallel planes originally caused by the intense directional pressure it was subjected to during its creation. The planes along which the rock splits are called “cleavage” planes. Slate also contains a secondary plane of fracture, called “scallop”, which usually runs perpendicularly to the cleavage planes. This secondary plane gives the slate a visible “grain”. For strength, the slate shingles should be cut so that the grain is aligned with the length of the shingles.

Thus slate is the end-product of a very lengthy process. The geological processes that transformed the initial sediment deposits into hard slate occurred some 435 to 570 million years ago during the geologic time period of the Early Paleozoic era. [11] As a matter of comparison, unless you happen to be a Creationist from a southern American state, modern humans (Homo-Sapiens) are about 130 000 years old, Australopithecus 4 to 5 millions years old, and the age of the Earth itself is about 4.6 billions years. (And if you really are interested the latest estimate for the age of the Universe according to the value of the Hubble constant, itself based on measurements of the Doppler shift in the light from distant stars, is 14 billion years). In other words slate is about 1/28 the age of the Universe, one tenth the age of the Earth, and 100 times older than the earliest ape-like animals.

Note that because of the sedimentary origin of slate, its chemical composition can vary considerably. Slate is composed essentially of
white mica (chiefly sericite) and quartz [1], but it will always contain a wide variety of other minerals depending on the particular region or quarry that it originates from. The properties of a particular slate depend on the chemical composition of the sediments it originated from, as well as the extent to which these sediments were chemically transformed by the pressure and temperature forces that transformed them into slate. Look at a quantitative chemical analysis of different varieties of slate from some of the major quarries in the U.S. in Appendix 1. Due to these local variations in mineral constituents, each quarry produces slates with unique properties in terms of color, water absorption coefficients, inclusion of impurities, mechanical strength, etc. All major slate distributors publish the relevant information on the physical characteristics of their slates with respect to color, durability, etc, for consideration by the designer.

4) Manufacture

Slate is a material occurring naturally in the Earth sub-soil. It is not man-made, i.e. processed or manufactured from other materials the way asphalt shingles or polymeric membranes are. Slate is only quarried, cut to its required dimensions, and shipped to the building site without any further transformations. This raw characteristic of slate probably contributes to giving it its strong and noble feel.

The production process of slate has not changed much since the day men first started quarrying slate a long time ago; mechanized heavy equipment instead of horses is now used to transport the rocks, electric saws are used to cut large blocks faster, and dynamite is used to speed up the extraction process, but much of the other steps involved remain the same.

The process starts in the quarry, where dynamite blasting is used to detach huge blocks of raw slate. These blocks are transported with heavy trucks to the production plant. There, using diamond-tip rotating blades, they are sawn perpendicular to their grain and cleavage planes to produce rectangular sections (Figure 10). Those rectangular sections are then split along the grain to produce sculpted blocks (the grain is a secondary cleavage plane – see the Mineralogy section). These sculpted blocks are then split by hand along their natural cleavage planes using only a chisel with a hammer, and this yields smaller blocks called “eights”.

![Figure 10: Cutting Steps][8]

Each of these eights is split again by hand along the cleavage plane into eight rough slates. The rough slates are then trimmed along their edges to produce nice rectangles; finally two or four nail holes are punched using a punching machine. Note that many of these operations require skill and experience in order to properly split the rocks without breaking or wasting them. Every single slate is split by hand to the required thickness using only a chisel and hammer. The thickness is estimated visually by the worker.

After all this is done, the slates are sorted according to size, and carefully packed on palettes for shipping. Even if the greatest care is taken to pack and transport the slate, it is expected that about 10% of the slates will be damaged before reaching the construction site.
This must be accounted for when preparing estimates for the required quantities.

Note that the extraction process is not very efficient: only 10 to 40% of the quarried material will be used. The rest is rejected because it contains impurities or has incurred small cracks during the blasting operation, which render it inadequate for use as roofing slate.

The final product (Figure 11) is a slate cut to its required dimension and proper thickness. Slate is usually produced in standard sizes, with a width varying from 6 to 14 inches, and a length varying from 10 to 24 inches. The thickness of the most commonly used slates (called “commercial standard slates”) is 3/16 in. but thickness may vary up to 2 in. for larger slates. The trimming process creates beveled edges around the slate; the slates are installed with their beveled edge facing outward.

5) A traditional industry

The techniques used for installing slate have been developed over hundreds of years and across different countries. Historically England was the country where slate was used the most (due to their harsh climate and the abundance of slate deposits in that country), so it is fair to say that most of the techniques in use today have been inherited from ancient slate roofing practices developed by English builders centuries ago.

Here in North America, as already noted, Welsh immigrants have brought with them in the 1700s some of these techniques and knowledge about slate use. However, American builders quickly adapted and modified these traditional techniques to suit our colder climate and particular architectural needs. Over the years, a number of North American slating practices evolved, and became generalized over North America. This convergence to a set of distinctive North American techniques occurred toward the end of the 19th century. The techniques in use today and recognized as sound practices all follow the basic tenets agreed upon in those years. In fact, almost all of the practices recommended today for slate laying, except for recommendations specific to modern roof systems, can be traced back to a single book that was published in 1926: Slate Roofs. [1] This book has become the de-facto universal reference for all the slate industry in North America, including Canada. This author quickly noticed this peculiarity when researching information for this report, because similar data keeps coming back over and over in almost all available sources of information on slate, including in internet sites! In fact, even the drawings used in modern books are often reproduced from this book. For example compare the following illustrations from Slate Roofs to a similar one appearing on the single page dedicated to slate roofing in the ubiquitous Architectural Graphics Standard of the American Institute of Architect (10th edition, published in 2000):
Another book borrowing heavily from *Slate Roofs* is the *Roofing Handbook*, a comprehensive source of information destined for contractors. In fact, the *Roofing Handbook* not only borrows the pictures from the original *Slate Roof*, it actually reproduces whole unaltered sections of text (actually without even acknowledging the source)! It seems the data from the original book has really entered public domain…

*Slate Roof* was published in 1926 (in the United States) by the National Slate Association (NSA) (see box) with the desire to “supply reliable and definite information on slate and its proper application.” It was the result of “the active cooperation of architects, slate producers and distributors, roofing contractors, governmental departments, manufacturers of accessories and many individual authorities.” [1]

**The National Slate Association**

The NSA was “first established in 1922 by producers of slate material. The goal then was to promote the use of slate for roofing and structural applications. It also set the standards in slate roof materials and construction still adhered to today.” [16] The NSA became inactive not long after the publication of *Slate Roofs*, but was re-established in 2002 with similar goals.

*Slate Roof* is out of print, but may be ordered from the websites of slate quarries or distributors such as Vermont Structural Slate Company or North Country Slate, and it is available for download (9.59 Mb) on the Greenstone Slate website at www.greenstoneslate.com/downloads.htm. This 84 pages book contains information on types of slate roofs, slate, installation, flashings, roof construction, re-roofing, and it furnishes samples of standard specification forms for different kinds of slate roofs.
A lot of the techniques and practices analyzed in this report are taken directly from that book.

Thus the U.S. slate industry, through the NSA and *Slate Roofs*, was instrumental in shaping the set of recognized practices of slate laying still in use in North America. In *Slate Roofing in Canada*, Mary Cullen acknowledges this leading role of the United States in implementing these practices in North America:

“A useful guidepost emerging from this study was the importance of American sources in Canadian slating practice. Many, if not most, of the popular design books, pocket manuals and encyclopedias referencing slating were American. How-to columns in the Canadian professional press were frequently extracted from United States periodicals.” [3]

She also states that *Slate Roofs* and *Architectural Graphics Standards* “provide the main references used by Canadian Architects regarding slating practice today.” Given that *Architectural Graphics Standards* has only a single page on the subject of slating and this page is furthermore a direct offspring from *Slate Roofs*, we might as well consider that *Slate Roofs* is still the authoritative reference on the subject today.

Even today, slating is done by skilled workers specialized in this field. It is not an officially recognized trade such as welding or pipe fitting, but everyone acknowledges the fact that installing slate is a trade that requires extensive experience with this material, and slate workers should be competent and should know what they are doing. Because of the relative fragility of slate, and the complexity of the detailing work involved, the care given to the installation will critically influence the performance and durability of the roof. In fact it is this dependency on the slaters’ (the person installing the slates) expertise and skills that has been partly responsible for the decrease in the popularity of slate after the 1920s. Because of industrialization and probably also because of a certain general decrease in work ethics among all trades, reliable slate workers have become scarce, and a number of badly done slate projects have tarnished the reputation of slate as an efficient roofing alternative.

Today, a limited number of craftsmen who seem to take pride in the high quality of their work are perpetuating the tradition of slate roofing.

6) Laying Slates

In some respects, slates are installed in the same manner as wood and asphalt shingles: they are manually nailed one by one in overlapping courses over the roof sheathing. However, due to the nature of the material, installing slate shingles requires special care and some specific techniques.

Slates must be nailed in a very specific manner: first of all, each slate must be secured by a minimum of two nails to ensure stability (slates thicker than ¾ in. and longer than 20 in. must have four nails). Nails holes must be pre-drilled in the slates. The holes should be located at specific distances from the edges depending on the size of the slate as shown below.

![Figure 14: Location of Nail Holes](image)

The worker must drive the nails at a specific depth: the head of the nail should just be level with the surface of the slate, and should not press down on the slate. If the nail head exerts pressure on the slate, the piece is likely to crack at the slightest movement of the roof’s surface. However the nail head must be deep enough so as not to protrude from the slate’s surface, so that it doesn’t affect the slate from the next course. Ideally the slate should just hang from its two nails, but should not be allowed to budge. If the slate is allowed to move too much, the nail holes may wear down and eventually become large enough for the slate to be lifted by the wind over the heads.
of the nails. To allow the nails to be driven under the surface of the slate so that they won't affect the slates laid on top of them, the nail holes must be counter-sunk with a conical opening on the top side of the slate.

Specific slating nails should be used; the adequate nail will have a large, completely flat head that will prevent the slate from being lifted over its nails by wind forces. A proper slating nail is shown in the picture below (second from the left); note the large head, and the absence of flanges below the head.

Generally the nail holes are punched using a punching machine at the factory (drills damage the material around the hole). The machine creates the countersinks automatically. For detailing work such as at the hips or valleys, slates must be custom-cut in the field and thus some of the holes need to be punched at the job site. This may be done with a moveable punching machine, but a skilled worker will be able to punch the holes by hand with a simple slater's hammer (see box).

Punching nail holes by hand:
The slate is held face down with the left hand. The worker gives a sharp blow on the slate at the desired location for the hole with the pointed tip of his hammer. The percussion energy disperses through the slate's thickness in a conical shape. On the other side of the slate, a large hole is blown out, creating a counter-sunk hole.

Specific slating nails should be used; the adequate nail will have a large, completely flat head that will prevent the slate from being lifted over its nails by wind forces. A proper slating nail is shown in the picture below (second from the left); note the large head, and the absence of flanges below the head.

The nail must have a relatively large diameter since they will be subject to a considerable shearing force from the slate; 3d nails are recommended for standard slates up to 18 inches in length. 4d nails are recommended for longer slates, and 6d nails are recommended for work at the hip and ridges. The nails should be long enough to extend through the plywood sheet or in the case of wood boards to penetrate 3/4 in. into the wood. Because the roof will only last as long as its weakest component, it is important to use high-quality nails that won't corrode: copper is the most durable and the most recommended. Copper nails are also easier to cut when it is necessary to remove broken slates during maintenance.

Note that slates have not always been laid with nails: in England, wood sticks or even small bones have been used instead of nails. Also, it is possible to lay the slates on a board-and-lath roof instead of a continuous deck (Figure 17); in this case the slates may be either nailed or attached to the laths using a wire passed through the nail holes and wrapped around the laths.
Figure 17: Laying Slates on Batten and Laths Roofs [20]

Slates are laid in courses that run perpendicular to the slope of the roof. Each course overlaps not only one but two of the preceding courses. The impermeability of slate roofs depend on the action of gravity to shed water down along the successive courses of slate. Thus for effectiveness the slates must overlap considerably. The degree of overlapping is governed by what is called the “lap” of the system (Figure 18). A minimum lap of 3 in. is universally recommended and is considered the “standard lap”. This 3 in. lap means that the roof is not only covered by a double layer of slate at any point, it also has a triple layer of slate for a length of 3 in. at the start of each course. This length of 3 in. seems to have been dictated by what experience has taught builders over the years. The exact length is arbitrary, but a minimum amount of overlap is mandatory to ensure impermeability: note on Figure 18 that if the slates have no lap (♯ 2), or worst if there is a gap instead of an overlap (♯ 3), water will be free to run through the open joint left between the neighboring slates as indicated by the arrow.
This high degree of overlapping is made necessary by the discontinuities between adjacent slates along horizontal courses: water is free to seep through these openings and this reduces the effective length of the slate. Note that these joints between adjacent slates must be adequately staggered from one course to the next. The extra number of thicknesses also helps to prevent water from seeping under the slates; remember that rainwater won’t only fall vertically: the wind will potentially push it upward under the slates, and capillarity will further tend to bring the water up under the slates. The recommended 3 in. lap can be reduced to 2 in. if the local climate is very dry or if the roof of the slope is very steep (more than 20 in. of rise per foot of run) as in mansards. The lap should be increased to 4 in. if the rise is less than 8 in. per foot of run. Roofs with less than 4 in. of rise per foot of run should be built as if they were flat roofs.

The 3 in. lap influences the coverage of the slates: for a given number of slates, a longer overlap will result in less coverage since the slates will be installed closer to each other. Stating the degree of overlapping is important when specifying slate quantities, because slate is sold by the “square”: a square is the quantity of slates required to cover an area of 100 square feet; by convention, slate quantities are specified and sold assuming a standard 3 in. overlap. If a roof requires a 4 in. overlap, one square will cover less than 100 square feet.

The specified lap will also influence how much of each slate is exposed to the weather: the longer the lap, the less the “exposure” will be (Figure 19). The exposure is “the portion not covered by the next course of slate above and is thus the length of the unit exposed to the weather.” [1] The exposure for a given lap may be obtained with the
The following formula: \( (L - \text{lap}) / 2 \) where \( L \) is the length of the slate.

Just as with wood and asphalt shingles, slates are laid starting from the eaves of the roof, working toward the ridge. The first course of slate has to be two (sometimes three) layers thick (Figure 20) so that the first course will be inclined at the same angle as the subsequent courses. The two slates of the first course are laid back-to-back, with their beveled surfaces facing away from each other.

Deck surfaces:
Today it is recommended to lay slates only on continuous deck surfaces; however, this has not always been the case. In utilitarian constructions such as barns, or for buildings in climates that did not require a well-insulated roof (such as in England), it was customary to simply lay the slates on an open grid of wood batten (laths) which were nailed perpendicularly to the rafters (Figure 17). These laths were 1 in. thick and 2 in. or 3 in. wide. The upper end of each slate had to rest on a lath, and the laths were spaced so that the nail holes would be over a lath. With this system the nails could be replaced by wires wrapped around the laths. This kind of roof had the advantage of offering natural ventilation and water vapor was free to escape along with the exfiltrating air.

Current construction practices dictate the use of continuous deck surfaces, if only to conserve heat and energy (Figure 21). A number of different surfaces are considered suitable as substrates for slates.
A deck of planks and boards may be used if the boards are closely spaced and forming a continuous surface. Preferably the boards should be of the tongue-and-groove type (like the wood boards used for wood floors) in order to minimize the vertical movement of the boards with respect to one another. Any warping or uneven lifting of the roof decking will result in unsightly displacement and misalignment of slates. If regular straight-edged boards are used, it is important to ensure that the end joints meet over supporting members in order to provide a solid nailing surface everywhere.

Usually the roof deck will be made of structural wood panels: plywood or oriented strand boards (OSB). The U.S. National Roofing Contractors Association (NRCA) discourages the use of OSB panels (which are made of glued and compressed wood strands) because these panels are subject
to dimensional changes under the effect of moisture, and also they may not offer enough holding strength for the nails retaining the slates. Plywood panels are the most commonly used decking material. They should be rated for structural use as roof sheathing. A minimum nominal thickness of 5/8 in. is recommended. The panels should be installed with a gap of 1/8 in. between each other in order to prevent warping in case they expand while absorbing moisture.

In 1926, Slate Roofs recommended three other alternative substrates which could be used to suit the needs of a fireproof roof system: concrete planks, gypsum panels, and steel angles serving as laths. Today the NRCA warns that slate should not be nailed into any other substrate than wood; for other substrates, the slates should be fastened using wire steel instead of nails. Alternatively a nailing substrate such as plywood can be installed on top of the main decking material; in such a case wood battens or metal channels should be used to elevate the nailing substrate over the roof surface in order to allow for some ventilation and to allow some clearance for the penetration of the nail.

Underlayment:
Ever since the days of Slate Roofs the use of a waterproof underlayment such as asphalt felt (see box) laid under the slates has been advocated. However it is not clear to this author if such underlayment can be thought of as mean to improve the impermeability of the roof; Slate Roofs underlines the fact that since every single one of the nails holding the slates goes right through the underlayment, one should not count on this underlayment to serve as a water barrier. However many of today’s sources promote the use of a waterproof underlayment as a way to improve the watertight-ness of the roof. It seems to this author that a properly installed slate roof should prove watertight in itself; in the days when slate was being developed in England, no underlayment material was in use or even existed. Slates were laid directly on wood laths. No additional barrier was used and apparently those roofs were sufficiently watertight since they were used extensively even for expensive buildings.

Asphalt felt

Asphalt felts are the most common underlayment used today for steep-slope roofs, whether with slate or other materials. They consist of a fabric (the mat) covered or saturated with asphalt flux. This constitutes in fact a composite material with the mat serving as the reinforcement and the asphalt being the matrix.

Asphalt flux is obtained from the fractional distillation of petroleum that occurs toward the end of the petroleum refining process.

The mat is usually made of an organic material, typically wood fibers or cellulose. In the past, various combinations of cotton rag and cellulose fibers have been used. The mat may also be inorganic, in which case it will consist of glass fibers bonded together with resin or plastic. The mat provides a support for the asphalt.

It seems the use of such underlayment is one of those practices that developed over time and which are now considered as standard sound practices by builders without questioning why exactly. Here is the opinion of the writers of Slate Roofs on this subject:

“IT SHOULD BE EMphasized that a standard slate roof can be laid water-tight on open laths without felt, as is often done on the South or on buildings where heat is not required. The thickness of felt has little relation to the water-tight qualities of a slate roof.”

In any case, a consensus exists on two clear roles served by an underlayment such as asphalt felt:

- Protecting the roof structure from the rain during the time it takes to install the slates
- Providing a protective cushion for the slates to prevent breakage (how ever as we have mentioned slates have been successfully laid directly on wood battens for centuries, so the need for a cushion is questionable.)

The underlayment also serves as an air barrier – remember that the slates have an irregular surface so they are not air-tight at all. Without felt, air would easily infiltrate through the slates and the 1/8 in. gaps left between the plywood subsurface. The felt also prevents the intrusion of insects and dust. Even if the roof substrate is continuous and air-tight, it may be necessary to
include felt just to comply with local building codes.

The type and grade of underlayment recommended and used most often for slate roofing (and for most other underlayment purposes for that matter) are the asphalt saturated organic felt, No.30. The number 30 refers to the nominal weight in pounds of the felt per 100 square feet. "Asphalt-saturated" means that a relatively soft asphalt with low viscosity fills and saturates the voids between the wood fibers of the mat. Another type of felt is the "asphalt-coated" felt; in this case a more viscous asphalt is used (it contains mineral additives increasing its viscosity) and the asphalts coats the mat instead of just impregnating it.

ASTM Standard D 226 provides the classifications for the two most commonly used saturated felts, the No.15 and No. 30. The NRCA considers that the No.30 thickness is adequate for roofs with a rise of at least 8 inches per foot of run. For roofs with a lesser slope, or for harsher climates with wind-driven rains, two layers of No.30 felt are recommended. Roofs with a rise of less than 4 inches per foot of run should be treated a flat roofs and have an impervious membrane included under the slates; in such a case the slates serve only a decorative purpose. Note that any asphalt felt used should be of the non-perforated kind. It is also possible to specify the use of polymer-modified bitumen sheets instead of the asphalt felt. Such bitumen sheets are made with asphalt that has been modified with polymers to make it more resistant to aging, weathering, and more waterproof. The reinforcement for these sheets is usually a mat of glass fiber or polyester. The NRCA estimates that "some of these materials are more resistant to wrinkling and distortion upon exposure or after installation and exhibit better watersheding properties than asphalt-saturated organic felts." [8]

In region with cold climates (where the average temperature in January is below the freezing point), it is recommended to provide a special waterproof underlayment near the eaves that will protect the roof in the eventuality that an "ice dam" forms in the winter. An ice dam (Figure 22) is an accumulation of ice at the eave of a roof which builds up gradually during the winter as freeze-thaw cycles cause some of the snow accumulated on the roof to melt during warmer periods and run down to the eaves of the roof where it freezes back on contact with the unheated eaves.

This problem is caused by a lack of ventilation under the roof’s deck which allows the heat from the house to transfer to the deck, allowing the deck to become warm enough to melt the accumulated snow. When the ice dam becomes high enough to trap large quantities of melted snow at the eaves of the roof, this accumulated water can rise enough to reach the portion of the roof above the eave. Then this water is free to seep under the slate shingles and to penetrate the roof, causing damages to the roof deck and to the insulation. A well designed roof should not be liable to this problem, but since it is difficult to guarantee that these problems won’t happen, it is customary to specify a suitable waterproof membrane around the eaves region just in case. This way even if water was to accumulate under the slates, the waterproof membrane would prevent the water from infiltrating further into the deck. The material recommended by the NRCA and most commonly used for this purpose is a self-adhering polymer-modified bitumen membrane with a minimum thickness of 40 mils (1.0 mm). This membrane should be applied (Figure 23) starting at the eaves and should extend upslope a minimum of 24 inches from the inside of the exterior wall line. It is also possible to specify the use of two layers of No. 30 asphalt-saturated felts (or a combination of saturated and coated felts) with the first layer fastened to the roof and the second layer adhered to the first one using adhesive or roofing cement so that no nails penetrate the second layer.
Equipment
A slater needs three basic tools: a slater hammer, a stake and a ripper. This equipment has remained the same over the centuries. All of these tools are of high quality and drop forged for durability.

The hammer (Figure 24) is used to punch the nails securing the slates. One of its two heads is pointed because it is sometimes used to manually pierce the nail holes through the slates while in the field. It is usually preferable to punch these nail holes with a special machine, but for detailing along ridges or flashing it is necessary to trim individual slates to custom dimensions and to punch holes at specific places on the slates while in the field.

The hammer is usually 12 inches long, and has a leather handle. It has two hooks on its side to remove nails. The helve is thick and flat because it is used to cut and trim the sides of the slates while in the field whenever necessary (Figure 25). To do this the slater lays the slate on a support, and while holding the slate with one hand he strikes small blows on the slate by pulling the hammer toward him with the other hand. Note that slate cutting can also be done using a little shearing device called a cutter (Figure 26). Apparently slate is cut relatively easily considering its hardness:

“Slate cutting is a process of shearing, or nibbling, through the slate, rather than a guillotine action. You cut the slate in the cutter face-side down. You hold the slate with one hand, and with the other hand you force the cutting edge through the slate in short strokes to nibble away at the stone. Slate cutting is surprisingly easy, and with practice any intricate shape can be cut.”

The stake (Figure 27) is an 18 inches-long T-shaped steel bar whose long edge is used either as a rest when manually cutting slate pieces or as a straight edge to draw lines on slates. The short end is sharp so that the stake may be held in place during use by planting it into some planks on the roof (Figure 25).
The ripper is a 24 inches-long thin steel blade with an offset handle and fitted with two hooks at its extremity. It is used when it is necessary to uninstall damaged slates.

Because installed slates overlap each other, the nails securing a slate are always hidden under the slates of the next horizontal course. Thus in order to remove a damaged slate (Figure 29), the worker must be able to cut or rip out the nails securing it by working under the given slate’s surface, between the damaged slate and the preceding one. This is done by carefully sliding the ripper under the damaged slate, and hooking the nails with the hooks at the end of the ripper. Then the worker uses a hammer to give a sharp blow on the offset handle of the ripper. This blow, when well executed, will cut or pull out the nail. The slate can then be simply pulled out.

7) Architectural considerations

Slate Roofs recognized as early as 1926 three classifications for steep-sloped slate roofs that are still in use today: Standard, Textural, and Graduated roofs. This book additionally mentioned the category of Flat roofs, in which slates are used to provide a decorative surface resistant to wear on top of an otherwise impervious roof material such as over an asphalt-felt built up roof; such flat slate roofs are not common today.

**Standard Roof**

The “standard” slate roof (Figure 30) is made of slates with uniform thickness and dimensions. It creates a regular surface, with a smooth and even texture. It is also the easiest to install and the less expensive. At most two sizes of slates (in terms of length and width) will be used for one area. For maximum simplicity and economy, rectangular slates will be used but various shapes such as fish scale or diamond shapes may be used to create patterns on all or parts of the roof (Figure 31). These designs will generally use the “Commercial Standard Slate”, a term first put forward by the National Slate Association in the 1920s to designate those slates having the standard thickness of 3/16” commonly used for residential roofs.
**Textured Roof**
The “textured” roof style (Figure 32) is employed when a more varied or textured appearance is desired for artistic effect. This result is achieved by installing slates of varying sizes or thicknesses, or by using slates with a relatively rougher texture. (The smoothness of slates’ cleavage surface varies according to the quarrying origin of the slate). For such roofs the thickness of slate used will not vary significantly since it will not usually exceed 3/8”.

Interesting texture variations may also be obtained by mixing various colors (see box) to create colored patterns or a mix of sprinkled colors. Such multi-colored roofs are referred to as polychromic roofs (Figure 33).

![Figure 32: Textured Roof](image)

**Graduated Roof**
The “graduated” roof (Figure 34) will achieve maximum artistic effect by using all of the above variations and by additionally making use of a significant gradation in slate thickness along the run of the roof. Typically, the first courses of slate at the eaves will employ thick, large slates and those dimensions will diminish toward the ridge of the roof. This creates a subtle, interesting visual effect.

![Figure 34: Graduated Roof](image)

Also, variations in exposure may be used, meaning that the courses will not form straight lines laterally, but rather they will have a broken irregular line. In fact this kind of roof will be custom-made and designed for specific buildings, and it will “harmonize with the general character of the building of which it becomes a part.” [1] (Figure 35)
Different architectural effects are also achieved by varying the ways slate is installed around some challenging detailing work such as the ridge of the roof, the hips, the valley junctions, or the places where the roof intersects vertical surfaces such as chimneys. Various elaborate techniques have been developed to create suitable ways to lay the slates at these lines of discontinuity.

Remember that slate roofs depend on the pitch on the roof’s surface to ensure impermeability; the water must shed down over successive superimposed slates and every slate must be covered by two slates from the above courses. This creates a difficulty when the roof’s surface encounters a discontinuity where no more slates can be laid on top of the previous ones, such as at the ridge and the other areas mentioned above. Note that unlike with asphalt shingles, slate shingles cannot be bent over the ridge to cap the top of the roof. In England, where soft sedimentary sandstones are sometimes used for laying stone roofs, it was sometimes possible to sculpt some stones into an inverted V in order to provide a capping for the ridge (Figure 36), but this is not possible with the hard, brittle slate.

Thus various techniques have been developed to lay the final course of slate at the ridge while preserving watertightness of the roof. Note that these techniques also vary according to regional preferences and practices. To ensure impermeability, detailing of the ridge (and of the other discontinuous areas of the roof) requires the use of metal flashing imbricate with the slates, or

**Color**

Slate varies in color and physical properties because of the different minerals that were contained in the sediments from which a particular deposit originated, and because of the extent to which these minerals were transformed during the metamorphic creation process. Different ‘brands’ of slate are classified using the following color nomenclature:

- Black (or Blue Black)
- Grey (or Blue Grey)
- Purple
- Mottled purple and green
- Green
- Red

Depending on the chemical constituents of particular veins in different quarries, these colors may fade with time or not. Thus colors are assigned the word “unfading” whenever it is known from experience that the particular slate will not fade with time or “weathering” if it is known that the slate’s color will change slightly.

**Figure 35**: Custom Made Graduated Roof with Varying Exposure and Slate Sizes [15]

**Figure 36**: Ridge Shingle Sculpted in Sandstones [20]

**Detailing Styles**

Different architectural effects are also achieved by varying the ways slate is installed around some
special roof cement applied to the joints and nail holes, or both. It is also possible to cap the ridge with a specially-made continuous metal flashing, or various types of imbricate tiles. Here are some of the detailing techniques used in key areas of the roofs.
a) Ridges

Three different techniques are used to finish the ridge with slates: (Figure 37)

- Saddle ridge
- Strip saddle ridge
- Comb ridge

Note that unlike the slates from the rest of the roof, the ridge slates are laid with their longest side running across the slope of the roof. This is done to retain a constant exposure, since the ridge slates are not covered by a next course of slates.

Also, it is usually necessary to provide a wood strip to serve as a nailing surface for the last slates course of slate in order to preserve the pitch of the slates.

The nails for the ridge slates have to be strategically placed; Slate Roofs suggests driving these nails just in between the butt ends of the slates from the second to last course. Needless is to say that this probably requires considerable dexterity. NRCA recommends avoiding contact with this second-to-last course by nailing above it completely; this requires the installation of a wood nailing strip especially for this purpose. A certain degree of precision is required to reach the wood strip while driving the nails.

Saddle and strip saddle ridges (Figure 38 and Figure 39):

These arrangements are thus called because the slates sit symmetrically over the ridge like a saddle. In both systems the slates from both sides of the roof extend to the ridge line so that their butt ends coincide.

In the saddle ridge system the ridge slates are laid with their long side aligned with the ridge and the butt ends are superimposed. The ridge slates overlap and are inclined. This creates a more textured, discontinuous effect. The nail heads are covered and hidden by the overlapping slates.

In the strip-saddle system, the slates are laid with their butt ends next to one another. This creates an even horizontal band with no overlapping. The nail heads are apparent since they are not covered by overlapping slates.

In both cases it is necessary to cover the nail holes with roofing cement and also to point with cement the horizontal joint where the slates from opposing sides meet along the ridge line. Sometimes a metal flashing is laid under the ridge slates and over the ridge.

Comb ridges:

This system is built like the strip saddle ridge except that the slates on one of the two sides of the roof are extended some distance (1/8 in. to ¼ in.) beyond the intersection of the two surfaces of the roof, creating a "comb" somewhat like the crest of a wave. It is apparently hoped that with this extension being provided on the side of the roof which is exposed to the prevailing winds, the...
wind will blow the rain water over the ridge and away from the joint between the slates along the ridge line.
Figure 38: Saddle Ridge [8]

Figure 39: Strip Saddle Ridge [8]

Figure 40: Combing Ridge [8]

Figure 41: Saddle Ridge [19]
b) Hips

The three major ways of finishing hips are: (Figure 42)

- Saddle hip
- Mitered hip
- Fantail hip

Saddle hip

The saddle hip requires a wood nailing strip under the slates. A line of slates is installed on top of the slates from the two sides of the roof; they overlap each other. No nails are apparent. Ideally the exposure of the hip slates should be so arranged that the ends of these slates align with the edges of the courses of slates on the sides of the roof. The slates have a regular rectangular shape. Because it breaks the regularity of the courses of slate from side of the roof to the next, this system is probably a little unsightly compared with the other more subtle hip systems.

Mitered hip

The mitered hip provides a soft transition between the sides of the hip. The hip slates have to be cut in a triangular shape, by hand, to fit the particular slope and profile of the hip. Ideally the horizontal lines of the slate courses should coincide from one side of the hip to the next. The fantail hip is similar to the mitered one, but the exposed corners of the slates are cut, which prevents breakage of the corners and creates a pleasing visual effect.

Figure 42: Various Hip Detailing [1]

Figure 43: Saddle Hip Seen From Above
Figure 44: Saddle Hip [8]

Figure 45: Mitered Hip [8]

Figure 46: Fantail Hip [8]

Figure 47: Saddle Hip [19]

Figure 48: Mitered Hip [19]

Figure 49: Fantail Hip [3]
c) Valleys

Valleys (the intersection of two downward-slope roof planes) are critical locations in terms of water leakage through the roof:

“Water runoff from the portions of the roof areas sloping into the valley flows toward and along the valley. Because of the volume of water and lower slope along a valley line, this area is especially vulnerable to leakage.” [8]

There are three basic types of valley systems:

- Open valley
- Closed or mitered valley
- Rounded valley

With any type of valley installation, it is important to first properly lay the underlayment across the valley, either with a continuous vertical piece running along the valley and centered on the valley line, or by interweaving the horizontal sheets from the two sides of the valley.

Note also that one should avoid locating any nails close to the center of the valley where they would create entry points for the water; they should be kept at least 18 inches from the center line.

**Open valleys**

Open valley have a metal flashing left exposed along the valley line:

“The open valley is formed by laying strips of sheet metal in the valley angle and lapping the slate over it on either side, leaving a space between the slate edges to act as a channel for water running down the valley angle.” [1]

This option is probably less desirable visually because it makes the valley look like a gutter, but it is nevertheless considered preferable in areas where a lot of foliage is expected to fall from the trees: such foliage may accumulate in the valley and eventually hamper the flow of water, creating water accumulation which can infiltrate in between the slates. The metal flashing, which should be thick enough to last as long as the other components of the roof, should preferably be “W” shaped with a little rib in its center: this protruding rib prevents water running down one of the sides of the valley to splash over the other side (this is especially important with valleys in which the two intersecting slopes have different pitch). Ideally the width of the valley should increase toward the bottom to accumulate the growing flow of water. The metal flashing should extend at least 4” under the slates.

**Closed valleys**

The closed valleys don’t display the unsightly metal flashing at the center of the valley:

“slates on both sides are cut at an angle parallel to the center line of the valley and are butted together, forming a mitered joint.” [8]

The metal flashing is actually present, but hidden under the slates; it may consist of a continuous strip running along the valley line, or of small
rectangles woven in one by one over the slates as they are being laid.

Closed rounded valleys are a variation in which the slopes from both sides of the valley are brought together with a rounded curve instead of intersecting along a straight line. This requires the construction of a rounded base in the valley to support the slates. This technique is labor intensive and requires a high degree of skills, and will apparently likely result in an unsightly mess unless done by very competent workers.
Figure 51: Open Valley [8]

Figure 52: Closed Mitered Valley [8]

Figure 53: Open Valley [19]

Figure 54: Rounded Valley
8) ASTM Standards

In the U.S., four standards are used to classify and rate roofing slate. They are published by the American Society for Testing and Materials (ASTM); this society designs procedures for testing the physical properties of certain materials used in the construction industry and other industries. The tests are conceived so that they can be reproduced to provide repeatable and consistent results, and they consist of series of objective procedures. These standards can be used to compare the quality of slates from different quarries and they are also useful for the designer who wants to specify a life expectancy desired for the slates. These tests were conceived in the 1930s [12] as a method to test the various types of roofing slates produced in the U.S. They have remained relatively unchanged since the 1940s. Much of the test ideology is based on work done in the 1930s by a certain William Kessler who had been commissioned for this job by the United States Bureau of Standards. In England, the Standard for slate roofing is BS680 and was first published in 1944.

The four standards used in North America for slates are:

- C 406 – 00 Standard Specification for Roofing Slate
- C 120 – 00 Standard Test Methods of Flexure Testing of Slate (Modulus of Rupture, Modulus of Elasticity)

Here is a summary of their relevant characteristics. [6]

C 406 – 00 Standard Specification for Roofing Slate

Scope: “This specification covers the material characteristics, physical requirements, and sampling appropriate to the selection of slate for use as roof shingles. Slates containing soft carbonaceous ribbons (impurities) are not considered by this classification as they are judged to be too liable to deterioration.” [6]
mottled, variegated, weathering, etc. are not defined. These color characteristics are typically assigned by the producers of the slates and are based on empirical judgment.

The Standard also recognizes the three roof types already mentioned earlier: standard, textural, and graduated. These types are described briefly and they closely match the original definitions given in Slate Roofs in 1926:

- Standard roofs - Sloping roofs utilizing a nominal thickness of 3/16 to ¼ in. (4.8 to 6.4 mm) are known as standard roofs. These shingles shall be rectangular in shape unless otherwise specified. These shingles shall be machine punched or drilled for two nails located for proper headlap.

- Textural roofs - Sloping roofs utilizing various sizes, thicknesses, textures, and colors for architectural effects, are known as textural roofs. These shingles shall be machine punched or drilled for two nails located for proper headlap.

- Graduated roofs - Sloping roofs utilizing a greater range of sizes, thicknesses, and exposed lengths of shingles, are known as graduated roofs. The slates are arranged on the roof so that the thickest and longest occur at the eaves and gradually diminish in size and thickness toward the ridges. These shingles shall be machine punched or drilled for two nails located for proper headlap. [6]

It is noted that the exposed corners should not be broken over more than a certain length (1 ½ inch), and that the curvature of the shingles should not exceed a certain amount (1/8 in. in 12 in.). It is also stated that knots and knurls are acceptable but should not prevent a proper contact of the shingles between one another.

C 120 – 00 Standard Test Methods of Flexure Testing of Slate (Modulus of Rupture, Modulus of Elasticity)

This test method consists of applying a load on the center of small slate samples that are supported at their ends. The load is gradually increased until the sample breaks in flexure, and the deflections successively induced in the sample as the load is increased are recorded. The slope obtained by plotting the load-versus-deflection curve is used to calculate the modulus of elasticity, $E$, of the slate from the following formula:

$$E = \frac{W' l^3}{4 \Delta b d^3}$$

where:

- $W'$ = load coordinate of the point, lbf (N)
- $\Delta$ = deformation coordinate of the point, in. (mm)
- $l$ = length of span, in. (mm)
- $b$ = width of specimen at the center, in. (mm)
- $d$ = thickness of specimen at the center, in. (mm)

The magnitude of the load necessary to obtain failure of the specimen yields the modulus of rupture ($R$) as follows:

$$R = \frac{3 W l}{2 b d^2}$$

According to [12], the test “attempts to simulate the effects of foot traffic and hail on natural roofing slate. The test tries to quantify the amount of load that can be placed upon a slate before it fails.” [12]

The procedure specifies that six samples should be tested, and the results from all six samples should be averaged; no provision is made to reject a result that would be clearly out of the range of the other results. The Standard recommends testing the sample both in the direction of the grain and against it (Remember that the grain runs perpendicular to the cleavage plane). Thus 12 samples should be tested in total. However the Standard is not very clear as to how to use the results along the grain versus the results against the grain. Note that the Standard for specification previously detailed makes use of the modulus of rupture across the grain to grade the quality of the slate. The slates are stronger in the direction of the grain; the producers usually make sure to cut their slates so that the long sides are in the direction of the grain. Determining the orientation of the grain is not easy and is usually done by examining broken samples.

This particular test has been criticized for its low repeatability and usefulness. [12] First of all, note that unlike the test for water absorption and resistance to degradation which concern properties that are intrinsic to the material, the flexure test is influenced greatly by extrinsic qualities: indeed, the strength of a particular slate is affected among other things by the techniques that were used to extract the rock from the quarry. The use of dynamite to detach the blocks of slate can create invisible fractures inside the slate which lower its strength. Also, the test does not call for machining the specimens to a precise thickness; the samples used for the test have
been split by the producer to the nominal thickness corresponding to the “commercial standard” slate thickness for standard-sized slates (3/16 in.) Remember that the slates are split by hand with a hammer and chisel and their thickness is estimated visually by the worker. The test simply requests the use of specimens with a thickness of 3/16 in. to ¼ in. In fact the procedure uses the samples with the thickness that they have when they come off the production line and are ready for shipping. Apparently the motivation for this procedure was to prevent quarries from producing slates that were too thin for their strength. [12] The quarries are left free to split the slates at varying thicknesses as long as their thickness is sufficient to pass the flexure test. Since the 3/16 in. slate was historically the most widely used in the roofing industry, ASTM decided to use this nominal thickness as a benchmark for its rupture test. The downside of this is that the samples sent from one quarry will not necessarily have the exact same thickness from one period to the next, or from one quarry to the next. Thus the flexure test loses its repeatability since the thicknesses vary constantly. Another issue is the fact that the slate is much stronger along its grain. It is difficult for the technician to see beforehand if the slate is cut exactly in the proper direction with respect to the grain: this can be seen only after the failure. But the test calls for keeping all the results obtained, even if one sample proves much weaker due possibly to an incorrect orientation of the grain. Some technicians will reject the results from such samples, but some will follow the ASTMN procedures to the exact wording.

“it is common knowledge within the slate industry that identical samples prepared from the same source piece of slate will undoubtedly receive different ASTM C-406 values when tested by different labs. (...) At present, the term ASTM C-406 compliant is synonymous with the term undefendable lawsuit. The ASTM standards on slate produce such unpredictable results that many quarries are discounting the whole test series and merely giving a warranty. (...) Without the confidence created by testing standards many projects are foregoing the use of slate for more predictable products. ASTM C-406 has become the slate industries Achilles heel.” [12]

Note in Table 1 that all three grades require the slates to have the same minimum modulus of rupture: 9000 psi. This value was chosen empirically by William Kessler when he designed the C-406 test. He chose that value after doing a survey of all the slates in use in the U.S. at the time: he observed that all of the “Commercial Standard” slates of 3/16 in. nominal thickness met or exceeded this strength.


The absorption test consists of immersing dry samples of slate in water for a specified period of time, and comparing the weight of the wet sample to the weight of the original dry sample in order to determine the amount of water that has been absorbed inside the microscopic pores of the slate.

“the correlation has been made that the greater the absorption percentage the more susceptible the slate is to freeze thaw cycles, which could directly reduce the expected service life of the slate.” [12]

The percentage of absorption is calculated as follows:

\[
\text{Absorption, } \% = \frac{W_2 - W_1}{W_1} \times 100
\]

where:

- \(W_1\) = weight of the dried specimen
- \(W_2\) = weight of the specimen after immersion

(This percentage is in fact the ratio of the weight of the water that fills the pores of the material over the weight of the material. It indicates the degree of porosity of the material, i.e. how much voids it contains.)


Scope: “This test method covers two procedures for weather resistance of slate in all outdoor installation by determining the depth of softening by an abraser or by hand scrapping. The test is based on the fact that slates containing pyrite, calcite, and carbon undergo a
chemical weathering which result in the conversion of the calcite particles into gypsum. The swelling action that results causes disintegration of the slate. The extent of this action on various slates in the test has been found to correlate with the durability of the materials in actual weathering." [6]

The test consist of soaking slate samples into a 1% solution of sulfuric acid (H₂SO₄) for seven days. The surfaces of the specimen are initially ground smooth with sand paper. The acid reproduces the effect of aging on the slate caused by chemicals in the air and rain water. After soaking, the sample are scratched either by a shearing tool applying a load of 2.2 lbf., or by scraping them by hand with a steel blade and a pressure of approximately 3 lbf. The depth of the grooves created is then measured. This depth corresponds to the depth to which the slate has been softened by the acid solution. The assumption is that the deeper the groove, the more the material is sensitive to detrimental effects caused by long-term weathering.

9) Durability

The "expected service life" specified by the ASTM standards represents only the minimum life that can be officially expected for each slate grade; historically, many slate roofs have lived for much longer than that. Estimates for the potential durability of slate roofs vary according to the sources, but are usually around one hundred years. [4] The New England Slate Company mentions a durability of 125 years for Vermont/New York slates, and 175 years for Virginia's. [10] Roofs of historical importance may be taken up every century and re-laid with the same slates after removing the ones that have failed. [4]

Many factors influence the durability of slate roofs:

"The durability of a slate roof depends primarily on four factors: the physical and mineralogical properties of the slate; the way in which it is fabricated; installation techniques employed; and, regular and timely maintenance." [10]

First of all the quality of the slate itself is key. The best slate will have a porosity as low as possible and no undesirable mineral impurities such as calcite and iron sulfides.

"The weathering of slate is chiefly due to mineral impurities (primarily calcite and iron sulfides-known as pyrite) which, in concert with alternating wet/dry and hot/cold cycles, react to form gypsum." [10]

Remember that the gypsum takes up twice the space as the impurities. Once the impurities start reacting to form gypsum, they create a vicious cycle in which the expansion caused by the gypsum creates a delaminating of the slate along its cleavage planes, and the delaminating allows more water to be absorbed by the slate and react with the impurities, thus forming ever more gypsum. This weathering will manifest itself by paper thin laminations flaking of the surface and the slate becoming soft and spongy. A loss of strength is also incurred, which makes the slates more prone to breakage, loss of corners, and cracking. Additionally, because of the increased porosity of the slates, water absorbed by the slates may reach the wood sheathing of the roof which will start rotting and decaying; rotting and weakening of the sheathing will, in turn, allow the slates to move or detach themselves since the wood won't retain the nails, aggravating the problem. "Such rot can go undetected for long periods of time since, often, there is no accompanying leak." [10]

The porosity of the slate will influence the degree to which the slate will resist the attack of the mineral impurities: for an equal amount of impurities, a slate with less porosity will last longer since it will initially allow less water to enter the crystalline structure and react with the impurities.

The mechanical effects of frost and thermal expansion are thus secondary in the weathering process: they will aggravate a problem initially caused by the chemical and physical properties of the slate. The degradation observed will be more severe on the areas of the roof more exposed to prevailing winds and rain, and areas with a lesser slope.

Additionally the durability of the slate roof will be greatly influenced by the general care taken in quarrying, cutting, transporting, and installing the slate. Since dynamite is used at the quarry to detach the blocks of slate, invisible fractures may be present in the material; care should be taken to cut the material in order to leave out such fractures. Fractures may also be created during transportation to the job site. Careless workers may damage the slates while installing them either
when punching holes, cutting the slates, or nailing them improperly. The holes must be properly countersunk to allow the nail head to sit in the hole properly. As mentioned already, the nails must be driven at just the right depth; otherwise either the nailed slate or the slate above it will be damaged by the nail. The slates must also be properly staggered from one course to the next; with unequally-sized slates, it is sometimes difficult to make sure the proper distances are respected between the joints of the slates from one course to the next. For improved strength, slates should also be cut and installed with their longest side oriented along the grain.

The durability of the roof will also be dependent on the care taken to properly maintain it. It is necessary to regularly check for any accumulation of leaves and debris in gutters or valleys that may retain water and either cause water to flow back under the slates and through the roof or ice to accumulate and break the slates. Slates may possibly be broken by falling tree limbs or hail, in which case the damaged slates should be promptly replaced by new ones to restore the impermeability of the roof. Note that it is customary to keep a reserve of spare slates for such needs.

Slates are sensitive to foot traffic. A worker walking carelessly on the roof to carry out any repair activity can greatly damage the slates simply by stepping too heavily on them. Ideally some scaffolding should be installed whenever it is necessary to go on the roof to perform repair work.

Note that visually, the effect of weathering will not affect the appearance of the slate; at worst, broken slates may hang out of place or may be missing completely, but normally these failing slates should be repaired and replaced as part of a regular maintenance program. Some slate colors are known to fade or change their tint with time, but the slates will basically retain their shape and texture for as long as the roof is standing. This is different from all other roofing materials, whose visual appearance gradually degrades over time: asphalt and wood shingles warp or break apart, painting on sheet metal peels, etc.
Observations on the durability of Montreal’s slate roofs:

Montreal has many slated mansard roofs dating from the end of the 19th century to the early 1900s. Many are still in perfect shape; some have degraded somehow, exhibiting broken or missing slates, or have been patched inappropriately with various materials. Often the slates have been painted over, probably to match the color of the rest of the façade. The repairs done can give an indication of the parts of the roofs that are more susceptible to damage and degradation, at least in this city’s climate.

a) Broken slates at the hips

For some reason the slates seem to break in particular along the hips (maybe due to the sharp edge of the hip being vulnerable to impacts from various tools or ladders?); nevertheless it is not uncommon to see metal flashing having been added on top of the hip edge to hide defects or broken slate corners. (Figure 55)

b) Slates replaced with inappropriate material

Because of the difficulty to order small numbers of slates for repairs or to find matching sizes or colors, we often see slates replaced with sheet metal shingles, sometimes painted the same color as the slate apparently in the hope that no one will notice. In fact such repairs are very apparent; only real slates of matching color and textured should be used. Owners should keep aside a reserve of spare slates after their roof is installed for such purposes.

Figure 55 (Personal Coll.)

Figure 56 (Personal Coll.)
c) Slates replaced entirely with asphalt shingles

Another common occurrence is roofs that have been entirely re-laid with asphalt shingles instead of slate, probably for economy. The visual effect is usually disastrous. The smooth-textured, even asphalt shingles give a flat and homogeneous feel to the roof which does not suit the elaborate architectural style that the rest of the building usually has. Additionally the “brand new” look of asphalt shingles contradicts the rest of the façade which is always weathered by the passage of time. These two neighboring buildings on Mont-Royal Street give a perfect example:

![Figure 57 (Personal Coll.)](image)

Note that the asphalt shingles have already started to deteriorate; their edges are warping and they are even decomposing near the window. The damages have probably been caused by high temperatures in the summer when the radiation from the sun causes the roof’s surface to become extremely hot.

These mansard roofs were designed with a slate surface in mind: slate is not sensitive to heat so no provisions were made to allow any ventilation under the slate surface. The slates are nailed directly to the sheathing. If the underside of the deck is insulated as is usually the case today, the heat from the slates cannot be transferred inside the building and the slate’s temperature rises considerably. Unlike slate, asphalt shingles are sensitive to this high temperature, and should normally be installed on ventilated roofs. Thus choosing to replace asphalt is not only unpleasant visually, it is not an economical choice in the long term.

Note also the broken slate shingles at the eaves. These damages were probably caused by ladders or possibly excessive ice accumulation at the eaves. Most often instances of broken slates are located at zones of discontinuities such as the eaves, hips, etc. The continuous surfaces seem relatively resistant but the exposed edges are vulnerable to impacts or ice dams.

![Figure 58 (Personal Coll.)](image)
10) Economic Issues

It will come as no surprise that slate roofing is relatively expensive. As mentioned before, slate shingles have to be manufactured one by one. One writer remarks that every single slate has to be split to the required thickness by a specialized worker using a simple hammer and chisel. The manufacturing process is made even less cost-efficient by the high rate of quarried material that has to be rejected due to various defects.

Slate also requires very experienced workers for installation. The detailing work to be done at the ridges and valleys is very intricate and on those portions of the roof every shingle must be trimmed and punched by hand on site:

“Slate roofing long has been considered a domestic art form because of the amount of skill it takes to properly install a slate roof system.” [18]

Additionally the installation process, because of its complexity, is very time consuming:

“Putting on a slate roof is slow (but satisfying) work. A typical job takes me about three months after the time slate arrives from the supplier. One huge job I did – 170 squares, laid on in a graduated, textural pattern – took me a year to complete.” [9]

Here is a comparison between the costs of slate in terms of material and labor, with the costs of other more common roofing systems according to data from the RSMeans Building Construction Cost Data, 2004: (note: these are the bare costs, without overhead)

<table>
<thead>
<tr>
<th></th>
<th>Daily Output (Squares)</th>
<th>Cost of Material (Per Sq.)</th>
<th>Cost of Labor (Per Sq.)</th>
<th>Total (Per Sq.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slate, Vermont, unfading, green, mottled green</td>
<td>1.75</td>
<td>$345.00</td>
<td>$131.00</td>
<td>$476.00</td>
</tr>
<tr>
<td>Asphalt Shingle, inorganic, Class A</td>
<td>5.5</td>
<td>$31.00</td>
<td>$41.50</td>
<td>$72.50</td>
</tr>
<tr>
<td>Wood Shingle, 16” No. 1 red cedar shingle, 5” exposure, on roof</td>
<td>2.5</td>
<td>$163.00</td>
<td>$106.00</td>
<td>$269.00</td>
</tr>
<tr>
<td>Clay Tiles, ASTM C1167, GR 1, severe weathering</td>
<td>1.65</td>
<td>$395.00</td>
<td>$139.00</td>
<td>$534.00</td>
</tr>
</tbody>
</table>

Note that including labor and material, slate is six times more expensive to install than asphalt shingles. Most of the price difference is caused by the cost of the material itself; the cost of slate alone makes up 72% of the total installation cost of slate. For asphalt shingles, that proportion is 43%.

Note also that slate is not necessarily the most expensive material: clay tiles are even more expensive at installation. Wood shingles are half the price of slate.

For comparison, the durability of asphalt-shingles or clay roofs is usually given in the 30-50 years range. The high initial cost of slate must be evaluated against its high durability.

11) Conclusion

Slate roofs have been used for centuries and the techniques used today for laying slates are inherited from ancient practices developed over the years in Europe and particularly England.

The slate industry in the U.S. published a book in 1926 which detailed the practices for laying slate that were considered accepted practices at the time; these instructions are still for a large part considered as reference today and are even reproduced in many roofing resources.

Slate experienced a large popularity in North America toward the end of the 19th century, mostly due to new efficient rail transportation and the arrival of architectural styles well suited to the use of slate. Slate-covered mansards were very popular in urban centers in Canada until the early 1900s.

The competition from mass-produced, easily installed asphalt shingles and the fall of the
architectural styles that promoted slate use relegated slate roofs to the statute of an expensive leftover from the past in the 1900s.

Slate has experienced a recent surge in popularity. Architects and owners are re-discovering its esthetic qualities and adapting it to new architectural styles.

Slate is as much as six times more expensive than asphalt shingles in terms of initial cost. However it possesses a very long service life in the order of century instead of decades as with other roofing materials. The raw and natural origin of slate gives it a noble look that cannot be surpassed. The high cost of the material, the expertise and skill required to install it properly, serve as testimony of the good taste and affluence of the owner who chooses this material.

The luxury offered by slate is hampered by certain disadvantages:

- slate shingles are vulnerable to damage caused by careless workers walking on the roof
- some areas of the roof, typically zones of discontinuities, are more prone to slate breakage than the rest of the roof, thus requiring localized maintenance
- installation of slate requires great care and expertise, and careless work can easily result in early failure of the roof
- no recognized education authorities exist to train workers as in other trades. Contractors must rely on the experience and reputation of the slate workers.
- the durability of slate is dependent on the level of chemical impurities in the stone. These levels vary from one quarry to the next. The standards published by ASTM to grade slate are based on three relatively simple tests measuring the strength in flexure, the porosity, and the resistance to acid exposure. The expected service lives associated with these grades are based on empirical observations done in the 1940s on existing slate roofs. The flexure tests are not considered reliable. No official way of specifying color or texture exists.
- The initial cost is very high, mainly due to the cost of the material itself
REFERENCES

Books


Articles


Internet


Various Sources

Appendix 1: Comparison of Chemical Components of U.S. Slates Published in *Slate Roofs* in 1926