PRELIMINARY RESULTS ON THE EROSION OF THE NORTHEASTERN CLIFF NEAR THE FORTRESS OF ORGAME / ARGAMUM

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Keywords: Cliffs erosion, landslides, the research of the Cape Doloșman cliffs evolution, Argamum, Dobrudja.

Abstract: To get a more realistic picture of urban development of ancient city Argamum, from the colonization era to Justinian's time, it is necessary to know the historic land shape as closely as possible. This study aims to reconstruct the outline of the cliff taking into account the scenario of a collapse generated by earthquake and the scenario of water erosion, initially by the Black Sea, followed by that of Lake Razelm after the deposit of sand seams. The method applied is based on simulating the evolution of erosion, based on existing data from the site of Argamum, using a calculation method applied in the design of buildings that encompass land slopes, which approximate their stable slope section, and a formula that assessing the necessary time erosion of the material resulted from cliff collapses. What we can state is that the shore – in the 18 meters high area roughly adjacent to the late Roman wall – has eroded with ~ 35 m ± 4 m in 1500 years and has eroded by an average of 16 ± 4 m in the period 500 BC - 500 AD. In the area where the cliff is less high, about 3 meters high, the predominant erosion is the long-term one, and the collapses did not play a significant role. In this area the erosion in 1500 years is about 24 m ± 2 m and the contour of the shoreline was 35 m ± 4 m more extended 2500 years ago.

Rezumat: Pentru a avea o imagine cât mai realistă a dezvoltarii urbane a cetății antice Argamum, din epoca colonizării până în epoca lui Justinian, este necesar să cunoaștem cât mai exact posibil forma uscatului din acea perioadă. Lucrarea de față încearcă să reconstituie conturul falezei luând în considerare scenariul prăbușirii generate de un cutremur și scenariul eroziunii sub acțiunea apei Mării Negre la început și a Lacului Razelm după depunerea cordoanelor de nisip. Metoda aplicată se bazează pe simularea evoluției eroziunii pornind de la date existente în situl de la Argamum, urmând o metodă de calcul aplicată în proiectarea construcțiilor care înglobează taluzuri de teren și care aproximează pantele stabile ale acestora, coroborată cu o formulă ce evaluează timpul de erodare a suprafeței prăbușite. Ceea ce putem afirma este că faleza – în zona înaltă de 18 metri, corespunzătoare în mare traseului adiacent falezei actuale a zidului de incintă roman târziu - s-a erodat cu ~ 35 m ± 4 m în 1500 ani și s-a erodat în medie cu 16 m ± 4 m în intervalul de timp 500 a.Ch. - 500 p.Ch. În zona unde faleza este mai puțin înaltă, în jur de cca. 3 m înălțime, eroziunea predominantă este cea de lungă durată, prăbușirile neavând un rol important. Aici eroziunea în 1500 ani este în jur de 24 m ± 2 m și conturul țărmului a fost cu 35 m ± 4 m mai în larg acum 2500 ani.

Argamum is one of the oldest ancient cities of Dobrudja. Situated in a part of Cape Doloșman,[1] Argamum lies on a promontory with varied heights (3-22 m) to the northeast, the terrain rolling down gently to the west. From a geological point of view, Cape Doloșman is situated in the North Dobrudja perimeter and was formed during the Late Cretaceous period, as part of the basin Babadag.[2] The settlement was inhabited during the Greco-Roman period until Justinian's time (6th century AD) when it declined sharply.[3] To get a more realistic picture of urban development in Antiquity, from the colonization era to Justinian's time, it is necessary to know the historic land shape as closely as possible. This study aims to reconstruct the outline of the cliff taking into account the scenario of a collapse generated by earthquake and the scenario of water erosion, initially by the Black Sea, followed by that of Lake Razelm after the deposit of sand seams.[4]

Research methods on cliff erosion are mainly based on observations over a certain period of time and on using extrapolations for future behavior. In the report on the cliff shore erosion in the Whangarei District, New Zealand,[5] the proposed formulas for the erosion of rocky cliffs are based on extrapolation of the observed annual mean value during a 50 years period.

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1 Mărgineanu Cârstoiu, Mănucu-Adameșteanu 1998.
2 Brustur, Anghel, Mălăgeanu 1998.
3 Mărgineanu Cârstoiu, Mănucu-Adameșteanu 1998.
4 *Ibidem*.
5 Liefting, Hamill, Ivamy 2010, p. 14.

Caiete ARA 2, 2011, p. 101-111, București.

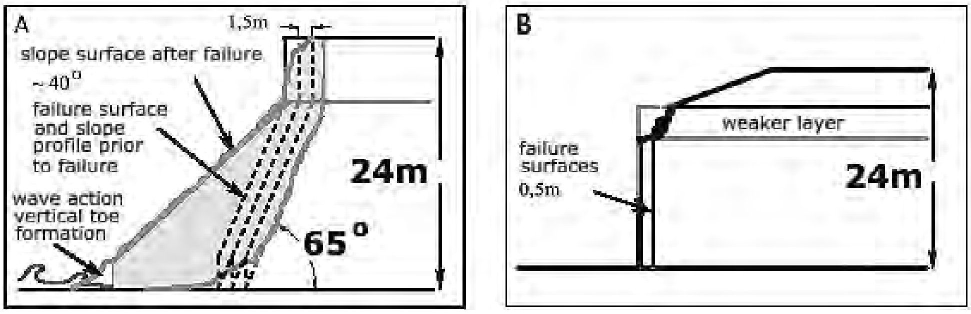

Fig. 1. The characteristic profiles of the cliffs after Collins, Kayen, Sitar 2007.

In the study of landslides along the coastline of the San Francisco coast line,[6] the proposed formulas are based on weekly observations of erosion from 2001 to 2006. It should be noted that the authors consider two types of cliffs, one consisting of cohesive lands and one consisting of non-cohesive lands.

The non-cohesive lands that are studied have a compressive strength not exceeding 30 kPa and an inclined profile. Those are characterized by the cutting angle (**Φ**) or the angle of the slope profile after failure and by the critical angle ($\boldsymbol{\alpha}_{cr}$) or the angle of the slope prior to failure. The value of the cutting angle (angle of collapse) is **Φ** ~ 40^0 and the value of the critical angle is $\boldsymbol{\alpha}_{cr}$ ~ 65^0. The typical crest failure is about 1.5 m (Fig. 1A).

The cohesive lands that are studied[7] have a compressive strength of up to 400 kPa and the failure surface is typically near-vertical. The typical crest failure has over 0.5 m length (Fig 1B).

The cliff-collapsed material behaves like a non-cohesive land.

Because we do not have data regarding the behavior of the cliffs of Cape Doloșman, we have adopted a different approach.

The method used in the research of the evolution of Cape Doloșman cliffs.

The method applied is based on simulating the evolution of erosion, based on existing data from the site of Argamum. In a first stage of our study we applied a simulation technique of landslides developed in 2004, which allows us to find the stable and the unstable section of lands.[8] In the second step we apply – for the erosion of the material resulted from collapses under the action of waves – a method based on assessing the necessary time for the erosion of a characteristic section of the cliff.[9]

The first phase, establishing the profile of the collapsed cliff. We considered that it is appropriate to use calculation methods applied in the design of buildings that encompass land slopes, which approximate their stable slope section. For our study it is important to determine the unstable section, in other words the area that would collapse. Therefore, in this stage of the study, we try to determine the failure shape section. For this purpose we apply the method mentioned above[10] – expressed by equations (1-3) – based on which we can determine the slope of the slipped surface of the cliff (**tg α**). The formulas we use are:

$$(1)\ tg\,\alpha_{cr} = tg\left(45^0 + \frac{\Phi}{2}\right);\ (2)\ c = \frac{H_{cr}\gamma}{2\,tg\,\alpha_{cr}};\ (3)\ tg\alpha = \frac{p + \sqrt{p^2 - 4c(p\,tg\,\Phi + c)}}{2c}$$

From equation (1), we obtain the angle after the slope starts to collapse ($\boldsymbol{\alpha}_{cr}$) knowing the angle after the collapse (**Φ**). We check the relation (1) by comparison with the results from the study of California's coastal cliffs[11] (**Φ** ~ 40^0 and $\boldsymbol{\alpha}_{cr}$ ~ 65^0) in the formula $65^0 = 45^0 + 40^0 / 2$.

6 Collins, Kayen, Sitar 2007.
7 *Ibidem*.
8 Has, Has 2004.
9 The 18 meters high cliff by the Late Roman road perimetric to the city wall.
10 Has, Has, 2004.
11 Collins, Kayen, Sitar 2007.

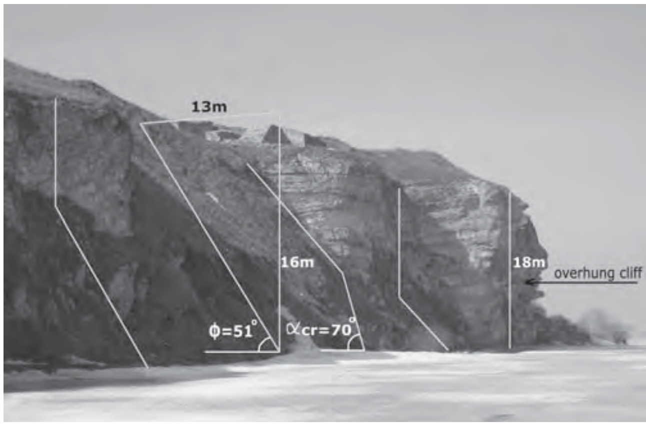

Fig. 2. Characteristic profiles of the cliff at Argamum

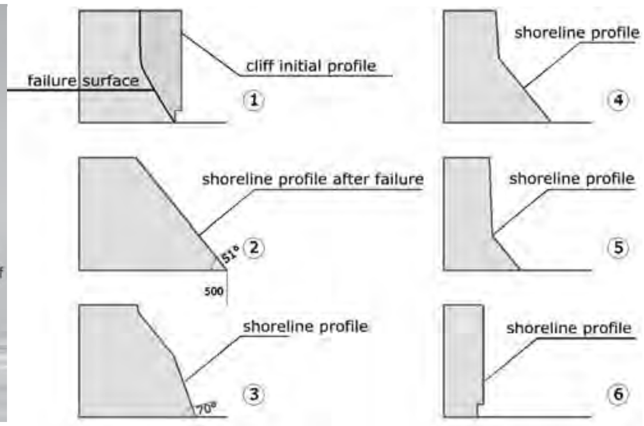

Fig. 3. Phases of an erosion cycle

From equation (2) we find the land cohesion parameter (**c**) knowing the critical height of the slope of a cohesive land ($\mathbf{H}_{cr}$), the unit weight of the rock (**γ**) and the critical slope angle ($\boldsymbol{\alpha}_{cr}$).

From equation (3) we obtain the slope of the sliding surface (**tg α**) knowing the gravity stress or the normal stress on a horizontal surface (**p**) - resulted from the weight of the land or from additional overload stress,[12] the land cohesion (**c**) and the internal friction angle of the rock (**Φ**).

Entering the values ($\mathbf{\Phi}$~51^0, $\mathbf{H}_{cr}$ = 18 m and **γ** = 2.4 g/cm^3) which are characteristic to the cliff Argamum (Fig. 2) in formulas (1-3) leads to the cliff collapsed profile, the width and its surface. We mention that, for a more realistic assessment of cliff erosion, we have taken into account an average value for **γ**, which corresponds generically to limestone (2.4 g/cm^3).[13]

Among the characteristics of the Argamum cliff profile, it is important to take into account in this study the presence of the overhung cliffs (Fig. 2) whose maximum depth reaches 2.5 m. Since the overhung rocks play a fundamental role in the collapse of the shoreline, in the simulations that we describe below, we allow the existence of this type of collapse due to overhung cliffs of this size.

The second stage. Setting the time erosion and the erosion length. To evaluate the erosion time of the landslide we define the notion of the **erosion cycle**.

The erosion cycle is the cycle after which the shoreline profile, after a collapse and after erosion, has the same angle as the horizontal surface of the sea. We distinguish six phases of erosion cycles (Fig. 3). A cycle has two characteristic sizes, the cycle time measured in years and the cycle length measured in meters. The cycle length is the distance by which the cliff has eroded during the cycle.

In the site of Doloșman Cape we can find all the stages of an erosion cycle (Fig. 2). Obviously, not all parts of the shore site are in the same erosion phase.

For assessing the erosion cycle time and the erosion cycle length, we have considered as a natural hypothesis that the section of the cliff before the collapse (Fig. 4, hatched area) has the same area as the cliff section after the collapse (Fig. 4, ABC area).

The formula that we propose to calculate the erosion time (see Appendix1) is:

(4) $$E_{ABC} = K\left(\frac{BC}{dx}\right)^2 \quad [years]$$

K is the ratio of BD / BC, characteristic to limestone, and **dx** is the distance by which the waves erode

[12] Generated for instance by an earthquake.
[13] Mihăilescu 1950, p. 646.

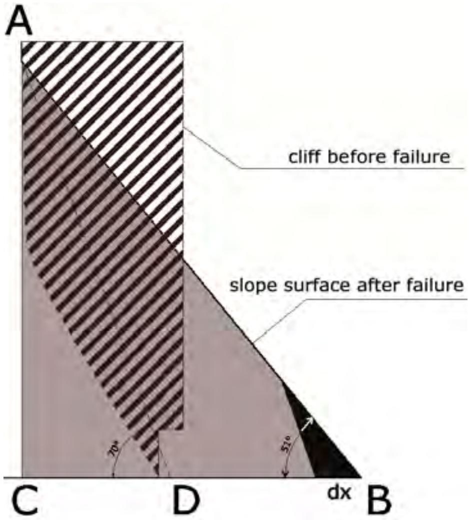

Fig. 4. The calculation approximation of the collapsed surface

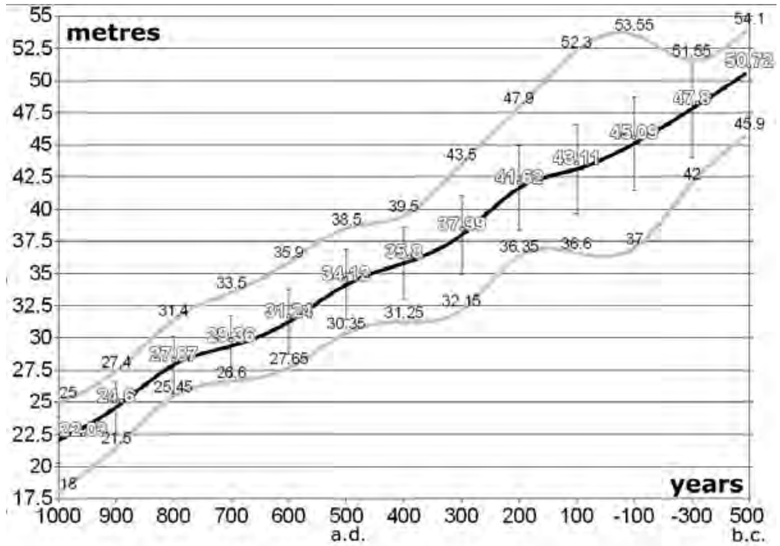

Fig. 5. Erosion of 18 m high cliff over time

the top of the rockslide within one year.

For computer erosion simulation we have considered:

Long term retreat erosion rate	0.01 m/year [14]
Wave erosion rate on intact rock	between 0.012 and 0.02 m/year [15]
Wave erosion rate on non-cohesive land **dx**	between 0.49 and 0.63 m/year

We have considered that **dx** is a function of the erosion surface of the top of the non-cohesive land (Fig. 4) and is proportional to ten times the speed of wave erosion on cohesive land.[16]

Cliff erosion simulation Orgame / Argamum. We distinguished two scenarios:

The scenario that in Justinian's time there was an earthquake which caused a major landslide.[17] We took into account an additional pressure (**p**) of at least 5200 g/cm^2 that gives a maximum landslide profile and we applied the method which determines the sliding surface[18] associated with formula (4) to evaluate the erosion time of the collapsed area (Table 1).

The conclusion of Table 1 expresses the fact that in the period 500 AD to the present date only one crash is possible that generates a maximum ~ 32.5 m erosion in the zone where the cliff is 18 m high. In other words before the earthquake, the land was more extended, by about 32.5 m, compared to the present coast line.

The second scenario, based on random unprovoked crashes and rockslides erosions, involves the procedure of determining the sliding surface[19] associated with formula (4) to evaluate the time erosion of the collapsed area as often as possible in the studied period. We took in consideration the possibility of three types of cycles of erosion. The cycle **A** involves collapses caused by erosion of one meter at the base of the shore wall and the erosion of the collapsed material (Table 2).

The conclusion of Table 2 expresses that the erosion cycle **A** can take between 324 and 540 years and

[14] Sunamura 1983.
[15] We considered a large range of values, between the eolian erosion and ocean erosion in the east New Zeeland shoreline, Collins, Kayen, Sitar 2007, p. 15.
[16] Collins, Kayen, Sitar 2007, p. 18; for sedimentary rocks *v.* Sunamura 1983.
[17] Mărgineanu Cârstoiu, Mănucu-Adameşteanu 1998, p. 254.
[18] Has, Has, 2004.
[19] *Ibidem*.

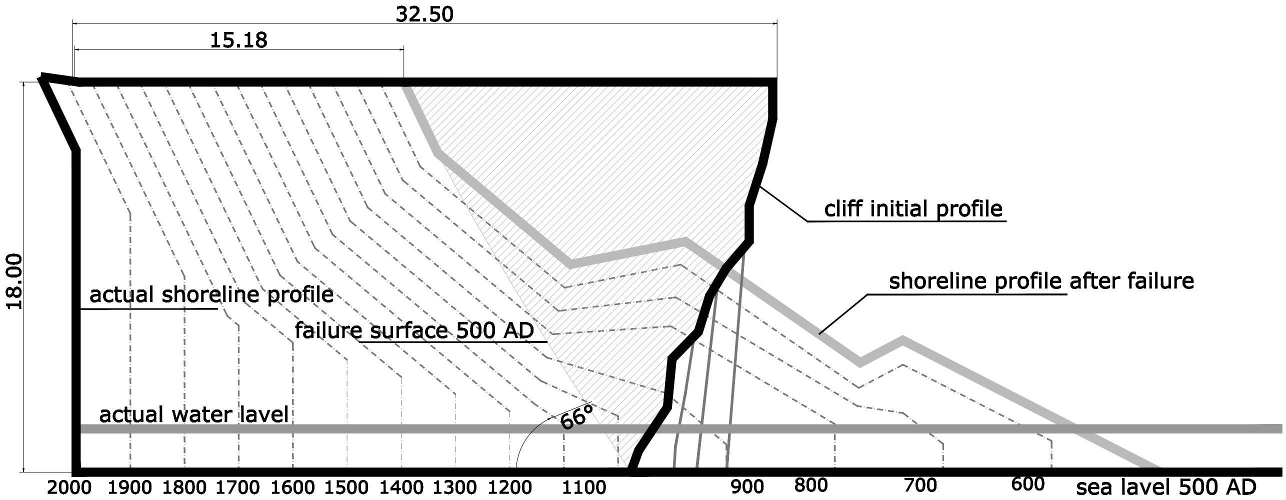

Fig. 6. Section feature in earth-quake scenario

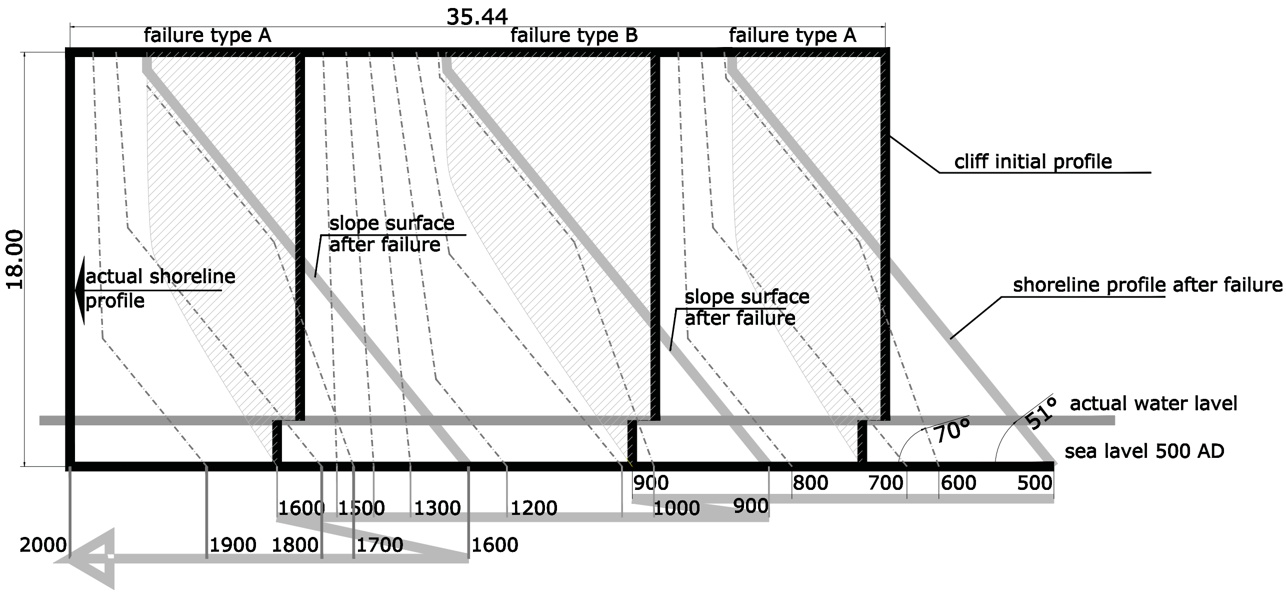

Fig. 7. Section suites feature unprovoked crashes

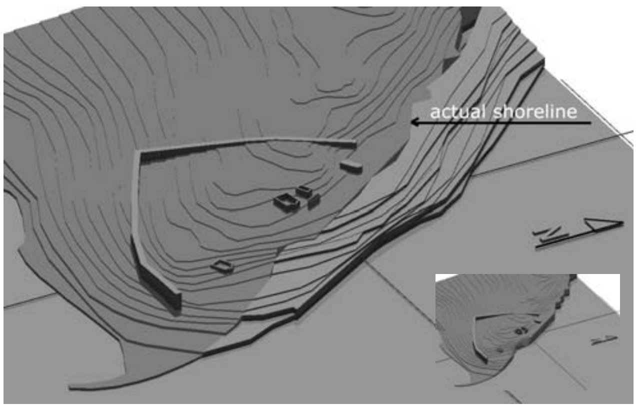

Fig. 8. 500 AD cliff simulation

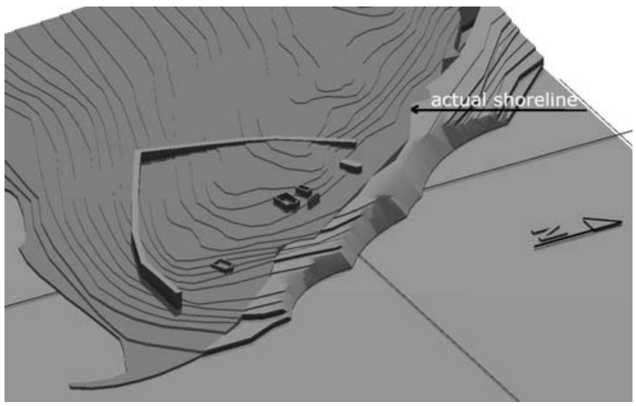

Fig. 9. 500 AD after feature scenario quake simulation

the resulting distance is 9.4 to 11.23 m.

The cycle **B** assumes collapses provoked by the erosion of overhung rocks with depths of 2 meters and the erosion of the collapsed material (Table 3).

The conclusion of Table 3 expresses the fact that the cycle of erosion B can take between 514 and 857 years, and that the erosion distance is 14.22 to 17 m.

The cycle **C** assumes collapses caused by erosion of 2.5 meters at the base of the shore wall and the erosion of the collapsed material (Table 4).

The conclusion of Table 4 expresses the fact that the erosion cycle **C** can take between 580 and 967 years and that the erosion distance is 15.61 to 18.65 m.

All three types of cycles of erosion may take up to 967 years. The period researched being of at least 1500 years, we can deduce that, under the unprovoked collapses scenario, combinations of erosion cycles are possible. In Table 5 possible combinations of cycles **A, B** and **C** were calculated (2 to 4 different cycles). The results were consolidated resulting in a maximum, minimum and average erosion value over time (Fig. 5).

Conclusions

The simulations were made by analyzing the current situation at the site. As shown in the study, we have considered two scenarios: a collapse caused by earthquake and unprovoked collapses. It is possible that the two scenarios have coexisted: in certain areas the cliff has fallen due to an earthquake (Fig. 6) and in other areas, the cliff falls were unprovoked (Fig. 7). Had we done this study 500 years ago we could have discerned what areas followed the first scenario and what areas followed the second one. The calculations and the presented method show that after some time the effect of an earthquake is erased, and one can consider an average evolution. Therefore, we cannot enunciate any hypothesis regarding the causes – earthquake or simple erosion – that led to the current coast line. What we can state is that the shore – in the 18 meters high area roughly adjacent to the late Roman wall – has eroded with ~ 35 m ± 4 m in 1500 years.

In the area where the cliff is less high, the predominant erosion is the long-term one, and the collapses did not play a significant role. In the area where the cliff is about 3 meters high, the erosion in 1500 years is about 24 m ± 2 m.

The interpretation of the results in Fig. 5, where we summarize the basic results from Table 5 and which shows the long-time evolution of erosion along the Argamense coast, reveals that the northeastern shore of the fortress in the high area has eroded by an average of 16 ± 4 m in the period 500 BC - 500 AD. Around 500 BC the cliff was wider in that area by approx. 50 m compared to the present time (Fig. 5). In the area which is now about 3 meters high, the contour of the shoreline was 35 m ± 4 m more extended 2500 years ago.

Looking at the graph in Fig. 5, it is interesting to note that the erosion evolution is not linear: between 100 BC and 100 AD the margin of error in determining the erosion is much higher than the average of ± 4 m for all the other chronological sequences.

In other words, taking into consideration the existing data regarding the site of Argamum and the method we have presented here, there are areas that appear more or less clear over the time line. We have a clearer picture of the coastline 1500 years ago (Figs. 8, 9) or even 2500 years, than for the period from around the beginning of the Common Era.

Using the described method deeper in the past (over 3000 years), we found that errors are becoming more significant, the "image" of the cliff becomes increasingly blurred, and the restoration of the shoreline is hazarded.

Appendix 1

The formula that we propose for computing the erosion time is:

$$E_{ABC} = K\left(\frac{BC}{dx}\right)^2 \quad [years] \quad (4)$$

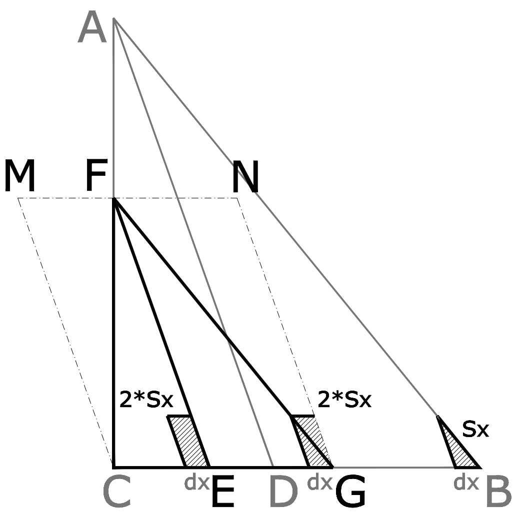

Fig. 10.

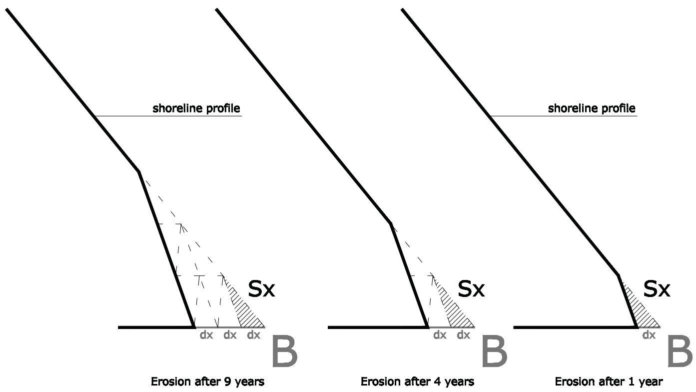

Fig. 11.

K is the ratio BD/DC characteristic to the limestone material and dx is the distance by which the waves erode the top of the collapsing surface during one year.

Proof:

ΔABC consists of ΔABD containing the non-cohesive material and ΔACD containing the cohesive material (Fig. 10). We have considered the erosion time E_{ACD} to be equivalent with E_{FCG} where the surfaces of the two triangles are equal and ΔFCG is made of non-cohesive material. It is as if ΔACD has collapsed and has taken the shape of ΔFCG. Thus, we have:

$$E_{ABC} = E_{ABD} + E_{ACD} = E_{ABD} + E_{FCG} = E_{ABD} + E_{FEG} + E_{FCE} \qquad (5)$$

Since $S_{ACD} = S_{FCG}$, we have that AC x CD = FC x CG (6). However, ΔFCG ~ ΔABC because the angle C is common and FG ‖ AB (both have the shape of a non-cohesive land). It follows that:

$$\frac{FC}{AC} = \frac{CG}{BC} \qquad (7)$$

From relations (6) and (7), it follows that $CG^2 = CD \times BC$ (8)

The erosion times of the triangular sections made out of non-cohesive material are equal to the ratio between the surfaces of the triangles and the surface of the top of the eroded slope during one year Sx, or, even more, with the ratio of the squares of the triangle basis and of **dx** square (Fig. 11).

Therefore:

$$E_{ABD} = BD^2 / dx^2 \text{ and } E_{FEG} = EG^2 / dx^2 \qquad (9)$$

We construct NG ‖ FE and MC ‖ FE, where NG≡FE and MC≡FE. The parallelograms MFEC and FNGE are formed. $S_{FNGE} = 2 \times S_{FEG}$ and $S_{MFEC} = 2 \times S_{FEC}$ (see the construction in Fig. 10). We have:

$$2 \times E_{FEG} = E_{FNGE} \text{ and } 2 \times E_{FEC} = E_{MFEC} \qquad (10)$$

Since:

$$E_{MFEC}=\frac{S_{MFEC}}{2\,x\,Sx}=\frac{FE\,x\,EC}{2\,x\,Sx}$$

and

$$E_{FNGE}=\frac{S_{FNGE}}{2\,x\,Sx}=\frac{FE\,x\,EG}{2\,x\,Sx}$$

it follows that

$$\frac{E_{MFEC}}{E_{FNGE}}=\frac{FE\,x\,EC}{FE\,x\,EG}=\frac{EC}{EG} \qquad (11)$$

From (10) and (11), we obtain: $\frac{E_{FEC}}{E_{FEG}}=\frac{EC}{EG}$ Since E_{FEG} = EG^2 / dx^2 (by equation (9)), we have:

$$E_{FEC}=E_{FEG}\,x\,\frac{EC}{EG}=\frac{EG\,x\,EC}{dx^2} \qquad (12)$$

From equations (5), (9) and (12), we obtain:

$$E_{ABC}=\frac{BD^2}{dx^2}+\frac{EG^2}{dx^2}+\frac{EG\,x\,EC}{dx^2}=\frac{BD^2}{dx^2}+\frac{EG\,x\,CG}{dx^2} \qquad (13)$$

Let K= BD/BC=EG/CG (14), (the characteristic parameter of the limestone). From (13), (8) and (14), we obtain:

$$E_{ABC}=\frac{K^2\,BC^2}{dx^2}+\frac{K\,x\,CG\,x\,CG}{dx^2}=\frac{K^2\,x\,BC^2}{dx^2}+\frac{K\,x\,CD\,x\,BC}{dx^2}$$

and

$$E_{ABC}=\frac{K^2\,BC^2}{dx^2}+\frac{K(BC-BD)BC}{dx^2}=\frac{K^2\,BC^2}{dx^2}+K\frac{BC^2}{dx^2}-\frac{K^2\,BC^2}{dx^2}$$

Thus

$$E_{ABC}=K\left(\frac{BC}{dx}\right)^2 \quad [years] .$$

This ends the proof.

Maximum tilt angle Degrees **ά max**	Internal friction angle Degrees **Φ**	Critical angle Degrees **ά cr**	Cohesion g/cm2 **C**	Slope height **H**	Slope length **D**	Slope	Rock density g/cm3 **γ**	Height M **H cr**	Overload g/cm2
50.91	50.91	70.45	766.89	16	13	1.23	2.4	18	5200

	Earthquake failure					
Altitude M	Normal stress g/cm2	Norm.+ overload stress g/cm2	Failure tangent	Failure angle	Failure angle Degrees	Length M
18	240	5440	1.86	1.08	61.72	0.54
17	480	5680	1.81	1.07	61.03	0.55
16	720	5920	1.76	1.05	60.44	0.57
15	960	6160	1.73	1.05	59.92	0.58
14	1200	6400	1.69	1.04	59.46	0.59
13	1440	6640	1.67	1.03	59.05	0.6
12	1680	6880	1.64	1.02	58.68	0.61
11	1920	7120	1.62	1.02	58.34	0.62
10	2160	7360	1.6	1.01	58.04	0.62
9	2400	7600	1.59	1.01	57.76	0.63
8	2640	7840	1.57	1	57.5	0.64
7	2880	8080	1.56	1	57.26	0.64
6	3120	8320	1.54	1	57.04	0.65
5	3360	8560	1.53	0.99	56.83	0.65
4	3600	8800	1.52	0.99	56.64	0.66
3	3840	9040	1.51	0.99	56.46	0.66
2	4080	9280	1.5	0.98	56.29	0.67
1	4320	9520	1.49	0.98	56.14	0.67

Failure length			11.15	M
Tangential stress			12483.81	g/cm2
Erosion rate	0.013	M/Year	19.5	M
Time	1500			Years
Overhung cliff depth			2	M
Earthquake erosion			**32.65**	**M**

Table 1. Erosion and landslides caused by earthquake.

Erosion cycle - Type A

Altitude M	Normal stress g/cm2	Failure tangent	Failure angle	Failure angle Degrees	Length M
18	480	100000	1.57	90	0
17	960	100000	1.57	90	0
16	1440	100000	1.57	90	0
15	1920	100000	1.57	90	0
14	2400	100000	1.57	90	0
13	2880	100000	1.57	90	0
12	3360	100000	1.57	90	0
11	3840	100000	1.57	90	0
10	4320	2.82	1.23	70.45	0.36
9	4800	2.09	1.12	64.38	0.48
8	5280	1.9	1.09	62.25	0.53
7	5760	1.79	1.06	60.82	0.56
6	6240	1.72	1.04	59.76	0.58
5	6720	1.66	1.03	58.92	0.6
4	7200	1.62	1.02	58.24	0.62
3	7680	1.58	1.01	57.67	0.63
2	8160	1.55	1	57.18	0.64
1	8640	1.53	0.99	56.77	0.66

Overhung cliff depth	1	M
Overload coefficient	2	

Failure length	5.66	5.66	5.66	5.66	5.66	5.66	M
Failure surface	119.83						M2
Slope length after failure	13.95	13.95	13.95	13.95	13.95	13.95	M
Wave erosion rate on intact rock	0.02	0.017	0.016	0.015	0.013	0.012	M/year
Long term retreat erosion rate	0.01	0.01	0.01	0.01	0.01	0.01	M/year
Wave erosion rate on noncohesive land **dx**	0.63	0.58	0.57	0.55	0.51	0.49	M/year
K	0.56	0.56	0.56	0.56	0.56	0.56	
Erosion time to verticaly profile	274.08	322.45	342.6	365.44	421.66	456.8	Years
Overhung cliff erosion time	50	58.82	62.5	66.67	76.92	83.33	Years
Erosion cycle time	324.08	381.27	405.1	432.11	498.58	540.13	Years
Erosion cycle length	9.4	9.88	10.08	10.31	10.87	11.23	M

Table 2. Erosion cycle A

Table 3. Erosion cycle B

Erosion cycle - Type B

Altitude M	Normal stress g/cm2	Failure tangent	Failure angle	Failure angle Degrees	Length M
18	720	100000	1.57	90	0
17	1440	100000	1.57	90	0
16	2160	100000	1.57	90	0
15	2880	100000	1.57	90	0
14	3600	100000	1.57	90	0
13	4320	2.82	1.23	70.45	0.36
12	5040	1.98	1.1	63.19	0.51
11	5760	1.79	1.06	60.82	0.56
10	6480	1.69	1.04	59.32	0.59
9	7200	1.62	1.02	58.24	0.62
8	7920	1.56	1	57.42	0.64
7	8640	1.53	0.99	56.77	0.66
6	9360	1.5	0.98	56.24	0.67
5	10080	1.47	0.97	55.8	0.68
4	10800	1.45	0.97	55.43	0.69
3	11520	1.43	0.96	55.12	0.7
2	12240	1.42	0.96	54.84	0.7
1	12960	1.41	0.95	54.6	0.71

Overhung cliff depth	2	M
Overload coefficient	3	

Failure length	8.07	8.07	8.07	8.07	8.07	8.07	M
Failure surface	181.35						M2
Slope length after failure	17.17	17.17	17.17	17.17	17.17	17.17	M
Wave erosion rate on intact rock	0.02	0.017	0.016	0.015	0.013	0.012	M/year
Long term retreat erosion rate	0.01	0.01	0.01	0.01	0.01	0.01	M/year
Wave erosion rate on noncohesive land **dx**	0.63	0.58	0.57	0.55	0.51	0.49	M/year
K	0.56	0.56	0.56	0.56	0.56	0.56	
Erosion time to verticaly profile	414.8	488	518.5	553.06	638.15	691.33	Years
Overhung cliff erosion time	100	117.65	125	133.33	153.85	166.67	Years
Erosion cycle time	514.8	605.64	643.5	686.4	792	857.99	Years
Erosion cycle length	14.22	14.95	15.26	15.61	16.46	16.99	M

Table 4. Erosion cycle C

Erosion cycle - Type C

Altitude M	Normal stress g/cm2	Failure tangent	Failure angle	Failure angle Degrees	Length M
18	840	100000	1.57	90	0
17	1680	100000	1.57	90	0
16	2520	100000	1.57	90	0
15	3360	100000	1.57	90	0
14	4200	100000	1.57	90	0
13	5040	1.98	1.1	63.19	0.51
12	5880	1.77	1.06	60.53	0.57
11	6720	1.66	1.03	58.92	0.6
10	7560	1.59	1.01	57.8	0.63
9	8400	1.54	0.99	56.97	0.65
8	9240	1.5	0.98	56.32	0.67
7	10080	1.47	0.97	55.8	0.68
6	10920	1.45	0.97	55.38	0.69
5	11760	1.43	0.96	55.02	0.7
4	12600	1.41	0.95	54.72	0.71
3	13440	1.4	0.95	54.45	0.71
2	14280	1.39	0.95	54.23	0.72
1	15120	1.38	0.94	54.03	0.73

Overhung cliff depth	2.5	M
Overload coefficient	3.5	

Failure length	8.56	8.56	8.56	8.56	8.56	8.56	M
Failure surface	199.04						M2
Slope length after failure	17.98	17.98	17.98	17.98	17.98	17.98	M
Wave erosion rate on intact rock	0.02	0.017	0.016	0.015	0.013	0.012	M/year
Long term retreat erosion rate	0.01	0.01	0.01	0.01	0.01	0.01	M/year
Wave erosion rate on noncohesive land **dx**	0.63	0.58	0.57	0.55	0.51	0.49	M/year
K	0.56	0.56	0.56	0.56	0.56	0.56	
Erosion time to verticaly profile	455.26	535.6	569.08	607.01	700.4	758.77	Years
Overhung cliff erosion time	125	147.06	156.25	166.67	192.31	208.33	Years
Erosion cycle time	580.26	682.66	725.33	773.68	892.71	967.1	Years
Erosion cycle length	15.61	16.41	16.75	17.13	18.06	18.65	M

Wave erosion rate on intact rock	0.02	0.017	0.016	0.015	0.013	0.012	M/year
Erosion cycle length – Type **C**	15.61	16.41	16.75	17.13	18.06	18.65	M
Erosion cylce time – Type **C**	580.26	682.66	725.33	773.68	892.71	967.1	Years
Erosion cycle length – Type **B**	14.22	14.95	15.26	15.61	16.46	16.99	M
Erosion cycle time – Type **B**	514.8	605.64	643.5	686.4	792	857.99	Years
Erosion cycle length – Type **A**	9.4	9.88	10.08	10.31	10.87	11.23	M
Erosion cycle time – Type **A**	324.08	381.27	405.1	432.11	498.58	540.13	Years
Compositions cycles							
Erosion cycle length – Type **C**					18.06	18.65	M
Erosion cycle – Type **C**					892.71	967.1	Years
A, C composition cycles length	25.01	26.3	26.83	27.44	28.94	29.87	M
A, C composition cycles time	904.34	1063.93	1130.43	1205.79	1391.29	1507.23	Years
B, C composition cycles length	29.83	31.37	32.01	32.73	34.52	35.63	M
B, C composition cycles time	1095.06	1288.3	1368.82	1460.08	1684.7	1825.1	Years
A, B composition cycles length	23.62	24.84	25.34	25.92	27.33	28.21	M
A, B composition cycles time	838.88	986.91	1048.6	1118.5	1290.58	1398.13	Years
A, A, C composition cycles length	34.41	36.18	36.91	37.75	39.81	41.1	M
A, A, C composition cycles time	1228.42	1445.2	1535.53	1637.89	1889.88	2047.37	Years
A, A, B composition cycles length	33.02	34.72	35.43	36.23	38.2	39.44	M
A, A, B composition cycles time	1162.96	1368.19	1453.7	1550.61	1789.17	1938.26	Years
A, B, B composition cycles length	37.84	39.79	40.6	41.52	43.79	45.2	M
A, B, B composition cycles time	1353.67	1592.56	1692.09	1804.9	2082.58	2256.12	Years
A, B, C composition cycles length	39.23	41.25	42.09	43.04	45.39	46.86	M
A, B, C composition cycles time	1419.14	1669.57	1773.92	1892.18	2183.29	2365.23	Years
A, A, B, C composition cycles length	48.63	51.13	52.17	53.36	56.27	58.08	M
A, A, B, C composition cycles time	1743.22	2050.84	2179.02	2324.29	2681.87	2905.36	Years
A, A, B, A composition cycles length	47.24	49.67	50.69	51.83	54.66	56.43	M
A, A, B, A composition cycles time	1677.75	1973.83	2097.19	2237.01	2581.16	2796.26	Years
A, A, B, C composition cycles length	53.45	56.2	57.35	58.65	61.85	63.85	M
A, A, B,C composition cycles time	1933.93	2275.22	2417.42	2578.58	2975.28	3223.22	Years

Table 5. Compositions of the cycles of erosion

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