Comune di San Dorligo della Valle - Občina Dolina

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RoofOfRock

Limestone as the common denominator of natural and cultural heritage along the karstified part of the Adriatic coast

CULTURAL HERITAGE AND LIMESTONE

Appendix 3.I.2
Site specific study for the Comune di San Dorligo della Valle/Dolina Municipality

Annex 3.I.2.1
Geological elaborate

Igor RIŽNAR

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Project »Roof of Rock - Limestone as the common denominator of natural and cultural heritage along the karstified part of the Adriatic coast«

Geological elaborate

for the study about the flysch / carbonates junction in the San Dorligo della Vale-Dolina Municipality and the influence of this junction on architecture

CLIENT

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1 INTRODUCTION

Geološka karta občine Dolina nad Trstom je nastala kot del strokovnih podlag za izvedbo »Študije za razumevanje stičišča fliša in karbonatnih kamnin ter vpliva slednjega na lokalno uporabo naravnega kamna«. Geološko kartiranje je potekalo med februarjem in julijem 2014 na topografski osnovi merila 1 : 5.000. Ker ne gre za geološki znanstvenoraziskovalni projekt, pač pa za interdisciplinarno študijo, kjer geološki podatki in interpretacije služijo kot izhodišče za razumevanje obravnavanega prostora v širšem smislu, bom v opisovanju geologom sicer popolnoma jasnih pojmov (kjer bo to potrebno za cilje študije) nekoliko bolj pojasnjevalen.

Da bi pri opisovanju in razlagi geološke karte lažje pojasnjeval določene geološke pojave na raziskovanem območju, naj najprej v grobem povzamem zgodovino nastajanja širšega območja, ki izvira iz številnih raziskav slovenskih hrvaških in italijanskih raziskovalcev. V zadnjem obdobju se z geološko problematiko Krasa intenzivno ukvarjata predvsem L. Placer s tektoniko in kinematiko, B. Jurkovšek pa s stratigrafijo in paleontologijo, zato bom v predstavitvi zgodovine nastajanja obravnavanega območja povzemal v glavnem njune izsledke iz objavljenih publikacij.

2 PALEOGEOGRAPHICAL OVERVIEW AND TECTONIC SUBDIVISION

The karst edge area has been formed along the border between the Dinaric and the Adriatic segment of the initially uniform **Adriatic-Dinaric carbonate platform**. The Adriatic-Dinaric carbonate platform is considered a microplate (microcontinent) that separated from the African plate during the Mesozoic era, when the supercontinent Pangea broke up into several continents and the Tethys Ocean started to open between the African and Eurasian plates. At the end of the Mesozoic era this process came to a halt, as the African and European continents began to converge. Today, the Mediterranean Sea represents the last remnant of the Tethys Ocean. Microcontinents separated from the African plate (with the Adriatic-Dinaric carbonate platform among them) and eventually collided with the European plate forming large mountain belts like the Alps, the Pyrenees, the Carpathians and, as subject of this study, the Dinarides.

The Adriatic-Dinaric carbonate platform is a microcontinent extending from northern Italy to Greece and from the Apennines to the central Dinarides (Figure 1.). The microcontinent is roughly divided into two segments along the eastern Adriatic coast: the Dinaric microplate refers to the northeastern segment, and the Adriatic-Apulian or simply Adria to the southwestern segment. The approaching African and European continents provoked a thrusting of the Dinarides due south-east in the Eocene epoch (approx. 30 million years ago). The **External Dinaric Thrust Belt** along the segment boundary is formed where the Dinaric segment is thrust upon the Adriatic one. The Thrust Belt is characterised by vast overthrusts observed throughout western Slovenia, southwestern Croatia and southwestern Bosnia. The southwestern part of the zone is imbricated and represents a deformed margin of the Adriatic segment (Adria), and is referred to as the **External Dinaric imbricated belt**.

Due to the continuous approach of the African and European continents the northwestern part of the elongated Adriatic-Dinaric microplate collided with the European plate in the Miocene epoch (approx. 23 million years ago). The northwestern part of the microcontinent (the Padanian segment) broke along the Kvarner fault that runs along the eastern Istrian coast. Because of the oblique position of the microcontinent against the European plate margin the Padanian segment started to rotate in a counterclockwise direction. Consequently, its eastern margin started to underthrust beneath the Dinaric segment of the Adriatic-Dinaric microplate. This underthrusting of the Padanian segment provoked intense a deformation of the External Dinaric Thrust Belt between Trieste and the Velebit mountains. This newly-formed zone is referred to as the **Istria–Friuli Underthrust Zone**. The underthrusting of the “Istria” (the southeastern part of the Padanian segment) under the Dinaric is still active today, and its influence is notable as far as the Želimlje fault at the eastern margin of the Ljubljana Moor (Placer, 2010).

The area referred to in this study therefore belongs to the External Dinarides – more precisely the External Dinaric Imbricated Belt – that deformed into the Istria–Friuli Underthrust zone due to said rotation and underthrusting of the Istria.

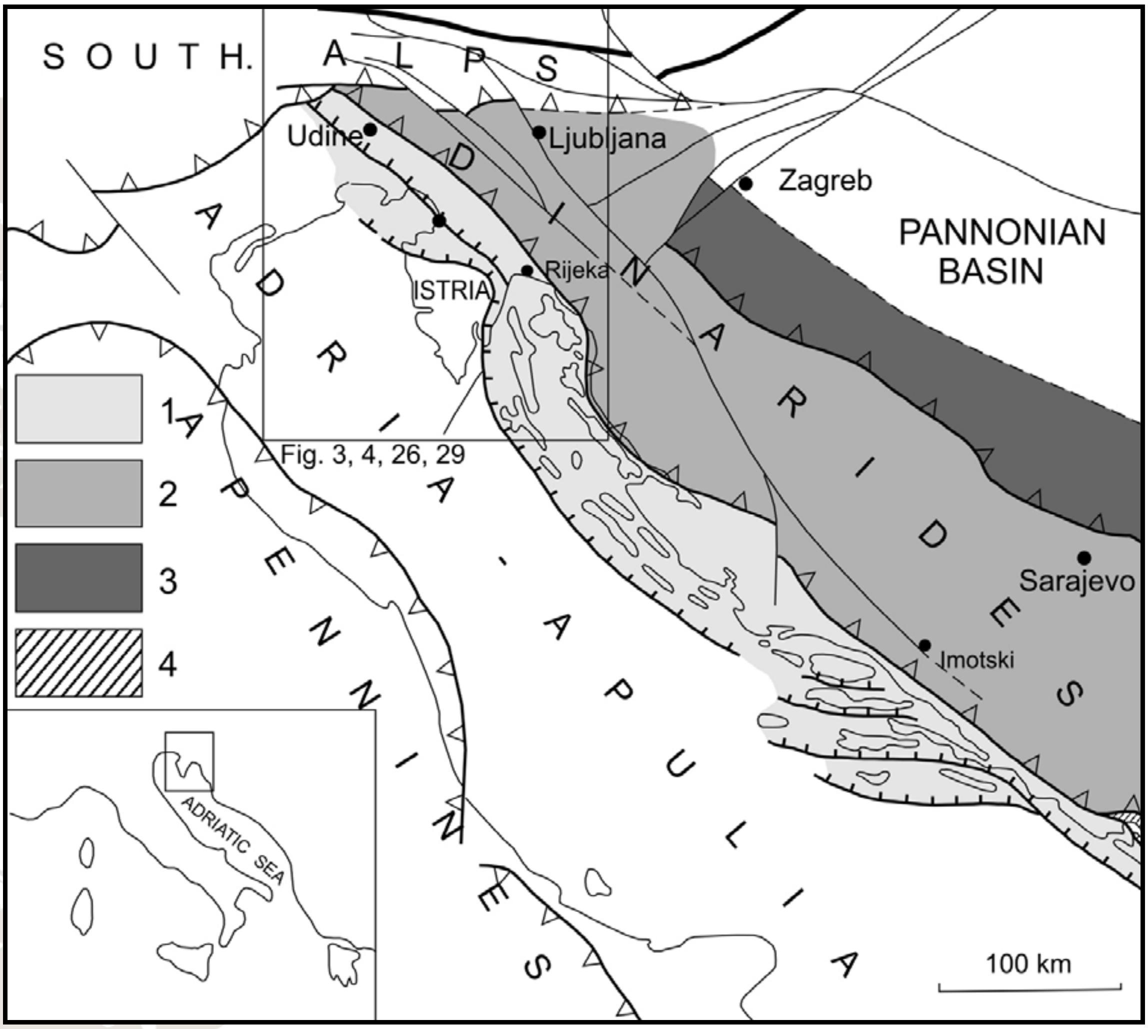

Figure 1. Tectonic subdivision of the Adriatic area: 1. External Dinaric imbricated belt; 2. External Dinaric Thrust Belt; 3. Internal Dinaric Thrust Belt; 4. Budva Trough. Reprinted by permission of the author and the publisher from Placer et al., 2010.

3 BASIC GEOMORPHOLOGICAL CHARACTERISTICS OF THE AREA

The essence of the area is already contained in the term "karst edge", as thoroughly elaborated by Placer (2007), and hence cited here: "A part of this geomorphologic step became known in the last decade of the 20th century as the *Kraški rob* (Karst edge). With respect to geological and geomorphologic considerations the term *Kraški rob* as a landscape term for cliffs above the valleys of the Osapska reka and upper Rižana rivers should be distinguished from the term karst edge (*kraški rob*) as a general term which is a synonym for the geomorphologic step consisting of precipitous cliffs and steep carbonate slopes situated between the mouth of the Timava River and Mt. Učka that form a border zone between the karstic plateaus of Kras and Čičarija on the one side, and the flysch Istria with the Trieste flysch coastal zone on the other side.".

Two types of transition from the karstic environment defined by a limestone geologic basement into the Istrian characterised by flysch are observed in the broader area. The transition is very sharp between Barcola-Barkovlje and San Giuseppe della Chiusa-Ricmanje, as the limestone–flysch boundary there runs in very straight NW–SE line and is represented by the Petrinje Thrust, along which limestone is thrust upon flysch. This is also the reason for the simple relief there: a steep limestone cliff (thrust front) called *Breg* that descends gradually into a flysch slope beneath the boundary all the way down to the shoreline. Minor springs feeding the creeks below are situated at the lithological boundary, as the limestone mass above the impermeable flysch represents a karstic aquifer. Deep gorges are incised into the steeper slopes in soft flysch formation leading the water down towards the sea. These creeks are systematically oriented orthogonally to the slope; consequently all of the ridges between the creeks are oriented in the same direction as well. A simple transition between limestone and flysch is illustrated by the geological cross-section across San Giuseppe della Chiusa-Ricmanje as seen in Figure 2. Here a steep limestone cliff is covered by a slope-scree. The Transitional Beds dip at an angle of 50–70°, but as their resistance to erosion is far lower than the limestone's the slope is not as steep here. The slope above San Giuseppe della Chiusa-Ricmanje is not as steep as the dip of the Transitional Beds, which is why there are no significant landslides. The ancient as well as recent traffic routes are built in the narrow belt of the Transitional Beds precisely for this reason. The flysch below the thrust is predominantly built of soft marl and thin sandstone layers resulting in relatively high erodibility and consequently an even gentler slope making it suitable for settlement. The flysch bedding dips toward the northeast, except along the thrust structures, where deformation features follow the thrust planes.

The ridge San Giuseppe della Chiusa-Ricmanje is built upon is delimited by two creeks running orthogonally to the limestone–flysch boundary. Above the village there is a high impassable limestone cliff protecting it from the northeast. The village is therefore protected or bounded on three sides and open towards the sea.

A similar type of transition from limestone to flysch is also present at Crogole-Kroglje, Dolina and Prebenicco-Prebeneg. Common to all of these cases is the fact that the village is never situated at the boundary itself, as mass movements here are far more common and active than elsewhere in the region.

Another type of transition from a karst- to flysch-dominated area is associated with the recently active subthrusting of the Istria. The tectonic boundary between limestone and flysch has been formed in a fairly straight line and remains so today, north of San Giuseppe della Chiusa-Ricmanje all the way to Sistiana-Sesljan. Due to the rotation and subsequent subthrusting of the Istria the thrust boundary eventually deformed in such a way that today it is skewed between the villages of San Giuseppe della Chiusa-Ricmanje and San Lorenzo-Jezero and from there on it re-adopts its original course. In a process of skewing – or rather shifting of the tectonic boundary (between limestone and flysch) – a set of folds and steep reverse faults have, due to subthrusting, formed between San Lorenzo-Jezero and Bagnoli-Boljunec.

Thrusting of the limestone mass upon the flysch, initially during the subsequent folding and tearing of the primal structures and finally, the erosion of geologic formations with very diverse erodibility, led to a large variety of relief forms described as **geodiversity**. Geodiversity is conceived as a diversity of outcropping rock formations with considerable structural complexity (thrusts, folds, faults...). It dictates the formation of the relief, the variety of relief forms and, as a final consequence, also other varieties. It dictates also the formation of climatic features, hydrogeological structure, biodiversity, and a whole range of related, consequent social factors (transport routes, political boundaries, etc.) that in the final stage also affect decisions on where and how settlements are established.

High geodiversity is demonstrated by geological cross-sections C–D, E–F and G–H (Figures 3 – 5). Along the 2300 m-long E–F cross-section trace there are 17 geologic boundaries on the surface. Comparing this with the A–B cross-section across San Giuseppe della Chiusa-Ricmanje (Figure 2), where only two geologic boundaries can be found along its trace, it becomes clear why the the cross-section E–F across San Lorenzo-Jezero and Bagnoli-Boljunec appears far more complex. Each lithological boundary and fault represents a potential erosion line into which, given enough precipitation, a valley can be incised. The larger concentration of lithological boundaries the more dispersed the erosion, which leads to gentler amplitudes in relief undulation and consequently very diverse relief without extremes.

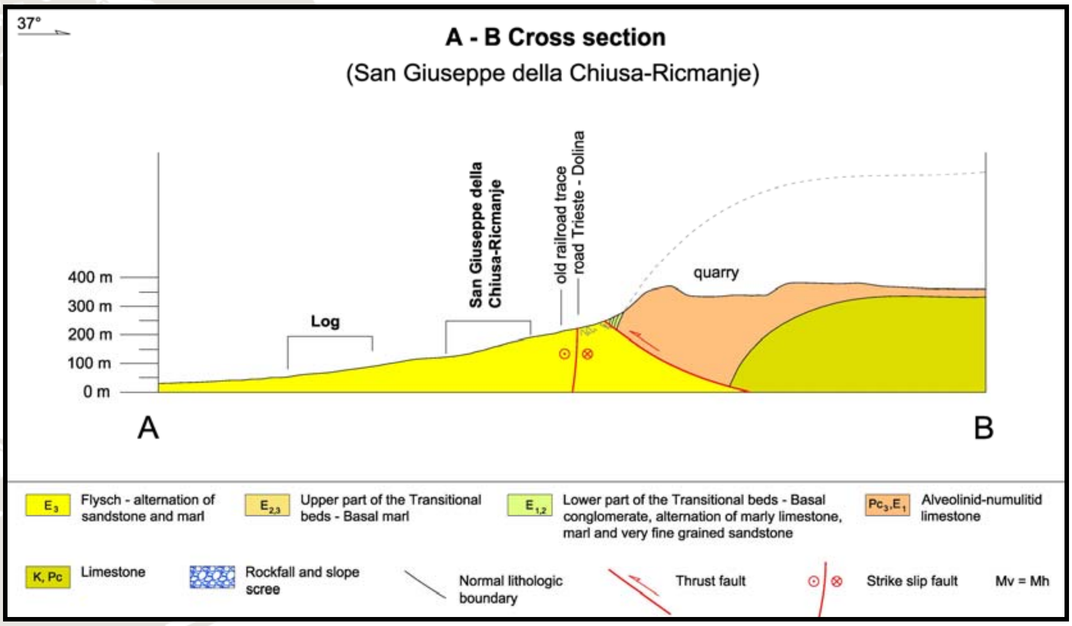

Figure 2. Geological cross-section across San Giuseppe della Chiusa-Ricmanje

An example of the opposite case in the nearby Karst is the Raša valley, between Štanjel and Divača (Slovenia), where the valley traces a very straight course. Geodiversity in the area is extremely low, with only one geological structure – the Raša Fault – into which the deep Raša Valley is incised. All the erosion is concentrated in the single geological structure that represents an extreme in the relief. Three different areas comprising three geological situations can be distinguished from the geomorphologic point of view in the area concerned: karstic relief, flysch area, and the transitional zone where geodiversity is unusually high. Areas with elevated geodiversity are marked on the geological map attached.

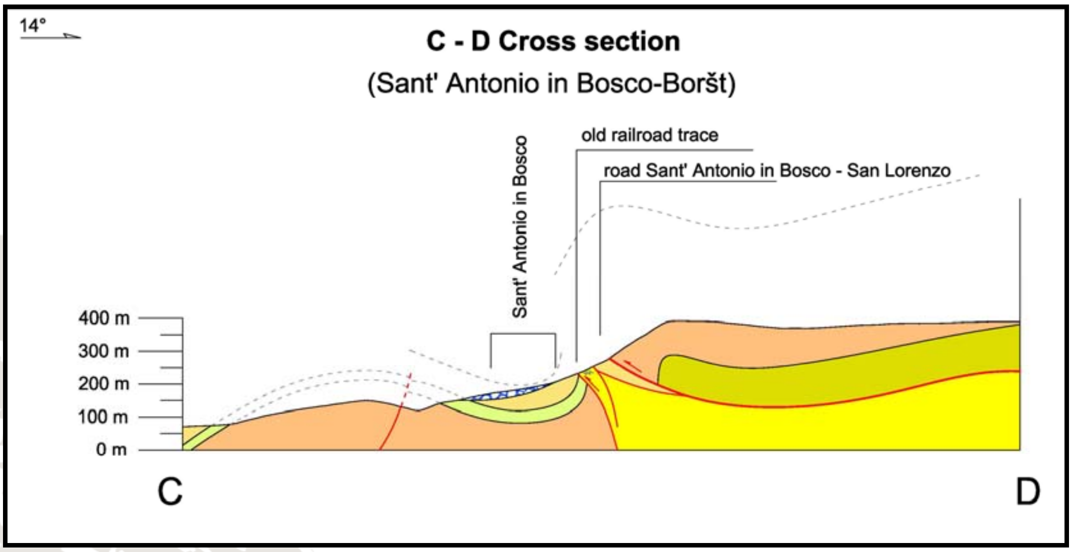

Figure 3. Geological cross section C–D (see key in Fig. 2)

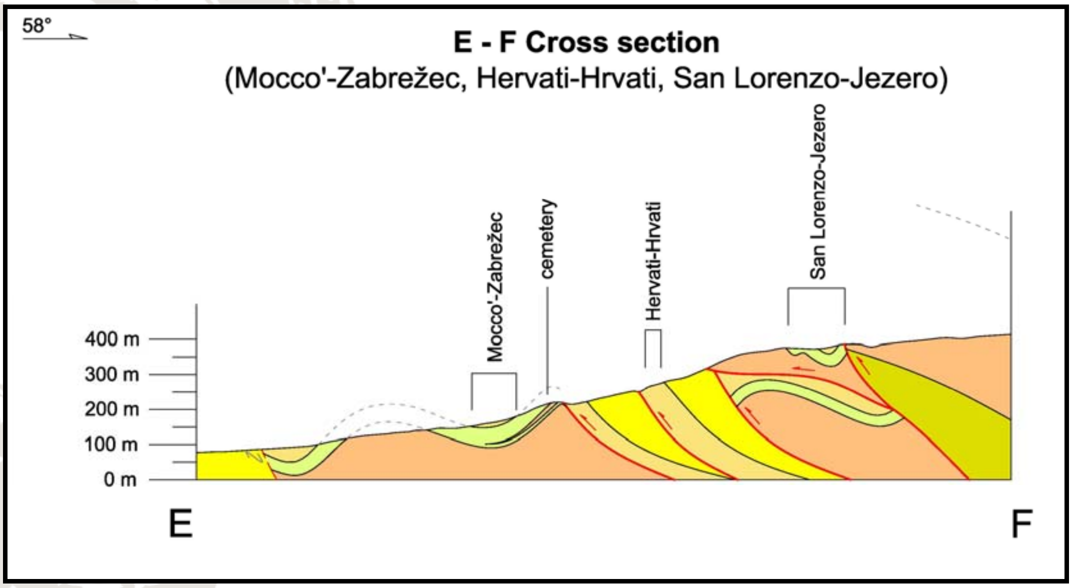

Figure 4. Geological cross-section E-F (see key in Fig. 2)

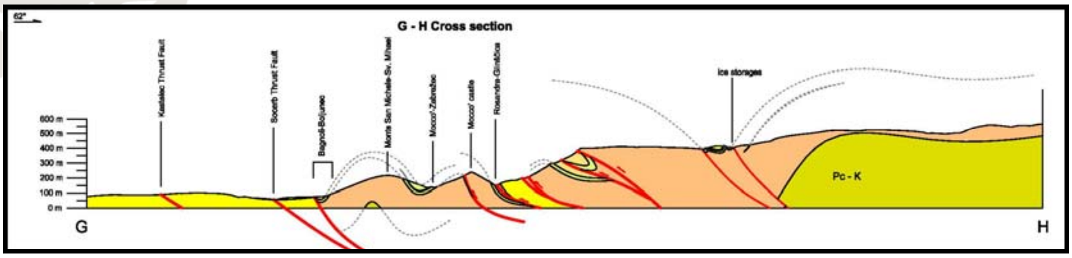

Figure 5. Geological cross-section G-H (see key in Fig. 2)

4 LITHOSTRATIGRAPHIC UNITS

4.1 THE ALVEOLINID-NUMULITID LIMESTONE

The oldest geological formation in the area in question is Alveolinid-numulitid limestone. According to the revised classification (Košir, 2003; Jurkovšek et al., 2008), the formation represents the youngest formation of the Karst Group that comprises shallow water and paralic carbonates of Liburnian, Trstelj, and Alveolinid-numulitid limestone formations. The lower section is composed of light grey micrite limestone with large benthic foraminifera visible to the naked eye (Figure 26). Stratification here is poorly expressed. In the upper part of the formation the limestone becomes darker, with grey varieties followed by dark brown varieties, biointracalcarenite and microbreccia, and dark grey kerogenic limestone at the top of the formation. According to Jurkovšek (2013) Planktonic foraminifera content is also higher in the upper part of the formation. Along with the darker colour and increased organic matter in the limestone we find a gradual subsidence of the sedimentary basin. Facial varieties were not distinguished in the process of mapping, as there is not enough physical diversity amongst them to introduce lithological boundaries expressed as a relief.

The Alveolinid-numulitid limestone crops out in two structural levels described in more detail in the chapter referring to tectonics. The Alveolinid-numulitid limestone in the northeastern part of the Dolina municipality forms a part of the Čičarija and the Trieste-Komen anticlinorium (Placer et al., 2010). The other area built of Alveolinid-numulitid limestone is Monte Carso-Veliki vrh, San Michelle-Sv. Mihael, and the Glinščica Canyon northwest of Botazzo-Botač. Exposed limestone above the village of Dolina also forms part of this structural level.

From the stratigraphic point of view, the Alveolinid-numulitid limestone has been deposited upon the Trstelj Formation, which does not crop out in the area concerned. The basement of the Alveolinid-numulitid limestone is only seen in geological cross-sections without internal division. The overburden of the Alveolinid-numulitid limestone is the Transitional Bed Formation marking the transition from shallow water carbonates to flysch sedimentation. Based on the geological cross-sections the thickness of the Alveolinid-numulitid limestone is estimated to be 450 m in the upper structural level (in the NE part), and approx. 250 m in the lower level (the SW part of the area). The most significant change in thickness appears to be at the Petrinje Thrust, indicating that the thrust itself may have been initiated along the previously existent structural boundary responsible for the thinning out of the Alveolinid-numulitid limestone. The age of the Alveolinid-numulitid limestone is determined as the lower part of the Eocene epoch (Jurkovšek et al., 1996) in the Karst on the basis of benthic foraminifer stratigraphy.

Use of Alveolinid-numulitid limestone in architecture

Fracturation of the rock that inhibited yields of large blocks of Alveolinid-numulitid limestone is the main reason it has never been seriously exploited for stone masonry in the researched area. Alveolinid-numulitid limestone is heavily folded along the thrust fronts, as seen from the geological cross-sections. Due to poorly expressed stratification, the rock mass is being deformed by fracturation and faulting rather than by flexural folding. The areas of largest stress in the folding and thrusting rock mass (this is the case of the Alveolinid-numulitid limestone along the Petrinje thrust) are located along the thrust itself (Figure 6) and in the hinge of the fold. The researched area is being further deformed due to the described recent subthrusting of the Istria, and this additional stress is affecting the Alveolinid-numulitid limestone most, as it represents the most recent deformation still ongoing (Figures 7 and 8). The fracturation of the Alveolinid-numulitid limestone is increasingly less pronounced as distance from the area of most intense deformation increases towards the village of Grozzana-Gročana, where the first poorly-shaped building blocks of Alveolinid-numulitid limestone appear to have been used for window frames (Figures 9 – 12). In fact the Ledenice (cylindrical stone ice sheds) in the Škrivnica area are also built of roughly-shaped Alveolinid-numulitid limestone blocks (Figures 13 and 14). The only sophisticated stonemason's product made from the Alveolinid-numulitid limestone has been identified in the Sant' Antonio in Bosco-Boršt, where the bollards and inscription plate of the public fountain in the village centre are fashioned from Alveolinid-numulitid limestone (Figure 15). Why the usual cretaceous limestone from quarries established as far back as the antiquity wasn't used remains unknown. Perhaps it was simply a case of local patriotism.

The Alveolinid-numulitid limestone crops out between the villages of Sant' Antonio in Bosco-Boršt and Socerb as well, but there it is a part of the lower structural level – in the External Dinaric imbricated belt – where the Alveolinid-numulitid limestone has been deformed into overturned folds thrust one upon another. Needless to say the limestone there is even more fractured and thus unsuitable for stonemasonry. The fact that Alveolinid-numulitid limestone there is not used for building blocks is even more understandable in view of the fact that there is exposed flysch in the vicinity. Namely, extracting and shaping flysch sandstone into equally thick blocks is far easier and less time consuming than is hard, massive limestone. Yet an interesting exception has been observed here, in the form of the Roman aqueduct built in the 1st century AD, from Fonte Oppia-Počivenca to the coast. What is interesting is the fact that the aqueduct is built of Alveolinid-numulitid limestone. Here the building blocks have not been shaped but just dimensioned (Figures 16 – 18). Flysch sandstone blocks have only been used in some places in the construction of the vault (Figure 16). We can only speculate as to why, but the fact is that limestone reacts chemically with hardening mortar better than flysch, which is porous and less resistant to freezing and thawing.

Figure 6. Fractures parallel to the Petrinje Thrust in the Alveolinid-numulitid limestone along the route of the old Hrpelje – Trieste railroad.

Figure 7. Alveolinid-numulitid limestone in the Scoria quarry above San Giuseppe della Chiusa-Ricmanje unsuitable for stonemasonry due to intense fracturing, despite the bedding in the quarry exhibiting no large displacements.

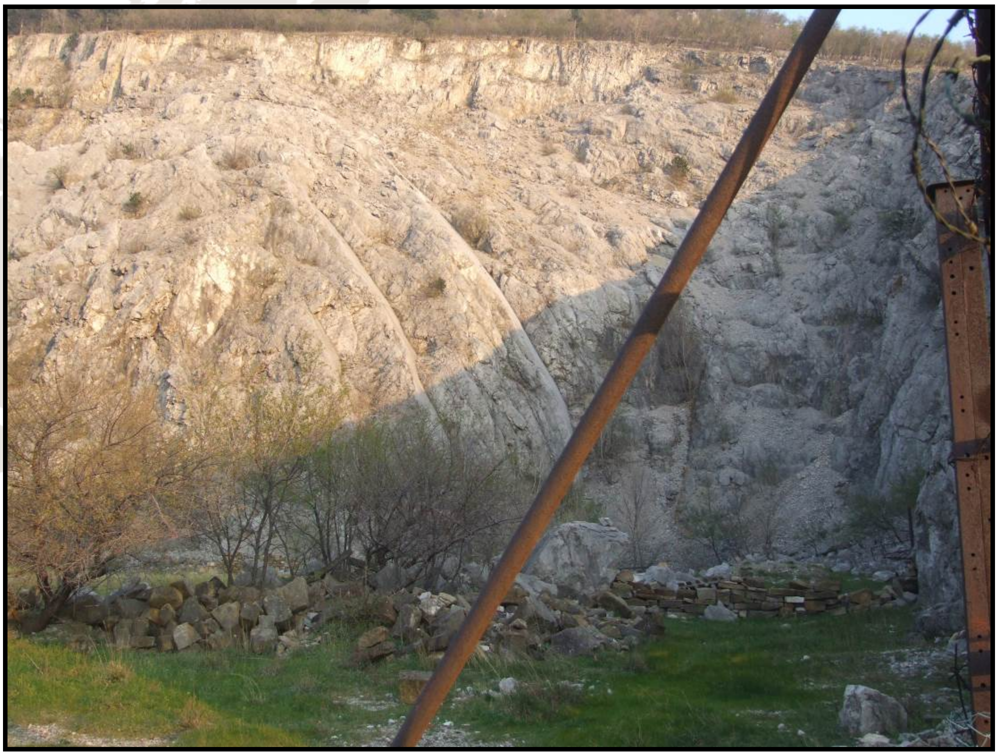

Figure 8. Heavily fractured Alveolinid-numulitid limestone in the core of the Boljunec anticline is suitable for the production of aggregate or lime, but not for stonemasonry.

Figures 9 (left) and 10 (right). Use of the Alveolinid-numulitid limestone in the village of Grozzana-Gročana.

Figure 11. Use of the Alveolinid-numulitid limestone in the village of Grozzana-Gročana actually shows that the stone material might be usable for stonemasonry there.

Figure 12. A poor quality stone frame made from local Alveolinid-numulitid limestone (Grozzana-Gročana).


Figures 13 (left) and 14 (right). The use of roughly-shaped stone blocks for construction of ice storage sheds between Pese-Pesek and Draga villages.

Figure 15. A public well in the village of Sant' Antonio in Bosco-Boršt. The bollards and inscription plate are fashioned from Alveolinid-numulitid limestone.

Figures 16 and 17. A vault of the Roman aqueduct made from Alveolinid-numulitid limestone and flysch sandstone (left), and of Alveolinid-numulitid limestone exclusively (right).

Figure 18. Aqueduct channel made of local Alveolinid-numulitid limestone.

4.2 TRANSITIONAL BEDS

Transitional Beds is a formation that marks the transition from shallow water carbonate sedimentation, where the sediment is formed almost exclusively of shallow water organisms, to deep-water gravity-driven predominantly clastic sedimentation. Subsidence of the sedimentary basin is obvious in the upper part of the Alveolinid-numulitid limestone due to its dark colour (from its high kerogen content that when broken makes the rock smell of petroleum) and pelagic foraminifera. From the lithological point of view, the Transitional Beds are represented by two members: a basal conglomerate with alteration of the marly limestone or marl, and a very fine-grained sandstone with a carbonate matrix make up the lower part of the Transitional Beds; and the upper part composed of Basal Marl.

The lower part of the Transitional Beds: a basal conglomerate and alternating marl, marly limestone and a very fine-grained sandstone or limestone with a significant proportion of quartz grains.

Basal conglomerate appears in the researched area already in the upper part of the Alveolinid-numulitid limestone. A layer several metres thick, with all the attributes typical of Transitional Beds, is exposed at the top of the steep slope some 200 m SW of the village of Pese-Pesek. As the layer pinches out to the northwest it does in fact constitute a large thin lens. A conglomerate layer less than a metre thick with relatively large limestone pebbles comprised exclusively of Alveolinid-numulitid limestone is deposited upon the Alveolinid-numulitid limestone. The pebbles are medium- to well-rounded, approximately 10 cm across on average, with a marly limestone matrix (Figure 19). A bed of marl several metres thick lies atop the conglomerate layer, followed by another mass of Alveolinid-numulitid limestone 50 m thick, on top of which a similar sequence is observed, consisting of alternating layers of dark grey marly limestone and a very fine-grained sandstone or limestone with a significant proportion of quartz grains. A continuous horizon of the Transitional Beds lies exposed from the cut of the old Hrpelje–Trieste railroad line 350 m SW of the abandoned Krvavi Potok border checkpoint to the NE and around the Škrivnica and Goli Vrh hills all the way to the village of Draga. The same horizon also surrounds the syncline at San Lorenzo-Jezero. Two horizons of the Transitional Beds are also exposed on the slope above the village of Botazzo-Botač and along the road between the villages of Hervati-Hrvati and Botazzo-Botač. The lower part of the Transitional Beds are most exposed SE of Mocco'-Zabrežec at the southern slope of a nameless hill on which stands a cemetery (Figure 20). The compact fine-grained sandstone of the Transitional Beds was quarried there for local use. The Transitional Beds formation runs south of Mocco'-Zabrežec, around the northern side of Mt. San Michele-Sv. Mihael, along national road No. 11. To the SE they are covered by the alluvial deposits of the Rosandra-Glinščica creek and emerge at the Antro Di Bagnoli-Na Jami karstic spring. To the SE the Transitional Beds are covered by colluvial deposits and emerge again at the belvedere above the forest trail between the villages of Crogole-Kroglje and Prebenicco-Prebeneg above Dolina. The Transitional Beds appear in two horizons separated by a package of Alveolinid-numulitid limestone also south of the village of Mocco'-Zabrežec and above the village of Botazzo-Botač as well.

Figures 19 (left) and 20 (right). The basal conglomerate as a part of the lower part of the Transitional Beds SW of Pese-Pesek (left). Alteration of the marly limestone and very fine-grained sandstone in the cut of the old railroad line.

Use of the Transitional Beds in architecture

The Transitional Beds, precisely their lower part in which the marly limestone alternates with very fine-grained sandstone or limestone (depending on the proportion of quartz grains in the rock) were certainly recognised as a source of good construction material by the locals. These rocks are most widely exposed at the southern slope of the cemetery hillock southeast of the village of Mocco'-Zabrežec. Due to alternating layers of the soft marly and the much harder sandstone the lower part of the Formation exhibits properties similar to flysch. Like the flysch sandstone, the weathered sandstone from Transitional Beds takes on a brownish colour due to its iron content of terrestric origin. One architrave (Figure 21 and 22), one washing basin (figure 23) and individual building blocks made of the sandstone from the Transitional Beds can be found in Sant' Antonio in Bosco-Boršt and Mocco'-Zabrežec. The sandstone from the Transitional Beds serves as a particularly good construction material, but the fact is that not all sandstone layers prove suitable. Namely, the quality depends on the proportion of silt and clay in the rock. The higher the silt and clay content in the matrix, the poorer the material strength and its resistance to weathering. Since the silt and clay content of the rock varies significantly in both the vertical and horizontal direction, the Transitional Beds do not represent a serious material source for stonemasonry. Additionally, the relatively poor thickness of the Formation is another factor in the truly limited use of the material in architecture.

Figure 21. Architrave made of sandstone from the Transitional Beds of Sant' Antonio in Bosco-Boršt.

Figure 22. A detail of the rear side of the Architrave from Figure 21 reveals it was originally built-in, and appears here in secondary use.

Figure 23. A washing basin made of sandstone from the Transitional Beds exposed in the background (village of Mocco'-Zabrežec).

The upper part of the Transitional Beds: Basal Marl

Greenish massive marl is present on top of the lower part of the Transitional Beds everywhere in the researched area, of which Basal Marl is an important component. On Italian geological maps it has frequently been merged with flysch due to the time-consuming determination process defining the boundary between them in the field. The thickness of the Basal Marl in the upper structural level (Trieste-Komen anticlinorium) between Pese-Pesek and Draga is approx. 15 metres, while in the lower structural level it grows to a full 75 m in the vicinity of Crogole-Kroglje. In its lower part, the Basal Marl is massive and quite compact, while higher up towards the flysch it becomes increasingly silty. Poorly expressed stratification without sharp boundaries dominates in the upper part of the Basal Marl. Pseudobeds here are up to 3 cm thick and are difficult to recognise in small outcrops of weathered bedrock. Basal marl is soft and hence highly deformable sedimentary rock. In the zones of intense deformation we find calcite slickensides up to 2 cm thick. As these are coated by limonite, they give the marl an appearance similar to flysch (Figure 24). However, the limonite-coated calcite slickensides must not be confused with the thin sandstone layers typical for flysch. Slickensides are formed along numerous fault planes in the fault zone. Occasionally, Alveolinid-numulitid limestone pebbles up to 10 cm are present (Figure 25) in the Basal Marl. They have been observed in the Škrivnica area SW of Pese-Pesek and above Dolina.

Large exposures of Basal Marl are present along the forest trail between San Lorenzo-Jezero and the road between the villages of Hervati-Hrvati and Botazzo-Botač. Large, sub-vertical cuts are observed also behind several buildings in the northeastern part of Sant' Antonio in Bosco-Boršt.

Deposisition of the Basal Marl is triggered by several events. Such deposits represent a relatively sudden onset of a deep-water environment only occasionally reached by shallow water deposits (occasional limestone pebbles). A sudden deepening is caused by the cumulative effect of progressive subsidence observed already in the upper part of the Alveolinid-numulitid limestone, combined with the eustatic rise in sea level at the Paleocene–Eocene boundary. Due to the subsiding shallow water environment and the sudden eustatic rise in sea level the coastal line moved significantly inland and consequently drastically reduced grain size and the amount of sediment reaching the sedimentary basin. The onset of the Transitional Beds in the Trieste Karst area is classified as Middle Eocene by Cucchi and Piano (2013).

Figure 24. Calcite slickensides in the Basal Marl (Scoria quarry above San Giuseppe della Chiusa-Ricmanje).

Figure 25. Occasional pebbles in the Basal Marl SW of the village of Pese-Pesek.

4.3 FLYSCH

Flysch lies on top of the Basal Marl in all of the researched area. The Flysch Formation is composed of alternating layers of sandstone and marl. Marl and relatively thin layers of fine-grained sandstone dominate in the lower part of the Flysch Formation, and is present in the entire southwestern part of the Dolina municipality. To the northwest it reaches the thrust front above the San Giuseppe della Chiusa-Ricmanje and Sant' Antonio in Bosco-Boršt, and in the east up to Bagnoli-Boljunec and the thrust plane above Dolina and Kroglje. Flysch is exposed also in two small-scale thrusts above Hervati-Hrvati, east of Mocco'-Zabrežec, at the confluence of the Griža and Rosandra-Glinščica creeks west of Botazzo-Botač, and in a very thin duplex along the thrust plane in a gorge between Fonte Oppia-Počivenca and Mali Kras hill.

A Flysch area between Pese-Pesek and Draga is in fact an eastward plunging anticline (the Škrivnica Anticline). As the Basal Marl does not differ from thick marly beds within the Flysch formation, the boundary between formations was identified as the first sandstone layer. In the process of geological mapping an attempt was made to distinguish between those areas distinguished by predominantly marly sedimentation and those predominantly of sandstone, but in such a tectonically disturbed area it is a difficult task rife with potential for incorrect conclusions, especially when lines are drawn based on poor data. Flysch with sandstone layers thicker than 20 cm (20–40 cm) is exposed at the Hervati-Hrvati village, in the cut of the old railroad line at the abandoned Krvavi potok checkpoint, and just above the village of Dolina. Otherwise, further to the west at Milje, among the several quarries once active at least one is still in operation.

Use of flysch sandstone in local architecture

Flysch is a rock formation in which two types of rock are interchanged, usually sandstone and marl or shale. The alternating of soft marly layers with much harder sandstone layers allows for the easy extraction of sandstone blocks of constant thickness. The individual layers are already separated, so there is no need to cut the horizontal planes, but only the vertical ones to achieve a block shape. The latter is true for the material from the quarry. However, we observe large variations in the quality of flysch sandstone building blocks. Certainly the Flysch sandstone building blocks in Sant' Antonio in Bosco -Boršt and Bagnoli-Boljunec and very likely in other villages as well were initially collected from the surface layers in the near vicinity. This because the building blocks are irregular in their thickness, are frequently laminated and are completely oxidized, also in the core of the block (Figure 26). Fresh flysch sandstone extracted from the quarry is greenish-grey in colour; once it comes into contact with air and humidity it gradually changes to brown as the iron minerals in the sandstone oxidize. Blocks of laminated sandstone of poor quality (due to its tendency to exfoliate) are frequently observed in older buildings (Figures 26 – 28). Freezing water trapped in laminated sandstone, with laminae containing enough clay minerals or open micropores that can host water, causes exfoliation and hence degradation of the blocks' integrity. The use of building blocks with large calcite veins (Figure 28) and blocks of irregular shape also demonstrate that the material was collected in the vicinity of the thrust zones near the villages of Hervati-Hrvati (Figure 29), Sant' Antonio in Bosco-Boršt or Bagnoli-Boljunec, where the oldest flysch beds are exposed. These beds are also intensely folded and tectonized, hence the large calcite veins and the absence of regular straight layers that would enable the easy production of regular blocks.

An old wall of entirely different appearance can be seen at Caressana-Mačkolje, where even the oldest buildings are built with far better blocks, regardless of their size (Figure 31). Considering the built objects crafted from small blocks of flysch sandstone very likely not acquired from the quarry, one can claim that the material at Caressana-Mačkolje and Prebenicco-Prebeneg is in general of a higher quality. Taking the geological map as reference we can suggest the reason for this lies in the younger part of the flysch formation, which exhibits a higher sandstone/marl ratio and the fact that the flysch is less tectonized there.

Only two recognizable extraction sites (not real quarries due to their size) are recognized in the Dolina municipality: one at the eastern margin of Dolina and the other at Hervati-Hrvati. Both are quite small, with sandstone beds up to 30 cm thick. Presumably, such extraction sites were once more common, but today have been built up due to the obvious shortage of suitable land for building development.

Figure 26. Laminated flysch sandstone and a block of Alveolinid-numulitid limestone with large benthic foraminiferae (white spots).

Figure 27. A partly-weathered block of flysch sandstone with lamination in the upper part (Caressana-Mačkolje).

Figure 28. Sandstone blocks with calcite veins are irregular in shape. Occasional blocks of Alveolinid-numulitid limestone are also present (Sant' Antonio in Bosco-Boršt).

Figure 29. Overturned fold in flysch sandstone in the road cut at Hervati-Hrvati.

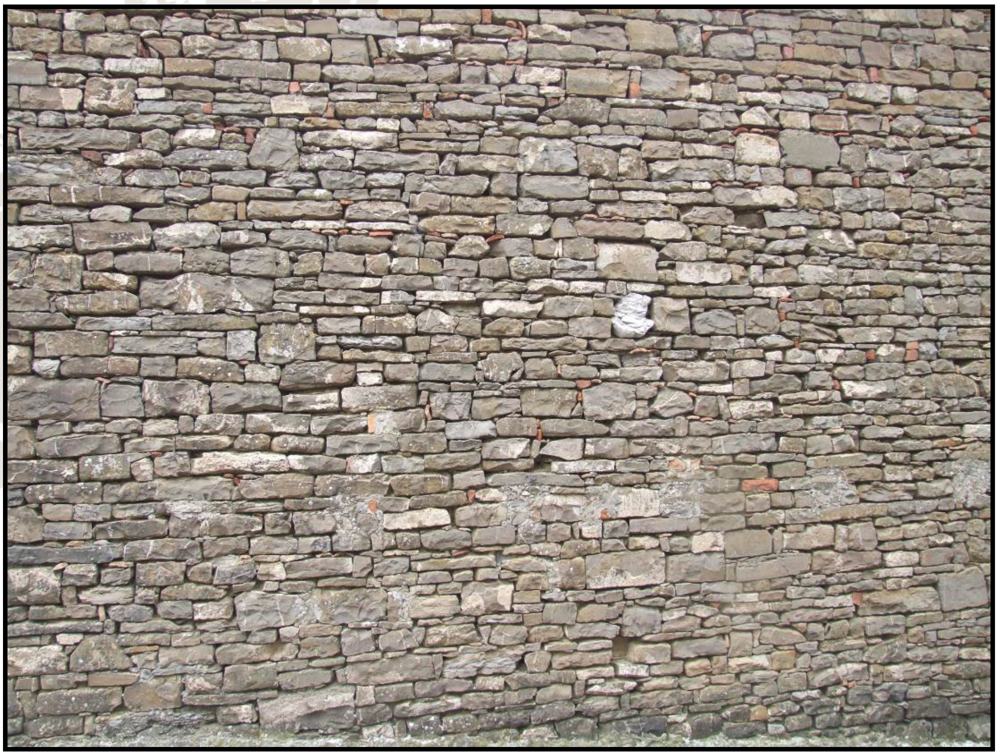

Figure 30. Building blocks of higher quality are used south and east of Bagnoli-Boljunec.

Figure 31. Fresh (not weathered) greyish-green sandstone blocks are a reliable indicator that flysch blocks originate from a quarry, dug out from deeper layers (Prebenicco-Prebeneg).

4.4 QUATERNARY DEPOSITS

Slope scree and breccia

A large part of the steep slopes is covered with Pleistocene gravel forming scree slopes. Extensive scree slopes were formed due to crioclastic weathering in the Pleistocene (Ice Age) when the temperature hovered around 0 °C. Extensive scree slopes are found in the Glinščica canyon below

Mt. Veliki Vrh, on the southern slope of the Mocco' Castle hill-Grad and Mte. San Michelle-Mt. Sv. Mihael.

The gravel is entirely carbonate where the slopes are composed of limestone, but is somewhat different where the limestone is thrust upon the flysch. There, the limestone gravel was poured on the weathered flysch or marly slope. In the lower part of the talus (below the thrust), the gravel is mixed with weathered flysch – more precisely with brown sandy silt (Figures 32 and 33). Such scree slopes are nevertheless quite fertile and were systematically transformed into cultivated terraces where mainly grapes were cultivated. Unfortunately (for our purposes), today all of these slopes are entirely overgrown with forest. The majority of scree slopes that have been converted into cultivated terraces lie above Crogole-Kroglje and Dolina, and on the southern slopes of Mt. Stena above Botazzo-Botač. Scree slopes weren't systematically bounded as they are already represented, to a degree, on the topographic map. What is more important, however, is they lack a distinctive morphology, as they were altered to become terraces. Only large scree slopes forming talus bodies obscuring insight into the geology beneath are presented on the geologic map.

Cementation of the gravel takes place when water saturated with CO_2 flows through the gravel. Changes in temperature and partial pressure of CO_2 enable precipitation of the carbonate between the gravel clasts binding them into breccia. Such breccia is observed in the Dolina area; however, the breccia there does not lie where it was originally cemented. In fact the boulders of breccia have landed at the base of the slope as the result of a large rockfall. Breccia boulders can be traced from the base of the slope at the western limit of the village along the Potok stream all the way up to the cliff above (see geological map). The old part of the village of Dolina is actually built on the rockfall talus composed of breccia and gravel (Figures 35 and 36). Similar breccia boulders were observed at the base of the Sant' Antonio in Bosco-Boršt ridge.

Figure 32. Slope limestone gravel with sandy silt and sandstone clasts from weathered flysch (Dolina).

Figure 33. Thick talus at Bagnoli-Boljunec. The reddish beds at the base are eolian sand (Cucchi, F., verbal communication, 2014).

Figure 34. Several large boulders of well-cemented breccia in the roadcut (No. 23 national road) at the W part of Dolina.

Figures 35 and 36. Dolina is built on large limestone (and breccia) boulders.

Proluvium and Alluvium

Proluvial and alluvial deposits were not thoroughly studied. They are represented as deposits by the Glinščica and its tributary that carry silt, sand, flysch sandstone pebbles and limestone pebbles from the re-sedimented colluvial deposits. A large part of the alluvial plain is now urbanised, obscuring the original morphology. Most of the sediment is derived from the flysch upstream of Botazzo-Botač, with the limestone pebbles originating from the talus between Botazzo-Botač and Bagnoli-Boljunec.

The use of Quaternary rocks and deposits in architecture

The use of pebbles in building

Large flysch sandstone pebbles from the Glinščica beds are used to form building blocks (Figures 37 and 38). An interesting fact is that most of the rounded boulders and pebbles are found in the proluvial beds rather than in the river channel itself at Boljunec (Figure 39).

Slope breccia

Slope breccia can be heavily cemented and as such can be used for building blocks in masonry. However, shaping the breccia into blocks is time-consuming, as it is usually massive rather than organised into layers of uniform thickness like the flysch sandstone. Breccia building blocks are only sporadically found in walls, indicating the preciousness of each building block (Figure 40). Probably more interesting, however, is the fact that millstones are carved from slope breccia. The only two perfectly preserved specimens found have been built into the stone wall at Mocco'-Zabrežec (Figure 41).

Travertine

Limestone is also excreted from the stream water on the surface in the form of travertine. Such is the case in the Potok creek above the village of Dolina and the Slavčji potok-Rio del Gias creek NE of San Giuseppe della Ciusa-Ricmanje. Travertine is also a very useful building material owing to its soft texture, which makes it very easy to shape. Only one vaulted window frame made of travertine was observed, in the church at the Dolina cemetery (Figures 42 and 43).

Use of non-local stone material

For the production of architectural elements such as door and window frames, architraves and columns, cretaceous limestone from numerous quarries, most of them relatively nearby, has commonly been used. Apart from the public well in the Sant' Antonio in Bosco-Boršt only a couple of columns and one architrave have been found to be made from a white Upper Cretaceous reef breccia, presumably from the Trstelj beds north of Gročana-Grozzana.

Door and window frames from a reddish calcareous tuffa, acquired from the stonemason workshops operating in the quarries in the Kras north and east of Basovizza, are also present in several villages.

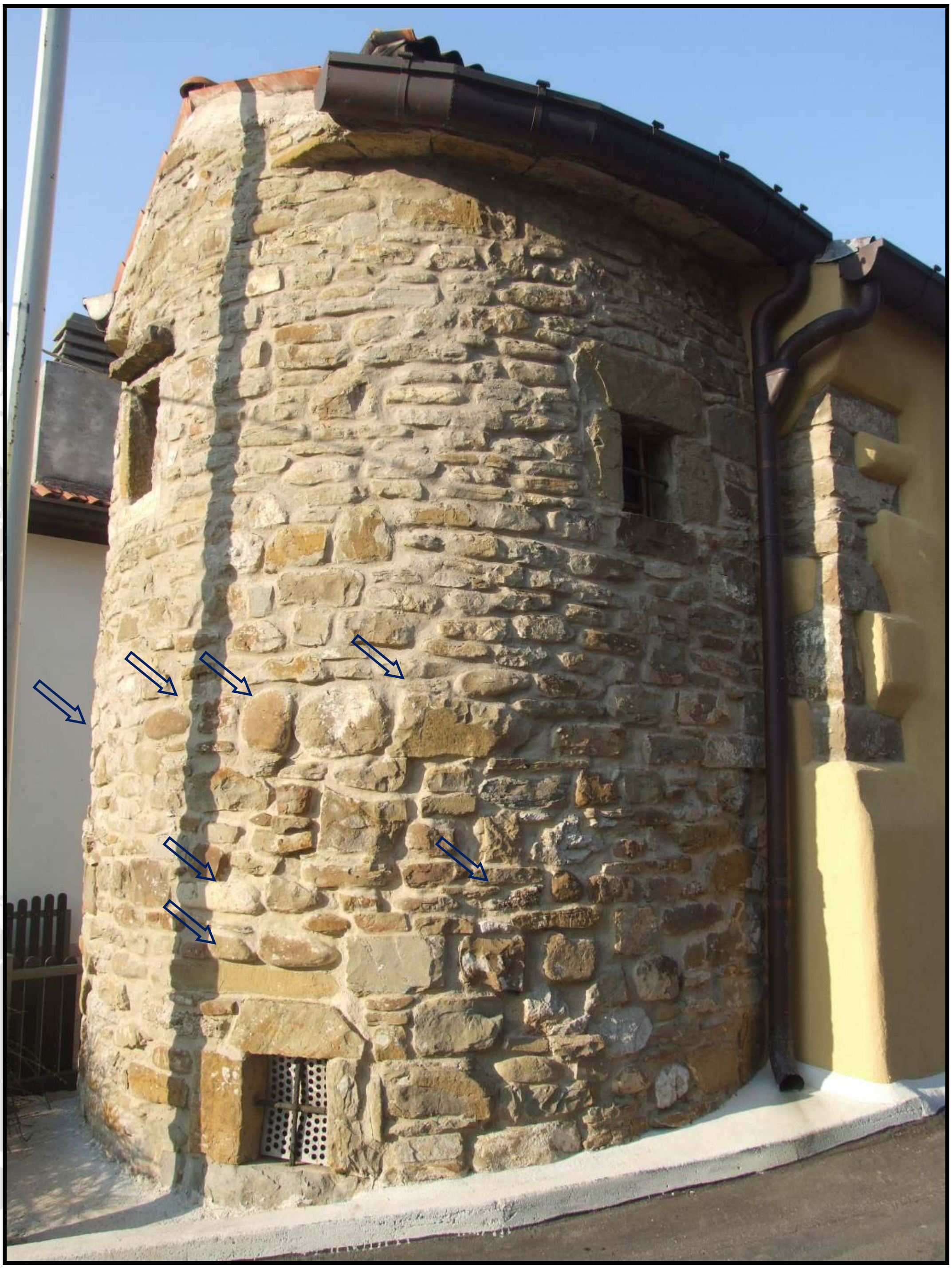

Figure 37. Large flysch sandstone pebbles in a building in Bagnoli-Boljunec.

Slika 38. A wall with sandstone pebbles in Bagnoli-Boljunec.

Figure 39. Pebbles in the Glinščica proluvial deposits at Bagnoli-Boljunec.

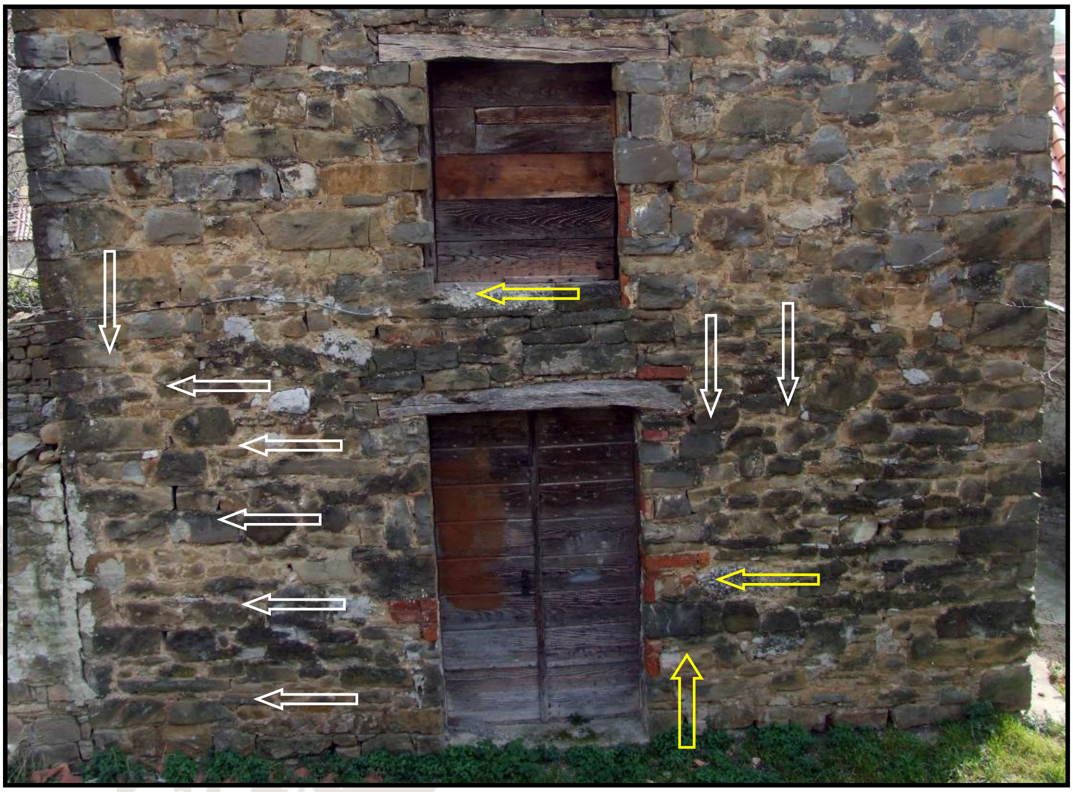

Figure 40. Blocks of slope breccia (yellow arrows) and flysch sandstone pebbles (white arrows) in a wall in Bagnoli-Boljunec.

Figure 41. Millstones carved in slope breccia built into a wall in Mocco'-Zabrežec.

Figure 42. Vaulted window frame made of the local travertine, in the church at Dolina.

Figure 43. The vaulted window frame was completely covered in plaster and painted.

5 TECTONICS

According to scheme of tectonic subdivision, the researched area belongs to the External Dinarides and with further division to the External Dinaric Imbricated Belt. Further subdivision divides the area into Trieste-komen and Reka sinclinoriums, which belong to the upper structural level. It covers the karstic area in the northern and eastern parts of the Dolina municipality. The lower structural level belongs to the Istria-Friuli subthrusting belt (Figure 44). The boundary between the two structural levels represents the Petrinje Thrust (Placer, 2010).

Petrinje Thrust

The NW-SE trending Petrinje Thrust runs above Longera-Lonjer and San Giseppe della Ciusa-Ricmanaje where it turns due east to San Lorenzo-Jezero and from there again due southeast above Botazzo-Botač into the Glinščica canyon towards the village of Petrinje. Geological cross-sections show that the Petrinje thrust divides moderately folded anticlinorium (upper structural level) from the imbricated belt (lower structural level). A shift in the course of the Petrinje Thrust Fault trace between San Giuseppe della Chiusa-Ricmanje and Draga is a direct consequence of the rotation and subsequent subthrusting of the Istria or more correctly, the eastern part of the Padanian segment under the Dinaric one (Placer, verbal communication, 2014). The shift of the Petrinje Thrust Fault, or rather its subsequent deformation, is accompanied by a continuous change in the strike of the Alveolinid-numulitid limestone bedding that follows the strike of the Petrinje Thrust Fault trace.

A transition from Alveolinid-numulitid limestone to the lower part of the Transitional Beds is exposed between the Italcementi quary and San Giuseppe della Chiusa-Ricmanje. Here the Transitional Beds are developed without any basal conglomerate. Just below the Thrust the flysch beds are intensely folded into tight and occasionally weakly-overturned folds with a wavelength of 10–20 m. A zone of intensely folded flysch beds approximately 300 m wide lies below the Petrinje Thrust.

Škrivnica Syncline

The Škrivnica Syncline is exposed in the Goli vrh and Škrivnica area between Pese-Pesek and Draga. Intensely folded flysch beds form the core of the syncline. Completely developed Transitional Beds can be followed along the northern limb of the syncline and east of Draga, with minor reverse faults present in the limbs of the syncline.

Jezero Syncline and Jezero Fault

A small SE trending syncline is exposed at San Lorenzo-Jezero. The syncline plunges gently to the SE and is cut by the Jezero Fault. It starts in the large oval depression just NW of the village and continues due south-east. The village (jezero = lake) is likely named after the depression with an impermeable core that retains water for some time after heavy rainfall. Though the depression resembles a kartic doline its marly core leaves no doubt as to its real genesis.

The Jezero fault trace runs along the northern margin of the village and due south-west along the electric power line beneath the road to Sant' Antonio in Bosco-Boršt. The fault divides tectonized Basal Marl and flysch in the northern block from the imbricated structure in the southern block. The obvious left-strike character of the fault is not the only deformation along its trace; complex vertical displacements likely exist along the Jezero Fault as well.

Imbricated structure and the associated thrust faults

The imbricated structure southwest of the Petrinje Thrust is a set of overturned folds, torn and thrust upon each other to form a series of duplexes bounded by thrust faults, the duplexes having been formed at the end of the Eocene epoch. The easternmost duplex lies south-east of Fonte Oppia-Počivenca, along the "Na opoki" gorge, so-named after the local term for the marl (opoka = marl) exposed in the gorge. A thrust contact exposed at several locations runs along the eastern flank of the gorge. Placer (verbal communication, 2014) named the structure the Opoka Thrust, while Italian geologists refer to it as *Faglia del* Crinale (Cucchi, 1987; Cucchi et al., 2005). The **Boljunec Anticline** is the next duplex, its anticline axis running from Monte San Michele-Sv. Mihael due south-east between Castelliere-Veliki vrh (436.8 m) and Monte Carso-Vrh Griže. The anticline (forming a duplex) is thrust upon flysch along the **Socerb Thrust** (Placer, 2007), known in Italian literature as *Sovrascorimento del Monte Carso* (Cucchi et al., 2005). The thrust trace runs 150 m south of the Antro delle Sorgenti-Na jami spring to the south-east. Above Crogole-Kroglje the thrust is covered by colluvial deposits and continues beneath the Griža cliff above the Socerb Castle. North of the Antro delle Sorgenti-Na jami spring the thrust is covered by alluvial deposits, but knowing its age and geometry we can infer that its behaviour to the north resembles that of the Petrinje thrust, as they both share the same kinematic history. The same is true also for the Kastelec thrust, stretching parallel to the Socerb thrust.

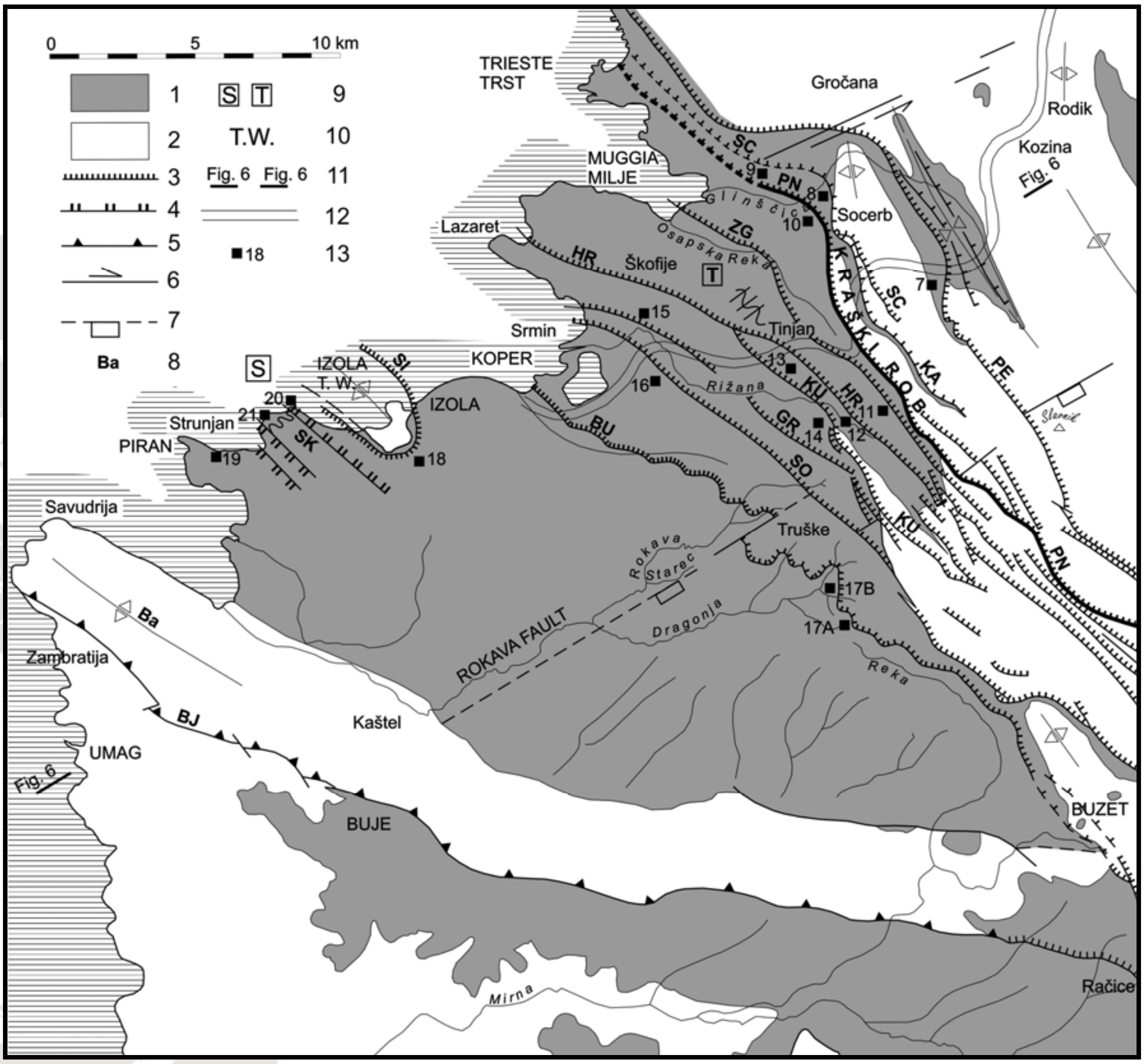

Figure 44. Istria-Friuli Underthrust Zone. Reprinted by permission of the author and the publisher from Placer et al., 2010.

Key:

1. Upper ductile horizon: flysch; 2. Platform carbonates; 3. Thrust faults: PE – Petrinje Thrust Fault, KA – Kastelec Thrust Fault, SC – Socerb Thrust Fault, PN – Palmanova Thrust Fault (local Črni Kal Thrust Fault), ZG – Zanigrad Thrust Fault, HR – Hrastovlje Thrust Fault, KU – Kubed Thrust Fault, GR – Gračišče Thrust Fault, SO – Sočerga Thrust Fault, BU – Buzet Thrust Fault, SI – Simon Thrust Fault; 4. Secondary thrust faults of the Strunjan Structure: SK – Sv. Križ Thrust Fault; 5. Thrust Front of External Dinarides: BJ – Buje Fault; 6. Strike-slip fault; 7. Normal fault; 8. Ba – Buje Anticline; 9. S – Strunjan Structure, T – Tinjan Structure; 10. Izola Tectonic Window; 12. Motorway.

6 GEOMORPHOLOGY OF SETTLEMENTS

6.1 GROZZANA-GROČANA

Grozzana-Gročana is situated at the edge of the Krasno Polje, a typical karst polje (karst field) approximately roughly 1500 m long and 300 m wide at its mouth. Krasno polje is formed along a hinge of a moderately expressed anticline, along which axis runs the **Gročana Fault**. A simple valley was formed out of fractured limestone along the anticline axis that also hosts a fault, as weathering (dissolution) of the limestone developed far faster here than elsewhere in the surroundings. The valley was eventually filled with fine-grained alluvium. Sinkholes are situated at the southwestern margin of the field, though only one of them is apparent in the morphology; the others are active beneath the surface at the limestone/alluvium interface. The underground water flow is directed from the sinkholes along the Gročana Fault zone in a south-easterly direction, emerging in a spring some 400 m due south-east.

Apart from the main creek running along the valley axis, several N–S oriented fault zones are apparent in the morphology of the northwestern side, acting as tributaries in the geologic history of the Krasno Polje. Shallow gorges have formed along these fault zones, though today the water only runs along the fault zones below the surface. The valley slopes are covered in colluvial rubble. The village of Grozzana-Gročana is conceived at the mouth of two such small valleys, where the limestone bedrock usually appears more fractured than elsewhere, making the slopes more gradual. Limestone rubble of various size stones served as a convenient source of building material.

An architectural survey of Grozzana-Gročana revealed that the greatest part of building materials employed consists of Alveolinid-numulitid limestone. As building blocks of the Alveolinid-numulitid limestone aren’t particularly well elaborated the question whether they originate from a large cut opened expressly for this purpose arises. Closer geological examination of the building material revealed that the lithotype of the limestone building blocks matches that of the local bedrock. Another argument favouring the local source theory is the weathered surface of many limestone building blocks, which is typical for a weathering process at the surface. This would indicate that the rock material was largely collected from the surface rather than quarried. As was observed during the architectural survey, the usual limestone building blocks are only roughly shaped (Figure 45), whereas larger blocks used for cornerstones and portholes (primitive windows) reveal better finishing (Figure 46). Examples of window frames with rough surface finishes are very rare (Figure 47) and can’t compete with the far more elaborated stonemason’s finish of the frames acquired from the workshops at the cretaceous limestone quarries in Kras.

Flysch sandstone was used as a secondary building material. Small building blocks 5 to 15 cm thick are used to form vaults above doors and windows (Figure 48) as well as to compensate for the irregular thicknesses of the limestone blocks (Figures 45 and 46). Individual examples of architraves made of the flysch sandstone are also to be found. Flysch sandstone was also used for window- and door frames, but was most frequently used for eaves, and for which 40 x 40 cm slabs 5 cm thick were used (Figure 49).

Grozzana-Gročana lies only a mile from the nearest flysch exposure, the closest source of which is Mt. Veliko Gradišče (Slovenia) connected by a road-route passing the village of Sv. Tomaž. However, a few pieces of flysch sandstone were found on a route along the southeastern margin of the Krasno Polje during geological mapping. A few pieces of flysch sandstone found on the path are interesting because the route is too narrow for motorized vehicles, suggesting that the sandstone has been carried along the route by a simple drawn carriage. As the route leads from Grozzana-Gročana to Krvavi potok and Draga, the assumption that the sandstone blocks for the buildings there might come from the immediate area, perhaps exclusively, is particularly relevant.

Figure 45. Roughly carved cornerstones made from local limestone at Grozzana-Gročana.

Figure 46. Roughly shaped building blocks made from local limestone used for portholes.

Figure 47. Roughly worked window frame carved from local limestone.

Figure 48. A vault built from flysch sandstone.

Figure 49. A flysch sandstone slab used for the eave.

6.2 SAN ANTONIO IN BOSCO-BORŠT

The village of San Antonio in Bosco-Boršt lies on the west side of a 1.2 km-long slope east of San Giuseppe della Chiusa-Ricmanje. The shape of the village as it is shown on historic maps reveals two principal axes (Figure 50): the more pronounced east–west axis, parallel to the flysch/limestone boundary and orthogonal to the slope, is seated a few hundred metres below the boundary (See geological map). The lithological boundary between the flysch and the limestone is tectonic, with the limestone thrust onto flysch. Due to the large differences in erodibility of the flysch and the limestone the area below the boundary is less favourable for a settlement as it is exposed to mass wasting. The road between San Giuseppe della Chiusa-Ricmanje and San Antonio in Bosco-Boršt is also placed at some distance from the lithologic boundary for the same reason. The other axis runs in the NNW–SSE direction, almost orthogonally to the E–W axis and coincides with a weakly pronounced ridge upon which the central square and church are built.

The ridge was formed by a succession of various factors. To the south the ridge is covered by large (up to 1 m^3) boulders of slope breccia. The latter was formed by cementation of the Pleistocene gravel of the scree slope. A stiff crust of breccia slid downhill due to heavy precipitation and the spring wetting the impermeable Basal Marl at the lithological boundary. During the collapse the cemented gravel crust (breccia) disintegrated into large blocks now exposed at the southern base of the ridge. In fact, the whole ridge is actually covered by rockfall debris (Figure 51). Due to the high permeability of the talus it acts as a secondary open aquifer with the Basal marl serving as an impermeable base. The described geologic conditions refer to the spring at Sant' Antonio in Bosco-Boršt, situated approx. 60 m E of the church, as marked on the historical maps. Judging by the position of the spring and the morphology of the area the rocky talus is up to 10 m thick.

The C–D geologic cross-section running along the ridge shows that the settlement is built upon the least steep part of the slope. The primary aquifer, the position of the talus (rockfall debris) representing the secondary aquifer, and the position of the outlet (the spring) are shown in the geologic cross-section using an exaggerated vertical scale (Figure 52). It is obvious that the water table is very close to the surface on the ridge, as can be seen in one of the original wells incorporated into one of the well-preserved existing houses here. Only a thin layer of rock debris had to be removed to reach the water level in order to fashion a simple well, which only required digging a shallow pit into the marly basement.

The geologic basement at San Antonio in Bosco-Boršt is represented by flysch in the western part, and breccia, gravel talus and the Basal Marl in the central and eastern parts. Flysch sandstone constitutes the predominant building material in San Antonio in Bosco-Boršt. The sporadic presence of unshaped limestone blocks demonstrates the value of each building block that did not have to be brought from elsewhere. A more detailed survey revealed that the flysch sandstone blocks represent a relatively poor quality rock material. In fact two kinds of flysch sandstone are present in building walls in San Antonio in Bosco-Boršt: the higher quality material has definitely been quarried, while the poor quality blocks were likely collected or dug out from the surface layer of nearby fields, or from small cuts like the one preserved at Hervati-Hrvati (Figure 29).

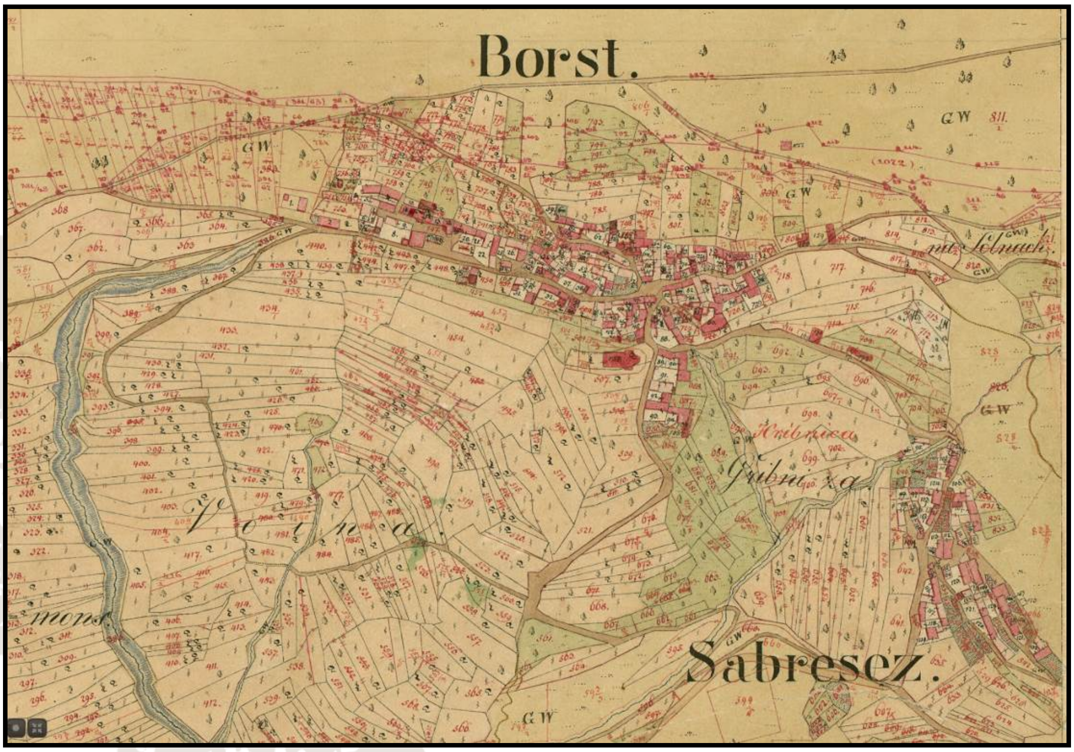

Figure 50. Shape of the settlement at the beginning of the 19th century.

Figure 51. A large boulder from the rockfall was incorporated into the wall *in situ*.

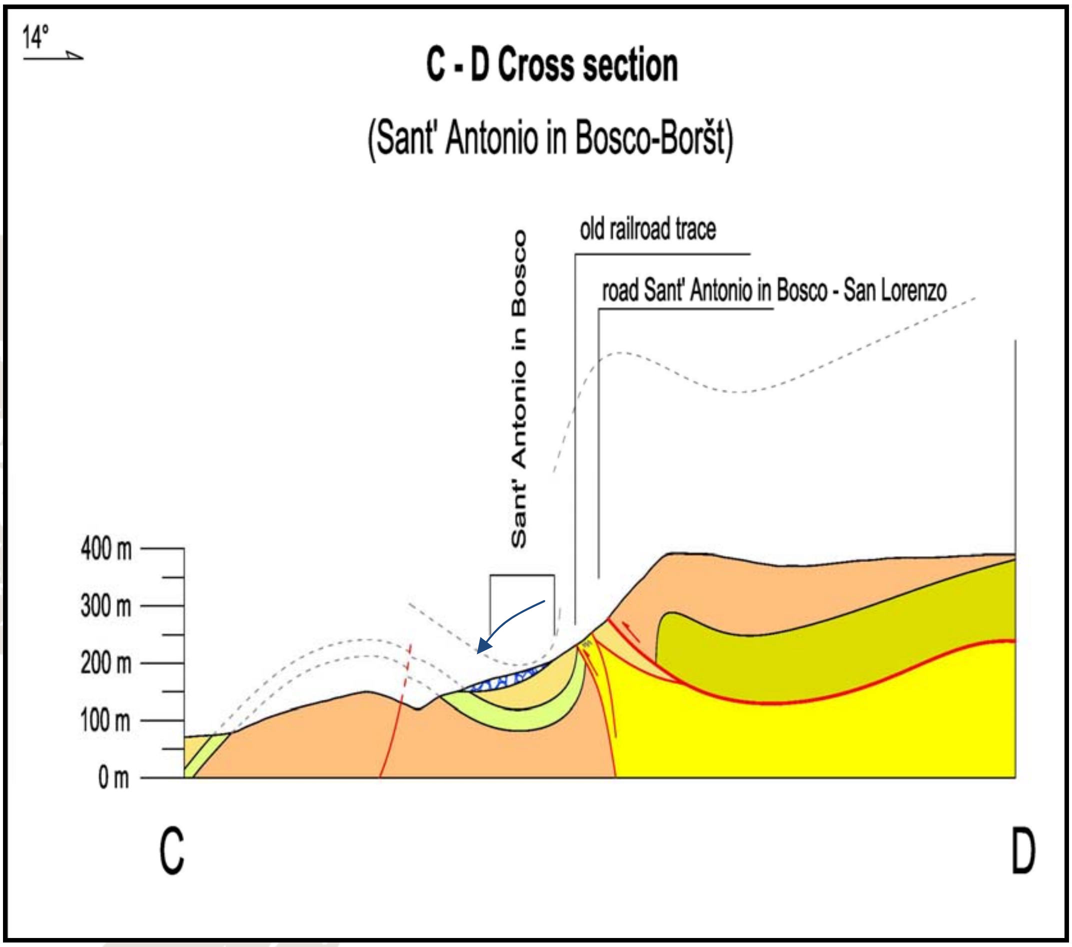

Figure 52. The C–D geological cross-section with exaggerated vertical scale across San Antonio in Bosco-Boršt (aquifer sediments (rockfall) are marked in blue).

6.3 DOLINA

The village of Dolina is built upon the toe of a large debris slide. Huge boulders of slope breccia can be found in the foundations of many buildings (Figures 35 and 36), among them in the foundations of a church tower. Toes of large rock debris slides usually prove a stable foundation substrate. The ridge of a debris slide toe is a dominant feature in the morphology of Dolina – just as in the case of San Antonio in Bosco-Boršt. Roughly 1.5 million cubic metres of debris have accumulated at the toe alone, but vast scree slopes are present both east and south of the settlement. The scree slopes in particular, with their large portions of weathered flysch, represent reasonably fertile ground. Terraces are still preserved around the abandoned settlement above Dolina, and lush gardens and orchards are still in use south of the village. The village's water supply comes from the thrust boundary above the impermeable flysch below Mt. Mali Kras, and runs through the gravel slope, so ground water is present also in the colluvial deposits that act as secondary aquifers (Figure 53).

The village grew towards Crogole-Kroglje along the N–S axis along the lower limit of the slope gravel towards the Antro delle Sorgenti-Na jami karstic spring.

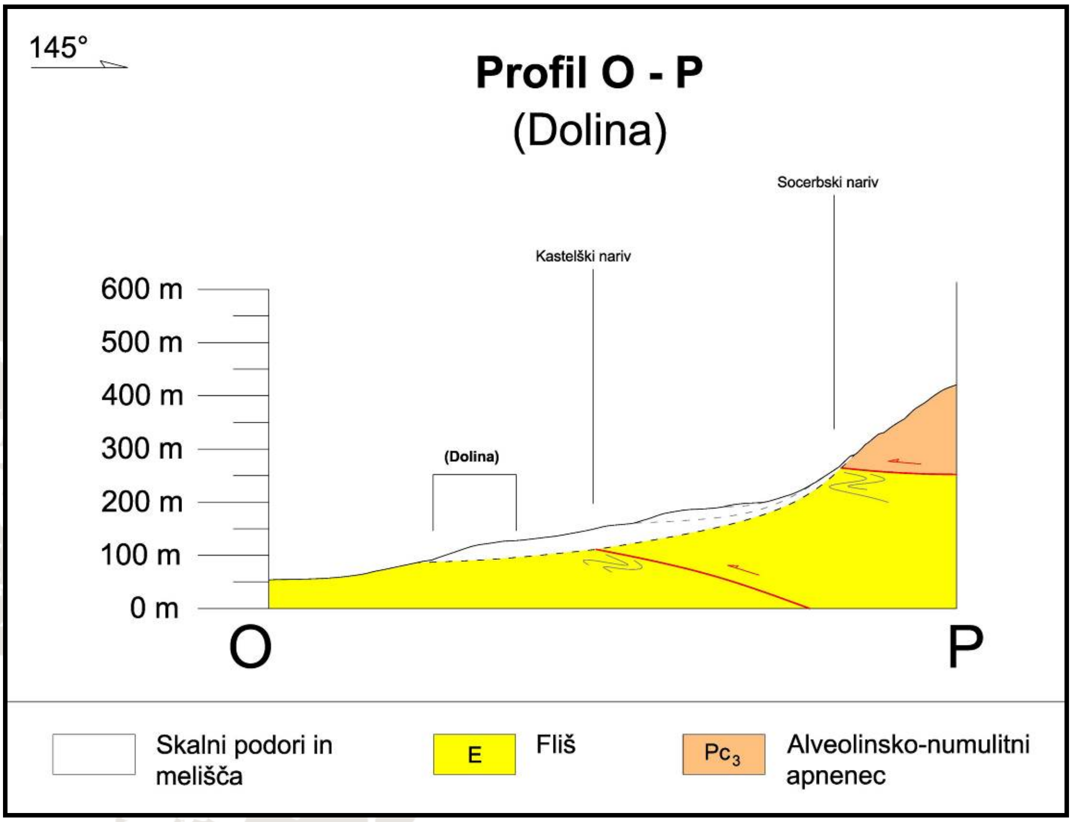

Figure 53. Geological cross-section across Dolina

6.4 PREBENICCO-PREBENEG AND CARESANA-MAČKOLJE

Both villages are situated in an area characterised by low geodiversity and are, from this point of view, quite alike. Both are situated at the start of a 5 km flysch ridge that represents the divide between the Glinščica and Osapska reka watersheds running from the village of Socerb (Slovenia) down to the sea. Growth of Prebenicco-Prebeneg is severely hampered due to the unstable southern and northern slopes of the ridge, where numerous fossil and active landslides are obvious. To the east, a very steep slope also acts as a natural barrier. The nearest source of limestone lies 1 km due west at Socerb, making flysch sandstone the dominant building material here. Only the occasional door- and window frame have been purchased from the quarries above Trieste-Trst. The differences between objects made from locally-sourced materials (Figure 54) and those quarried from one of the nearby flysch quarries (probably the Elleri-Jelarji quarry) (Figure 31) are obvious; the same is true also for Caresana-Mačkolje (Figures 55 and 56).

Similar to Prebenicco-Prebeneg is Caresana-Mačkolje, which is built along the Črni Kal thrust fault trace. It would be difficult to claim that the morphology of the settlement is a direct consequence of enhanced erosion processes along the fault zone in the flysch, as the area is covered in vegetation. Yet in both villages ground water is captured in the weathered surface layer and drawn from relatively shallow wells (only a few metres deep), but water is not particularly abundant owing to the small size of the catchment area.

Figure 54. A wide range of building block sizes and above all, thin building blocks, are likely indicators of local sourcing (Prebenicco-Prebeneg).

Figures 55 and 56. The poor quality of the flysch sandstone building blocks (lamination) and large variations in block sizes are common in older buildings (left); better materials in some other buildings (right) at Caresana-Mačkolje indicates the same pattern of acquiring building materials as in other villages.

6.5 SAN GIUSEPPE DELLA CHIUSA-RICMANJE

San Giuseppe della Chiusa-Ricmanje is built on a flysch ridge just like Prebenicco-Prebeneg and Caresana-Mačkolje. In this case the relief is interesting because it has been formed in a subthrusting process of the Istria-Friuli segment. The karst edge runs in a very straight line from Aurisina-Nabrežina to San Giuseppe della Chiusa-Ricmanje with the principal slope facing southeast. The subthrusting of the Istria-Friuli segment provoked the initially straight Petrinje Thrust Fault trace to bend as it was pushed towards the NE as much as 1500 m.

This is the reason the slope between San Giuseppe della Chiusa-Ricmanje and San Lorenzo-Jezero today faces south. The San Giuseppe della Chiusa-Ricmanje ridge therefore represents a corner in the relief, which makes the village much like Prebenicco-Prebeneg. Both villages are situated on a corner offering a 145 degree view to the area below. Two creeks emanating from the limestone massif above cut small gorges into relatively soft flysch beds on either side of the ridge that divides it from the surrounding area; more importantly, however, the ridge is protected from erosion as all the water is channelled through the creeks. Colluvial deposits some metres thick in the upper part of the village also act as a secondary aquifer.

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