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NATURAL STONES IN EARTH`S HISTORY

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Abstract: Natural stones used in building industry and art come from all continents and were formed during almost the whole geological history. Granites, gabbros and migmatites are quarried especially from the Archean to Proterozoic shields and Hercynian Belts. True marbles and ophicalcites were created in the Tertiary during the Alpine orogeny, some in the Paleozoic and the Neoproterozoic. Limestone rich periods were the Devonian, the Jurassic and the Cretaceous.

1. Introduction

In city centres there are many natural stones used like building material, cladding, paving and plastic art. Many people are curious of stone origin, among them also university teachers and students. Stone companies know only commercial names and sometimes whether it is marble or granite in commercial sense or the stone country. The article aims to help people interested in stone to provide some information of the most world used granites and marbles with some accent to European stones. It familiarizes the reader with the most rich periods for various stone types in the Earth's history.

It is possible to search out information on natural stones, e.g. petrography and quarry location based on commercial name on web pages and catalogues (e.g. Müller, 1984 and 2001). Geology including age of stones were gained from many geological maps and scientific articles. Some universities and museums worked out walking tours downtown cities or city building descriptions in USA (e.g. Wilson, 1979, Hannibal, 2000, Ketter, 2002), in Slovakia (Pivko, 1999), in Bohemia (Březinová et al., 1996), where the origin and petrography of some stones were described. Some data are published in the education papers describing geology of certain region (e.g. Lusardi, 2000). There are summary information of the most popular natural stones on Internet (Pivko, 2002 and 2003).

Natural stones or dimension stones are rocks formed by various natural processes during almost all the Earth's history. Sedimentary rocks as *conglomerates, sandstones* (PIETRA SERENA) and *shales* (ARDESIA) are made of rock particles with decreasing grain size. *Limestones* are created from calcareous remnants of organisms, named by many stone experts like marbles. The limestones are composed of shells (ROJO ALICANTE), algae (BOTTICINO), crinoids – sea lilies (TENNESSEE MARBLE), corals (ROSSO FRANCIA), bryozoans – moss animals (INDIANA LIMESTONE), large single-celled organisms -foraminifers (CHIAMPO) or microscopic skeletons of foraminifers (ROSA PERLINO) or there are ones formed from angular limestone particles like debris below coral reefs (BRECCIA PERNICE).

Some limestones were created by chemical precipitation, e.g. oolithic limestones from small calcite balls (PORTLAND). *Travertines* were formed from mineral springs (TRAVERTINO ROMANO).

Magmatic rocks are of different composition. They consist of various portion of felsic (quartz, feldspars) and mafic minerals (micas: muscovite and biotite, amphibole, pyroxene and olivine). Felsic plutonic rocks with quartz, feldspars and micas are *granites*, for instance BIANCO SARDO. Mafic plutonic rocks with pyroxene, olivine and feldspars are *gabbros*, e.g. NERO IMPALA. The intermediate rocks with feldspars, biotite, amphibole and pyroxene are transitional between both groups, e.g. *syenites* (BLUE PEARL) or *diorites*. Sometimes magma crystallised in dykes, e.g. SWEDISH BLACK.

Sandstones are metamorphosed to *quartzites* (AZUL MACAUBAS), limestones to true *marbles* (BIANCO CARRARA), shales with increasing temperature and pressure to *phyllite, shist and paragneiss* (SILVER CLOUD), granite to *orthogneiss* (SERIZZO). At very high temperature and pressure *granulites (*KASHMIR WHITE) can be formed. Usually with rising temperature and pressure, gneisses are partly melted and *migmatites* (granite gneisses) are created (PARADISO). There is the problem of the boundary between limestone and marble. Strongly consolidated limestones like CREMA MARFIL are considered as marbles.

The Earth's history is divided into geological eras: the Archean and the Proterozoic, which can be marked as prehistory and they represent about 90% of the Earth's history. Further there are the Paleozoic as ancient, the Mesozoic as medieval and the Cenozoic divided to the Tertiary as modern and the Quaternary as contemporary.

The results are summarised in a table.

2. Earth's history and natural stones

2.1 Archean (4.6 – 2.5 Ga) Earth's Prehistory

The Earth age is about 4.6 Ga (Giga annum – billion years ago). In the first period the Earth's core, mantle and atmosphere were formed. Melted iron followed gravity and accumulated in the core. Lighter materials, such as silicate minerals, migrated upwards in exchange and created magmatic ocean at the Earth's surface. Gases were released and formed atmosphere. The magma ocean cooled to basaltic crust similar to today's oceanic crust. The crust was later covered by condensed water vapour. The plates of primary crust were moved by convection flows in the mantle and plate tectonics probably began. Above hot spots and within subduction zones felsic magma was created from which the first small protocontinents were formed. During the Earth's history the continents grew and after plate collisions accreted together. The rocks from the oldest Earth's history (the Archean and Proterozoic) are accumulated in Precambrian cratons or shields which represent cores of all continents.

The Archean rocks were many times reworked by geological processes. The oldest rocks were found in Canada and their age is about 4 Ga. In sediments of one of the oldest rocks from Australia mineral zircon with age approximately 4.4 Ga was determined (Earle, 2000). Zircon is mineral typical for felsic igneous rocks that form continental crust.

In the Archean, the Earth was covered by clouds. Only small lands were emerged from global ocean of brown colour, which reflected orange sky without oxygen. Primitive life was organised below sea level. The earliest known evidence of organisms comes from carbon isotope pattern in 3.85 Ga old Greenland sediments. The bacteria and blue-green algae were the first organisms, their oldest occurrences are 3.5 Ga old (Cowen, 2000).

The oldest dimension stone comes from Minnesota (USA). It is RAINBOW gneiss with age of about 3.6 Ga (Dalrymple, 1991, Lusardi, 2000). Many dimension stones comes from Saő-Francisco Craton (Brazil) and Dharwar Craton (India), which were formed in the mid-Archean about 3 Ga and more (Engler et. al., 2002, Moyen et al., 2001). Very old stone up to 3 Ga – BARENTS BLUE is from northern Norway (Barent Stein, 2001). From the late Archean, when final stages of Algoman orogeny took place (2.6 – 2.7 Ga), there are granite massifs in South Dakota and Minnesota, from which DAKOTA MAHOGANY and AGATE are quarried, similarly CRYSTAL GOLD from Ontario (Dalrymple, 1991, Lusardi, 2000, Easton, 2000).

On the boundary of the Archean and the Proterozoic very large Closepet granite and small bodies were formed inside the mid-Archean crust in Dharwar craton along shear zone (Karnataka and Tamil Nadu – India) in depth many tens of kilometres (Jayananda et al., 2000, Moyen et al., 2001). RUBY RED and NEW IMPERIAL RED are exploited from these granites. In addition, migmatites as partly melted rocks are connected with this granite. There are many well-known migmatites like MULTICOLOR, PARADISO, JUPARANA INDIA, HIMALAYAN BLUE, maybe KUPPAM GREEN (VERDE MARINA). Granite creation was also accompanied with basaltic dykes (veins) – HASSAN GREEN. IMPERIAL WHITE gneiss, SAPPHIRE BROWN granite and TAN BROWN orthogneiss (?) are probably of similar origin as Closepet granite (Pivko, 2002).

2.2 Proterozoic (2,5 – 0,55 Ga) Earth's Prehistory

In the Proterozoic oxygen produced by blue-green algae colonies was gradually surged into the atmosphere. From several bacteria more organised cells were created about 1.8 Ga ago. By the end of the Proterozoic the first multicellular organisms appeared. At about 0.7 Ga scientists supposed “Snowball Earth”, covered by ice and snow (Hoffmann, Schrag, 2000).

In the Proterozoic larger masses of continental crust were formed because plates broke apart and then reconnected, and long orogenic belts were created. During some periods of the Earth's history there were one or several large continents and during other periods there were many small continents.

Paleoproterozoic (2,5 – 1,6 Ga). Previously, the scientists thought that the greatest layered plutonic body in the world – Bushveld complex in South Africa was created as a consequence of an asteroid impact about 2 Ga ago. Today it is explained by processes in mantle below thinned continental crust (Viljoen, 1999, Knoper et al., 1999). In layered magmatic intrusion, heavier mafic rocks are in the bottom (IMPALA and BELFAST BLACK gabbros) and felsic rocks are on the top (AFRICAN RED granite).

Near from there in Zimbabwe continental crust crashed 1.8 – 1.9 Ga ago (Evans et al., 2001). Basaltic magma crystallised in broad fractures and created dolerite (microgabbro), today quarried as ZIMBABWE BLACK.

In Saő-Francisco craton in Brazil 1.9 Ga ago weak metamorphism changed originally strong metamorphosed the mid-Archean rocks (Engler et al., 2002, Carneiro et al. 2000), among them also migmatites today known as VERDE MARITACA, VERDE SAN FRANCISCO, VERDE LAVRAS, VERDE TROPICAL, LILLA GERAIS and GRAN VIOLET (Pivko, 2002). Green colour is caused by new-formed minerals like chlorite. JACARANDA and KINAWA come also from Saő Francisco craton (CPRM, 2001).

Between 1.5 – 1.8 Ga many granites, today used as natural stones, were formed at different parts of the Earth when many continents accreted to a supercontinent. In Minnesota during final stages of Hudsonian orogeny (1.8 – 1.7 Ga) granite massifs were intruded. Today they are quarried as CHARCOAL BLACK and DIAMOND PINK (Lusardi, 2000, Ketter, 2002). Great anorthosite- rapakivi granite massifs were formed in Baltica and Ukrainian shields after the finishing of the Svecofennian orogeny (Siddall, 1999, Sharkov, 1999). Rapakivi (Finnish word) is the type of granite with red colour and characteristic structure and mode of disintegration in the course of weathering. In Ukraine there are two large massifs of 1.7 – 1.8 Ga age (Yashchenko, Shekhotikin, 2000, Sivoronov et al., 2001, Bogdanova, 1999) with BLUE VOLGA anorthosite, ROSSO SANTIAGO granite and ROSSO TOLEDO granite. *Anorthosites* are mafic plutonic rocks, commonly but not correctly called labradorites, which belong to gabbro group and consist mainly of feldspars. Anorthosites are frequent rocks on the Moon. BLUE EYES anorthosite from eastern Canada, Labrador (origin of labradorite name) and LABRADOR ANTIQUE anorthosite from south Norway are also of Proterozoic age but much younger (Ryan, 2001, Schärer et al., 1996). There are typical rapakivi granites and similar rocks of 1.5 – 1.7 Ga (Rämö et al., 2002, Evins, 2000, Sharkov, 1999) in south Finland: CARMEN RED, BALTIC BROWN, EAGLE RED and BALMORAL and in south Sweden: SWEDISH MAHOGANY, GOTENROT and maybe TRANAS.

Mesoproterozoic (1.6 – 1 Ga). In north-west India in Rajasthan the Delhy orogeny was formed by connection of Aravalli and Singhbhum continents between 1.6 – 1.4 Ga. The parts of oceanic lithosphere with mantle igneous rocks – peridotites – were thrusted over continental crust at that time or maybe later during the Pan-African orogeny (Mamtani et al., 2000, Mooney et al., 2001, Siddall, 1999). The rocks were deformed and metamorphosed to green *serpentine marbles* (ophicalcites). There are a few quarries with RAJASTHAN GREEN or darker EMERALD GREEN. These green Rajasthan marbles are known in Europe as VERDE GUATEMALA. The famous white MAKRANA MARBLE of the Mesoproterozoic age (Maheshwari et al., 2002) comes also from Rajasthan.

On Saő Francisco craton in Brazil, sand was deposited probably in river environment with typical cross lamination (systems of oblique bands). The sand was further consolidated to sandstone and changed during metamorphism to the quartzite – ROSA QUARTZITE, FLAMENCO and AZUL MACAUBAS (confer CPRM, 2001, Monteani et al., 2001)

Widespread Grenvillian orogeny had been formed 1.4 – 1.0 Ga ago (Siddall, 1999) which created Rodinia supercontinent (from the Russian word for “homeland”) from smaller continents. The collision of continents was accompanied by granite plutons. In South Africa there are VERDE FOUNTAIN charnockite (1.2 – 1.0 Ga) (Robb et al., 1999, Waters et al., 1996). *Charnockites* are felsic or intermediate plutonic rocks with quartz and pyroxenes.

In Texas many quarried granites are of Grenvillian age (1.1 Ga), e.g. TEXAS RED and SUNSET RED (Davis, 2000, Reed, 2002). In the eastern Canada there are AUTUMN BROWN (1.1 Ga), POLYCHROME and CALEDONIA of about 1 Ga age (Nadeau, Van Breemen, 2001, Church, 2003).

Neoproterozoic (1 – 0.54 Ga). In the period marine limestones and dolomites were probably formed from which marbles were created in today’s northern Greece (THASSOS, VOLAKAS, AJAX), Bulgaria (MURA) and Macedonia (SIVEC) after several phases of metamorphism in the Paleozoic, the Mesozoic and the Tertiary (Zagorchev, 2001, Moores, Fairbridge, 1997).

During 900 – 500 Ma (Mega annum – million years ago) the Pan African orogeny was formed and finished by the creation of Pan-African continent. The manifestation of the orogeny there were also granites (700 – 800 Ma) in Rajasthan, India (Rathore et al, 1999, Torsvik et al., 2000), where e.g. ROSY PINK is quarried. Ribeira Belt (600 – 500 Ma) along Brazil coast is part of the orogeny (Fischel, 1998, Nogueira, Choudhuri, 2000) in which UBATUBA charnockite (Gasparini, Mantovani, 1979, Macluf, Buchwaldt, 2001), CAPAO BONITO granite, GIALLO VENEZIANO and GIALLO SANTA CECILIA granites to orthogneisses, JUPARANA CLASSICO and similar gneisses, and VERDE EUCALIPTO granulite were created (Pedrosa-Soares et al., 1999, Mendes et al., 1999). Saudi-Arabian VIOLETTA and TROPIC BROWN granites belong probably to the same orogeny (Thieblemont, 2000).

Thanks to geological movements and orogens only in the southern India a continuous cross-section through the middle to the lower continental crust is available. The deepest crust levels are visible in the Eastern Ghats. The Eastern Ghats Belt of the southern and eastern India was subjected to very complex geological development. Original rocks from the late Archean and early Proterozoic were several times metamorphosed during the Proterozoic orogenies. During the Paleo- and the Mesoproterozoic very high temperature metamorphism created metamorphic *granulites* and magmatic *charnockites* rocks originating from old gneisses mainly. The Grenvillian orogeny was very important in the southern India and formed the Eastern Ghats Belt. Some rocks were also reworked by Pan-African orogeny (Bartlett at al., 1998, Mezger, Costa, 1999, Rickers et al., 2001, Gliko et al., 1999, Narayana et al., 1999, Pandey et al., 1995). Many well-known stones come from the Eastern Ghats Belt. From the southern part there are TROPICAL GREEN and KASHMIR WHITE granulites, JUPARANA COLOMBO and SIVAKASI migmatites, RAW SILK and TIGER SKIN gneisses (?), BLACK GALAXY gabbro and FOREST GREEN granite. In northern part of the Eastern Ghats Belt VIZAG BLUE, LAVENDER

BLUE and ORISSA BLUE charnockitised gneisses (migmatites) and WHITE GALAXY granulite are quarried (Pivko, 2002).

2.3 Paleozoic (540 – 250 Ma) Earth's Ancient

The Paleozoic is bounded by two of the most important events in the history of animal life. At its beginning, multicelled animals underwent a dramatic "explosion" in diversity, and almost all living animal phyla appeared within several millions of years. At the other end of the Paleozoic, the largest mass extinction in history wiped out approximately 90% of all marine animal species.

Rodinia supercontinent began to fragment into smaller continents. Toward the end of the Paleozoic, the continents came back together to form a new supercontinent, called Pangea.

The Paleozoic is divided into six periods: the Cambrian, the Ordovician, the Silurian, the Devonian, the Carboniferous and the Permian.

Cambrian (545 – 495 Ma). It is the time when most of the major groups of animals first appear in the fossil record caused by the first mineral tubes and skeletons of brachiopods, trilobites, primitive sponges, molluscs, echinoderms, and others. World climate was mild, there was no glaciation.

Georgian marbles (e.g. ETOWAH, CHEROKEE) and Portuguese marbles (known as ROSA PORTOGALLO, ROSA AURORA or ESTREMOZ) were originally Cambrian limestones, maybe barrier reefs of primitive sponges and algae (USGS, 2002, Hannibal, 2000, UGS, 2003, Ribeiro, Sanderson, 1999, Rosas et al., 1999). Georgian marbles were formed on Iapetus ocean margin and later sometimes metamorphosed during the Taconic (450 Ma), Acadian and Alleghenian (340 – 320 Ma) orogenies (Steltenpohl et al., 2001, Church, 2003) and Portuguese ones were metamorphosed during the Variscan orogeny in the Devonian (Cordani et al., 2000, Moores, Fairbridge, 1997).

Ordovician (495 – 440 Ma). The period is best known for the presence of more diverse marine invertebrates than in the Cambrian. Among the organisms, primitive fish, cephalopods, corals appeared. The primitive plants invaded the deserted land for the first time in the Earth's history. At the Ordovician time, the area north of the tropics was almost entirely ocean, and most of the world's land was collected into the southern supercontinent Gondwana (present-day Africa, South America, Antarctica, India, and Australia). Throughout the Ordovician, Gondwana shifted towards the South Pole. During the Late Ordovician, massive glaciers formed causing shallow seas to drain and sea levels to drop. This likely caused the mass extinctions by the end of the Ordovician.

VERMONT MARBLE is true serpentinite representing metamorphosed part of the oceanic lithosphere bottom included into the Taconic orogeny during the Cambrian – Ordovician (about 500 Ma) (Chiment, 1999, Davis, 2000).

Georgian and Vermont marbles are situated in the Appalachians. The Appalachians Mountain Belt runs parallel to the East Coast of USA and Canada. The Appalachians Mts. are product of three orogenies: the Ordovician Taconic, the Devonian Acadian and the Carboniferous-Permian Alleghanian orogeny.

Silurian (440 – 415 Ma). During the period the melting of large glaciers occurred. This contributed to a substantial rise in the levels of the major seas. Coral reefs made their first appearance during this time, and the Silurian witnessed also a remarkable time in the evolution of fishes, from jawless fishes to fishes with jaws, and freshwater ones. It was also at this time that our first good evidence of life on land is preserved, including relatives of spiders and centipedes, and the earliest fossils of vascular plants.

Peculiar BLACK FOSSIL limestone from Morocco (Müller, 2001) contains many cornet-like shells of cephalopods (Orthoceras), similarly LOCHKOV from Bohemia (Březinová et al., 1996).

Devonian (415 – 355 Ma). The vegetation of the early Devonian consisted primarily of small plants, the tallest being only a meter tall. By the end of the Devonian, ferns, horsetails and seed plants had also appeared, producing the first trees and the first forests. In addition, during the Devonian, the first land-living vertebrates and the terrestrial arthropods, including wingless insects, appeared.

Many Devonian limestones are used as natural stones. There are weakly metamorphosed FIOR DI PESCO CARNICO, maybe GRIGIO CARNICO, reef limestones from northern Italy (Hubich et al., 1999, Industria, 1972), BELGIAN BLACK limestone from Belgium (Boulvain, Pingot, 2003) and SLIVENEC limestone with crinoids from Bohemia (Březinová et al., 1996), NOIR ST. LAURENT limestone, ROUGE INCARNAT and ROUGE LANGUEDOC (ROSSO FRANCIA) reef limestones from the southern France (Müller, 2001, Institut, 2003).

The Acadian orogeny in the Appalachians was connected with creation of granite massifs. There are SALISBURY PINK, CAMELIA PINK, SOLAR WHITE and MOUNT AIRY from North Carolina, BARRE GRAY and BETHEL WHITE from Vermont, and DEER ISLE from Maine (Dennis et al., 1995, Ratcliffe et al., 2001, Wilson, 1979, USGS, 2002, Johnston et al., 2002).

Carboniferous (355 – 295 Ma). The Carboniferous is separated into the Mississippian (Lower Carboniferous) and the Pennsylvanian (Upper Carboniferous) in the United States. The Carboniferous was rich in swamps where forests of vesicular trees grew. Such swamps produced the coal from which the term "Carboniferous", or "carbon-bearing" comes. One of the greatest evolutionary innovations of the Carboniferous were egg-laying animals appearance, which allowed the further exploitation of the land. This way the first reptiles became independent of water environment. In the late Carboniferous widespread glaciation was present.

Confused named PETIT GRANIT limestone with crinoids comes from Belgium (Boulvain, Pingot, 2003). INDIANA (SALEM) LIMESTONE is a deposit of warm shallow sea made of calcareous remnants of bryozoans, sea lilies, brachiopods and foraminifers (Davis 2000, McKenzie, Gnidovec, 2000).

The Late Carboniferous collision of present-day Europe with North America (Alleghanian orogeny) produced the Appalachian Mountain Belt of the eastern North America and the collision of Europe with Gondwana produced the Hercynian (Variscan) Mountains in Europe. A further collision of Siberia and the eastern Europe created the Ural Mountains. The mentioned collisions had already started in the Devonian and continued to the Permian period. During the orogeny formation, large granite massifs were intruded. Many of them of the Carboniferous age are used as natural stones: ROSA BETA, ROSA LIMBARA and BIANCO SARDO from Sardinia – Italy (Boni et al., 2001), BLANCO CRISTAL and ROSA PORRINO from Spain (Fuertes-Fuente et al., 2000, Gomez, Alonso, 2000, Castro et al., 2000), TARN from France (Darrozer, 1998), STRZEGOM from Poland (Halvorsen et al., 1989), many Bohemian granites (Mísař et al., 1983, e.g. LIBEREC, MRÁKOTÍN, ŽULOVÁ, POŽÁRY), OCONEE from Georgia and KERSHAW from South Carolina (Samson, 2001).

At the Carboniferous – Permian boundary, southern Scandinavia began to crush, magma rose up along deep thrusts and created magmatic massifs and dykes under surface. BLUE PEARL and EMERALD PEARL syenites (more precisely larvikites), and SWEDISH BLACK gabbros (more precisely dolerites) came from the event (Dahlgren et al., 1996, Moores, Fairbridge, 1997).

Permian (295 – 250 Ma). This dry period is typical by many deserts. The glaciation retreated. The great forests of fern-like plants shifted to gymnosperms, modern conifers. On the land, there were many reptiles. By the end of the Permian the largest mass extinction recorded in the history of life on the Earth occurred. It affected many groups of especially marine organisms.

By the beginning of the Permian, the motion of the Earth crustal plates had brought much of the dry land together, fused in a supercontinent known as Pangea. Most of the rest of the surface area of the Earth was occupied by a corresponding single ocean, known as Panthalassa, with a smaller sea to the east of Pangea known as Tethys.

During the Permian, about 260 Ma ago, distinctive volcanism appeared in the northern Italy. Great eruptions released glowing clouds and from their melted particles *welded tuffs* (ignimbrites) of rhyolite composition were formed (Giraldi, 2000, Cop.P.Po., 2003), e.g. PORFIDO DEL TRENTINO.

2.4 Mesozoic (250 – 65 Ma) – Earth's Medieval

During the era, the world fauna changed drastically from that which had been seen in the Paleozoic. Dinosaurs are perhaps the most popular organisms of the Mesozoic. In dinosaur shade the first mammals were developed. Typical organisms for the Mesozoic seas were cephalopods (snail-like ammo- nites, cigar-like belemnites), corals, algae, forams, brachiopods and crinoids, which are constituents of many limestone types. Dinosaurs and many land and marine organisms became extinct by the end of the Cretaceous. The Mesozoic was a time of gymnosperm plants but in the end of the era, angiosperms became to replace the gymnosperm. The climate was warm and the Earth was without glaciation.

Triassic (250 – 205 Ma). In many ways, the Triassic was a time of transition. It was at this time that the world-continent of Pangea existed, altering global climate and ocean circulation. The Triassic also followed the largest extinction event in the history of life, and so it was a time when the survivors of that event spread and recolonized the emptied spaces. The Triassic was period of relative tectonic peace.

Variegated SALOME marble from Turkey was originally Triassic limestone metamorphosed in the same period (Kocak, 2003). Also variegated TUHAR marble from Slovakia is from the Triassic, but metamorphosed during the Alpine orogeny in the Cretaceous (Lexa et al., 2000). PORTORO limestone from Italy comes from the end of Triassic and maybe the beginning of Jurassic (Desio, 1973, Industria 1972). The limestone like similar black ones deposited in isolated sea parts with bad water circulation therefore inside them there is large amount of undecomposed organic matter.

Jurassic (205 – 135 Ma). Great plant-eating dinosaurs were roaming the Earth, feeding on lush growths of ferns and palm-like trees. Smaller but vicious carnivores were stalking the great herbivores. Oceans were full of fish, squid, and coiled ammonites, plus great ichthyosaurs and long-necked plesiosaurs. Vertebrates started to take the air, like the pterosaurs and the first birds. During the Jurassic, Pangea supercontinent was separating into small continents. The Atlantic and Indian oceans began gradually to open. Evidence of the Atlantic opening provide dolerite dikes filling deep fractures at the boundary of the Triassic and the Jurassic. These rocks not quite correctly named as diabases are quarried in Virginia – JET MIST (McHone, 1996, USGS, 2002).

During the Jurassic, many dimension stones, limestones and later marbles were created in the Mediterranean region. Extensive carbonate platforms with shallow sea organisms produced various limestones. There were limestones with algal balls – ONCOIDS – BOTTICINO (Italy), MOCA CREME (Portugal), limestones with crinoids – ROSA ZARCI (Spain), and probably ERETRIA (Greece). Limestones as a source for further created CARRARA and SIENA marbles in Italy were formed also in the Jurassic.

The coral reefs usually built borders of carbonate platforms. The reefs were destructed by rock slides controlled by strong surf and *carbonate breccias* were formed under the reefs made of angular particles. BRECCIA PERNICE, BRECCIA ONICIATA and GIALLO REALE from Italy and ROJO CORALITO from

Spain were probably created such way (Moores, Fairbridge, 1997, Lemoine, 1978, Desio, 1973, Industria, 1972, Müller, 2001).

To the contrary, red *nodular limestones* like ROSSO VERONA from Italy and similar Hungarian TARDOS (with ammonites), Austrian ADNETER and Romanian MONEASA (with belemnites) were created in deeper sea with good bottom circulation, with abundant oxygen. Nodular appearance is probably result of unconsolidated sediment slumping. Related to this group there is ROJO ALICANTE with abundant cuts of thin shells from Betic Chain (Spain) and inconspicuous nodular PERLINO ROSATO (Italy). BIANCONE (Italy) is very pure limestone composed of planktonic microorganisms (Moores, Fairbridge, 1997, Lemoine, 1978, Desio, 1973, Industria, 1972, Müller, 1984 and 2001).

The previous limestones were later folded, however the shallow-sea JURA MARBLE algae limestone with ammonites and belemnites, and SOLENHOFEN foraminifera limestone come from unfolded platform from Germany (Viohl, 1985, Völker, 2002, Müller, 2001). The last one, which is well-known by fossil skeleton discoveries, e.g. bird ancestor Archaeopteryx, was also used by painters like lithographic limestone. COTSWOLD STONE and PORTLAND STONE are oolithic limestones from shallow platform in England. Over PORTLAND there is shelly PURBECK STONE of the lowermost Cretaceous (West, 2003, Hawkins, 1999, BRE, 2003).

Italy serpentine marbles from W Alps (e.g. VERDE ALPI, VERDE ISSORIE) and from NW Apennines (ROSSO LEVANTO) have complex history. Original rocks – peridotites – were created as a part of oceanic lithosphere during the Jurassic, maybe the Cretaceous, when ocean was opened. During the Tertiary the ocean was closed and peridotites were metamorphosed up to serpentinites or serpentine marbles (Moores, Fairbridge, 1997, Bigi et al., 1990). Red colour of ROSSO LEVANTO is not typical for the marbles, it is caused by the hematite mineral.

Greece serpentine marbles, VERDE TINOS, VERDE ANTICO LEPANTO and probably ROSSO from Turkey, are also of the Jurassic and the Cretaceous origin (Moores, Fairbridge, 1997, Michard et al., 2001, Ring et al., 1999).

Cretaceous (135 – 65 Ma). The Cretaceous is usually noted for being the last period of the “Age of Dinosaurs”. Also during this time, we find the first fossils of many insect groups, modern mammal sand bird groups, and the first flowering plants.

The break-up of the world-continent Pangea, which began to disperse during the Jurassic, continued. The Atlantic and Indian oceans were opened to true oceans. The Cretaceous is period of strong tectonic activity, e.g. Alpine orogeny started.

The end of the Cretaceous brought about the end of many previously successful and diverse groups of organisms. It was the result of catastrophic event, the most probably impact of an asteroid.

During the Cretaceous orogeny in California the gigantic body of granite was created in the Earth’s crust, quarried as a SIERRA WHITE. The ancestor of the granite in the Jurassic period was gabbro, quarried as a ACADEMY BLACK (Irwin, Wooden, 2001).

Orogeny appeared also on the opposite side of the Pacific Ocean. Granite masiffs were created in today SE China during it, quarried as e.g. ALMOND MAUVE and PADANG (Chen et al., 1995, Science, 2000).

In the period there were abundant carbonate platforms created by rudists colonies. The rudists are special shells of pipe-organ or cornet shape. On polished limestone surface we can see oval cross-sections or broken pieces of rudists like in NEGRO MARQUINA (N Spain), AURISINA FIORITO, PERLATO SICILIA and PERLATO SVEVO (Italy), LIPICA FIORITO and TOMAJ (Slovenia), VESELJE FIORITO, VALTURA FIORITO and LUCIA (Croatia), ELPIDA (Greece), CREMA NUOVA (Turkey), and PEARLY YELLOW (Egypt).

KANFANAR from Croatia, DAINO REALE (Italy) and KARNEZEIKA (Greece) limestones with algal balls, VRATZA limestone (Bulgaria), CREMA VALENCIA limestone (Spain), MARRON EMPERADOR dolomite breccia (Spain), TRANI limestone with snails (Italy) and SERPEGGIANTE limestone (Italy) with laminae created probably by blue-green algae were also deposited in the shallow seas (Vlahovic et al., 2002, Poubová, 1975, Dionyssomarble, 2003, Desio, 1973, Industria, 1972, García del Cura et al. 1999, Ordónez et al. 1999).

In the middle Cretaceous there was one of the highest sea levels in the Earth’s history. In that time also JERUSALEM LIMESTONE was deposited in shallow warm sea (Sabbah, Isaac, 1996). From the Upper Cretaceous to Paleogene there are GALALA famous limestones from Egypt (Kuss et al., 2000).

The further era named Cenozoic is divided into two main sub-divisions: the Tertiary and the Quaternary.

2.5 Tertiary (65 – 2 Ma) Earth’s Modern

The Tertiary started the Age of Mammals, because the largest land animals have become mammals since time up to recent. The Tertiary and the Quaternary could be also called the Age of Flowering Plants or the Age of Insects or the Age of Bony Fish or the Age of Birds just as accurately.

Continuing movement of Africa to Europe caused the culmination of the Alpine orogeny and creation of the Betic Cordillera (S Spain), the Pyrenees (Spain and France), the Alps (mainly Helvetia and Austria), the Apennines (Italy), the Carpathians (mainly Slovakia and Romania), the Dinarides (last Yugoslavia), the Balkanides (Bulgaria), the Hellenides (Greece) and the Anatolides (Turkey).

Paleogene (65 – 25 Ma). The Himalayans were created by the collision of India and Asia. The oldest known fossils of most of the modern orders of mammals appear in a brief period during the middle Paleogene and all were small, under 10 kg. The Late Paleogene includes the appearance of the first elephants with trunks, early horses, and the appearance of many grasses.

For shallow seas the large foraminifers (single-celled organisms) were typical, named nummulites, which look like coins or lentils. The nummulites and other fossils are visible in CHIAMPO limestone from N Italy, BEIGE OF MISSOLONGHI (Greece), SUNNY and SILVIA from Egypt, less markable in CREMA MARFIL from Spain (Ordónez et al. 1999). From the Paleogene there are violet-rosy ORCHIDEA SIERRA limestone with snails from Cuba (Belikov et al., 1981) and probably ROSA TEA rosy limestone from Turkey (Kocak, 2003).

During the Paleogene, some rocks of the Western Alps were metamorphosed to gneiss (SERIZZO) and marbles (PALISSANDRO). Gneisses were sometime metamorphosed before in the Paleozoic and the Mesozoic. Marbles come probably from the Mesozoic dolomites and limestones (Bigi et al., 1990, Desmons, Hunziker, 1988, Masson, 2000).

Neogene (25 – 2 Ma). The beginning of the Neogene was a time of warmer global climates, when comparing with those in the preceding Paleogene. The grasslands and savannas were very widespread at the Neogene time. The change in vegetation undoubtedly was a major factor in the rise of long-legged grazers who came to dwell these areas. To the end of the Neogene the climate grew colder, the Antarctic polar cap was created. The accumulation of ice at the poles led to the extinction of most species.

In middle Italy PERLATO ROYAL algal limestone (Sud Italia Marmi, 2003) was created in shallow sea and PIETRA DORATA sandstone was deposited like beach sand (Martini et al., 1995). Its brown belt is caused by ferric hydroxide (limonite) which was periodically precipitated from groundwater after rock strengthening. On the contrary PIETRA SERENA sandstone was formed from turbidite currents on deep sea bottom (Uchman, 1995). The turbidite currents are the type of slope movements, in which unconsolidated sand and mud moves down the slope to deep sea, e.g. after earthquake.

During the Neogene subduction Taiwan EMPRESS GREEN marbles (serpentinites and ophicalcites) were formed from elevated oceanic lithosphere (Huang, 1999, Chang et al., 1999).

Already by the end of Paleogene and in the Neogene, the Jurassic limestones of Italy were subducted during the Apenninian orogeny into depth and subjected to high pressure metamorphism up to 1 GPa pressure (pressure in tyres is 5 thousands times lower), and to 500 °C temperature. In the course of this process and by further weaker metamorphism (up to 0.4 MPa and 400 °C), various marbles were created (Brunet et al., 2000), e.g. BIANCO CARRARA, STATUARIO VENATO, BARDIGLIO, CALA- CATTA, some ARABESCATO, CREMO DELICA- TO and probably also GIALLO SIENA.

Similarly during the Tertiary the Paleozoic and the Mesozoic limestones were in Greece Cycladic territory altered to marbles by high pressure metamorphism and further regional metamorphism (Ring et al., 1999, Cheney et al., 2000, Trotet et al., 2001, Schliestedt et al., 1987), e.g. NAXOS, PAROS, AGHIA MARINA, PENTELIKON (DIONYSSOS), STIRON GREEN, maybe ROSA EGEO, maybe AFYON (Turkey) and BLANCO MACAEL (Spain).

During giant volcanism similar to present Kamtchatka many Slovakian rhyolites (HLINIK) and andesites (DOBRA NIVA) were formed.

2.6 Quaternary (2 – 0 Ma) Earth’s Contemporary

The biota in the beginning of the Quaternary was extremely close to the modern one – many species of conifers, mosses, flowering plants, insects, molluscs, birds, mammals, and others have survived until present. The time was also characterised by the presence of distinctive large mammoths, mastodons, sabre-toothed cats and giant ground sloths. Much of the world's temperate zones were alternately covered by glaciers during cool periods and uncovered during the warmer interglacial periods when the glaciers retreated.

The first part of the Quaternary saw the evolution and expansion of our own species, Homo sapiens, and humans had spread through most of the world. People started with stone using.

From the Quaternary many *travertines* and *onyx marbles* came, which were formed from mineral springs. Pores in travertines are caused by gas escape from water on surface. The travertine and onyx marble precipitation is controlled by bacteria and blue-green algae activity. There are for instance TRAVERTINO ROMANO and TRAVERTINO NOCE from Italy, many travertines and onyxes from Spain, Slovakia (SPIŠ TRAVERTINE, LEVICE GOLD ONYX), Hungary, Macedonia, Greece, Turkey (DENIZLI), Iran (TRAVERTINO ROSSO) and Pakistan (GREEN ONYX) of such origin.

3. Conclusion

All natural stones have their geological history within certain period of Earth’s history. Each stone as a rock is a source of information about processes in the past. Some periods are rich in granites, others in limestones, and others in marbles used as natural stones.

┼ Granite and related migmatite rich periods are related to the end of the Archean (2.6 – 2.5 Ga), Paleoproterozoic (1.6 – 1.8 Ga), Mesoproterozoic (1.1 – 1.0 Ga), Neoproterozoic (750 – 500 Ma) and Paleozoic (400 – 300 Ma). They are connected with final stages of large orogenies, with accretion of supercontinents.

┼ Limestone rich periods are the Neoproterozoic to Early Cambrian, the Devonian, the Jurassic and the Cretaceous. The Tertiary is as well rich in limestones, but due their short geological history they are mostly insufficiently firm and therefore unsuitable for natural stones.

┼ True marble rich periods is the Paleozoic with many orogenies (Portugal, USA) and the most fruitful period is the Tertiary. During the Alpine orogeny many marbles from older limestones were created in the Mediterranean (Italy, Greece, Turkey). The orogenies existed also in the Archean and the Proterozoic, but limestones for marble creation were rare because the rock-forming organisms are abundant from the Paleozoic.

┼ During orogenies the rocks were subjected to tectonic deformation. Near surface, the deformation was of brittle character and at depth there was plastic deformation. Large blocks of dimension stones are quarried from the territories where no brittle deformations occurred. Therefore posttectonic granites provide suitable dimension stone. In the case the territory was subjected multiple deformation (Greece, Eastern Ghats), the rock got into sufficient depth with ductile deformation conditions and later it was risen to the surface.

┼ Colours of natural stones are not distributed evenly in Earth's history. It is the best visible at magmatites and hard metamorphites (granites in commercial sense). The most of white to light grey granites come dominantly from the Hercynian orogeny (the Devonian to the Carboniferous), the yellow ones from the Proterozoic the red ones from the Upper Archaean to the Lower Proterozoic (2.6 – 1.5 Ga), and the brown ones from the Upper Archaean to the Proterozoic.

Geological origin, age and petrography of natural stones find also didactic use. Walking tours downtown cities can be arranged for Earth science students, teachers and public. Knowledge of the characteristics can increase attractiveness of natural stones for customers of stone companies.

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