Extraction methods in historical quarries in Slovakia and nearby areas for dressed stone products

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Abstract: Over 150 historical quarries with its extraction time span were identified in Slovakia and nearby areas on basis of dressed stone products, petrography, historical quarry database, historical and geological maps, aerial photos, and local names. Almost all known extraction methods were identified in the quarries according to tool marks. Most of the stone blocks were extracted in open quarries from rock walls. Some valuable stones were extracted in chambers. Roman ruins were also the source of quality stone in medieval. Some blocks like boulders were obtained from regolith, rock avalanches or volcanic breccia. The most used extraction method was wedging joints because of significant brittle deformation of Slovak rocks. The method was dominant in bedded flysch sandstones. The blocks from massive soft rocks were extracted by the carving with pick or chisel and hammer. The explosives used in the quarries accelerated and facilitated work but fissured a rock. Gunpowder in quarries was used especially in mining regions from the 17th century which left behind hemi-spherical explosion holes. High explosives, which explosions caused radiating joints, were used since 1870. The drilling a set of vertical parallel boreholes has become the proven method since the late 19th century. The wedges, splitters or expansive cement were placed into each borehole to split off the block. A more modern way of block extraction is the cutting a soft stone by a wire, chain or circular saw. The methods have been used since the 1930s in marble, travertine, and tuff quarries. In the Middle Ages, the smaller blocks up to 1 m were extracted in the stepped walls without a significant quarry organization. In the 17th century, the blocks over 2 m appeared for portals and columns. The evolution from the stepped carved quarry walls to more effective straight walls took place in the 17th century. Some quarries were active only in medieval up to the 16th century. Many of them were worked-out, other ones were abandoned due to the competition or increased demands on quality.
Key words: historical quarry, quarrying methods, tool marks, dressed stone, Slovakia

1. INTRODUCTION

Slovakia as a mountainous country is rich in stone resources. Its disadvantage is a strong deformation by ductile tectonic. Despite significant jointing, our forefathers were able to find the quality stone blocks in open quarries for stone mason products. Many castles, medieval churches and monasteries, pillars, numerous tombstones and sculptures testify to it. Some stone types were imported from nearby areas behind today's state border. It was before within Austro-Hungarian Empire. Therefore, the localities up to 100 km from the today's border were included to this paper.

The issue of historic quarries is being processed by many experts, especially for the antiquity period in the Mediterranean countries. From many works it could be mentioned the proceedings of ASMOSIA conferences (asmosia.org), the publications of QuarrySpace project (e.g., Heldal & Bloxam, 2008), Egyptian (Klemm & Klemm, 2008), Greek (Korres, 2001) and French quarries (Bessac & Aucher, 1996) and the US quarries (Gage & Gage, 2005). Many important information provides "Per Storemyr Archaeology & Conservation" (per-storemyr.net) and "The Stone Structure of Northeastern United States" (www.stonestructures.org) web sites.

Many historic quarries in Middle Europe were identified, but quarrying methods are not described. Historic quarries are summarized on web site hq.chc.sbg.ac.at and commented on Uhlir et al. (2013). Austrian historic quarries presented Kieslinger (1964), Czech quarries Mrázek (1993) and Březinová et al. (1996), and Polish quarries Rajchel (2004).

No one has been systematically interested in the themes of historical stone quarries in Slovakia. An excellent source of information on the old stone quarries of Hungarian Kingdom is the quarry inventory (Schafarzik, 1909). Natural stone of Slovakia was intensively studied by Čabalová (e.g., 1989, 2013). An overview of Slovakia's most important dressed stones is in Pivko (2010). Medieval stone sources are described in Pivko (2012). Laho et al. (2010) deals with the source of the stone for Banská Štiavnica. Pivko (2017) describes the sources of the "Ľubovňa marble" and Rybár et al. (2017) underground quarries.

In Slovak territory, the stones in block size were searched for easily workable products since the 1st century BC (Pivko, 2014). Porous rocks with weak tectonic jointing such as sandstones, porous limestones, tuffs, volcanic sandstones, rauwackes, less travertines and tufas, had required properties. In the Middle Ages, stone quality requirements have gradually increased. The rocks, that could be polished, began to be searched for. The stones, called "marbles", with clearly decorative function, had low water absorption. The "marbles" include petrographically compact limestone and marbles. Gerecse red "marble", which was called the royal stone, appeared for the first time in Slovak territory (Bíňa) at the end of the 12th century (Pivko, 2017). Since the 14th century, the period of red "marble" tombstones has begun. The number of "marble" types has increased since

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the 16th century in Slovak territory, where they were also used in the interiors for cladding, flooring, altars, sculptures, balustrades and baptismal fonts.

Study of historical quarries has several meanings. Firstly, it provides important evidence of quarrying technology evolution in our territory. Revealing of quarry age and its connection with important monument can increase attractivity of the microregion with regards to tourism development. Such quarry could be protected from human and natural devastation, preserved and propagated to take visitors.

2. METHODS

To evaluate the time development of the stone block extraction methods in quarries, it is necessary to determine in which period the given stone was used. Multiannual research on the petrography and microfacies analysis from thin sections and the provenance determination of the stone products used in historical monuments is summarized in Tab. 1 and Fig. 1. The stone products in the building exterior or interior such as ashlars, architectural elements (vaulting elements, portals, window frames), cladding, flooring, and plastic products (statues, baptismal fonts, tombstones) were investigated.

The age classification of the Slovak historical monuments (Tab. 1) is based on many sources. Most valuable of them are the Encyclopaedia of Slovak monuments (Kresánek, 2009), Register of the Slovak Monuments (www.pamiatky.sk), the Encyclopaedia of Castles (Plaček & Bóna, 2007) and the review of medieval churches (apsida.sk).

Petrography and provenance monument study helped to the selection of quarrying areas. Database of old Hungarian quarries (Schafarzik, 1904, 1909) was a valuable source of information. Precise locations of historic stone quarries were determined on basis of a map and photo study. The most useful were on-line Geological map of Slovakia (apl.geology.sk/gm50js/), aerial photos, historical and modern maps (geoportal.gov.sk, mapire.eu/de/ and mapy.tuzvo.sk/HOFM/). Topographical names as "Baňa" (old name for quarry) or "Pod kameňolomom" (Bellow the quarry) help to identify old quarries in some cases.

Old quarries have been verified in the field. Extraction methods and petrography of various rock types were studied. Quarry faces with tool marks were documented (Tab. 2) and compared to their figures and explanations, e.g. in Heldal & Bloxam (2008[a], 2008[b]). The logical universal scheme of historical and modern quarrying methods has been prepared (Fig. 2).

Then the rocks from the quarries were compared with the rocks in monuments. According to the age of stone monuments, the time span of the quarry extraction was determined (Tab. 1). The result of the work is the evolution of extraction methods in historical quarries.

3. RESULTS

Various quarry forms and surfaces of faces are summarized on Tab. 2. Some former quarries are revealed in the field only by

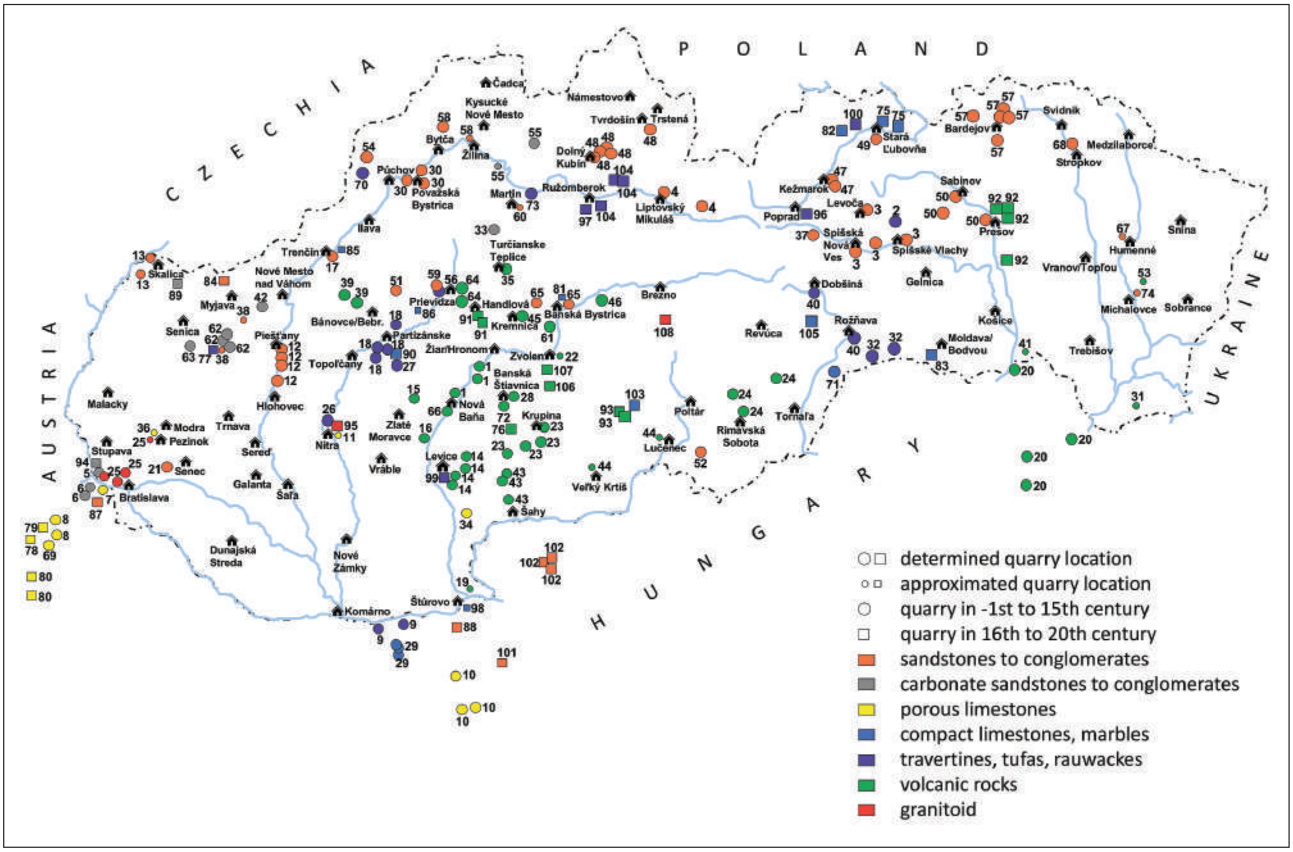

Fig. 1. The location and petrography of the historical quarries for dressed stone products in Slovakia and nearby.

Tab. 1. Historical quarries for dressed stones in Slovakia and near surroundings and the realisations in Slovakia: + – dressed stones for building and sculpture, m – millstone, g – grinder tools, q – quarry stone. Identified quarries are bold.

№ on map	Determined quarry location or area	Important memorials	Stone type	Century/ Time scale	-1st	1st to 4th	9th	10th	11th	12th	13th	14th	15th	16th	17th	18th	19th	20th
1	**Hliník nad Hronom, Nová Baňa, Vyhne**	Banská Štiavnica, Hliník nad Hronom, Hodruša-Hámre, Nová Baňa, Bratislava	rhyolite	Serravallian (Sarmatian)	m	m	m	m			m	+m	+m	m	m	+m	+m	+
2	**Spišské Podhradie and Žehra on Dreveník**	Spišské Podhradie, Spišský hrad, Spišská Kapitula, the whole Slovakia	travertine	Pliocene to Pleistocene	q	q				q	+	+	+	+	+	+	+	+
3	Spišská Nová Ves area: **Spišská Nová Ves, Levoča, Spišské Vlachy, Odorín** and others	Spišská Nová Ves, Markušovce, Gelnica, Žehra, Levoča, Spišský Štvrtok, Spišské Vlachy, Spiš castle, Spišské Podhradie, Spišská Kapitula, Rožňava, Košice	flysch sandstone	Eocene to Oligocene	q	q					+	+	+	+	+	+	+	?
4	Liptovský Mikuláš area: **Liptovský Mikuláš, Hybe**	Liptovský Mikuláš, Smrečany, Likava castle, Liptovská Mara, Liptovský Ján	flysch sandstone	Eocene to Oligocene	q	q					+	+	+	+	+	+	+	+
5	**Devín**	Bratislava, Devín, Malacky, Stupava, Svätý Jur, Pezinok, Modra	hybride sandstone to porous limestone	Serravallian (Badenian)	+	+	s		?s	s	s+	+	s+	+	+	+	+	
6	**Hainburg** AT, **Hundsheim** AT	Rusovce Gerulata, Bratislava, Pezinok, Nitra, Šamorín, Trnava, Senec, Svätý Jur, Malacky, Červený Kameň castle	carbonate breccia, conglomerate to porous limestone	Serravallian (Badenian)		+			?s	s	s+	s+	+	+	+	+	+	
7	**Wolfsthal** AT	Rusovce Gerulata, Bratislava, Bernolákovo, Svätý Jur, Pezinok	porous oolitic limestone	Serravallian (Sarmatian)		+			?s	s	s	s+	+	?	+	+	+	
8	Bruck an der Leitha area AT: **Winden** and others	Rusovce Gerulata, Bratislava, Bernolákovo	porous algal limestone	Serravallian (Badenian)		+	s		?s	s	s	s	s					
9	**Dunaalmás** HU, **Süttő** HU	Komárno, Bratislava, Nitra, Nové Zámky, Bíňa, Šamorín, Pezinok, Trnava, Stupava, Senec, Zlaté Moravce, Rimavská Sobota	travertine	Pliocene to Pleistocene		+			s	?s	?s+	+	+	+	+	+	+	+
10	**Sóskút** HU, **Zsámbék** HU, **Diósd** HU	Bíňa, Komárno, Nové Zámky, Želiezovce, Levice, Trenčín, Krásnohorské Podhradie	porous limestone	Serravallian (Sarmatian)		+				?	+					+	+	+
11	Nitra area	Nitra	porous limestone	Serravallian (Sarmatian)			+		s	s	s	s						
12	**Banka, Ratnovce, Sokolovce, Koplotovce,** ?Ducové	Piešťany, Hlohovec, Topoľčany, Nitra, Bratislava, Trnava, Nové Zámky, Vrbové, Senica, Dunajská Streda, Beckov, Ducové	sandstone	Tortonian to Messinian (Pannonian)			+		+	+	+	+	+	+	+	+	+	+
13	**Holíč, Skalica**	Skalica, Holíč, Kopčany, Šaštín-Stráže, Radošovce	sandstone	Serravallian (Sarmatian)			?	+	?	?	?	+	+	?	+	+	+	
14	Levice area: **Mýtne Ludany, Kalinčiakovo, Brhlovce, Žemberovce,** Jabloňovce, Nový Tekov?, Bohunice?	Starý Tekov, Kalinčiakovo, Levice, Pukanec, Bátovce, Žemberovce, Brhlovce, Bratka, Mýtne Ludany, Hontianska Vrbica, Trávnica	epiclastic sandstone and conglomerate, pumice tuff	Serravallian (Sarmatian)					+	+	+	+	+	+	?	+	+	+

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	Determined quarry location or area	Important memorials	Stone type	Century/ Time scale	-1st	1st to 4th	9th	10th	11th	12th	13th	14th	15th	16th	17th	18th	19th	20th
15	**Obyce**	Nitra, Veľký Klíž, Zlaté Moravce, Obyce, Hodruša-Hámre, Hrušov castle, Gýmeš castle,	tuff (ignimbrite)	Serravallian (Sarmatian)					+	+	+	+	+	+	+	+	+	+
16	**Hronský Beňadik**	Hronský Beňadik, Hrušov castle, Gýmeš castle	epiclastic conglomerate	Serravallian (Sarmatian)					+	?	?	+	+	+	?	+	+	
17	**Trenčín**	Trenčín, Skalka nad Váhom, Sedmerovec	sandstone	Burdigalian (Eggenburgian)					+	+	+	+	+	?				
18	Partizánske area: **Veľký Klíž, Nedanovce, Bošany, Sádok, Malé Kršteňany**	Nitra, Dražovce, Veľký Klíž, Oslany, Bratislava	travertine	Tortonian (Pannonian)					+	s		s		+	?	+	+	+
19	Štúrovo – Ezstergom HU area	Štúrovo, Bíňa, Malé Kosihy, Želiezovce	epiclastic sandstone and conglomerate	Langhian (Badenian)					?	?	+	+	+	?	?	+	?	
20	Sárospatak area HU: **Abaújvár, Sárospatak, Erdőbénye, Bodrogkeresztúr**	Košice, Rožňava, Moldava nad Bodvou, Gelnica, Michalovce, Trebišov, Vranov nad Topľou, Humenné	rhyolite epiclastic sandstone, rhyolite tuff	Serravallian (Sarmatian)					?	?	+	+	+	+	+	+	+	+
21	**Bernolákovo**	Bernolákovo, Boldog, Štvrtok na Ostrove, Kaplna, Mierovo	sandstone	Messinian (Pannonian)						+	+	?		?	?		+	
22	Zvolen area	„Pustý hrad“ castle, Zvolen, Zolná, Sliač, Horná Mičiná, Čerín, Dúbravica, Vígľaš	epiclastic sandstone to conglomerate	Langhian to Serravallian						+	+	+	+	?				
23	Krupina area: **Sebechleby, Krupina, Bzovík, H. Nemce,** Sása, Babiná, Dobrá Niva	Krupina, Bzovík, Čabraď castle, Sása, Babiná, Dobrá Niva, Sebechleby, Hontianske Nemce	epiclastic sandstone and conglomerate	Langhian to Serravallian						+	+	+	+	+	+	+	+	+
24	Rimavská Sobota area: **V. Pokoradz, N. Skálnik,** Kraskovo?, Kyjatice?, **Skerešovo,** Rybník?, Ratková?	Rimavská Sobota, Rimavské Janovce, Štítnik, Plešivec, Kameňany, Rybník, Ratková, Sirk, Kyjatice, Kraskovo, Jelšava, Nižný Skálnik	epiclastic sandstone	Serravallian (Badenian to Sarmatian)						+	+	+	+	+	+	+	+	+
25	South Malé Karpaty Mts.: **Bratislava, Devín,** Pezinok	Bratislava, Devín, Trnava, Ivanka, Svätý Jur, Pezinok, Červený Kameň castle, Boldog, Bernolákovo, Kostolné Kračany, Holice, Modra, Šamorín?	granite to granodiorite	Carboniferous						+	+						+	+
26	**Podhorany**	Podhorany, Nitra, Gýmeš castle	rauhwacke	Cretaceous metamorphism						+	+	+	+					
27	**Veľký Klíž**	Sádok, Hrušov castle, Veľký Klíž	rauhwacke	Cretaceous metamorphism						q	+	?	?	+				
28	**Banská Štiavnica,** Sklené Teplice, Vyhne	Banská Štiavnica, Ilija, Hodruša-Hámre, Banská Belá, Sklené Teplice, Vyhne	andesites	Langhian to Serravallian						?	+	+	+	+	+	+	+	+
29	**Tardos, Süttő Kis Gerecse, Piszke Nagy Pisznice HU**	Komárno, Bíňa, N. Zámky, Bratislava, Galanta, Bojnice, Trenčín, Palárikovo, Nitra, Z. Moravce, Želiezovce, Levice, Dunajská Streda, the whole Slovakia	compact limestone	Early Jurassic						?	+	+	+	+		+	+	+

	Determined quarry location or area	**Important memorials**	**Stone type**	**Century/ Time scale**	**-1st**	**1st to 4th**	**9th**	**10th**	**11th**	**12th**	**13th**	**14th**	**15th**	**16th**	**17th**	**18th**	**19th**	**20th**
30	**Považská Bystrica, Vrtižer, Milochov**	Považské Podhradie, Považská Bystrica, Orlové?	sandstone	Cenomanian Turonian						?	+	+	+	+	+	+	+	
31	Kráľovský Chlmec area	Kráľovský Chlmec, Svätuše, V. Kamenec castle, Klin n. Bodrogom, Borša?, Leles?, Brehov?	andesite to rhyodacite	Langhian to Serravallian (Badenian)						?	+	?	+	+				
32	Rožňava area: **Hrhov, Hrušov, Slavec** and others	Lipovník, Hrušov, Hrhov, Slavec, Turňa castle, Turňa nad Bodvou, ?Štítnik castle	tufa	Holocene						?	+	+	+	+				
33	Martin area: **Slovany**	Kláštor pod Znievom, Diviaky, Mošovce, Necpaly	carbonate conglomerate	Serravallian (Sarmatian)							+				+	+		
34	**Sikenica**	Hronovce-Čajakovo, Želiezovce	porous limestone	Serravallian (Sarmatian)							+	+						
35	**Háj**	Martin, Kláštor pod Znievom, Turany, Mošovce, Belá-Dulice	pumice tuff, epiclastic sandstone	Serravallian (Sarmatian)							+	+	?					
36	Pezinok area	Pezinok, Svätý Jur, Báč, Bernolákovo, Doľany, Kaplna	limestone	Serravallian (Badenian)							+	+	+					
37	Spišský Štiavnik, Hrabušice?	Spišský Štiavnik, Hrabušice, Kláštorisko, Spišský Štvrtok, Smižany	conglomerate	Eocene							+	+	+					
38	North Malé Karpaty Mts.: Dobrá Voda?	Dobrá Voda castle, Čachtice castle	conglomerate	Burdigalian (Karpatian)							+	+	+					
39	**Veľká Hradná, Bánovce n. B. Horné Ozorovce,** Ruskovce?	Trenčín castle, Topoľčany castle, Beckov castle	epiclastic sandstone	Serravallian (Sarmatian)							+	+	+	+				
40	Rožňava area: **Dobšiná, Rožňava**	Dobšiná, Ochtiná, Koceľovce, Štítnik, Rožňava, Plešivec	rauhwacke	Early to Middle Triassic							+	+	+	+				
41	Košice area: Skároš? and others	Košice, Moldava nad Bodvou, Slanec? castle	dacite to andesite	Serravallian (Sarmatian)							+	+	+	+	?	+		
42	**Čachtice**	Čachtice, Nové Mesto nad Váhom, Beckov castle, Trnava	carbonate conglomerate	Burdigalian (Eggenburgian)							+	?	+	?	+	+		
43	Šahy area: **Terany,** Sazdice?, **Dolné Turovce,** Demandice?, **Hont. Tesáre,** Hokovce?	Sazdice, Demandice, Horné Semerovce, Hokovce, Dolné Turovce, Šahy?	epiclastic sandstone	Serravallian (Badenian)							+	?	+	?	?	+	?	
44	Veľký Krtíš and Lučenec area:	Modrý kameň, Halič, Stará Halič	epiclastic sandstone to conglomerate	Serravallian (Badenian)							+	+	+	?	+	+	+	+
45	**Kremnica**	Kremnica, Kremnické Bane, Lúčky?	andesite	Serravallian (Badenian)							+	+	+	+	+	+	+	
46	Ľubietová area: **Ľubietová, Lučatín,** Strelníky?	Ľubietová, Slovenská Ľupča, Poniky?, Radvaň?, Martin, D. Kubín, Brezno	epiclastic sandstone and conglomerate	Serravallian (Badenian)							+	+	+	+	+	+	+	?
47	Poprad area: **Kežmarok, Ľubica** and others	Poprad, Matejovce, Spišská Sobota Kežmarok, Spišská Belá, Ľubica, Vrbov	flysch sandstone	Eocene to Oligocene							+	+	+	+	+	+	+	?

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48	Dolný Kubín area: **Oravský Biely Potok, Medzibrodie, Bziny, Dolný Kubín, Pucov**	Dolný Kubín, Oravský Biely Potok, Orava castle, Trstená, Ružomberok area, Martin area, Varín	flysch sandstone	Eocene to Oligocene							+	+	+	+	+	+g	+g	+g
49	**Stará Ľubovňa,** Matiašovce?, Podolínec?	Stará Ľubovňa, Červený kláštor, Podolínec, Spišská Stará Ves	flysch sandstone	Eocene to Oligocene							+	+	?	+	+	+	+	?
50	Prešov area: **Prešov, Sabinov, Bertotovce**	Prešov, Veľký Šariš, Šariš castle, Sabinov, Lipany, Pečovská Nová Ves, Brezovica, Kapušany, Hanušovce n. Topľou, Košice	flysch sandstone	Eocene to Oligocene							+	+	+	+	+	+	+	+
51	**Žitná-Radiša**	Uhrovec, Uhrovec castle, Bánovce nad Bebravou, Kšinná	sandstone	Eocene to Oligocene							+	?	+	+	+	+	+	+
52	Lučenec to Rimavská Sobota area: **Fiľakovo**	Lučenec, Fiľakovo, Rimavská Sobota, Halič, Ožďany	sandstone	Burdigalian (Eggenburgian)							+	?	?	+	+	+	+	
53	Michalovce area: Vinné	Michalovce, Vinné, Jasenov castle?, Brekov castle?, Budkovce	epiclastic sandstone to conglomerate	Serravallian (Sarmatian)							+	+	+	+	?	+	+	
54	Púchov and Ilava area: **Lysá pod Makytou** and others	Púchov, Beckov, Pruské, Ilava, Beluša, Lednické Rovne, Dubnica nad Váhom, Lednica castle, Trenčín?	flysch sandstone to conglomerate	Eocene							+	+	?	?	+	+	+	+
55	Žilina to Rajec area: Strečno, **Terchová** and others	Súľov castle, Hričov castle, Lietava castle, Strečno castle, Rajec, Rajecká Lesná, Stránske, Beluša, Ružomberok, Žilina, Terchová, Martin, Dolný Kubín	carbonate sandstone to conglomerate	Paleocene to Eocene							+	+	+	+	+	+	+	+
56	Bojnice	Bojnice, Diviaky nad Nitricou, Červený Kameň castle?	tufa to travertine	Pleistocene to Holocene							+	?	?	?	+			
57	Bardejov area: **Bardejov Dlhá Lúka, Kľušov, Sveržov, Zborov, Andrejová**	Bardejov, Zborov, Gaboltov	flysch sandstone	Paleocene to Eocene							?	+	+	+	+	+	+	?
58	Bytča to Žilina area: **Veľké Rovné**	Žilina, Bytča, Veľké Rovné, Turzovka?	flysch sandstone	Late Cretaceous to Eocene							?	+	?	+	+	+	+	?
59	Bánovce nad Bebravou, Partizánske and Prievidza area: **Bojnice,** Uhrovec? and others	Bojnice, Diviacka Nová Ves, Prievidza, Handlová, Nitrianske Pravno, Nováky, Bánovce nad Bebravou, Uhrovec, Uhrovec castle, Timoradza, Sádok	conglomerate to sandstone	Eocene							?	?	?	?	+	+	+	+
60	Martin area	Martin, Diviaky, Sklabiňa castle, Necpaly	flysch sandstone	Eocene to Oligocene							q	q	+	?	+	+	+	
61	**Badín**	Badín, Banská Bystrica, Zvolen, Slovenská Ľupča?	epiclastic conglomerate	Serravallian (Sarmatian)							?	+	+	+	+	+		
62	**Dobrá Voda, Chtelnica Malé Skalky and Trianová, Dechtice Šidlová**	Trnava, Modra, Skalica, Senica, Piešťany, Hlohovec, Sereď, Myjava, Šaľa, Bratislava	carbonate conglomerate	Burdigalian (Eggenburgian)								+	+	+	+	+	+	+

	Determined quarry location or area	Important memorials	Stone type	Century/ Time scale	-1st	1st to 4th	9th	10th	11th	12th	13th	14th	15th	16th	17th	18th	19th	20th
63	**Cerová-Rozbehy**	Korlátka castle, Ostrý kameň castle, ?Plavecký castle	conglomerate	Burdigalian (Eggenburgian)								+	+			?		
64	Prievidza area: **Prievidza, Chrenovec-Brusno**	Prievidza, Bojnice, Partizánske, Zemianske Kostoľany, Nováky, Mošovce?	epiclastic sandstone and conglomerate	Serravallian (Sarmatian)								+	+	+	?	+	+	
65	**Banská Bystrica Rudlová, Králiky**	Banská Bystrica, Slovenská Ľupča, Kremnica, the whole Slovakia	sandstone	Eocene								+	+	+	+	+	+	+
66	**Nová Baňa**	Nová Baňa, Kláštor pod Znievom, Nitra, Hronský Beňadik, Vyhne, Topoľčianky	tuff (ignimbrite)	Serravallian (Sarmatian)								+	+		+	+	+	
67	Humenné area	Humenné, Brekov castle, Jasenov castle, Vranov nad Topľou, Vinné, ?Michalovce	flysch sandstone	Paleocene to Oligocene								?	+	+	+	+	?	
68	Stropkov area: **Tisinec**	Stropkov, Medzilaborce, Vyšný Komárnik	flysch sandstone	Paleocene to Eocene								?	+	?	+	+	+	+
69	**Breitenbrunn** AT	Bratislava, Senec, Šaštín, Dunajská Streda, Červeník	porous limestone	Serravallian (Sarmatian)								?	+	?		+	+	
70	North Biele Karpaty Mts.: **Zubák** and others	Lednica castle, Vršatec castle	tufa	Holocene								?	+					
71	**Silická Brezová**	Plešivec, the whole Slovakia	compact limestone	Late Triassic									+					+
72	**Ilija**	Banská Štiavnica	pumice tuff	Serravallian									+	+	+			
73	**Turčianska Štiavnička**	Turčianska Štiavnička, Sklabiňa castle, ?Starhrad castle, ?Stránske, ?Lietava castle	tufa	Holocene									+	+	+	+		
74	Michalovce area	Michalovce, Vinné castle, Ložín, Budkovce	sandstone	Serravallian (Badenian)									?			+	+	
75	**Stará Ľubovňa Marmon, Údol**	Stará Ľubovňa, Sabinov, Levoča, Košice, Kežmarok, Poprad, Prešov, Bardejov	compact limestone	Late Jurassic										+	+	+	+	+
76	**Prenčov**	Banská Štiavnica, Svätý Anton, Vyhne, Topoľčianky	epiclastic conglomerate	Langhian to Serravallian										+	+	+	+	
77	North Malé Karpaty Mts.: **Dobrá Voda** and others	Katarínka, Dobrá Voda castle, Plavecký castle	tufa	Holocene										+	+			
78	**Mannersdorf** AT	Bratislava, Svätý Jur, Voderady, Senica, Trnava	algal limestone	Serravallian (Badenian)										+	?	+	+	
79	**Kaisersteinbruch** AT	Bratislava, Červený Kameň castle, Malacky, Pezinok, Pajštún castle, Komárno, Trnava	algal limestone	Serravallian (Badenian)											+	+	+	
80	**St. Margarethen** AT, **Fertőrákos** HU	Bratislava, Pezinok, Modra, Malacky, Trnava, Dunajská Streda, Šamorín,	porous limestone	Serravallian (Badenian)											+	+	+	+

	Determined quarry location or area	Important memorials	Stone type	Century/ Time scale	-1st	1st to 4th	9th	10th	11th	12th	13th	14th	15th	16th	17th	18th	19th	20th
		Galanta, Sereď, Hlohovec, Šaľa, Trenčín, Nitra, Nové Zámky, Banská Bystrica, Topoľčany, Levice, Žilina, Hr. Beňadik																
81	Banská Bystrica	Banská Bystrica	compact limestone	Early Cretaceous											+			
82	**Podolínec**, Belianske Tatry?	Spišská Sobota, Kežmarok, Brezovica?	compact limestone	Middle Triassic											+	?	?	
83	Rožňava area: **Žarnov** and others	Rožňava, Štítnik, Jasov, Košice, Leles?	compact limestone	Middle Triassic											+	+	?	
84	Myjava and Skalica area: **Myjava Poľana**	Myjava, Lubina, Skalica, Stará Turá	sandstone	Paleocene to Eocene											?	+	+	+
85	Trenčín area	Trenčín	compact limestone	Middle Triassic												+		
86	Prievidza area	Prievidza, Kremnica, Močenok, Tužina	compact limestone	Middle Triassic												+		
87	**Edelstal** AT	?Rusovce Gerulata, Bratislava, Devín, Pezinok, Malacky, Šamorín	sandstone	Messinian (Pannonian)												+	+	
88	**Esztergom** HU	Bíňa, Nové Zámky, Štúrovo, Komárno	sandstone	Eocene												+	+	+
89	**Chropov**	Chropov, Lopašov, ?Radošovce	conglomerate	Burdigalian (Eggenburgian)												?	+	+
90	**Veľký Klíž**	Veľký Klíž, Zlaté Moravce, Nitra, Hlohovec, Trnava, Nová Baňa	compact limestone	Middle Triassic													+	+
91	Handlová area: **Handlová, Janova Lehota**	Handlová, Nová Lehota, Jánova Lehota	epiclastic sandstone to conglomerate	Serravallian (Badenian)													+	+
92	Prešov area: **Fintice, Brestov, Vyšná Šebastová, Kapušany**	Prešov, Bardejov, Gelnica, ?Košice	andesite	Serravallian (Sarmatian)													+	+
93	**Horný Tisovník, Dolný Tisovník**	Horný Tisovník, Dolný Tisovník, Suché Brezovo, Červeňany	volcanic breccia to conglomerate	Serravallian (Badenian to Sarmatian)													+	+
94	**Devínska Nová Ves**	Devínska Nová Ves, Pezinok, Malacky	conglomerate	Serravallian (Badenian)													+	+
95	**Nitra**	Nitra, Hajná Nová Ves	granodiorite	Carboniferous													+	+
96	**Gánovce, Hozelec**	Poprad, Margecany, Spišský Štiavnik	travertine	Pleistocene													+	+
97	**Ružomberok Biely Potok**	Ružomberok, Banská Bystrica, Bratislava	travertine	Pleistocene													+	+
98	Esztergom area	Komárno, Nitra, Šaľa, Banská Bystrica	compact limestone	Late Triassic													?	+
99	**Levice**	Levice, Bratislava, Hlohovec, Banská Bystrica, Ružomberok, Nitra, Trnava, Zlaté Moravce, Topoľčany, Partizánske, Púchov, Levoča, Bíňa, Krupina,	travertine, onyx marble	Pliocene														+
100	**Vyšné Ružbachy**	Vyšné Ružbachy, Stará Ľubovňa, Žilina, Bratislava, Považská Bystrica	travertine	Pleistocene														+

	Determined quarry location or area	Important memorials	Stone type	Century/ Time scale	-1st	1st to 4th	9th	10th	11th	12th	13th	14th	15th	16th	17th	18th	19th	20th
101	**Pilisborosjenő Harshegy** HU	Bratislava, Nové Zámky	sandstone	Oligocene														+
102	**Romhany, Bánk, Petény** HU	Veľká Čalomija	sandstone	Eocene														+
103	**Tuhár**	Bratislava, Stupava, Nové Zámky, Topoľčany, Partizánske, Sklené Teplice, Banská Bystrica, Trebišov, Lučenec, Staré Hory, Dudince, Ružomberok	marble	Cretaceous metamorphism														+
104	**Bešeňová, Lúčky, Ludrová**	Bratislava, Modra, Trnava, Myjava, Skalica, Partizánske, Zvolen, Banská Bystrica, Ružomberok, Poprad, Levoča, Prešov, Humenné	travertine	Pleistocene														+
105	**Ochtiná, Markuška**	Ochtiná	white marble	Jurassic metamorphism														+
106	**Dobrá Niva**	the whole Slovakia	andesite	Serravallian (Sarmatian)														+
107	**Breziny**	the whole Slovakia	andesite	Langhian (Badenian)														+
108	**Čierny Balog**	Bratislava	tonalite	Carboniferous														+

unnatural depressions on surface (Fig. 3A). Locally there are poorly visible *stone walls*, which are without natural appearance, but tool marks were not found on them because of weathering (Fig. 3B). *Boulder* extraction was identified from rock avalanche (Fig. 3C), volcanic conglomerate (Fig. 3D), and regolith (Fig. 3E). Abandoned *stone blocks* are very often bellow the quarry faces or there are left on roadsides leading from the quarry. Stone blocks can be with natural broken surface or they are approximately prismatic in shape (Fig. 3F) covered with tool grooves (Fig. 3G,H). Sometimes finished stone products are left in a quarry (Fig. 3I).

When identified old quarry is not destroyed by weathering, it has preserved unnatural stone walls with *extraction traces*. *Quarry face* with *tool marks* can be *stepped* (Fig. 4A–G) or *flattened* (Fig. 4H–N). Straight faces sometimes cut older stepped walls (Fig. 4H,L). In Slovakia, some stones were extracted under *overhang* (Figs. 4F, 5A–C) or in underground *chamber* (Figs. 4G, 5C–M, 10M), which were up to several dozen meters long. Some of them are intentionally filled by debris (Fig. 5I) or others are partly destroyed by collapse (Fig. 5J,K). Some chambers have been used like dwellings or cellars (Fig. 5L–N).

Quarry faces could be with irregular *broken surfaces* or almost flat *joint surfaces* (Fig. 6A–G). They are cut by regular or irregular joint system (Fig. 6A–G) and bedding planes (Fig. 6C–E). Some joints are open (Fig. 6A). Flat surfaces can be covered by the evident *parallel grooves* of tools (Figs. 6I–L, 7). The tool grooves can be *curved* (Fig. 7A,B,J) or *straight*, inclined to one side or with different pitch angle (Fig. 7C–F). The inclination of curved and straight grooves can be changed in vertical direction, which is like *"herringbone-pattern"* (Fig. 7J–L) or irregular pattern (Fig. 7M,N). Sometimes the tool grooves are not parallel, running in different directions (Fig. 7H–I). In a few quarries, very regular and *fine curved* or *straight grooves* of tool were found (Fig. 6I–K).

The *channels* covered with grooves (Fig. 8) are very rare presented in the quarry faces. The *channel walls* could be parallel (Fig. 8A,C–H) or convergent (Fig. 8B). Channels are usually long, deep to a few tens of cm, and wide from a few cm to a few dm. Narrow and long channels with very straight parallel wall are wide up to a few cm (Fig. 8C). Some of them are perpendicular each other (Fig. 8D). Only in three quarries, very wide up to 50 cm vertical channels were found (Fig. 8E–G). The indication, the beginning of channel creation is more often preserved (Fig. 8B,H–M). The stone blocks bounded by the channels on four sides are very rare presented (Fig. 8L,M).

Sets of rectangular, trapezoidal, cylindrical or round depressions are present very rarely on quarry faces (Fig. 9). They are arranged vertically (Fig. 9A–E,J), horizontally (Fig. 9G–I) or in both directions (Fig. 9K,L). Sets of longitudinal holes along to joint (Fig. 9E,F) are also present.

In some places, the deep *holes* with the diameter of 2.5 to 4 cm are present (Fig. 10A–D). On other places, they are with *cylindrical cross-sections* of a few dozens in length and the diameter of a few cm (Fig. 10B,F–I). The cross-section of the hole is usually circular (Fig. 10A–C) or sometimes almost triangular (Fig. 10D). Circular holes or their perpendicular cylindrical cross-sections can be sometimes arranged to *row* with spacing from several to ca. 20 cm (Fig. 10A,F–J). Cylindrical marks are usually parallel in sets (Fig. 10F–I), rarely non-parallel (Fig. 10J, 6H). Parallel holes are in some cases filled with whitish material (Fig. 10E).

Locally, the quarry face is covered by *hemi-spherical holes* with a diameter of 15 to 40 cm, along which cylindrical cross-sections can be present (Fig. 10M–O). The cylindrical cross-sections can be rarely terminated small spheres (Fig. 10K,L). Some quarry walls with uneven broken surface contain the holes with radiating joints (Fig. 10P–S).

4. INTERPRETATION AND DISCUSSION

4.1. Distribution of dimension stones in time and in Slovak territory

In classical era, tribes living in Slovak territory constructed only wooden buildings expect for Celts in Bratislava castle hill in the 1st century BC. During Roman Empire (the 1st to 4th century), the dimenstion stone quarries were only near Danube River as a Pannonia province border. In medieval period, stone ashlars were rare used in the 9th and 10th century for Great-Moravian churches. The consolidation of Early Hungarian Kingdom in the 11th century caused growth in stone products. Most buildings were from wood, but castles, monasteries, churches, and some public buildings in towns were constructed from stone. Most of the dimension stone quarries (Tab. 1) were opened in the 13th century because of building boom induced by the prosperity. Climate was warm and stable (Medieval Warm Period) and political situation was also stable and Roman ruins like stone source were exhausted.

Quality stone quarries for stonemason products were found up to 30 km. Only special polishable stones for tombstones were transported up to some hundred's km from the 14th century. Porous rocks like sandstones, porous limestones, tuffs, rauhwackes, and travertines were especially used for products in medieval because of better stoneworking. In modern period, the import distance of quality stone increased, up to 300 km in the 16th and 17th century, up to 500 in the the 18th and 19th century. Magmatic and metamorphic rocks were used like dimension stone very rare because of its hard stoneworking caused by hardness and inappropriate fissility and jointing.

4.2. Extraction methods for stone blocks in quarries and chambers

The dimension stones, the stones for stone blocks, were the most extracted by the surface method in open-cast quarry, called "baňa" in old Slovak. When they prefered the lower part of a quarry with better quality stone, the quarrying was transferred to the underground chamber (Fig. 5), sometimes called gallery (Heldal & Bloxam, 2008[a], 2008[b]). For local use, the boulders from quality stone were sometimes exploited (Fig. 3C–E). At the beginning of the town development, the ruins of Roman buildings were a suitable source of stone blocks (Pivko, 2016[b]).

To obtain a quality stone block for masonry product or sculpture, it is necessary to separate a stone block from the continuous wall of the rock. Extraction methods have been not changed in main principles since ancient Egypt (Heldal & Bloxam, 2008[a], 2008[b], Fig. 2). We can use natural joints in the rock. If they are not present, a block can be separated from a wall by carving (Fig. 7). Pick ("špicák" in Slovak), a tool with two spikes, and pointed chisel ("špicatý sekáč" or "dláto" in Slovak) were used. In recent times, the explosives have been used, which have been introduced into holes drilled with chisels. When the machines were invented, the technology of parallel wells began to be used, in which wedges or an expansion clay were inserted (Fig. 10). Another technology is cutting off a soft rock from the wall by saw or wire (Fig. 6I–K). Fire as a next method was not used in Slovakia for dimension stone.

4.2.1. Separating a block from the quarry face along natural joints

The use of natural joints was the most common method for the separating blocks in Slovakia. Western Carpathians rocks had been subjected to a severe pressure during the Alpine orogeny phases that caused the rocks fracturing. In massive rocks, the joints are irregular, or they are with a regular network in three directions (Fig. 6A–G). Thick bedded rocks are very often fractures perpendicularly to the bedding planes (Fig. 6C–E). The stone blocks can be separated along these vertical joints and from the top and bottom along the bedding planes. The quarrymen called a joint like a "fuga" (Stano, 1969), which is derived from German with the meaning of the joint, the crack, the groove or the gap. The open joints (fissures) had to be enlarged by force, it means that, a stone block bounded by the joints could be broken off. If the joint was closed, it was necessary to open it at least in one part for a lever. Into the selected joint, the holes were cut with a chisel (Fig. 9B), where iron wedges were inserted. Then the stone block was separated by gradual hitting with a hammer on the wedges (Fig. 9). Sometimes dry wood wedges were also used, which were watered to swell and open the joint. This process was used, for example, in the Roman period in the Carrara quarries (Dozolme, 2017). Frost effect was applied to the granite in the winter by filling the joint with a water (Jundrovský & Tichý, 2001).

If a wider joint was naturally present in the quarry or it was formed by the wedges, then a lever (Fig. 6F–H) was inserted into it in the form of a long iron lever or crowbar, "sochor", "páčidlo", "štanga" (Stano, 1969) or "stangľa" in Slovak (Povala & Prikryl, 1968). The last two are derived from German (Stange is rod, Stängel is stem). In order not to close the other joints during levering, steel balls were inserted into them (such as Slivenec near Prague, Hájek & Kroupa, 1964). For greater separating of a stone block from quarry face, for example, the mechanical rack jack was used in the 20th century (e.g., Bruno Pripko stone mason from Dobrá Voda). The wedging and levering are the ancient extracting methods (Fig. 11A).

4.2.2. Separating a block from the quarry face after artificial joints by wedging

If no suitable joints were present in the rock and the rock was too hard to use carving, it was necessary to create a joint in the stone by force. The artificial joint under the block had to be done also when the block had been already separated from the sides and top. Quarrymen also divided the large blocks into smaller pieces. Creating the desired joint has been achieved in a few ways (Fig. 2). Systematic hammering (percussion) the stone surface by the stone or iron hammer was ancient method (Heldal & Bloxam,

Tab. 2. The extraction method marks in historical quarries in Slovakia and near surroundings for dressed stones: + – dressed stones, ? – disputed evidence.

quarry location (number according Fig. 1 and Tab. 1)	traces and forms of extraction in quarry faces / stone type	tracks of pick or chisel	separation tranches or their indication	stepped worked face	straight worked face	holes +traces of wedges	fault planes +lines	traces of individual boreholes	bore-hole set	hemi-spherical holes	holes with radiating joints	traces of cutting the saw	drainage traces	chamber extraction	boulder extraction	left blocks	unpreserved walls, only depressions in the field
54 Lysá pod Makytou	flysch sandstone						+	+								+	
58 Veľké Rovné	flysch sandstone						+	?								+	
48 Oravský Biely Potok	flysch sandstone		?			+	+	+									
4 Hybe	flysch sandstone						+									+	
47 Kežmarok	flysch sandstone					?	+										
3 Levoča	flysch sandstone		?			?	+										+
3 Spišská Nová Ves	flysch sandstone						+										+
3 Spišské Vlachy	flysch sandstone					+	+			?						+	+
49 Stará Ľubovňa	flysch sandstone						+										+
50 Sabinov	flysch sandstone						+										+
50 Prešov	flysch sandstone					?	+									+	+
50 Bertotovce	flysch sandstone						+									+	+
13 Holíč	sandstone						?										+
65 Banská Bystrica Rudlová	sandstone																+
12 Sokolovce	sandstone						+										+
12 Ratnovce	sandstone		?			+	+									+	
17 Trenčín	sandstone																+
51 Žitná-Radiša	sandstone					?	+									+	
30 Považská Bystrica	sandstone						+										+
101 Pilisborosjenő Harshegy HU	sandstone						+	+	+		?			?		+	
12 Banka	sandstone	?	?			+	+							+			+
65 Králiky	sandstone	+	?		+		+		+	?	?					+	+
21 Bernolákovo	sandstone	+			+		+							?			
87 Edelstal AT	sandstone	+			+												
55 Terchová	carbonate conglomerate						+				?						
59 Bojnice	carbonate conglomerate						+								+	+	+
62 Dobrá Voda	carbonate conglomerate	+	+	+	+	+	+	+	+		+						+
62 Dechtice Šidlová	carbonate conglomerate	+		+	+	+	+				+					+	
62 Chtelnica Malé Skalky	carbonate conglomerate	+	+	+	+	+	+	+	+		+					+	+
42 Čachtice	carbonate conglomerate	?		?	?		?									+	+
62 Chtelnica Trianová	carbonate conglomerate						+	+	+		?					+	+
89 Chropov	carbonate conglomerate																+
33 Slovany	carbonate conglomerate						?								+	?	
94 Devínska Nová Ves	carbonate conglomerate	+				?	+	+		?	?					+	
6 Hainburg town AT	carbonate conglomerate	+		?	+												
6 Hainburg Pfaffenberg AT	carbonate conglomerate	?		?			+	+			+					+	
6 Hundsheim AT	carbonate conglomerate						+	+			+					+	
5 Devín	carbonate sandstone	+	+	+	+	?		+	+				+	+		+	+

quarry location (number according Fig. 1 and Tab. 1)	**traces and forms of extraction in quarry faces** / **stone type**	tracks of pick or chisel	separation tranches or their indication	stepped worked face	straight worked face	holes +traces of wedges	fault planes +lines	traces of individual boreholes	bore-hole set	hemi-spherical holes	holes with radiating joints	traces of cutting the saw	drainage traces	chamber extraction	boulder extraction	left blocks	unpreserved walls, only depressions in the field
80 St. Margarethen AT	porous limestone	+	+	+	+	+	+	+	+			+	+			+	
80 Fertőrákos HU	porous limestone	+	+	+	+	?	+			?				+		+	
10 Sóskút HU	porous limestone	+		+	+	+	+						+	+		+	
10 Diósd HU	porous limestone	+	+	+	+	?	+					+		+			
7 Wolfsthal AT	porous limestone	?		+		+	+	+		+	+					+	+
8 Winden AT	porous limestone	+	+		+	+	+									+	
69 Breitenbrunn AT	porous limestone	+		?	+	+	+									?	
78 Mannersdorf AT	algal limestone						+	+			+					+	
79 Kaisersteinbruch AT	algal limestone	+			+	+	+	+			?					+	+
2 Žehra	travertine	+	+		?		+	+	+		+	+			+	+	
9 Dunaalmás HU	travertine	+		+			+	+								+	
97 Ružomberok Biely Potok	travertine	+	+				+									+	+
18 Sádok	travertine						?								+		
18 Veľký Klíž	travertine						+	+	+		?					+	
18 Nedanovce	travertine						?								?		+
99 Levice	travertine						+	?							+		
104 Ludrová	travertine						+		+							+	
104 Lúčky	travertine					+	+	+			?						
104 Bešeňová	travertine						+	+	+		+	r				+	+
96 Gánovce	travertine						+										
96 Hozelec	travertine						+									+	
100 Vyšné Ružbachy	travertine						+		+							+	
2 Spišské Podhradie	travertine						+	+	+		?	?			+	+	
9 Süttő HU	travertine						+	+	+			+				+	
73 Turčianska Štiavnička	tufa																+
90 Veľký Klíž	compact limestone						+									+	
71 Silická Brezová	compact limestone						+	+			+					+	
83 Žarnov	compact limestone						+				+					+	
75 Stará Ľubovňa Marmon	compact limestone	+		+	+	+	+	+	+		+					+	
75 Údol	compact limestone	?		+			+										
29 Tardos HU	compact limestone						+		+	?	?	+				+	
29 Süttő Kis Gerecse HU	compact limestone						+	+			+					+	
29 Piszke Nagy Pisznice HU	compact limestone	+			+		+	+	+							+	
25 Bratislava	granodiorite						+	+			+					+	
25 Devín	granodiorite						+				?					+	
95 Nitra	granodiorite						+	+								+	+
108 Čierny Balog	tonalite						+	+	+							+	
1 Nová Baňa	rhyolite						+	?	+		?					+	
1 Vyhne	rhyolite														+	+	
1 Hliník nad Hronom	rhyolite						+				+			?		+	+

quarry location (number according Fig. 1 and Tab. 1)	traces and forms of extraction in quarry faces / stone type	tracks of pick or chisel	separation tranches or their indication	stepped worked face	straight worked face	holes +traces of wedges	fault planes +lines	traces of individual boreholes	bore-hole set	hemi-spherical holes	holes with radiating joints	traces of cutting the saw	drainage traces	chamber extraction	boulder extraction	left blocks	unpreserved walls, only depressions in the field
28 Banská Štiavnica Barlangy	andesite	+	+	+		+	+							+		+	
45 Kremnica	andesite	+	+	+	+	+	+	+			?			+		+	
106 Dobrá Niva	andesite						+				?					+	
107 Breziny	andesite						+				+					+	
92 Fintice	andesite						+				+					+	
92 Vyšná Šebastová	andesite						+				+					+	
72 Ilija	pumice tuff	?															+
20 Sárospatak Megyer HU	rhyolite tuff	+		+	+	+	+							?			
15 Obyce	tuff (ignimbrite)	?		?		+	+				+					+	+
66 Nová Baňa	tuff (ignimbrite)	+			?	+	+			?	+					+	
93 Horný Tisovník	volcanic breccia						+								+	+	
39 Veľká Hradná	epiclastic sandstone						+										+
14 Mýtne Ludany	epiclastic sandstone	?			?												+
14 Brhlovce	epiclastic sandstone	+	+		+		+					+		?			
14 Žemberovce	epiclastic sandstone	?			?		+										+
14 Jabloňovce	epiclastic sandstone	+					+							?			+
43 Terany	epiclastic sandstone	+			+	?	+			+				?			
43 Hontianske Tesáre	epiclastic sandstone	+	?		+		+			+				+		+	
23 Sebechleby	epiclastic sandstone	?			+	?	+	+									+
46 Ľubietová	epiclastic sandstone					?	+			?						+	
35 Háj	epiclastic sandstone						+										+
24 Vyšná Pokoradz	epiclastic sandstone	?			?		+	+		+				+		+	
24 Nižný Skálnik	epiclastic sandstone	+	+	+	+	+	+							+			
16 Hronský Beňadik	epiclastic conglomerate	?				?	+			+	+					+	+
64 Prievidza	epiclastic conglomerate	+					+									+	
76 Prenčov	epiclastic conglomerate	+	+	+	+	+	+	+		+	+					+	+
23 Krupina	epiclastic conglomerate	+		+	+	+	+	+						+		+	
61 Badín	epiclastic conglomerate	+	+		+	+	+	+		+						+	
26 Podhorany	rauhwacke						+								+		
27 Veľký Klíž	rauhwacke						+									+	
103 Tuhár	marble						+	+				+				+	
105 Ochtiná	marble				+		+	+			+	+				+	
105 Markuška	marble				?		+					?				+	+

2008[a], 2008[b]), not yet known in Slovakia, where the technology was like breaking the blocks along the joints mentioned in point 1.

In the volcanic sandstones in Brhlovce (Stano, 1969), firstly the channel with sloping walls ("jarček" in Slovak) was carved out in stone, wide on the top up to 25 cm. Technical term "šramovanie" (carving) is derived from the German "Schramme", "Schram" and means scratch, scrape. In a carved channel (Figs. 8H, 9A,J) or without it (Fig. 9C,D,H), the holes were excavated each 10 to 15 cm, in which the iron wedges were inserted. Systematic hammering the wedges splits a stone wall along vertical or horizontal joint and the block was separated from the other stone mass (Fig. 6F). Large broken blocks were as needed divided by carving with pick and hammering the wedges in Brhlovce (Stano, 1969), by the hammering the wedges near Dolný Kubín (Povala & Prikryl 1968) and by the hammering the spiked chisels in Dobrá Voda (Kahounová, 1962) and Nižný Skálnik (Fig. 9C,G,I).

Iron wedges were usually covered from both sides by flat iron pieces ("plechy" in Slovak), so that the stone around the wedge was not crushed and the hole edge was not split. Iron shims divided the wedge force over a larger area (cf. Kahounová, 1962; Jundrovský & Tichý, 2001; Hájek & Kroupa, 1964).

In granite quarries in the Czech Republic, the holes for wedges were cut every 15 to 30 cm, about 4 cm deep, up to 3–4 cm wide. The wedges were covered with steel sheets. By systematic hammering the wedges with sledgehammer for to provide a pressure effect, the block was split. Nowadays, the holes are drilled with pneumatic hammers up to 10 cm deep. Special wedges named plugs with shims named feathers are inserted into holes (Hájek, 1931; Hájek & Kroupa, 1964). The technology with wedge line was used in ancient Egypt for limestone and sandstone mining (Kirby et al., 1990) or in Roman times, for example, in the Carrara quarries (Dozolme, 2017).

4.2.3. Separating a block from the quarry face by carving

In the softer massive stones, where joints were not present or were not suitable, the block were usually separated from the wall by a channel creation ("jarček" in Slovak), which was carved by the steel tools. The width of the channel ranged from a few cm to the width of the leg that could be inserted into the gap up to human width (Fig. 8). This technology has been used since ancient times (Fig. 11B,C). The block was carved from the sides and back, and later was separated from the bottom by wedges. Wide channels can be used for drainage water from the quarry (Devín, St. Margarethen, Fig. 8E–G). It can also serve like the separation of working field (Sóskút, Devín).

In porous soft stones, e.g. in Devín, St. Margarethen, Fertőrákos and Diósd, pick with changeable handle length was used for carving. Carving by pick is like digging with pickaxe (Fig. 11B). Characteristic curved grooves remained on the wall surface (Fig.

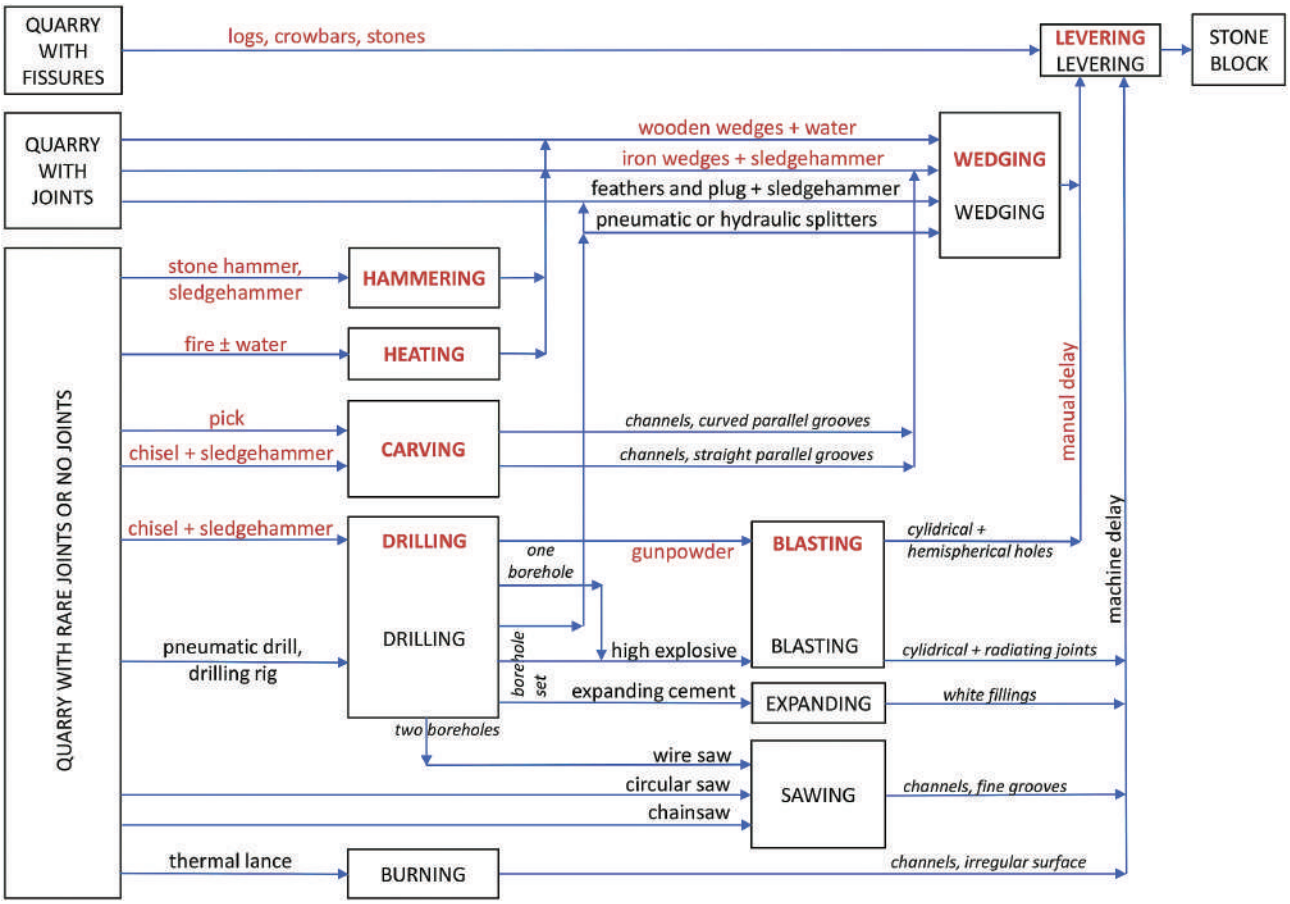

Fig. 2. Historical and contemporary quarrying methods, tools and marks improved according to the table in Heldal & Bloxam (2008). Historical methods, invented before the 19th century, are highlighted in red.

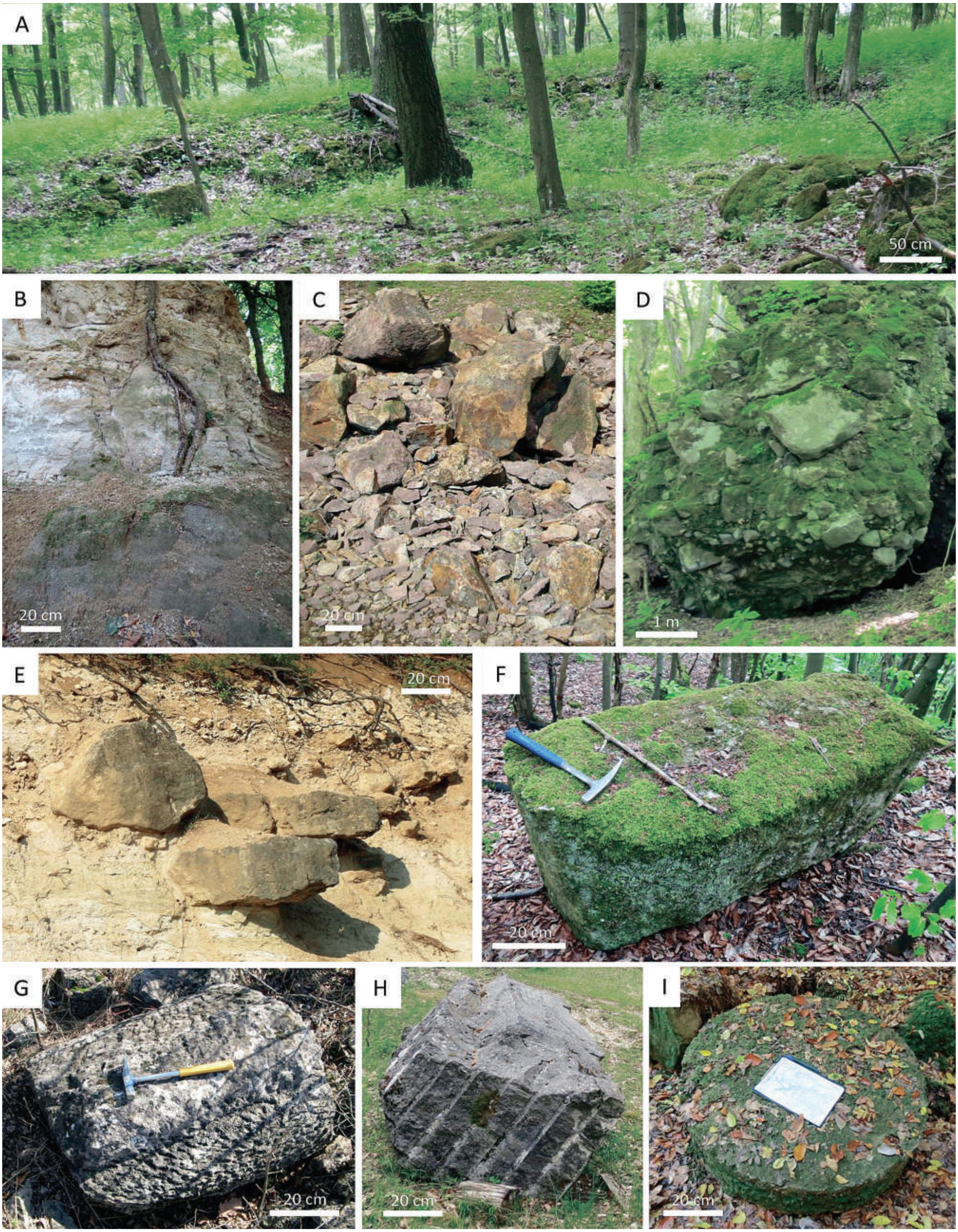

Fig. 3. Weathered quarries, boulders extraction and abandoned blocks. A – unnatural depressions on surface after weathered quarry (Chtelnica – Malé skalky). B – weathered quarry face of volcanic sandstone without tool marks (Mýtne Ludany). C – boulder extraction from rock avalanche in rhyolite (Vyhne). D – boulder extraction from volcanic conglomerates (Horný Tisovník). E – travertine boulder extraction from regolith (Sádok). F – Dressed conglomerate block (Chtelnica – Malé skalky). G – Carved sandstone block (Devín). H – Conglomerate block with borehole grooves (Chtelnica – Trianová). I – Millstone left in rhyolite quarry (Hliník nad Hronom).

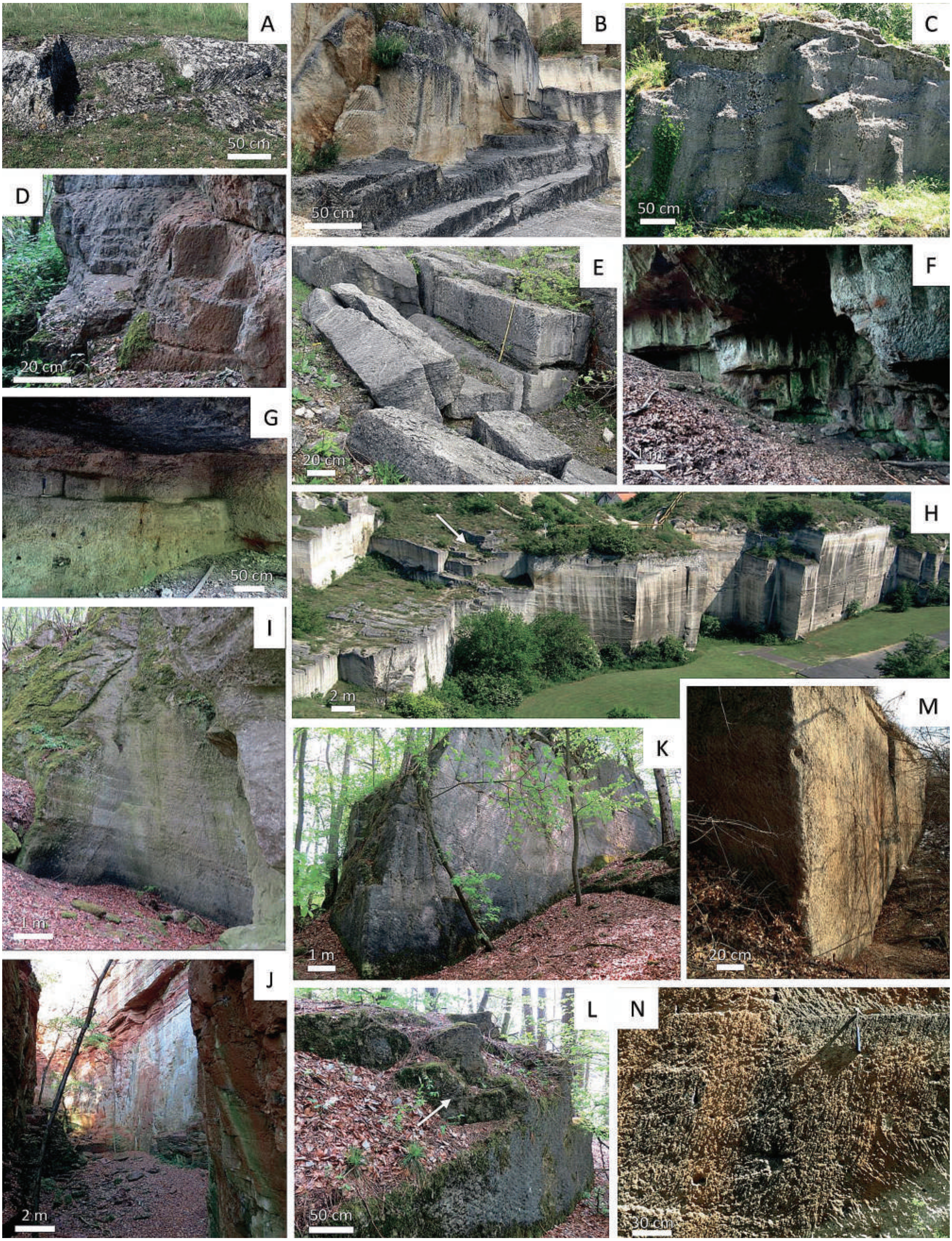
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Fig. 4.

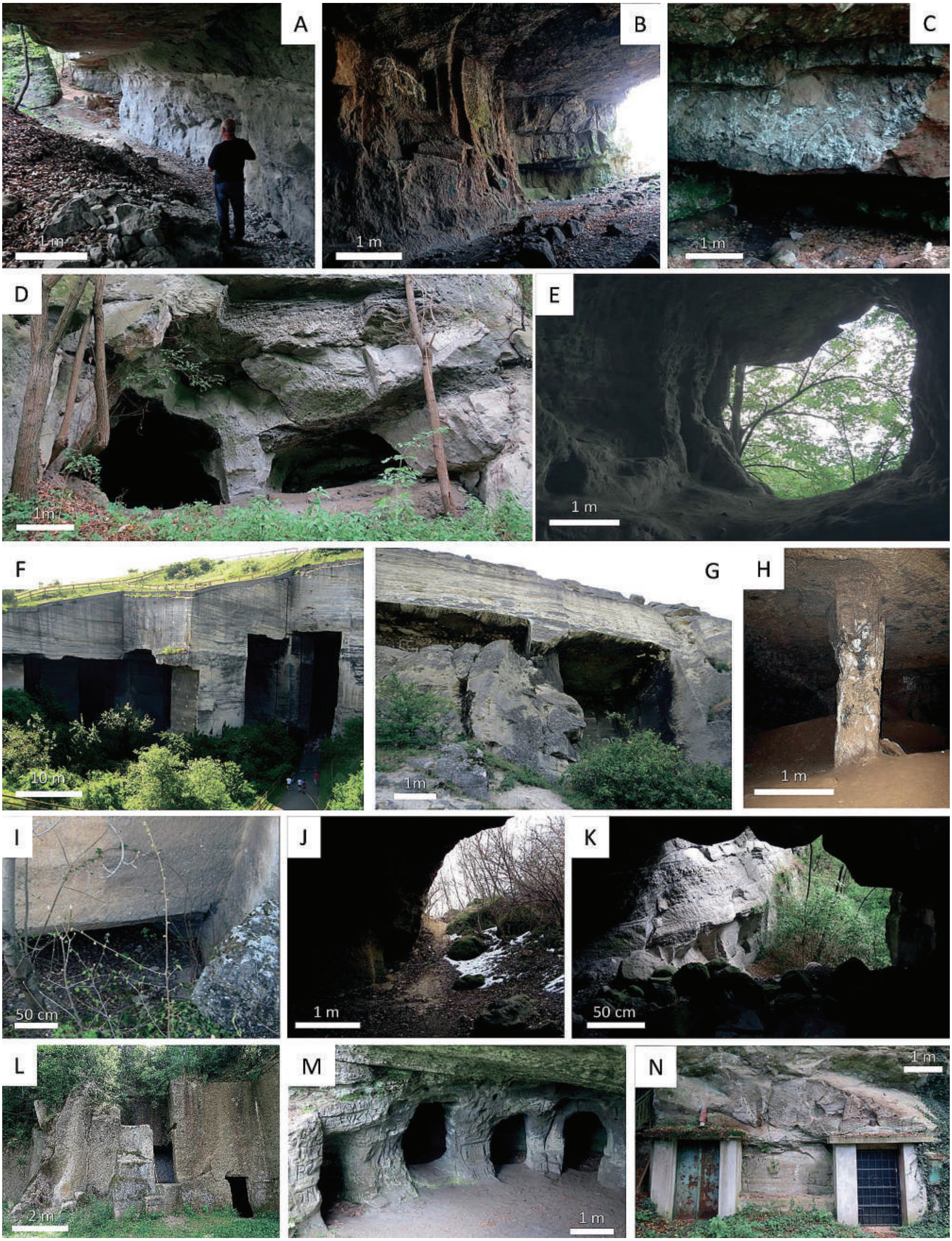

Fig. 5.

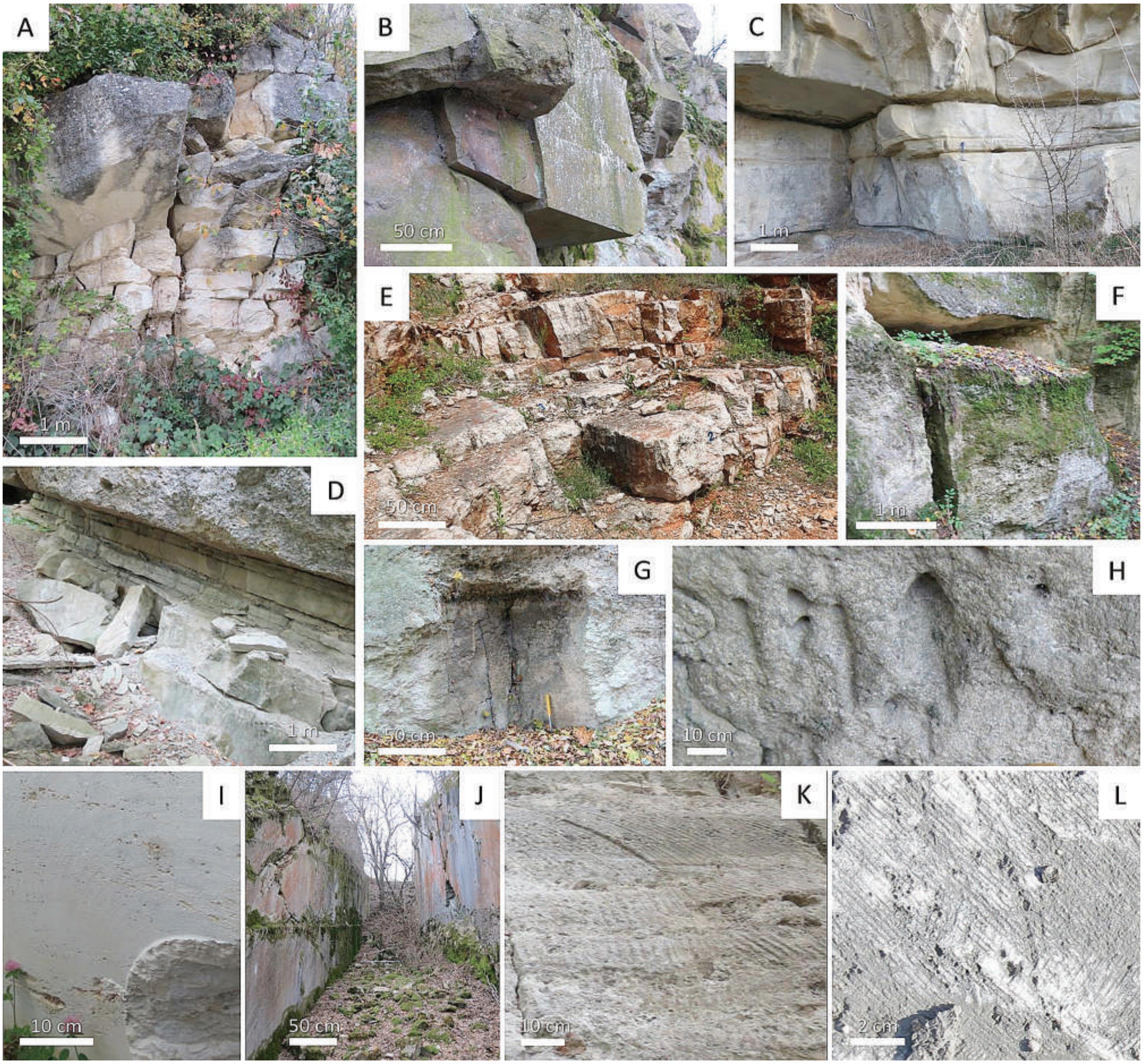

Fig. 6.

Fig. 4. Stepped and flattened quarry faces. A-B – Stepped quarry face in porous limestone (St. Margarethen AT). C – Stepped quarry face in conglomerate (Dobrá Voda). D – Stepped quarry face in compact limestone (Stará Ľubovňa – Marmon). E – Archaic conglomerate extraction from stepped face (Chtelnica – Malé skalky). F – Stepped overhang quarry in andesite (Banská Štiavnica Barlangy). G – Stepped sandstone extraction in chamber (Devín). H – Flattened quarry faces with older stepped quarry, marked with an arrow (Fertőrákos HU). I – Flattened face carved in conglomerate (Chtelnica – Malé skalky). J – High flattened faces in limestone quarry (Piszke Nagy Pisznice HU). K-L – Flattened face in conglomerate cut older stepped face, marked with an arrow (Dechtice Šidlová). M – Flattened faces in sandstone quarry (Devín). N – Block marks on flattened face (Devín).

Fig. 5. Overhang and chamber extraction. A – Volcanic sandstone extraction in overhang (Vyšná Pokoradz). B – Andesite extraction in chamber (Kremnica "Körmendyho jaskyňa"). C – Overhang and entrance to a chamber (Banská Štiavnica Barlangy). D – Chambers in volcanic sandstone quarry (Nižný Skálnik). E – Chamber in volcanic sandstone (Hontianske Tesáre). F – Great extraction chambers in porous limestone quarry (Fertőrákos HU). G – Extraction chambers in porous limestone quarry (Sóskút HU). H – Support pillar in large chamber (Banská Štiavnica Barlangy). I – Chamber filled by debris in sandstone quarry (Devín). J – Partly collapsed chamber (Devín). K – Partly collapsed chamber (Nižný Skálnik). L – Chambers used like dwelling in volcanic conglomerate quarry (Krupina). M – Chamber in volcanic sandstone with possible carved dwellings (Hontianske Tesáre). N – Cellars in volcanic sandstone quarry (Terany).

Fig. 6. Joints and fine groove surfaces. A – The blocks extracted according to fissures in porous limestone quarry face (Winden AT). B – Regular joint system allowed block extraction in granitoid quarry (Bratislava). C – Horizontal bedding planes and perpendicular joins allowed block extraction in sandstones (Oravský Biely Potok). D – Block extraction in bedded sandstone quarry with joints (Žitná-Radiša). E – Block extraction in bedded limestone quarry with regular joint system (Silická Brezová). F – Released block with joint and bedding plane surfaces in porous limestones (Winden AT). G – Mark after the block released along the joints in porous limestones (Wolfsthal AT). H – Marks of an iron lever in porous limestone (Wolfsthal AT). I – Curved groove marks of wire saw in travertine (Spišské Podhradie). J – Straight marble walls cut by wire saw (Ochtiná). K – Curved groove marks of circular saw in pumice tuff (Brhlovce). L – Straight groove marks of chain saw in travertine (Žehra).

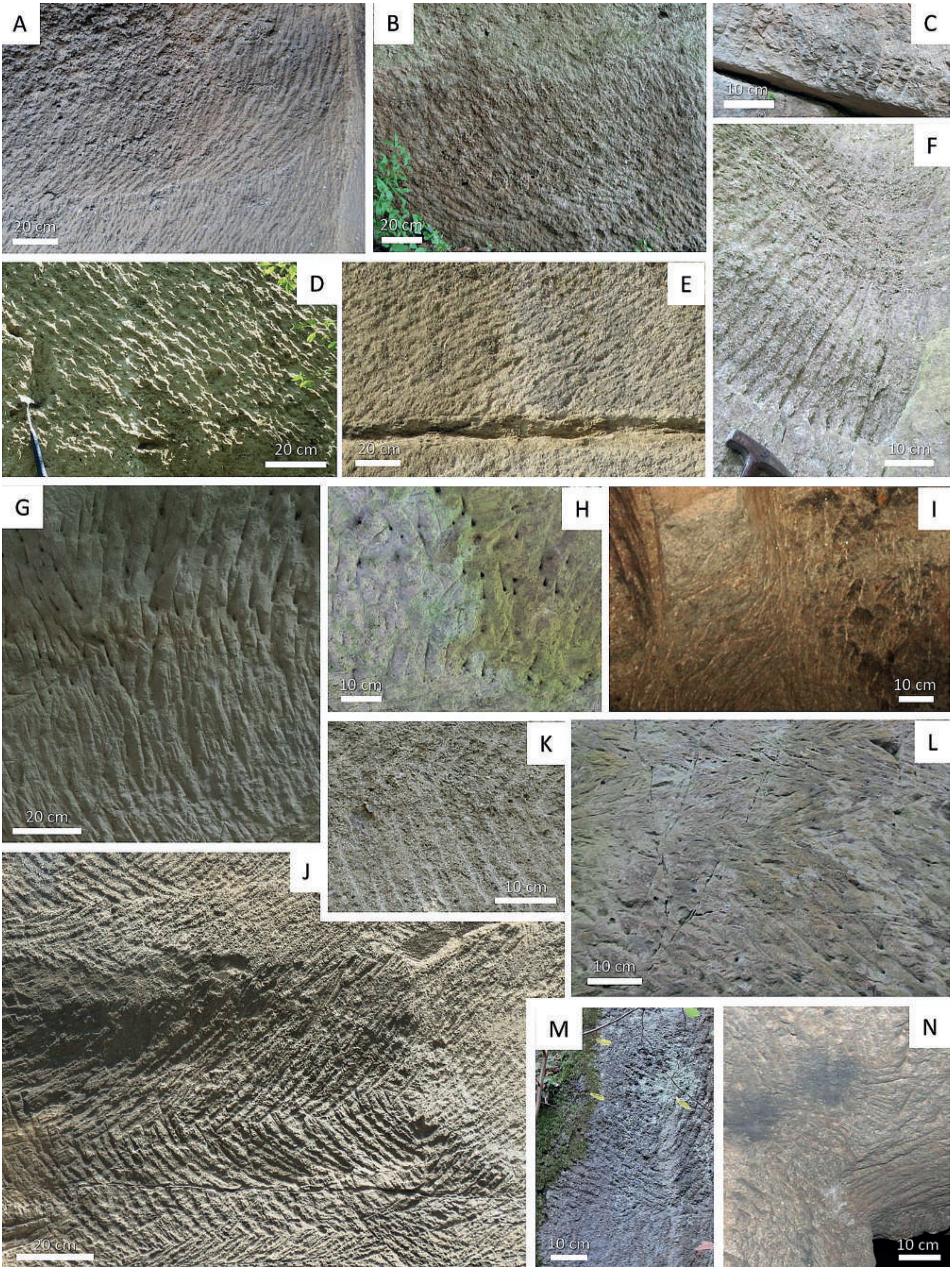
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Fig. 7.

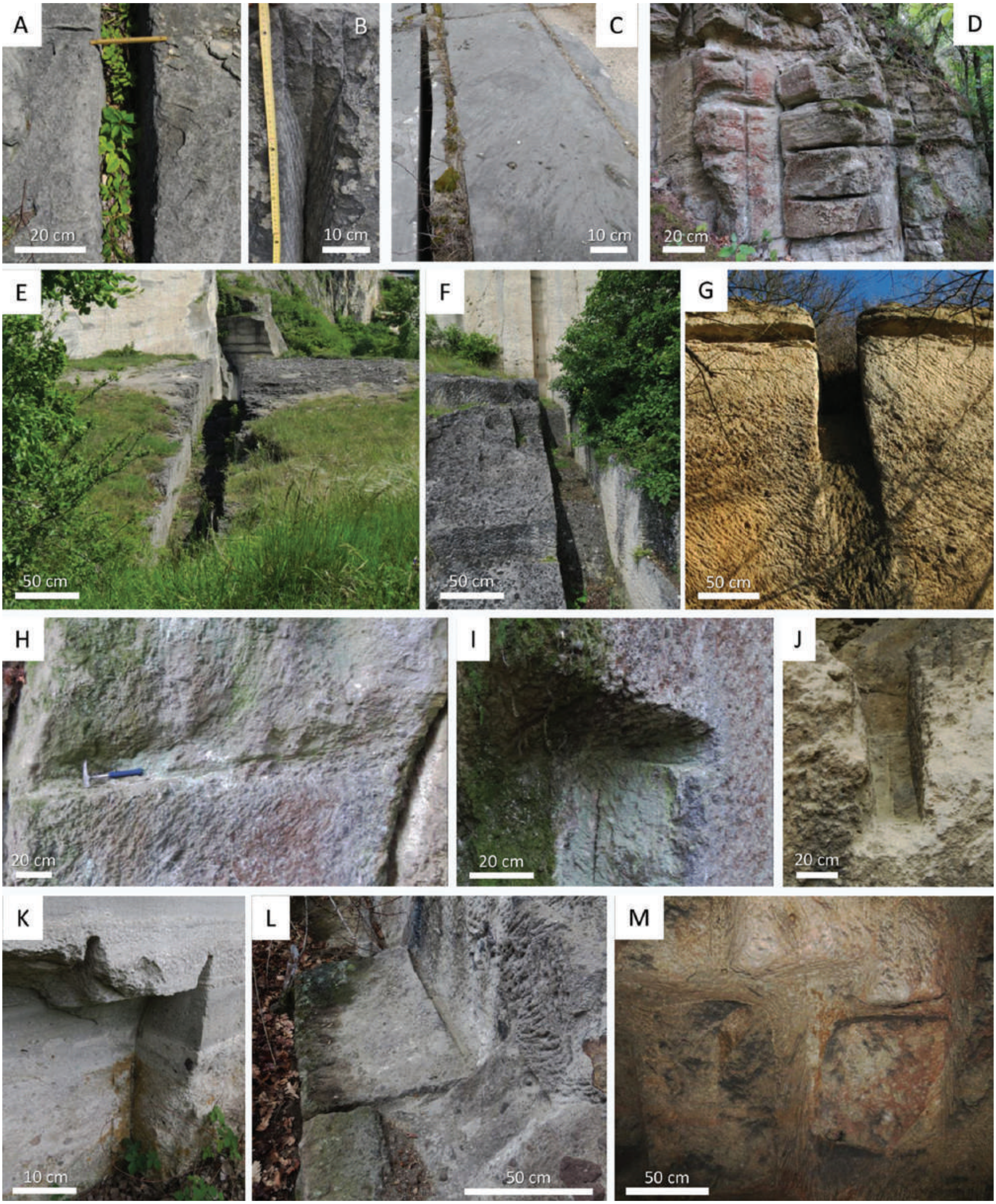

Fig. 8.

7A,B). The opposite dip of the grooves was sometimes visible on the walls like "herringbone" pattern (Fig. 7J), therefore the quarrymen changed the direction of carving. The result of pick carving was probably recorded in volcanic sandstones (Fig. 7G,H)

In more compact rocks like compact limestones, carbonate conglomerates or in harder stones like sandstones, a channel was carved by hammering the chisel (Fig. 11C). In Dobrá Voda, the chisel, named „špicajzna", and sledgehammer up to 5 kg was used for hitting (Kahounová, 1962). Inclined chisel marks in the form of straight parallel grooves remain on the walls (Fig. 7C-F). The quarrymen also changed the direction of carving with "herringbone" pattern (Fig. 7K).

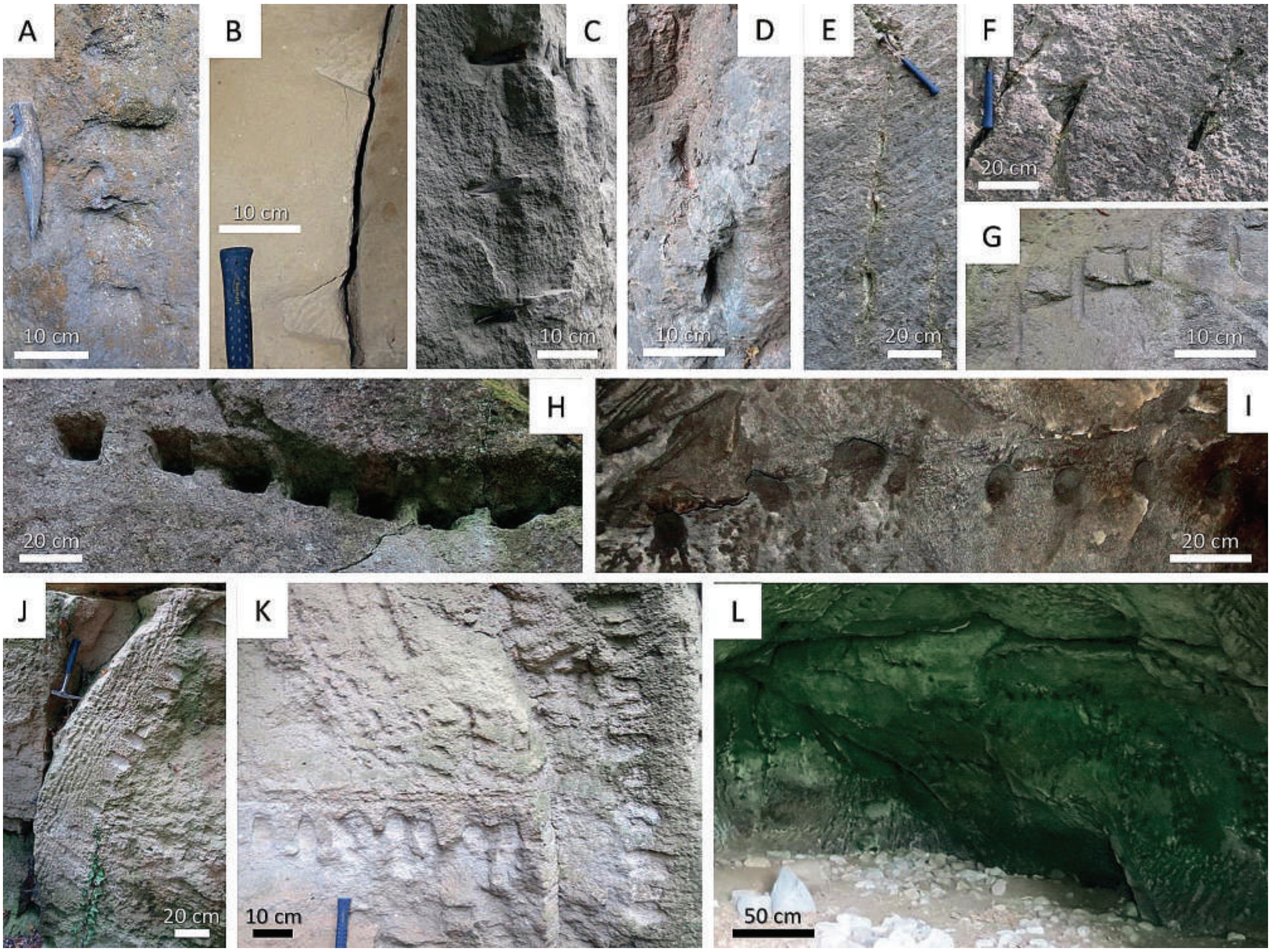

Fig. 9.

Fig. 7. Carving grooves on quarry faces. A-B – Curved parallel grooves of pick in porous sandstone (Devín). C – Straight parallel grooves of chisel in compact limestone (Stará Ľubovňa Marmon). D-E – Straight almost parallel grooves of chisel in porous sandstone (Devín). F – Straight parallel grooves of chisel in conglomerate (Chtelnica Malé skalky). G – Approximately paraller grooves of pick in volcanic sandstone (Nižný Skálnik). H – Irregular grooves of pick or chisel in volcanic conglomerate (Krupina). I – Irregular grooves of pick in andesite (Banská Štiavnica Barlangy). J – Curved grooves of pick in the form of "herringbone" pattern testify to the change of curving direction (St. Margarethen AT). K – Straight grooves of chisel in the form of "herringbone" pattern (Dobrá Voda). L – Almost parallel grooves in the form of "herringbone" pattern (Králiky). M – Irregular pattern of parallel grooves in volcanic conglomerate (Badín). N – Irregular pattern of parallel grooves in andesites (Banská Štiavnica Barlangy).

Fig. 8. Channels in quarry faces. A – The channel with parallel walls carved by chisel in sandstone quarry (Chtelnica Malé skalky). B – Convergent channel walls carved by chisel in sandstone quarry (Chtelnica Malé skalky). C – The channel with parallel walls sawn by chain saw in travetine (Žehra). D – Narrow channels of circular saw in pumice tuff quarry (Brhlovce). E-F – Upper and lower part of wide channel carved for water drainage in limestone quarry (St. Margarethen AT). G – The wide drainage channel carved in hybrid sandstone (Devín). H-I – The beginning of channel creation in volcanic conglomerate (Badín). J – The beginning of channel creation with parallel walls in hybrid sandstone (Devín). K – The beginning of channels caused by circular saw cut in pumice tuff (Brhlovce). L – The unfinished block extraction with indicated boundaries – channels (Prenčov). M – The unfinished block extraction with indicated boundaries – channels (Banská Štiavnica Barlangy).

Fig. 9. Wedge marks. A – Approximately rectangular marks of wedges (Badín). B – Trapezoidal holes for wedges carved by chisel (Oravský Biely Potok). C – Approximately trapezoidal marks of wedges in volcanic sandstone (Nižný Skálnik). D – Wedge holes in compact limestone (Stará Ľubovňa Marmon). E-F – Wedge holes along joints in conglomerate (Dechtice Šidlová). G – Cylindrical wedge holes in conglomerate (Dobrá Voda). H – Rectangular wedge holes carved in conglomerate (Chtelnica Malé skalky). I – Round holes of wedges in volcanic sandstone (Nižný Skálnik). J – Channel wall with chisel grooves and wedge marks (Winden AT). K – Wedge mark sets in porous limestone (Winden AT). L – Wedge hole sets in volcanic sandstone chamber (Nižný Skálnik).

Fig. 10. Borehole and explosive marks. A – Borehole set in compact limestone (Stará Ľubovňa Marmon). B – Borehole cross-section in conglomerate (Devínska Nová Ves). C – Round mouth of borehole in volcanic sandstone (Vyšná Pokoradz). D – Triangular borehole carved by chisel in conglomerate (Dobrá Voda). E – Borehole filled by expansion cement (Chtelnica Trianová). F – Parallel borehole set in tonalite quarry (Čierny Balog). G – Parallel borehole set in sandstone quarry (Králiky). H – Parallel borehole set in travertine quarry (Ludrová). I – Parallel borehole set in conglomerate quarry (Chtelnica Trianová). J – Nonparallel borehole set in conglomerate quarry (Dobrá Voda). K – Borehole with small hole of unsuccessful gunpowder explosion (Badín). L – Borehole with small hole of unsuccessful gunpowder explosion (Prenčov). M – Chamber with gunpowder explosion holes (Nižný Skálnik). N – Detail of M with boreholes and gunpowder explosion holes in volcanic sandstone (Nižný Skálnik). O – Gunpowder explosion hole in volcanic conglomerate (Badín). P – The borehole and hole with radiating joints of high explosive in conglomerate (Dobrá Voda). R – The hole with radiating joints of high explosive in limestone (Hundsheim). S – The hole with radiating joints of high explosive in compact limestone (Silická Brezová).

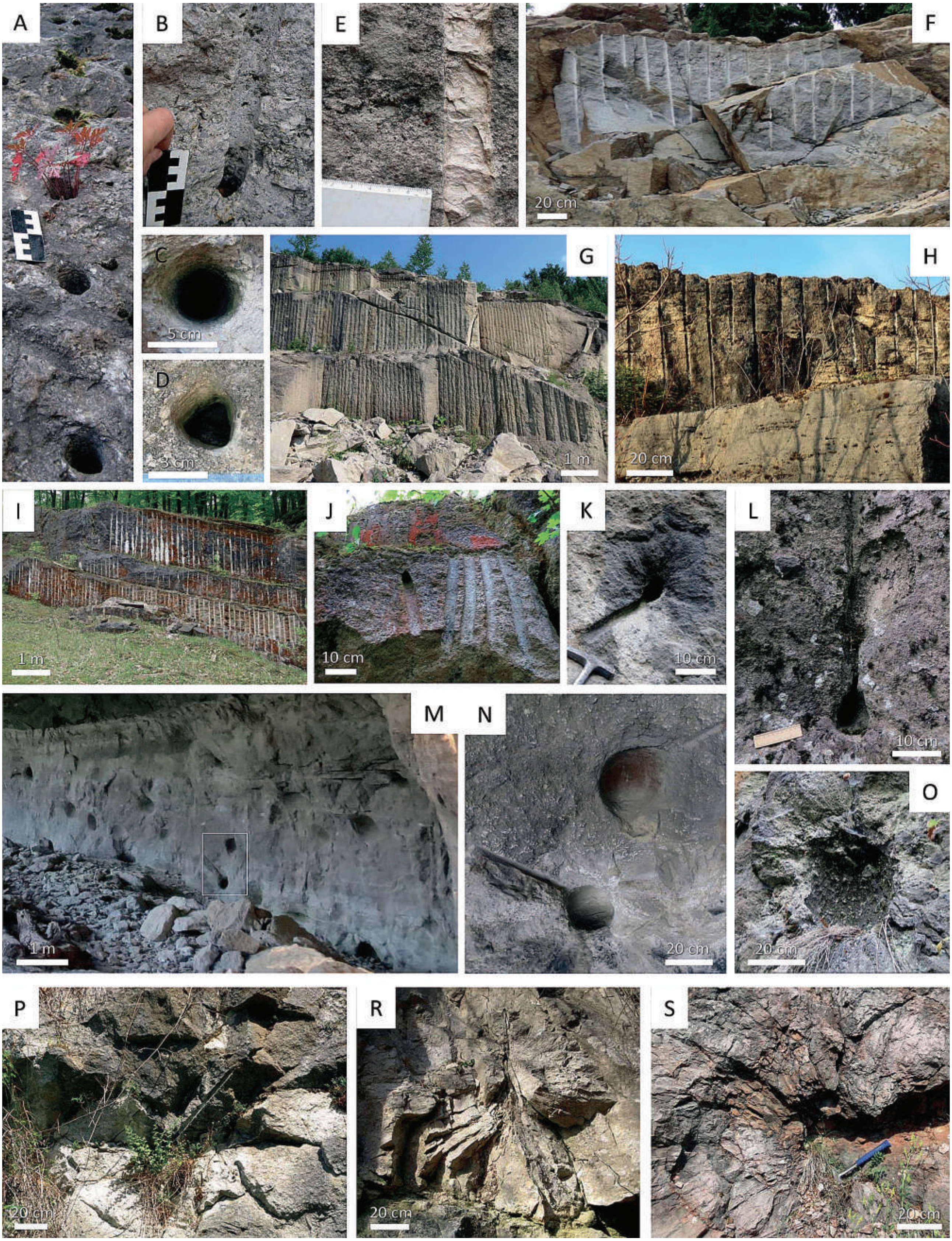
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Fig. 10.

The channels in the underground chamber in Banská Štiavnica (Barlangy) and Kremnica (Körmendyho jaskyňa) were carved by other tools. The both towns are important ore mining areas, for that the quarrymen or miners used a proven hammer and mining pick. The pick left after hammering a system of irregular grooves on the walls (Fig. 7I,N).

4.2.4. Separating a block from the quarry face by drilling and wedging

A block was separated by a set of vertical boreholes (Fig. 10A), that were drilled up to the depth such as block thickness. The distance of the individual boreholes in a row was approximately 10 cm. Boreholes were initially cut by pneumatic drill worked by steam, later by petrol drills and finally by pneumatic drill worked by compressed air. It is assumed that the machine drilling in the quarries began to be used in our country at the end of the 19th century, just as it was in the mines since 1873 (Gindl, 1971; Magula, 1971). Cylindrical grooves after the system of not parallel boreholes were found in Dobrá Voda quarry (Fig. 10J) and probable in Devín quarry. Later the boreholes were parallel, and their marks were found in many quarries (Fig. 10F–I).

Into each borehole, a pair of steel feathers and one plug were placed, and the block was split off the wall by gradual hammering. To eliminate the hard work of hammering, a pneumatic and hydraulic splitter has been developed. In some quarries in Slovakia, such as Ludrová, Dobrá Voda, Chtelnica Malé skalky and Trianová, a special expansive cement was used, which splits the rock along the boreholes with the expansion force. Previous methods, which split the stone in a gentle way, were used in valuable marbles and compact limestones that are brittle. Low explosives (e.g., black powder) was sometimes inserted to boreholes in granites or sandstones in Czech (Hájek, 1931; Hájek & Kroupa, 1964). The boreholes with three-piece wedges (feathers and plug long to 1 m), manually hammered or pneumatically disconnected, was used in Bešeňová, the pneumatic drilling and blasting in Spišské Podhradie and Ružbachy (Hájek & Kroupa, 1964).

4.2.5. Separating a block from the quarry face by sawing

A more modern way of block extraction is cutting a stone by a wire, chain or circular saw. Wire saw technology has been used since the late 19th century, for example, in the Carrara quarries. From the beginning, it was a moving 4–6 mm diameter steel helical wire combined with the abrasive action of quartz sand and an abundant amount of water as a lubricant (Dozolme 2017), also used for cooling. This type of wire saw was used in Slovakia for extraction of Tuhár marble, Bešeňová travertine and experimental extraction of marble at Ochtiná (Fig. 6J) and Markuška in the 1930s. Still at the beginning of the 1960s, this method was used in the former Czechoslovakia, with a rope driven by an electric motor (Hájek & Kroupa, 1964). A diamond wire saw was invented in England in the 1950s and produced in Italy in 1969. Steel carrier rings separated from each other by helical compression springs are fitted over the tension wire. The rings are coated with synthetic diamonds (McCarthy, 2011). The wire saw is currently used in the travertine quarry near Spišské Podhradie (Fig. 6I).

The circular saw is equipped with a disc coated with segmented carbide saw blade. It is used for cutting blocks from soft and medium hard rocks. An improved sawing harvester according to Soviet patterns was produced by Piesok Machine Works at Podbrezová. It worked in pumice tuff quarries in Brhlovce (Figs. 8D,K, 6K) and Čajkov for a short time only until 1949. It sawed at the same time with 4 discs vertically, then horizontally. Finally, the block was cut with 2 discs (Hájek & Kroupa, 1964). The marks of circular saw are visible in limestone quarry in Diósd (Hungary). The chain saw of Bulgarian production was used in the travertine quarry in Žehra (Figs. 8C, 6L) in the 1980s (Stupák et al., 1993).

4.2.6. Separating a block from the quarry face by drilling and blasting

The aim of this method was to accelerate and facilitate work in the quarry. The explosive was to be inserted into a drilled borehole behind or under the required block. From the beginning, the black powder or gunpowder was used as an explosive. Gunpowder has begun to be used for civilian purposes, to build roads in the mountains, in the 15th and 16th centuries, more often in the second half of the 17th century. The first documented use of gunpowder in mine was around 1574 in the mountains near Schio in Vicenza. At the beginning of the 17th century it appeared in several mining areas of Europe, firstly in the southern Vogézach near the village of Le Thillot (1617). The oldest recorded use of black dust in the Saxony quarry dates to 1611 (Vergani, 2003, 2009). The technology was used, for example, during the 18th and 19th centuries in the Carrara quarries (Dozolme, 2017). However, it soon became clear that blasts violated marble, and this technology is inappropriate for obtaining blocks of good quality stone.

In our country, the gunpowder was used for the first time in Banská Štiavnica (1627) and Banská Bystrica (1629) mines. From the previous dates it can be deduced that in the quarries in our territory the black powder could be used occasionally from the 17th century, more often from the 18th and 19th centuries. In several historic quarries (Tab. 2), the evidence of gunpowder use is recorded by the hemispherical bursting traces with a diameter up to a few dm and the adjacent cylindrical traces of boreholes (Fig. 10M–O). Sometimes gunpowder fill was not quite effective, and the result is recorded in small sphere at the end of borehole (Fig. 10K,L). The borehole was deepened by the hammering into special long chisel and its cross section was usually circular (Fig. 10C), very rarely triangular (Fig. 4D). After the inserting gunpowder, the borehole was sealed with an oak stopper with an opening for fuse, an iron stopper since 1673 and a clay tumping since 1685. Dynamite as a high explosive was used for disconnecting rocks since 1870 (Gindl, 1969, 1975; Kladivík & Hock, 2012).

In Czech granite quarries, the explosives were used to separate large blocks from the wall. A narrow crack had to be widened either by drilling and blasting, or explosive was inserted directly into the crack and sealed (Hájek & Kroupa 1964). Using high explosives in the quarries for dimension stone is an inappropriate way of separating, for that it causes irreparable damage. A characteristic feature of the high explosive use is the trace on the wall in the form of radiating joints originated from the explosion point (Fig. 10P–S).

4.3. Extraction places for dressed stones in Slovakia and immediate surroundings

4.3.1. Stone block extraction in open cast quarries and chambers – quarry preservation and appearance

The stone quarries of the Roman period were according to the products near Bratislava and Komárno, but they can not be demonstrated for a long time since their founding. Either they were grown over by vegetation or destroyed by Medieval extraction. The Roman and Medieval quarrying technology was similar, so marking a quarry as a Roman is almost impossible. The finding of medieval stone quarries is also problematic today. Only according to the composition of the products, we know where they were. Medieval walls have either been removed by the continuation of the extraction or have been lost because of weathering and growing over. According to the research, the medieval stone quarries have an irregular appearance. The blocks were extracted almost chaotically with small quarry organization. The step-like character of walls was the result of the quarrying (Tab. 2; Fig. 4A–G). The best examples of step-like walls are in St. Margarethen, Dobrá Voda and surroundings, and Devín. Not all parts of these stone quarries are necessarily medieval, because archaic methods were used locally later (Fig. 4E). The medieval parts have been mostly preserved in the upper parts of the stone quarries (Fig. 4H,L) or in the chambers (Fig. 4F,G) or occasionally in another part of the quarry where the stone was not of sufficient quality for modern time demands. The extraction under overhangs up to chambers (Fig. 5H–J). was rare for their difficulty (Devín, Banská Štiavnica, maybe Kremnica). There was a risk of collapse, necessity of lighting, leaving support pillars (Fig. 5H) and sometimes draining water. The quarrymen approached to the method, when the quality stone was only in a narrow horizontal layer (a few m) covered with thick poor-quality material. Removing the overburden would be very costly. In the Middle Ages, small blocks up to 1 m were extracted, except of flat stones for tombstone plates up to 2m. In the 15th and 16th centuries, the larger blocks from 1 to 2 m^3 were quarried only for luxury tombstones, in the 17th century also for portals.

The change from the stepped to more efficient straight carved faces took place gradually in the 17th century. In the 18th and 19th centuries, quarry faces were generally straight not only at carved walls (Fig. 4I–N) but also it was an effort to straighten the split walls. During block extraction, the perpendicular faces were systematically formed (Fig. 4H,M). The new technology has enabled the extraction of large blocks over 2 m long, e.g. for carving a column since the second third of the 17th century. The quarrying methods with higher productivity could be brought to our territory by Italian experts for building fortresses in the 16th and 17th centuries. Many of the modern time quarries, which have not been used for a long time, are weathered and covered by a regolith (Fig. 3A,B, e.g. in Mýtne Ludany or Kalinčiakovo). The largest chambers with the tracks of modern technologies can be found at Fertőrákos (HU). In Slovakia there are Rimavská Sobota - Vyšná Pokoradz (Figs. 5A, 10M) and Nižný Skálnik (Fig. 5D,K).

Historical quarries for dimension stones were also identified on basis of left block (Fig. 3F-H), rarely products (Fig. 3I) and access road with possibly abandoned blocks.

In the near future, airborne lidar technology will be used to search for abandoned quarries (e.g., Kluiving & Guttmann-Bond, 2012), but the images have not yet been available in Slovakia. Airborne lidar, a laser scanner attached to an aircraft during flight, forms a 3-D point cloud model of the landscape, a digital elevation maps, which are currently the most accurate and detailed. One great lidar advantage is the ability to measure subtle topographic features, elevations and depressions beneath the vegetation canopy, through trees.

4.3.2. Roman ruins as a source of quality stone

The localities near the Roman ruins were used as a source of quality stone material during Medieval. The first building with recycled material was the Great Moravian church on the Bratislava castle hill in the 9th century (Pivko, 2014, 2016[b]). After the stabilization of the Hungarian state in the 11th century, the stone buildings began to be more abundant in Slovakian territory. Roman ruins near Bratislava provided stone for churches in Podunajské Biskupice, Bernolákovo and Boldog, the ruins near Komárno e.g. for Komárno and Bíňa. When there was a huge built development in the 13th century, the recycled stone in these localities was not enough. It was necessary to find natural sources of stone.

4.3.3. Boulders extraction

When our ancestors searched for suitable stones for dressed stone production, sometimes extracted stone boulders from regolith, e.g. travertines in Sádok (Fig. 3E) or onyx marble in Levice. Creeping blocks on the slopes of Dreveník travertine mound were used from the Middle Ages to the 19th century (Pivko, 2016[a]). Other cases are rhyolite boulders in rock avalanche at Vyhne (Fig. 3C) or andesite boulders from volcanic breccia at Horný Tisovník (Fig. 3D) and other sites in Novohrad region, that they were used to produce the tombstones at the turn of the 19th and 20th centuries (Pranda, 1970, 1981).

5. CONCLUSIONS

The stone products in the building and other memorials in Slovakia provided the data for a time span in possible quarries. Petrographic analysis of the stones pointed to the extraction area. Historical quarry database, historical and geological maps, aerial photos and local names on maps helped to identify the location of historic stone quarries (Tab. 1, Fig. 1). Some quarries are situated near the Slovak border in the former Kingdom of Hungary in today's Hungary and Austria.

Extraction marks (Figs. 3 to 10, Tab. 2) and time span in the quarries allowed to define the evolution of quarrying methods in Slovak and nearby quarries, which were compared with quarrying method scheme (Fig. 2). Almost all extraction methods were identified in the quarries for dressed stones except for the archaic method of joint creation by stone or hammer (hammering) and by fire (heating), and modern thermal lance (burning). Fire was used only in medieval granite quarry for building stone near Bratislava castle.

Most of the stone blocks were extracted in open quarries from rock walls. During medieval and later some valuable stone was extracted in chambers like in Banská Štiavnica, Kremnica, Devín a Rimavská Sobota surroundings. Roman ruins were also the source of quality stone in Middle Ages. Some blocks like boulders were obtained from regolith, rock avalanches or volcanic breccia.

The quarries with the most preserved extraction marks are Devín, Dobrá Voda and surroundings, Badín, Nižný Skálnik, Králiky and the surroundings, Banská Štiavnica Barlangy, Kremnica, Dreveník, Stará Ľubovňa Marmon, Prenčov and Krupina. It would be appropriate for the state to take over the protection of the sites and to declare them to be technical monuments. Near the border, the remarkable quarries are St. Margarethen, Kaisersteinbruch and Wolfsthal in Austria, Fertőrákos, Sóskút, Diósd and Sárospatak in Hungary.

The most used extraction method was wedging joints because of significant brittle deformation of Slovak rocks. The method was dominant in bedded flysch sandstones alternated with mudstone layers, also in rhyolites, andesites, granitoids, compact limestones and travertines.

The blocks of massive porous limestone, carbonate conglomerates, sandstones, tuffs and volcanic sandstones to conglomerates, sometimes compact limestones and andesites were extracted by the carving with pick or chisel and hammer. The block bottom was losen by wedging. This archaic technology has been used so far in Dobrá Voda.

The explosives used in the quarries accelerated and facilitated work but fissured a rock. The explosive was inserted into cut borehole. Gunpowder in quarries was used especially in mining regions from the 17th century (Vyšná Pokoradz, Badín). The explosion marks are hemi-spherical holes. High explosives, which explosions left radiating joints, were used since 1870.

The proven method has become drilling a set of vertical parallel boreholes since the late 19th century. Boreholes were cut by a machine drilling. Into each borehole, wedges were placed, and the block was split by gradual hammering, and later the pneumatic and hydraulic splitters were used. In some quarries in carbonates and travertines, a special expansive cement was utilized for splitting.

A more modern way of block extraction is cutting a soft stone by a wire, chain or circular saw. Wire saw technology has been used since the 1930s in marble and travertine quarries. The harvester with circular saws made in Slovakia worked in pumice tuff quarries in Brhlovce and Čajkov for a short time only until 1949. The chain saw was used in the 1980s in the travertine quarry in Žehra.

In the Middle Ages, the smaller blocks up to 1 m were extracted except of flat stones for tombstone plates up to 2 m. Its extraction was performed in the stepped wall without a significant quarry organization. In the 15th and 16th centuries, the larger blocks of 1–2 × 1 m only for luxury tombstones were quarried. In the 17th century, 1–2 m blocks appeared also for portals, from the 2nd third of the 17th century for columns more than 2 m. The evolution from the stepped quarry walls to more effective straight walls took place in the 17th century. During the 18th and 19th centuries, the blocks were mainly extracted in straight worked faces not only where the walls were carved, but also where the joints were used. Stepped and straight faces are visible in Dobrá Voda, St. Margarethen, Fertőrákos, Stará Ľubovňa Marmon, Prenčov and Krupina quarries.

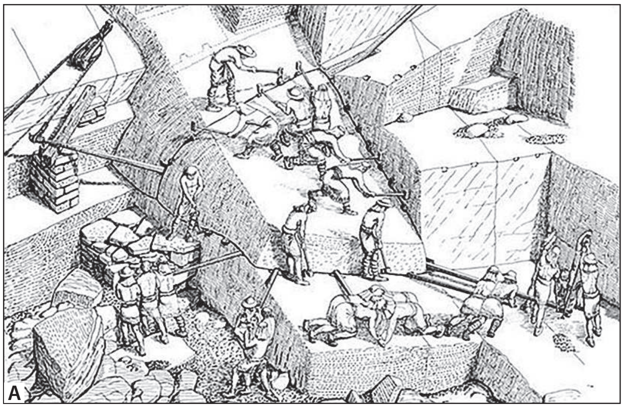

Fig. 11. Extraction methods for stone blocks. A – Wedging and levering the stone block in ancient Greece (Korres 2001). B – Carving stone block by a pick in the ancient (Bessac & Aucher 1996). C – Carving stone block by a chisel (F. Stürmer in Zogelsdorf museum).

During Roman Empire, the dimenstion stone quarries were only near Danube River as a Pannonia province border. In medieval period, most buildings were from wood, but castles, monasteries, churches and some public buildings in towns were constructed from stone, in the 9th and 10th century very rare. The consolidation of Early Hungarian kingdom in the 11th century caused growth in stone products. Most of the dimension stone quarries were opened in the 13th century because of building boom induced by the prosperity. Quality stone quarries for stone mason products were found up to 30 km. Only special polishable stones for tombstones were transported up to some hundred's km from the 14th century. In modern period, the import distance of quality stone increased, up to 300 km in the 16th and 17th century, up to 500 in the the 18th and 19th century.

Some quarries were active only in medieval up to the 16th century. Many of them were worked-out (Nitra, Pezinok, Sikenica, Trenčín), other ones were abandoned due to competition (Čachtice, Zvolen, Hrabušice, Háj) or increased demands on quality (Dobšiná, Rožňava, Veľký Klíž).

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