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RECOGNITION AND DECAY OF THE UPPER DEVONIAN DOLOMITE LITHOLOGICAL MORPHOLOGICAL TYPES IN ARCHITECTURAL HERITAGE

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Abstract: In Latvia local dolomite has been used for architectural buildings that nowadays are a significant part of Cultural Heritage. However there is a lack of scientifically founded and approbate methodology on recognition of dolomite lithological types in Architectural Heritage. The current work is aimed to evaluate application *in situ* of methodology on recognition and identification of the Upper Devonian dolomite lithological types and to study decay forms of individual lithological type in order to evaluate decay processes of dolomite in Architectural Heritage. Methodology is based on structurally genetic classification system according to *in situ* simply readable complex of rock's macroscopic features: texture, fabric, colour and related physical/mechanical and durability properties. Expression of results is based on cartographical method used in conservation practice. Methodology on recognition and identification of lithological types of the Upper Devonian dolomite has been approbate and could be recommended as the non-destructive preliminary rock's investigation method in Architectural Heritage Monuments. Study of decay forms of individual lithological dolomite type concludes that correlation between rock's intrinsic properties could be establish, however up to date obtained results are insufficient to recommend this methodology for evaluation of weatherability of lithological dolomite types.

Keywords: structurally genetic classification, identification, cartographical method

1. Introduction

In Latvia starting from the 13th century local dolomite has been used as the building material for construction of the first stone churches and castles. Historically local dolomite was used as the building stone, for architectonic details and as raw material for production of dolomitic lime. Among the main buildings located in Riga and its surrounding, 12th century castles Ikskile and Salaspils, 13th century Vecdole castle, Riga Dome, and Riga castle (14th century), could be mentioned. According to previous investigations (Hodireva 2003), historically local dolomite mainly from the Upper Devonian Pļaviņu and Daugavas formation was used. Devonian dolomite is one of the most widespread sedimentary rocks and important raw material in Latvia. In the depth suitable for production dolomite dominates in the three Upper Devonian formations (Fig. 1): Pļaviņas, Daugava and Stipinai (Hodireva 2001). Nowadays dolomite from the local deposits is extracted mostly for crushed stone production for industrial needs because only 20-30% of the reserves in a layer can be expected to contain blocks of the necessary size for dimensional stone (Kondratjeva and Hodireva 2000).

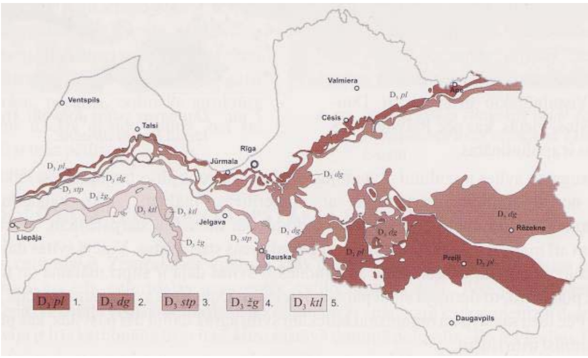

Fig. 1. Spread of the Upper Devonian dolomite in Latvia (Kondratjeva and Hodireva, 2000). The Upper Devonian Formations: 1-Pļaviņas; 2-Daugava, 3-Stipinai.

Recognition and identification of dolomite lithological types used in Architectural Heritage Monuments in correlation with other scientific branches as architecture, building construction, art history and history, is significant source of information on historically used raw materials, crafts traditions of extraction and processing of rock, and stone workmanship. Detailed investigation of dolomite layers in outcrops and correlation of various types of dolomite in carbonate rocks sections, characterise the properties of the given lithological dolomite type. This information could be used in conservation practise for identification the most appropriate dolomite type in nowadays quarries.

2. The problem situation and aim of work

The performance of dolomite in Monuments is directly determined by rock's properties formed by its geological origin and is essential point in qualitative approaches for the most appropriate conservation treatment for safeguard Architectural Heritage. There are comprehensive geological investigations of dolomite deposits and outcrops in Latvia with detailed characterisation of dolomite quality (Hodireva, 1997; Kursh and Stinkule, 1997). However there is a lack of scientifically founded and approbate methodology on recognition and identification of dolomite lithological types in Architectural Heritage, where dolomite has been subjected to decay resulting in changes in rock's texture and fabric. Thereby recognition of dolomite types turns into complex problem that could be solved by linking up investigation methods used in geological science and conservation practice of Architectural Heritage. Detailed differentiation of various dolomite types by the mean of systematic and scientifically based characterisation could be established.

The study is based on previously summarized scientific investigations aimed to elaborated methodology for recognition of the Upper Devonian dolomite lithological types used in Architectural Heritage (Hodireva et.al., in press). The current work is aimed to evaluate application *in situ* of this methodology by the mean of cartography of dolomite types and to establish possible interconnection between the dolomite type and decay processes. The practical significance of the assessment of weatherability of dolomite types in Architectural Heritage was evaluated.

3. Methodology

Methodology on recognition and identification of the Upper Devonian dolomite lithological morphological types is based on structurally genetic classification system according to *in situ* simply readable complex of rock's macroscopic features: texture, fabric and colour (Sorokin 1978) and related physical/mechanical and durability properties (Hodireva, 1997) (Tab. 1). Internationally assumed R. J. Dunham and M. Tucker classification system (Tucker 2001) in the current research was inapplicable, because Latvian local Upper Devonian dolomite is classified as one type: dolosparite.

Macroscopical identification *in situ* of lithological dolomite types according to rock's macroscopic features allows to conclude on rock genesis, processes of secondary changes, geological build of region, occurrence of layers and their stratigraphical sequence, use and extraction of various dolomite types. Dolomite physical/mechanical properties characterise possible extraction and production types, recommended branches of use of the given dolomite type and provide data for indirect conclusions on rock's durability. Advantages of the methodology are non-destructive character, possibility to avoid bulk sampling, cost-effectiveness and achievement of objective appraisal due to investigation of the given Monument as a whole. However methodology has limited application in the cases, where detailed rock's petrographical and mineralogical investigation is necessary.

Expression of results of recognition and identification of dolomite types is based on cartographical method used in conservation practice (Fitzner and Heinrichs, 2002; NORMAL, 1988). Main advantage of this method is non-destructive character used to obtain necessary information and objectiveness, usability and traceability in a long-term scale. Method used for current study is based on cartography system used in Latvia in conservation practice (Sidraba et al., 2008).

4. Recognition and identification of dolomite lithological types

In the frame of conservation works carried out in the Riga Dome in 2008/2009, approbation of methodology on recognition and identification of lithological dolomite types was done. Location of the studied objects is represented in Riga Dome plan (Fig. 2). The construction of Riga Dome was started in 1211 followed by the several reconstructions during the centuries. For Northern entrance portal (Fig.3) and Pilaster P6 (Fig.4) remained from the first building period detailed study of dolomite lithological types was carried out. Results on identification of dolomite lithological types are presented in cartograms (Fig. 3, 5). In the Northern entrance portal mechanically resistant marble-like dolomite (M-M) of local origin and in minor amounts low resistant earthy-like dolomite (M-E) of imported origin were detected. In the 19th century the restoration of portal was done (Bergholde et al. 2008, Sidraba 2008) and detected earthy-like dolomite, most probably, from Silurian dolomite deposits in Saaremaa Island, Estonia, could be related to this restoration. Although for the construction of portal only marble-like dolomite was used. According to cartograms it could be concluded that the use of different sub-types was not unintentionally. Sub-types were chosen according to the specific demands of portal elements - for colons exclusively M-M2 sub-type was used, for bases - dominantly M-M3 sub type was used. Specific use of M-M2 sub-type leads to conclude that in a layer this lithological dolomite type can be expected to contain material of the necessary size for carving colons more than one metre in length along the bedding planes. In visual observation of the Southern entrance portal (remained from the first building period) similarly to the Northern portal, marble-like dolomite (M-M) of local origin and in minor amounts low resistant earthy-like dolomite (M-E) of imported origin was detected. It leads to conclude that for the both portals the same dolomite types in construction and in the 19th century restoration were used.

In Pilaster P6 (Fig. 5) the same marble sub-types as in the Northern and the Southern portals were detected. In Pilaster minor use of local quartzite-like dolomite and gypsum was detected. Quartzite-

Table 1. Structural-genetic classification system of the Upper Devonian dolomites.

Types and sub-types		Lithologic classification			Lithologic-industrial classification		
		Macroscopic properties			Physical/mechanical properties		
		Texture	Fabric	Colour	Compressive strength, MPa	Porosity %	Frost resistance, cycles
METASOMATIC (M)							
M-K	**Quartzite-like**	**Various crystal size**	**Vuggy**	**Dark grey, brownish, violet grey**	100-140	< 5	50-150
	M-K1	Very fine crystalline (10-30 μm)	Ingomogeneous vuggy	Dark yellowish grey			
M-M	**Marble-like**	**Fine crystalline**	**Vuggy or massive**	**Grey, yellowish-grey, pinkish-grey**	100	5-10	25-50
	M-M1	Fine crystalline (20-70 μm)	Vuggy or massive	Greyish			
	M-M2	Fine crystalline (20-60 μm)		Ligth yellowish			
	M-M3	Fine crystalline (40-60 μm)					
	M-M4	Medium crystalline, (100-200 μm)	Vuggy	Pinkish-gray			
M-S	**Sandstone-like**	**Various crystal size**	**Uneven, spotted or stripped**	**Yellowish grey**	40-60	< 20	25
	M-S1	Inhomogeneous medium crystalline (100 mm)	Laminated	Yellowish grey			
PENECONTEMPORANEOUS (A)							
A-Z	**Earthy-like**	**Very fine crystalline**	**Fine laminated**	**Light grey**	20-40	7-20	15-20
	A-Z1	Very fine crystalline (30 μm)	Laminated	Yellowish grey			
	A-Z2	Very fine crystalline, (<20 μm)		Light greyish			
	A-Z3	Very fine crystalline (10 μm)	Fine laminated				
A-K	**Chalk-like**	**Very fine crystalline**	**Fine laminated**	**Light-yellowish**			
	A-K1	Micro to fine crystalline (7-8 μm)	Laminated	Light-yellowish			

like dolomite is of highest mechanical resistance and due to its physical/mechanical properties is hardly worked. Therefore it could be supposed that this lithological type was used only for quadrangular stones. Occurrence of gypsum slabs could be explained by the presence of gypsum layers in Latvian dolomite deposits. This indicates that there was no selection of building stone material for the construction of pilaster. In the lower part of pilaster (levels F1-F2 in fig. 5) greater variability of lithological dolomite types was detected, while in the upper part of pilaster dominantly marble subtype dolomite M-M2 was recognised. This information should be evaluated in the correlation with building history of Riga Dome and particularly the given pilaster, as the explanation could be either changes in extraction and/or supply of stone material in the frame of construction works or even differences in building periods. Analyses of individual samples from Riga Dome fundaments of pilaster S4 (remained from the first building period), showed the presence of the marble-like dolomite of local origin, and previously in Riga Dome unidentified sandstone-like and earthy-like dolomites of local origin.

Results on investigation in Riga Dome were correlated with the data from previous geological investigations of individual samples from Monuments in Riga and its surrounding and distribution of lithological dolomite types expressed in percents from investigated objects was done (Fig. 6). In Riga castle (St. Spirit Tower's fundaments from 13th century; walls from 16th century) and Riga's fortification wall in Triangular bastion (17th century) marble-like dolomite was identified. It could be concluded that the marble-like dolomite and particularly, two its sub-types M-M1 and M-M2, are the most widely used dolomite types in analysed Architectural Monuments. In Katlakalns Evangelic Lutheran church (18th century, Kekava parish) dolomite slabs were used to build plinth all around the church fundaments. For church plinth all slabs were positively identified as one lithological type: chalk-like dolomite. This lithological type is of very low mechanical and frost resistance and stone material in object is preserved in critical technical condition. Up to now the use of chalk-like dolomite in historical buildings in exterior was not stated and should be classified as individual case study. It is possible that the use of this dolomite type was reasoned primary by the geographical vicinity of outcrops and no choose according to stone properties was done. Although this is the example of poor craftsmanship, it is also the evidence on location of historical local dolomite deposits.

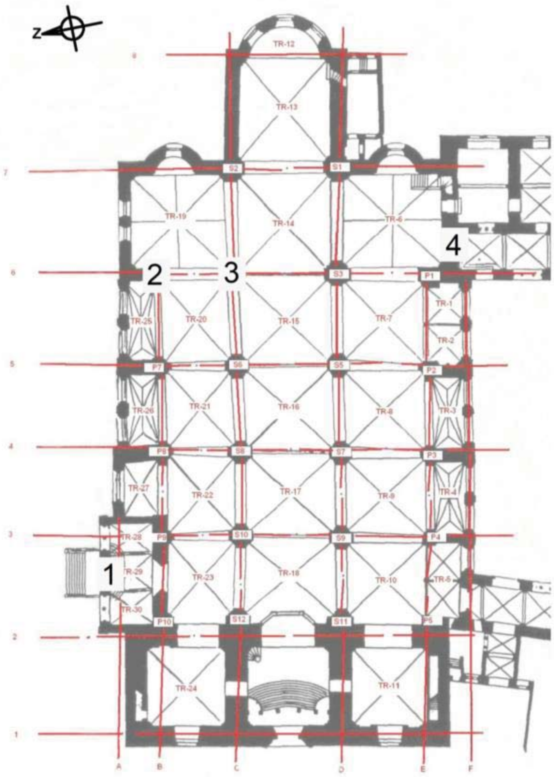

Fig. 2. Localization of investigated objects in Riga Dome. 1 – Northern entrance portal; 2 – Pilaster P6; 3 - fundaments of pilaster S4; 4 – Southern entrance portal. Drawing Material provided from "Riga Dome board" Ltd.

5. Decay of lithological dolomite types

Decay forms of individual lithological dolomite types were evaluated for Riga Dome Northern entrance portal. In the frame of conservation works carried out in the Riga Dome detailed mapping of decay forms of portal was done (Sidraba, 2009). The cartograms were used in order to study decay processes of individual dolomite types. In the current study only those rock's ageing processes that could be correlated with the rock's properties were evaluated: 1) decay that is any chemical or physical modification in the intrinsic stone properties, and 2) weathering that is any chemical or mechanical process by which stones exposed to the weather undergo changes in character and deteriorate (ICOMOS-ISCS glossary). Alteration, degradation and deterioration forms of anthropogenic origin or any exceptional ageing occurrence was excluded. Theoretically there are decay forms in dependent of the stone structure (like mechanical damages caused by man action), and those related

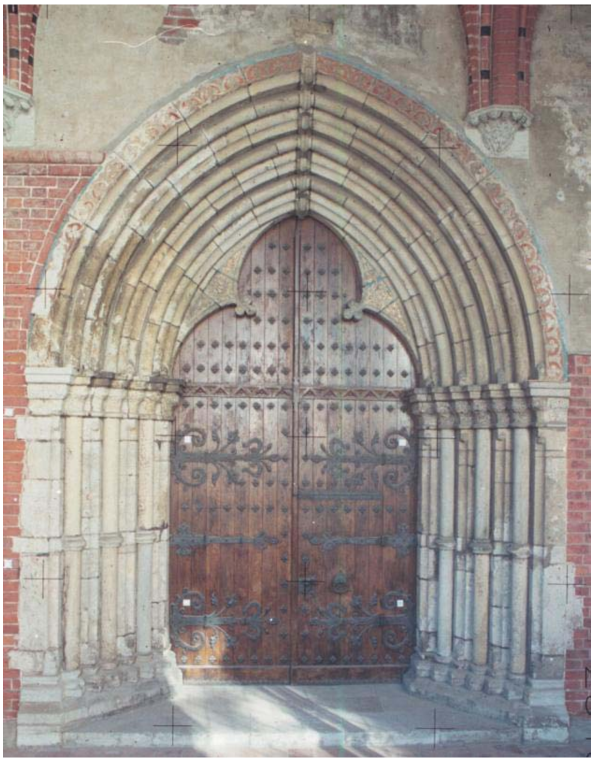

Fig. 3. Front view of Riga Dome Northern entrance portal. Photo M. Kalinka.

to the stone intrinsic properties (like differential erosion). However *in situ* this is not always so unequivocal due to numerous factors that could impact rock's performance. In the Northern portal decay forms detected and related to the dolomite intrinsic properties were as follows (according to ICOMOS-ISCS glossary):

1. Differential erosion - loss of original surface, leading to smoothed shapes, it occurs when erosion does not proceed at the same rate from one area of the stone to the other, this feature is found on heterogeneous stones containing harder and/or less porous zones. Differential erosion may result in loss of components or loss of matrix of the stone;
2. Alveolization – kind of differential erosion, formation on the stone surface of cavities which may be interconnected and may have variable shapes and sizes, alveolization is possibly due to inhomogeneities in physical or chemical properties of the stone;
3. Detachment in the form of powdering - detachment of single grains or aggregates of grains.

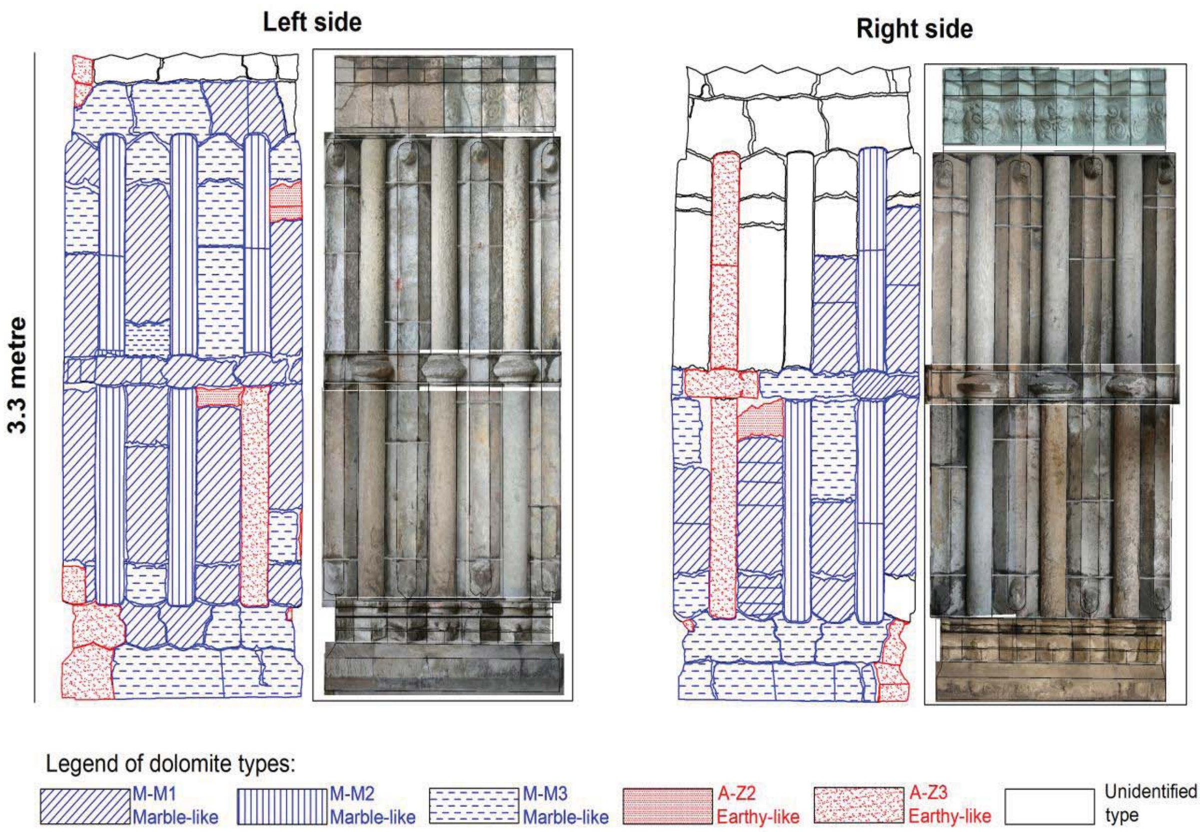

Fig. 4. Cartogram of lithological dolomite types of right and left pilasters of Northern entrance portal in Riga Dome.

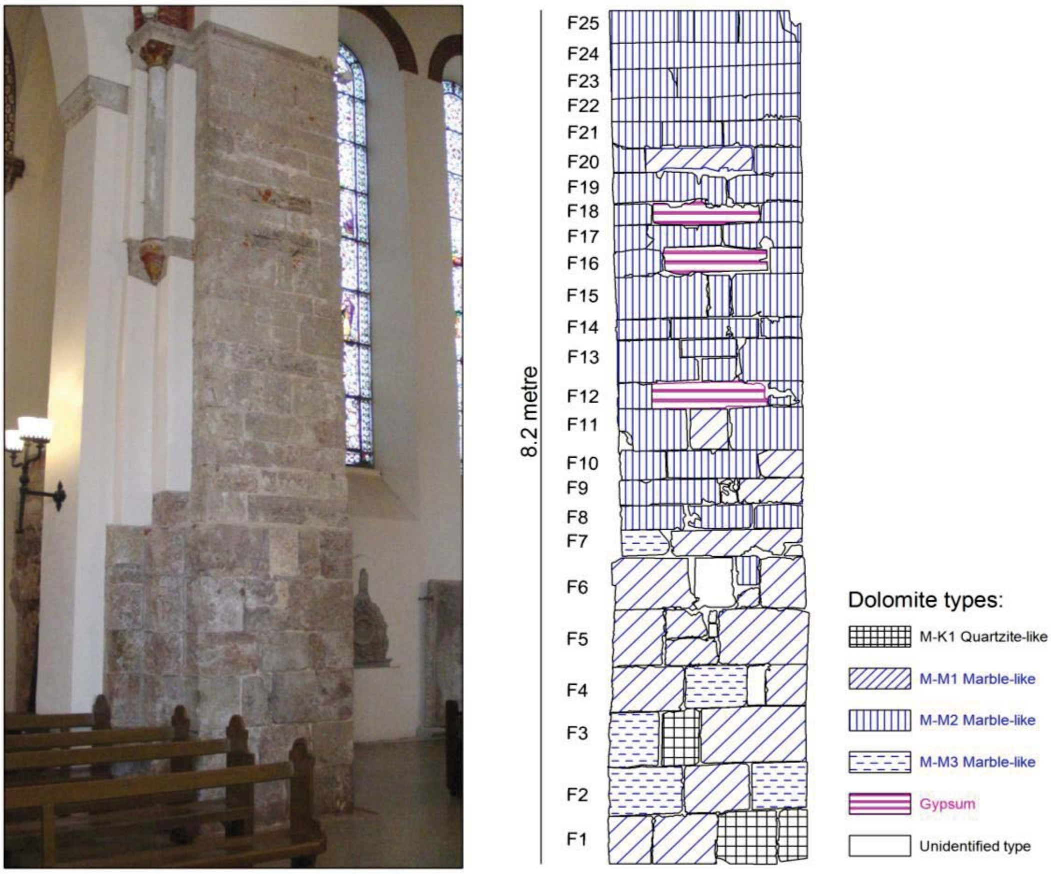

Fig. 5. Cartogram of lithological dolomite types of pilaster P6 in Riga Dome. Cartogram was elaborated on drawing provided from "Riga Dome board" Ltd.

In order to compare results for each individual lithological dolomite sub-type distribution of the individual decay form in percents of the total area of sub-type was calculated (Fig. 7).

For earthy-like dolomite differential erosion and detachment in the form of powdering is characteristic. Detected decay forms confirms well with the fine laminated fabric and very fine crystalline texture (crystal size 20-30 μm) of this dolomite type. It could be concluded that both earthy-like dolomite sub-types are close by their intrinsic properties and decay similarly that agrees with the structurally genetic classification system showing similar rock's properties.

For marble-like dolomites significant differences in decay forms for sub-type M-M2 compare to sub-types M-M1 and M-M3 could be detected. According to structurally genetic classification system rock's properties for all three sub-types are similar. However detected differences in decay forms leads to conclude on differences in chemical composition and, probably, in rock's fabric. For sub-types M-M1 and M-M3 differential erosion is not characteristic, that means that these lithological types has comparatively homogeneous texture, fabric and composition. Powdering as a form of detaching of material confirms well with the fine crystalline texture of this lithological type. In contrary, for sub-type M-M2 alveolization, that is a type of differential erosion, is the dominant form of the loss of material. Presence of alveolization leads to conclude on more marked vuggy fabric compare to other marble-like sub-types and possible inhomogenities in chemical composition, like presence of clayey compounds. Differences in decay forms point out necessity for further comparative petrographical and composition study of marble-like dolomites in order to improve structural-genetic classification system and explain causes for the differential erosion for M-M2 sub-type.

It should be mentioned that delamination - decay form that is detachment process affecting laminated stones and corresponds to a physical separation into one or several layers (in cm scale) following the stone laminas (ICOMOS-ISCS glossary) was not detected. This means that either marble-like and earthy-like dolomites do not have strongly

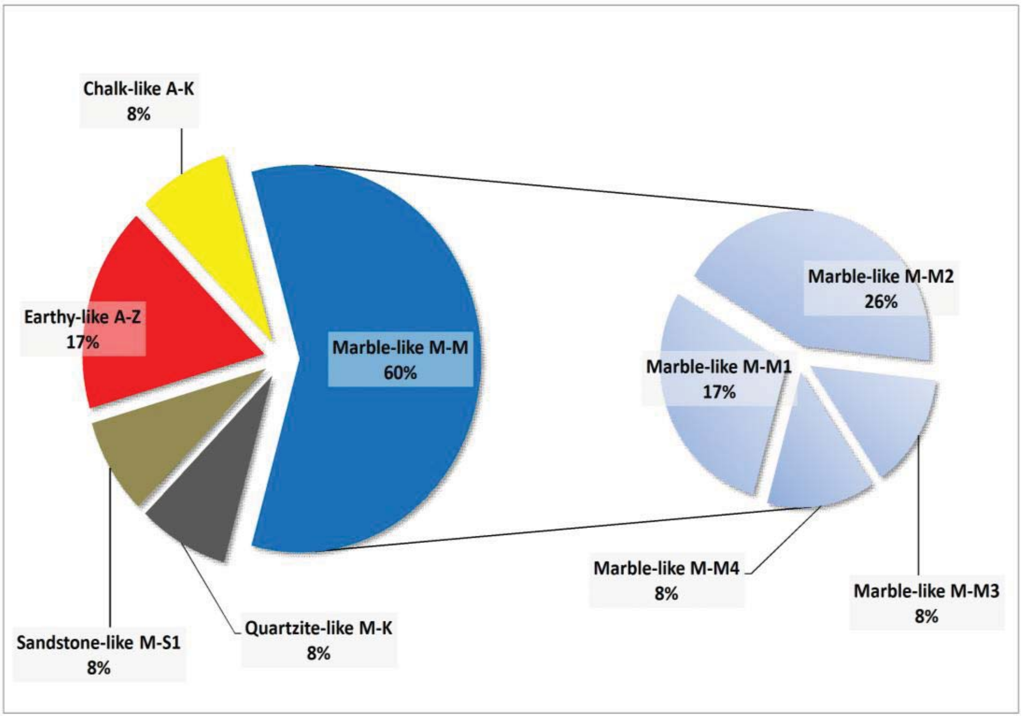

Fig. 6. Distribution of lithological dolomite types expressed in percents from investigated Architectural heritage objects.

marked laminated fabric, and detected decay forms primary leads to conclude on inhomogenities in composition (presence of clayey compounds) than in fabric.

According to structurally genetic classification system there are considerable differences among the marble-like and earthy-like lithological dolomite types compare their physical/mechanical properties (Tab. 1) and it could be presupposed that earthy-like dolomites have lower resistance to rock's ageing processes. However the study showed no considerable interconnection between extends of the decay forms on marble and earthy-like dolomites. Marble-like dolomite, preserved from the 13th/14th century has the same decay extend as earthy-like dolomite build in 19th century, e.g., 600 years later. So only with the help of historical information it could be concluded that earthy-like dolomite is more susceptive to decay processes compare to marble-like dolomite. This means that up to now we do not have appropriate data base and *in situ* approbation for evaluation of weatherability of individual lithological dolomite types according to mapping of the decay forms.

6. Conclusions

Methodology on recognition and identification of lithological types of the Upper Devonian dolomite has been approbate and could be recommended as non-destructive preliminary rock's investigation method in Architectural Heritage Monuments. Cartography method could be used for documentation and assessment of lithological dolomite types in Architectural Heritage Monuments and could be used as data base and presentation's form of the rock's investigation results.

Adequate, well-founded recognition and identification of lithological dolomite types could be done only by the specialist in geology, petrology and mineralogy and by the aid of the standard collection of the rock's reference samples. For the further studied it should be stated that in the case of Architectural Heritage Monuments rock's samples collected from the Monuments should be correlated and fixed to the scientific (academic) collection of Latvian bedrocks and to the collection of the core drill samples from the Latvian Devonian dolomite deposits. This will give scientific background for the correlation of historically used lithological types in Monuments and lithological types found in Latvian Devonian dolomite deposits and defined layers.

Historically for construction of stone buildings in Latvia predominantly qualitative, mechanically resistant marble-like dolomite was selected and used according to the construction needs both for build-

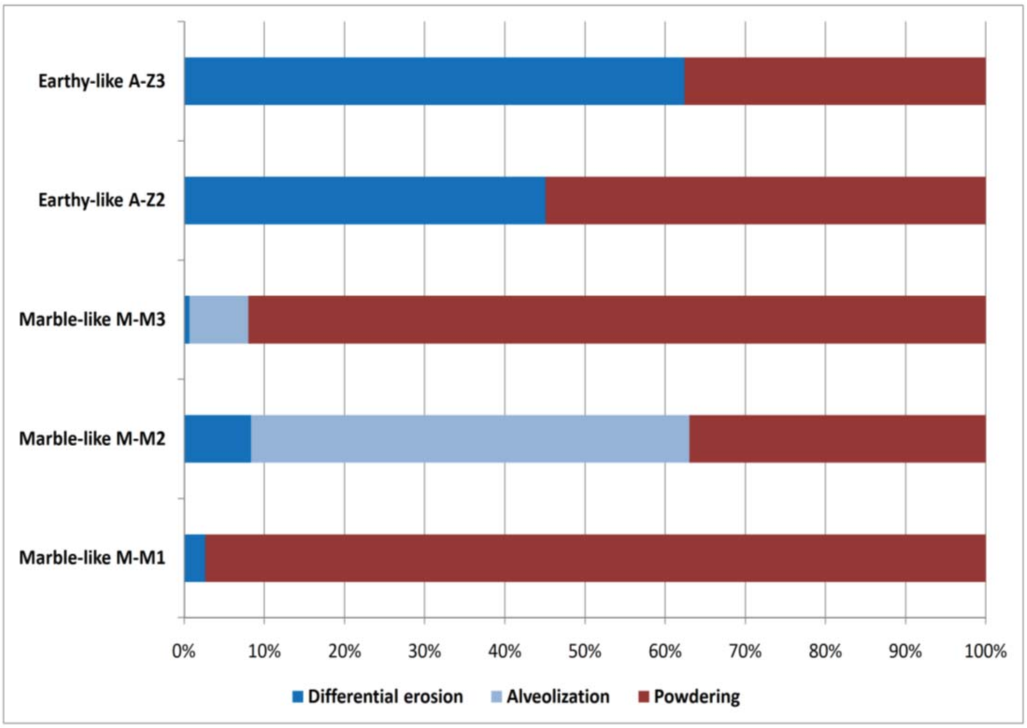

Fig. 7. Ration of the individual decay forms in percents of the total area of individual lithological dolomite sub-type for Riga Dome Northern portal.

ing stone, carvings and architectonic details. It could be assumed that marble-like of dolomite was either easiest to extract and produced or the qualitative physical/mechanical properties of this lithological dolomite type was appreciated historically by the craftsmen.

Study of decay forms of individual lithological dolomite type concludes that correlation between rock's intrinsic properties (texture, fabric, physical/mechanical properties) could be establish, however up to date obtained results are insufficient to recommend this methodology for assessment, evaluation and prediction of weatherability and durability of lithological dolomite types.

Local dolomite used in Latvia's Architectural Heritage is valuable as authentic material, source of information on historical outcrops and craft traditions, and conservation approaches should be aimed to maximal safeguard of dolomite building stone in its historical location in particular Monument.

Acknowledgments

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