Rudarsko-geološko-naftni zbornik	Vol. 3	str. 63–67	Zagreb, 1991.

UDC 553.551.1:624.012.1

*Izlaganje na znanstvenom skupu**

THE ORIGIN OF THE DIMENSION STONE OF THE ARENA IN PULA

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Key-words: Dimension stone, Origin, Vinkuran quarry, the Arena in Pula

The paper presents results of investigations of stone samples from the Vinkuran quarry, the ancient »Cava Romana«, in the vicinity of Pula, Istria. The samples are compared with the stone from the external curved wall of the Arena in Pula. It has been established that the external curved wall of the Arena has been built entirely of stone blocks originating from Vinkuran quarry. The stone has been petrographically determined as coquina limestone, coquinite and microcoquinite, known in the market as »fiorito« or » travertino«, and »unito« or »statuario«. A detailed description is given of the ancient and present quarries.

Ključne riječi: Arhitektonski kamen, Porijeklo, Kamenolom Vinkuran, Arena u Puli

Izloženi su rezultati istraživanja uzoraka kamena iz kamenoloma Vinkuran, antičke »Cava Romana«, nedaleko Pule, Istra. Kamen je uspoređivan s kamenom vanjskog plašta Arene u Puli. Utvrđeno je, da je vanjski plašt Arene izgrađen od kamenih blokova porijeklom iz kamenoloma Vinkuran. Kamen je petrografski determiniran kao coquina vapnenac, coquinit i mikrocoquinit, na tržištu poznat kao »fiorito« ili »travertino« i »unito« ili »statuario«. Detaljnije su opisani antički i današnji kamenolomi.

The dimension stone of the Arena in Pula has a twofold character and origin regarding its function as a building material. One kind of stone has been used to build the external curved wall, which blows up four floors high with its 72 monumental arcade arches. The other kind of stone has been used for interior construction, to build the central space, the stone staircase, and the rows of seats divided into storeys, as well as the underground rooms with various functions. The stone was to meet the requirements of each of its functions, not only with respect to its physical and mechanical properties and its durability, but also with regard to the dimensions and forms of blocks or stone elements built into the curved stone wall of the Arena and its inner constructions.

The stone used for the inner constructions, which has from the ancient times to the recent past been repeatedly taken down and changed in great amounts, will not be payd much attention to. The interior has been built with stone elements of relatively small dimensions, of smaller stone plates and more or less regular prisms. Judging by its properties, part of the stone originates from the immediate vicinity of Pula. The elements are visibly thyn-layered limestones of the Lower Cretaceous (Albian) age, nowadays quarried from the Rakalj quarry. The rock mass can be splite along surfaces of the layers and the stone processed into plates. This was the technique of acquiring smaller stone elements which were easily applied in building walls, staircases, seats and other building constructions. There are opinions to the effect that part of the stone of the Arena's construction originates from the Solina bay near Rovinj. There are also Lower Cretaceous limestones with thin layers. which could, due to their properties, be used only for constructions inside the Arena.

The massive pilasters of the curved wall were built of regular blocks, often larger than 2 m^3. Apart from thickness, the dimensions of the large monolith orthostyles are in no way smaller, nor are the rustic stone plates on the tops of the pilasters, nor the monoliths and particularly the stone beams in the wall crenels.

The large dimensioned stone building-elements could be processed from stone blocks quarried from a rock mass with thick layers or massive structure, as well as with insignificant or minor tectonic damage. That is to say from a rock mass with a low density of planar discontinuities, layer surfaces and cracks.

The outer curved wall of the Arena has fortunately not been used as a »quarry« of processed stone blocks for the building of new, post antiquity buildings in Pula, from the ancient times to the present. Although the outer curved wal stone wall was threatened by demolition, even by removal to the another place several times, the curved wall remained preserved, or more precisely, damaged mostly by natural factors. The dimension stone in the curved wall of the Arena has in this case also proved its durability, having resisted nature for centuries, aided by sporadic reconstruction to prolong its existence and appearance.

Except for the stone used in later reconstructions, the curved wall of the Arena was built entirely from limestone blocks originating from the ancient »Cava Romana«, today the operating quarry Vinkuran some 6 km south of Pula (Fig. 1). In this area (Fig. 2) there is an old quarry from the ancient times to the west (I) and a still operating ancient quarry to the east (II).

* *Primo convegno scientifico internazionale »Tre Arene: Pola, Verona, Roma«, Pola 1988.*

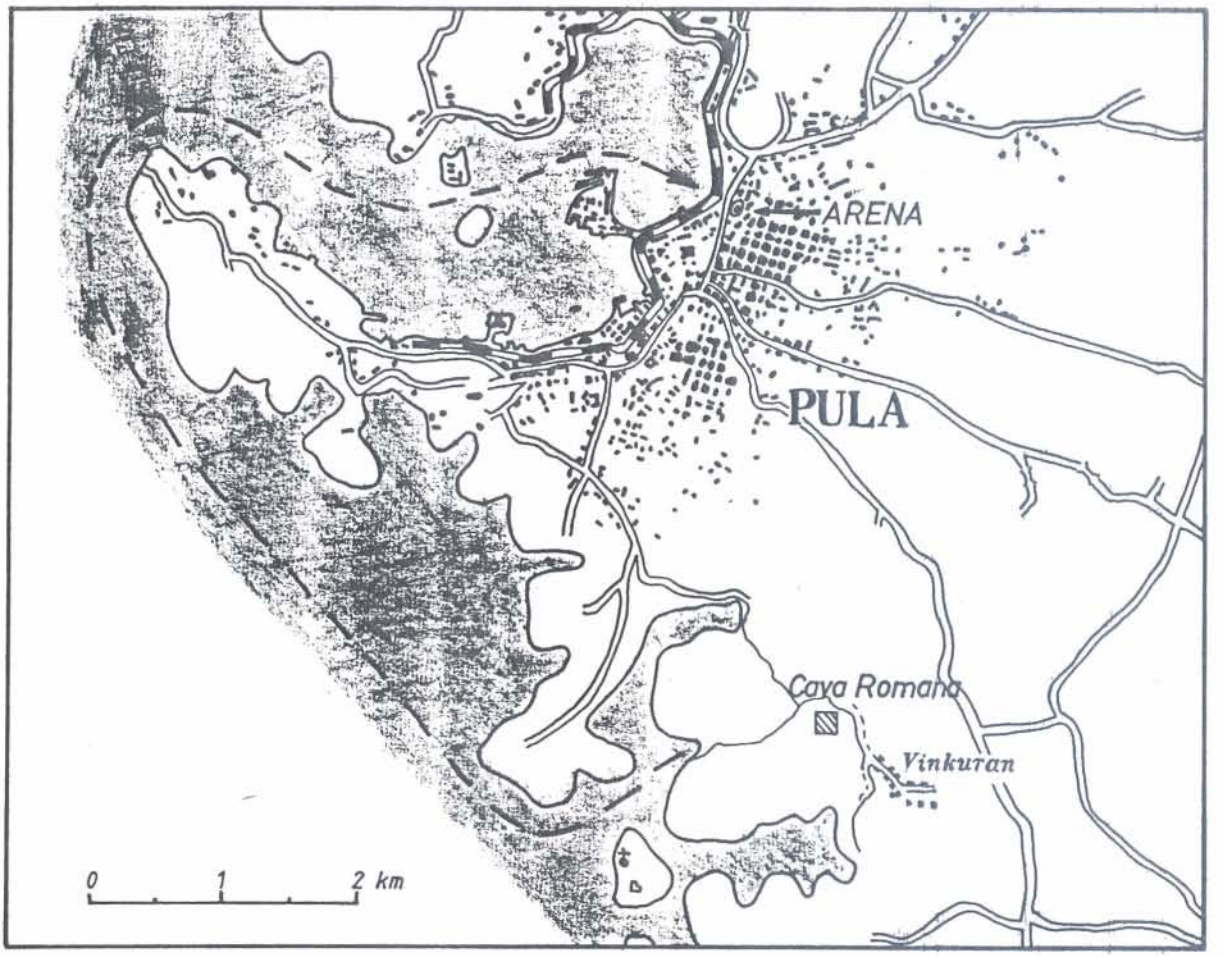

Fig. 1 The geographical position of the ancient quarry »Cava Romana«, or the deposit of the dimension stone Vinkuran, and the most likely route for the transport of stone blocks by sea (interrupted line).

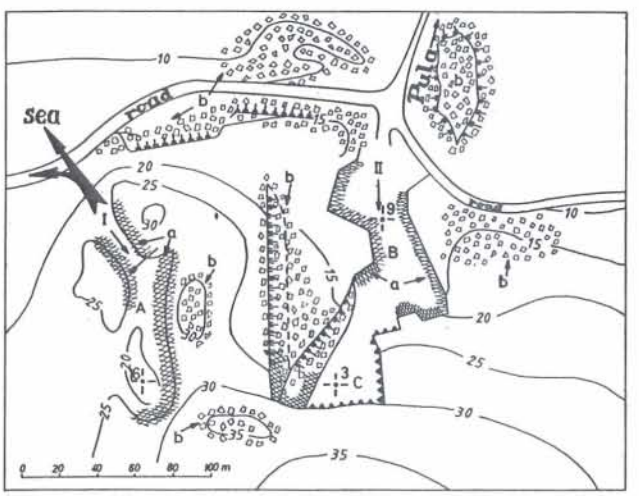

Fig. 2 An outline of the »Cava Romana« quarry, i. e. the now operating Vinkuran quarry.
Legend:
I access to the western quarry
A the ancient quarry with only morphologically clear contours remaining to the present
II access to the eastern quarry
B the ancient quarry with remaints and traces of the quarrying in ancient times
C the new, now operating Vinkuran quarry
a traces of stone blocks quarrying in ancient times
b the waste remaining from stone blocks quarrying from the antiquity until today

In the western quarry (I) morphological contours of the old opencast working of an area of 20 to 30 m spreading east-west, and lengthwise in the direction north-south approximately 100 m. The quarry accordingly covered an area of about 2,500 m^2. The lowest point in the morphologically defined hollow filled with stone waste, detritus and debris, is at 16 m. This means that the workings of a once operating quarry was at an elevation lower than 16 m. To the west of the hollow there are slopes to a level of 25 m, and to the east they rise to 30 m. It folows from this that the height of the workings was over 10 m.

The stone blocks from this quarry were most likely transferred to the close-by seashore, and then freighted to the Arena building site in Pula by sea.

The eastern quarry (II) extends in the same direction as the western one. Its northern part (B) on the eastern and western sides along the vertically cut workings there are traces and remnants of the quarrying in the ancient times. These traces can be faintly seen in the southwestern part of the quarry as well.

In the southern part of the quarry (C) stone blocks for industrial processing have been quarried to the present.

Figure 3 is a schematic presentation of this (present) quarry. In the ancient times quarrying was concentrated in the northern part, which is logical considering the land morphology and the geological

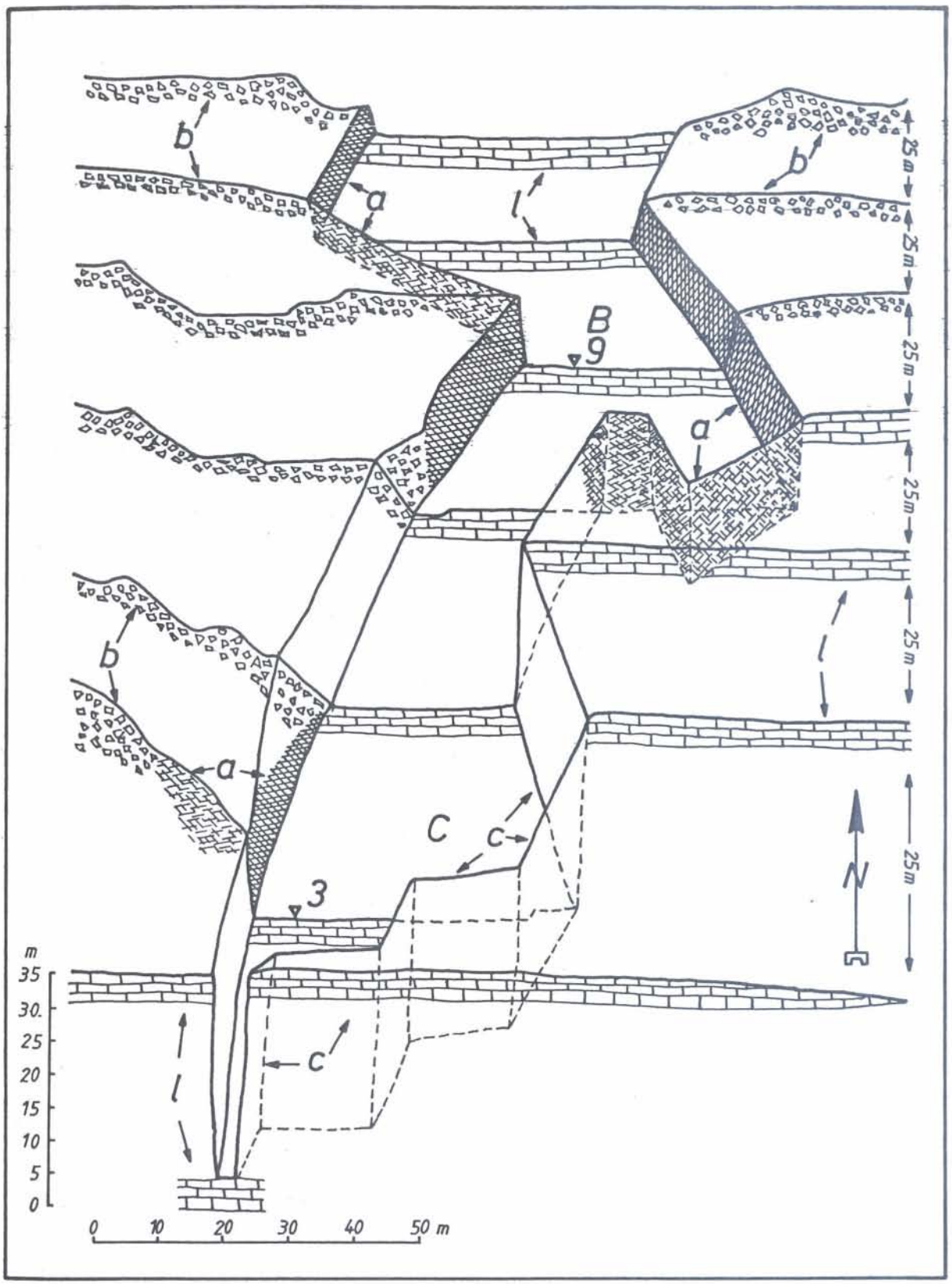

Fig. 3 A scheme of the ancient »Cava Romana«, the eastern quarry (II) and the now operating Vinkuran quarry.
Legend:
B the area of quarrying in antiquite
C the now operating part of the Vinkuran quarry
a traces of the stone blocks quarrying in antiquity
b the waste remaining from the stone blocks quarrying from antiquity until the present
c the present quarry front cut by wire saw
l quarrying potentials of rudist limestone, the spacing between profiles is 25 m

conditions of the bed in deposit. The rock mass is in this part cut approximately to an elevation of 9 m. On both sides of the quarry there are large masses of stone waste on the surface. today it is difficult to asses which part of the waste belongs to the ancient stone quarry and how much has been accumulated in recent times. It is obvious that this waste has greatly changed the morphology of the terrain.

The width of the ancient quarry in the direction east-west varies between 25 and 40 m, and the length in the direction north-south is difficult to establish, but it certainly must have been 75 m. The depth of the quarry varies from several metres in the northern part to about 15 m moving southwards. The depth in the direction south gradually increases, due to the gentle morphological elevation of the surface and the gently sunk-in layers. If the mean width of the quarry is considered to be 30 m, and the length 75 m, this quarry covered in ancient times an area of 2,250 m^2.

On ground of the assessment of the surfaces taken up by the ancient quarries, and of the depths of the rock mass cut into, it is possible to give an approximation of the quantity of stone mass, blocks and waste that has been dug out. In the western quarry this amounts to approximately 25,000 m^3, and in the eastern quarry approximately 22,500 m^3 of stone mass, that is a total of 47,500 m^3 of stone blocks and waste. Since the surface wasting zone was thin and the block structure suitable because the rock mass was tectonically preserved, and since the quarrying coefficient was 0.5, approximately 23,750 m^3 of stone blocks were exploited for construction purposes.

Both quarries described are set in the rudist limestones of the Upper Cretaceous (Cenomanian), which were dealt with by T i š l j a r (1976) in detail.

The total thickness of these massive limestones in this area is up to 30 m.

The limestone were petrologically determined as rudist coquina limestone, coquinites and microcoquinites. They were originated by the decomposition of rudist colonies and by accumulation of large masses and cementing of the fragments and detritus of rudist shells in perireefal environment with great water energy.

The coquina limestones are composed of low sorted and unsorted as well as slightly rounded fragments of rudist shells and relatively large-sized Chondrodonts (to 200 mm), with calcite partly filling the intraskeletal and interskeletal space.

The conquinites are more compact and more firmly cemented limestones containing mechanically abrased and highly sorted rudist debris, and rudist shells and Chondrodonts. The bioclasts are firmly cemented either by shell microdetritus, or microcrystalline calcite, or calcilutite.

Microcoquinite are characterized by a content of highly sorted and fine-grained rudist shell-debris of under 2 mm.

All three types of rudist limestones alternate vertically and laterally, so that microcoquinites and coquinites are dominant in the lower part, and coquina limestones in the upper part of the rock mass (deposit), as a consequence of reef progradation by sedimentation.

The coquina limestone is nowadays known in the market as Vinkuran »fiorito« or »travertino«, and coquinite and microcoquinite as Vinkuran »unito« or »statuario«.

All the three varieties of limestone described are built into the outer curved wall of the Arena.

The rudist limestone of Vinkuran is an extremely pure calcite rock. The chemical composition of the variety coquina is, according to T i š l j a r (1976), as follows:

L. O. I.	43.64%
CaO	54.20%
MgO	0.09%
$SiO_2 + R_2O_3$	2.05%
	99.98%

Both varieties of the stone are snow-white, the »unito« variety is fine-grained and homogenous in texture, while the »fiorito« variety is characterized by large skeletons of rudists which are clearly visible within the microcoquinite matrix. After the stone is built into facades, particularly in urban environments, it relatively soon acquires a greyish to grey patina on its surface.

The massive structure of the limestones in their deposit, without an obviously layered structure and lacking bedding planes as planar discontinuities, facilitated in ancient time, as it does today, the excavation of blocks without any limitations on their height. the tectonically undisturbed rock mass has also had a favourable influence on the quarrying of blocks of practically unlimited dimensions. This has a favourable effect on the excavation of blocks from the rock mass in any dimension and form required. Practically no dimension of the block excavated by natural planar elements is not limited. From the point of view of stone qurrying this is a particulary favourable feature of this deposit. Such a facility was certainly of great significance in the antiquity, since it made possible the production and processing of elements needed in the building of the outer curved wall of the Arena.

The outer curved wall of the Arena was in the past repaired with varying success, from the point of view of the technical realization and from the esthetical one. The repairs done on the northern entrance were both technically and esthetically successful. However, the original building stone of the Arena was not used, but a stone of the »orsera« type, a dense stylolitic limestone. For this rason, when carefully observed, these elements visually contrast with the rest of the stone in the curved wall, due to their textural and structural features.

From the esthetical point of view the external curved wall of the Arena is spoiled by the »patchwork« of large blocks, monoliths and larger elements, with smaller stone elements of dense, layered and platey limestone of a greysh and yellowish-greyish colour. This »patchwork« stand out in a very conspicuous way spoiling the harmony of the curved wall. It has hardly ever, technically speaking, contri-

buted to the preservation of the statical stability of the curved wall.

In the recent restoration work performed on the outer curved wall of the Arena by the »KAMEN« company from Pazin, the original stone material, the rudist limestone from the ancient »Cava Romana«, i. e. Vinkuran quarry, is used for the insertion and replacement of damaged astragals, orthostyles and other stone elements that were either missing or were so damaged that they had to be replaced. The newly inbuilt stone elements stand out from the other elements of the curved wall by their white colour, but after a relatively short time they will acquire the colour of the stone used in the antiquity through the patina on its surface. Thus the difference in the nuances of the white and grey colours of the recently inserted stone and the one used in antiquity will be lost and replaced by a new visual effect of an architectural unity.

Acknowledgments

I am grateful to the KAMEN company from Pazin, which has helped the realization of field work, and dr Josip Tišljar, Professor at the Faculty of Mining, Geology and Petroleum Engineering in Zagreb, for useful discussions on the geological structure in the deposit of the dimension stone Vinkuran, as well as to Roland Barić, student of geology at the same Faculty for the drawings.

Received: 30. V. 1989

Accepted: 25. VI. 1991.

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Porijeklo kamena Arene u Puli

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Kamen ugrađen u Arenu u Puli dvojakog je karaktera, kako s obzirom na njegovo porijeklo, tako i njegovu funkciju kao građevnog materijala, te petrografska i tehnička svojstva. Jednoj vrsti pripada kamen ugrađen u vanjski plašt, a drugoj kamen ugrađen u unutrašnjem dijelu Arene.

U vanjski plašt Arene ugrađeni su kameni elementi, često veći od 2 m^3, porijeklom iz antičkog kamenoloma »Cava Romana«, danas aktivni kamenolom Vinkuran nedaleko Pule.

Kamen ugrađen u unutrašnjem dijelu Arene je manjih dimenzija, elementi su pločastog do prizmatskog oblika, porijekom iz bližeg okoliša Pule.

Vanjski plašt Arene ostao je očuvan, jer u daljoj i bližoj prošlosti nije predstavljao »kamenolom« iz kojega bi se rušenjem uzimao kamen za gradnju novih zdanja u Puli.

U ležištu arhitektonskog kamena Vinkuran, približno 6 km od Pule (sl. 1), iz kojega su vađeni blokovi za gradnju plašta Arene, nalaze se u zapadnom dijelu antički, danas napušteni kamenolom, te u istočnom dijelu antički i danas aktivni kamenolom (sl. 2, oznake I i II). U oba kamenoloma vidljivi su tragovi antičke eksploatacije blokova, bez obzira na današnju eksploataciju (sl. 3).

Na osnovu današnjeg izgleda morfologije terena procijenjeno je, da je u antičkim kamenolomima izvađeno približno 47.500 m^3 blokova kamena i jalovine, što uz procjenjeni povoljni eksploatacijski koeficijent od 0,5 daje približno 23.750 m^3 blokova kamena različitih dimenzija.

Oba kamenoloma se nalaze u rudistnim vapnencima gornje krede (cenoman) koje je detaljno opisao Tišljar (1976).

Vapnenci su petrografski determinirani kao rudistni coquina vapnenac, coquinit i mikrocoquinit. Nastali su razgradnjom rudistnih kolonija, te akumuliranjem i cementacijom fragmenata i detritusa rudista.

Coquina vapnenac je izgrađen od slabo sortiranih i nesortiranih, slabo zaobljenih fragmenata rudista i relativno velikih Chondodonta, s kalcitom u intraskeletalnom i interskeletalnom prostoru.

Coquiniti su kompaktniji, bolje cementirani, sadrže mehanički abradirani i visoko sortirani debris rudista.

Mikrocoquiniti su okarakterizirani sadržinom visoko sortiranog i fino granuliranog rudistnog debrisa dimenzija ispod 2 mm.

Sva tri tipa rudistnih vapnenaca izmijenjuju se vertikalno i lateralno, s time, da mikrocoquiniti i coquiniti dominiraju u donjem dijelu, a coquina vapnenci u gornjem dijelu ležišta.

Coquina vapnenci su danas na tržištu poznati kao vinkuran »fiorito« ili »travertino«, a coquiniti i mikrocoquiniti kao vinkuran »unito« ili »statuario«.

Sva tri varijeteta vapnenaca ugrađena su u vanjski plašt Arene.

Rudistni vapnenac vinkuran je ekstremno čista kalcitna stijena.

S obzirom na sklop ležišta, bez naglašene slojevitosti i tektonike, znači bez izražene gustoće planarnih diskontinuiteta, praktički nema ograničenja dimenzija izvađenih blokova. To je svakako bio jedan od značajnih elemenata u gradnji plašta Arene.

Naknadne izmjene manjega dijela elemenata u plaštu sastojale su se u izmjeni pojedinih blokova, ali i krpanja. U prvom slučaju odstupilo se pri izboru kamena od izvornog materijala, korišten je kamen drugih značajki. Krpanje elemenata narušilo je mjestimice vizuelni sklad plašta Arene.

Današnje rekonstrukcije na plaštu Arene izvodi poduzeće KAMEN iz Pazina, koristeći izvorni kamen iz ležišta Vinkuran, odnosno antičke »Cava Romane«. Netom što je ugrađen, kamen se vizuelno ističe svojom bjelinom, ali će kroz relativno kratko vrijeme poprimiti svoju poznatu sivkastu patinu, čime će se izgubiti vizuelne razlike novo ugrađenih elemenata od kamena ugrađenog u doba antike.