

Slate Rock Mines: From formation to Extraction

D. Ben Ghida

Abstract: Slate rock has been analyzed for more than 170 years and was among the first geological features to be used in a number of countries such as Spain, France, Wales, North America and Brazil. Early observations recognized the importance of slate into the construction of roofs, cladding, pavements, or roads. Natural slate has many features that make it one of the most valuable, versatile and sustainable construction materials e.g. slate waste is particularly used as an alternative to conventional aggregates. In this paper, I will review the slate rock, geological formation, mining, production and uses in construction. This paper gives the reader a comprehensive overview of slate geology, formation, extraction as seen in the light of all the vast body of work made there up to the present time.

Index Terms: Slate extraction, Geology, Stone mining, Quarry.

I. INTRODUCTION

Since the Stone Age, man broke rock and shaped stone to design tools and build shelters. The oldest quarries of slate schist were discovered in Brittany in the Middle Ages, but it is not until the 17th and 18th Centuries that its exploitation developed. Cairn of Barnenez (Barnenez Tumulus) located in the northern Finistère of Brittany in France (Figures 1 and 2) is the concrete example of natural materials durability. With more than 6700 years old, the megalithic structure is not only defined as the oldest structure on the world that man ever built, but also as the most durable structure dating back to the Neolithic Era.



Fig. 1. Cairn of Barnenez: Bird view.

This large tumulus consists of two juxtaposed cairns (heap of stones) with an immense mass of different types of granite dry-stones (Giot et al., 1995) carefully stacked together, covering eleven funerary chambers with corridors.



Fig. 2. Cairn of Barnenez: Close view of juxtaposed stones

Natural slate was first used by Romans in their constructions and the oldest example is dating back to the 1st Century at the Roman fort in Segontium in Caernarfon, North-West Wales, Great Britain (Figure 3). People have been quarrying slate in the northern of Wales for over 1800 years. The world oldest and largest natural slate quarry is “Penrhyn Quarry” which is located in North Wales, Great Britain (Figure 4). As far as known, it has been operating since the 13th Century as a traditional small industry. Its full commercial expansion did not start until 1784 holding an important impact on British economy and history.

Quarry developed in the 18th Century leading to a gradual economic expansion in the following decades. With the increase in housing needs, slate production spread significantly during the 19th Century onwards. Roofing slates were more particularly in high demand during that period of time. As a result, demand and annual output for the slate extraction and production kept on increasing making the “roofing slate industry” one of the most important impacts on landscape change around the world.



Fig. 3. Bath house remains, Segontium Roman Fort 70s AD, Wales, UK

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Fig. 4. Penrhyn Quarry, North Wales UK.

II. SLATE ETYMOLOGY

Foliation is the main characteristic of most metamorphic rocks caused by silicate layers' orientation. Any type rock with foliation producing aligned lustrous surfaces, known as slaty cleavage, is named "slate".

Slate is a fine-grained rock easily split into smooth flat plates (Oxford Dictionaries-English,2017). Partridge (1966) defined slate as a piece of laminated rock. In the 1520s, the word was used to define the action of covering with slate (Etymonline, 2017). The appellation was borrowed from Middle English "scalate or sklate" (Oxford Dictionaries-English, 2017) or "sclat" (Partridge, 1966) which derives from a shortened mid 14th Century Old French word "esclate" which is a feminine synonymous of "esclat": meaning split piece (Etymonline, 2017) or a broken piece of material (Oxford Dictionaries-English, 2017).

III. SLATE FORMATION

Slate is a laminated shaly fine-grained, homogeneous and compact metamorphic rock formed from fine clay, sometimes sand or volcanic dust metamorphism. At least 95% of grain size varies from 2µm to 63µm (BaunetzWissen, 2017) so a naked eye cannot see these grains. Slate has an efficient mechanism for producing foliations on the grain scale (Hoinkes et al., 2005).

Metamorphic rocks are either from a magmatic or sedimentary origin, they are classified under three different rock groups:

1. Ultramafic
2. Mafic
3. Quartzo-feldspathic

Fig. 5. Increasing metamorphic levels of Protolith Sediment "Pelite": from Low-Grade [fine-grained] to High-Grade [coarse-grained].

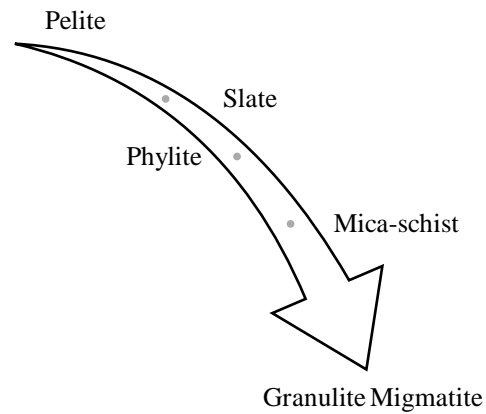
Pelitic protoliths, which belong to the quartzo-feldspathic protoliths group (Figure 5), are sedimentary rocks composed from clay minerals derived from weathered and eroded continental crust (Ibid). At an increasing metamorphic grade, pelite are transformed into slates, phyllites, mica-schists and granulites (Ibid).

During the earth historical Devonian Era 350 to 400 million years ago, the clay forming the shale rocks was transformed chemically and crystallized to mica due to thousands of years of process under different stress in an environment of extreme pressure between 0.05 to 0.2GPa, at different heating rates, between 200 to 400 degree Celsius

(Ibid).

So, with either directed pressure or stress, slate is formed with its main "fissility" characteristic which plays a dominant role in its strength (Kay et al., 2005). During a later mountains' formation, the formed consolidated clay layers have been unfolded under lateral pressure.

The water and rock cycles (Figure 6) represents the closed



earth system which is a continuous circulation and conservation of matter within the three realms of our physical world (Slatesite, 2017): the lithosphere (mineral resources: land), the hydrosphere (water), and the atmosphere (weather and climate: air). All together creating the biosphere; the home of all known life.

With the increasing of burial depth, slate passes on to phyllite, schist and gneiss because it is a low to medium grade metamorphic rock (Sandatlas, 2017), and rich in phyllosilicates (Hoinkes et al., op. cit.).

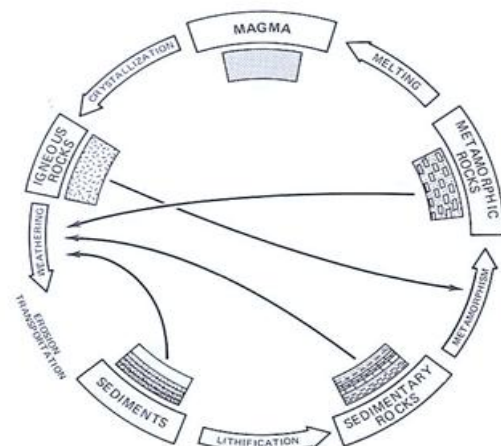


Fig. 6. The Rock Cycle.

Variscan is the name of the European mountain chain which was formed by continental (plates) collision million years ago in a period known as Paleozoic Era. All European slates come from the Variscan; this shale stratum extends from Portugal to Germany through Spain and France. On the other hand, the Slate deposit in Wales (UK) was formed by another period know as Precambrian.



This is the reason why slates mechanical and physical properties along with chemical characteristics differ from one country to another, and from one sub-region to another.



Fig. 7. Natural slate chunks.

Very often slate is confused with shale rock because it shares similar properties. Unlike shale construction uses which require extra steps, slate does not have to be broken down and mixed with other components (Figure 7). However, shale is a rich energy source of natural gas and oil. In addition, there is a commercial definition of calcareous shale “marl slate” which is not a true slate because of its very high lime contents. Such shales have substantially different minerals composition and show a completely different chemical analysis value (BaunetzWissen, 2017).

IV. SLATE EXTRACTION METHODS

Slate extraction can take place (mainly) according two different procedures:

1. Open cast mine and;
2. Underground mine.

In the first one, slate is extracted directly from the mountain surface in an open cast site which can be identified as quarry mine using mainly three different saws to produce vertical or horizontal cuts in the rock: disc/crosscut saw; a chain saw or an innovative cutting technology like the diamond cutting wire gives a clean cut with minimal losses and zero environmental nuisance. Sometimes the slate quarries are wrongly named open pits which describes also a surface mining for different bedded deposits, other than building materials or dimension stones.

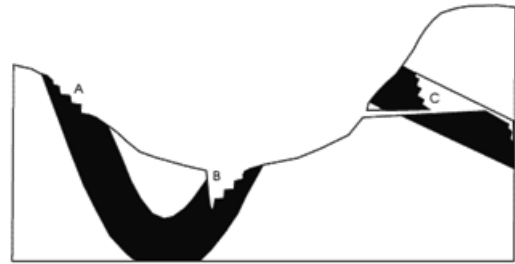


Fig. 8. Diagrammatic representation of slate bed.

The second type is used to reach a profound deposit of dimension stone using horizontal tunnels and usually an innovative transport technology called narrow-gauge rail systems. Extraction methods are shown respectively in figures 8 and 9, open quarry (A), open pit (B), or underground mine (C)(Slatesite, 2017).

The final product price is highly affected by the extraction method type. The open cast mines are much easier in terms of extraction and workability, low capital cost and low mechanization than the underground mine; therefore, these open cast mines are bringing a cheaper final product.

In underground mines, tunnels are enlarged in a dome shaped form to insure a good load resistance of the superior strata. These curved surfaces allow maximum tunnel stability, but sometimes a slate pillar is left at the center for a better upper rock layers’ support.

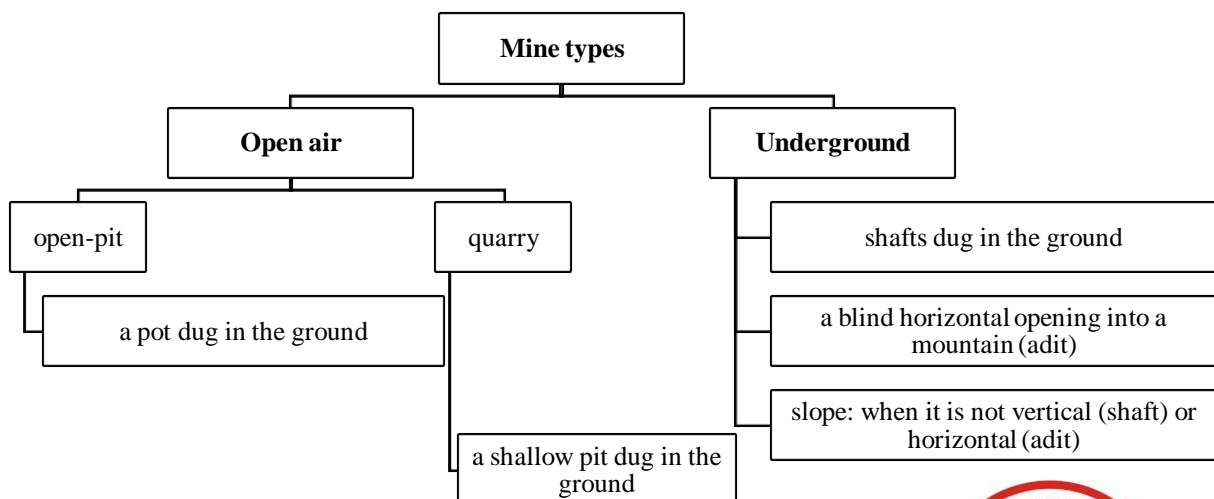


Fig. 9. Slate extraction

V. CONCLUSION

With the diverse uses of slate in the construction sector, several extraction and mining slate sites are available across the world: Wales (UK), Spain, Portugal, Italy, Germany, Brazil, and China. Slate demand has been continuously growing since the 13th Century, and represents a potential market for every country. A substantial investment is required in order to supplying this product demand.

An adequate return on investment in the slate extraction industry is realized through an efficient investment process and decision-making. The stakes are high, with a payback period that is up to 200 years long because slate has proved to be advantageous for both its high durability, and its attractive appearance. However, sustainable geotechnical methods must be applied in these extractions' sites for a future reduction in potential ground control hazards.

The implementation of innovative extraction methods and machinery will increase productivity, reduce waste, and enhance sustainability.

REFERENCES

1. Giot, P.R.; Chauris, L. ; Morzadec, H. (1995) L'apport de la pétrographie à l'archéologie préhistorique sur l'exemple du cairn de Barnenez en Plouezoc'h (Finistère), Revue archéologique de l'ouest, Vol. 12 (1), pp. 171-176
2. Etymonline.com. (2017). Online Etymology Dictionary. [Online] Available at: http://www.etymonline.com/index.php?allowed_in_frame=0&search=slate [Accessed 19 Mar. 2019].
3. Oxford Dictionaries-English. (2017). Slate - definition of slate in English | Oxford Dictionaries. [online] Available at: <https://en.oxforddictionaries.com/definition/slate> [Accessed 19 Mar. 2019].
4. Partridge, E. (1966). Origins, a short etymological dictionary of modern English. 4th Ed, London, Routledge & Kegan Paul PLC
5. Hoinkes, G., Hauzenberger, C. and Schmid, R. (2005). Metamorphic Rocks | Classification, Nomenclature and Formation. Encyclopedia of Geology, pp.386-402.
6. Kay, S., Mpodozis, C. and Ramos, V. (2005). ANDES. Encyclopedia of Geology, pp.118-131.
7. Costa, J. and Barker, V. (1981). Surficial geology. New York: Wiley.
8. Sandatlas. (2017). Rock Types. [Online] Available at: <http://www.sandatlas.org/rock-types/#Slate> [Accessed 19 Mar. 2019].
9. BaunetzWissen. Einfamilienhaus in Schindellegi, Dynamische Deckung für die Fassade eines Betonbaus. [Online] BaunetzWissen. Available at: <https://www.baunetzwissen.de/schiefer/objekte/wohnen-efh/einfamilienhaus-in-schindellegi-4727812> [Accessed 19 Mar. 2019].
10. Slatesite. (2003). Slate-The slate formation. Gwynedd Council [Online] <http://www.llechicymru.info/SlateAreas.english.htm> [Accessed 19 Mar. 2019].