ABSTRACT – Petra and Beida are two adjacent archaeological sites in southern Jordan characterised by both a striking monumental heritage, and an imposing geomorphologic landscape. These sites, besides preserving important remains of protohistorical cultures, contain the most important Nabatean vestiges of the entire Middle-East and have more recent, Roman, Crusade and Islamic, significant remains as well. On account of their archaeological and monumental heritage, the two sites are included in the UNESCO’s World Heritage list and are the heart sites of a National Archaeologic Park. Less known, yet not less interesting, is the rich and striking geomorphologic heritage of the Petra-Beida area, characterised by tectonic troughs alternating with steep mountains riddled by canyons and passages to form a town of rocks. The intrinsic beauty and significance of landforms and landscapes could be the driving elements for touristic and educational aims, towards an integration of the geomorphologic heritage with the archaeological-monumental one. In this connection, both Nabatean water management systems and historical burials of monumental areas by flood events are primary links to an integrated approach, suitable for being exploited for tourism and cultural goals. Ongoing researches by means of GPS systems and laser scanning allowed us the detailed reconstruction of both parts of the Nabatean water systems and historical alluvial fills. The digital elaboration and modelling, as well as computer simulations and reconstructions, besides their intrinsic scientific meaning, can be powerful tools for tourism improvement and educational work.

KEY WORDS: Geoarchaeology, Geotourism, Hydraulic System, Alluvial fill, Petra, Jordan.

Petra and Beida (Jordan): two adjacent archaeological sites up to an exploitation of geomorphology-related topics for a cultural and touristic development

Petra e Beida (Giordania): due siti archeologici confinanti idonei per una valorizzazione di temi connessi con la geomorfologia nel quadro di un loro potenziamento turistico - culturale

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archeologico-monumentale. In tale contesto, sia i sistemi Nabatei di gestione delle acque sia le testimonianze storiche di aree monumentali seppellite da eventi di piena sono elementi chiave per un approccio integrato archeo-geomorfologico adatto anche a scopi turistici e culturali. Ricerche tuttora in corso con sistemi GPS e laser scanner hanno permesso di ottenere una dettagliata ricostruzione sia dei sistemi di approvvigionamento idrico dei nabatei, sia delle colmate alluvionali. L’elaborazione digitale e la modelizzazione, così come simulazioni virtuali e ricostruzioni al computer, ac- canto al loro significato scientifico intrinseco, possono rappresentare anche efficaci strumenti per la valorizzazione turistica e per la didattica.

PAROLE CHIAVE: Geoarcheologia, Geoturismo, Sistemi Idraulici, Riempimenti alluvionali, Petra, Giordania.

1. – INTRODUCTION

Petra – UNESCO World Heritage Site since 1985, National Archaeological Park established in 1993 by the Jordanian Department of Antiquity and the District of Ma’an under the UNESCO’s auspices (UNESCO, 1991) - is a unique place for the splendid blend of landforms and architectural elements evocatively complementing one another. On a smaller scale, the same elements characterise the near Beida - not by chance known with the telling name of “Little Petra” - which, besides being an important protohistorical site (COMER, 2003), is part of the same World Heritage Site of Petra itself. Being the destination of a crowd of tourists, the Petra-Beida site is justly famous all over the world: nevertheless, only the aesthetic beauty rather than the intrinsic significance of its notable geologic-geomorphic heritage is well known and exploited. Indeed quite every tourist guide or leaflet reports about issues as the impressive physical landscape, the astonishing chromatism of Petra and Beida sandstones, the imposing Nabatean water system, the deviation of the Siq in order to prevent flooding and, not least, the serious problem of monument weathering. The geomorphic importance of this site is somehow implicit in the first denomination of “Naturalistic and Archaeological Park” already given by Jordanian author- 10ities to the initial protected area. Indeed, the importance –also for cultural and touristic purposes- of geologic-geomorphic features is substantiated by several papers both by earth scientists (e.g. PANIZZA & PIACENTE, 2003; FRANCHI et alii, 2004 and 2005) and archaeologists (e.g. LUBICK, 2004 ZAYADINE, 1992; PALUMBO et alii, 1995). Specifically, several places in the Petra-Beida territory could be regarded as sites of specific geologic and geomorphologic interest (i.e. geosites or geomorphosites): namely, the Siq (cf. PANIZZA & PIACENTE, 2003, p. 289) and the canyon housing the monumental area of Beida are both suitable for being improved as geomorphosites (sensu PANIZZA, 2001). Nevertheless, being the area included in an already formalized (year 1985) UNESCO site of major monumental, archaeological and historical value, the geologic-geomorphic elements are suitable for being improved and exploited as primary value-added components in an integrated cultural and touristic framework. A key to such integration is how the Nabatean and Roman cultures adapted to a hard physical environment, a topic already known to and attractive for many visitors. Indeed, a first major issue is the impressive Nabatean-Roman water-system, consisting of thousands of channels chiselled into the rocky slopes and flowing to cisterns and fountains. A further attractive issue is concerned with historical flood-evidence throughout the entire Petra-Beida territory and the impressive Nabatean works addressed to flooding prevention.

The aim of this paper is a concise description of the geologic and geomorphic framework of the Petra-Beida area (fig. 1) in connection with both the exploitation of the physical environment by the ancient cultures and the modern weathering and conservation problems. Ongoing surveys and 3-D modelling of both the Petra-Beida hydraulic system and the alluvial fill in the Siq, performed in the framework of an international co-operation between Urbino University, Italian CNR and French CNRS, are also briefly reported. Actually, the results of such studies, besides their intrinsic scientific meaning, could give an innovative impul- se to a better popularisation -for tourism pur- poses as well- of both the fascinating topic of skilful water exploitation by the inhabitants of Petra and Beida, and the flooding impact on this territory during historical times (HENRY, 1985; RAIKES, 1985).

2. – GEOLOGIC AND GEOMORPHOLOGIC OUTLINE

Petra and Beida (fig. 1) are situated on the eastern side of the Dead Sea–Wadi Araba tectonic depression (Dead Sea rift, according to BENDER, 1968; MART, 1991 cum bibl.; a transform valley, according to GARFUNKEL & BEN AVRAHAM, 1996), a c.ca 15 km-wide topographic low formed by shearing along the transform separating the Arabian and Sinai plates (cf. SNEH, 1996; GINAT et alii, 1998, cum bibl.). Petra and Beida are placed in a rugged mountain area, characterised by heights ranging from c.ca 850 m to over 1.000 m a.s.l. Such mountain
territory corresponds to the regional escarpment separating the Wadi Araba tectonic trough (south of the Dead Sea, RAIKES, 1985) from a regionally-extended high carbonate plateau (Qa’ Al Jafr, to the East). The Petra-Beida area as a whole is part of the Seil Wadi Musa hydrographic basin, which drains from the eastern margin of the carbonate plateau to Wadi Araba with an overall E-W stream flow-direction. The main stream (i.e. Seil Wadi Musa) results from the junction of two main tributaries - namely Wadi es Siq and Wadi Siq el Ghrurab-Wadi Beida - flowing across Petra and Beida, respectively.

In the Petra-Beida area, the Precambrian crystalline rocks of the Arabian-Nubian shield are cut by an almost flat late pre cambrian–early Cambrian peneplain unconformably overlain (fig. 2) by Cambro-Ordovician, mostly quartz-rich arenitic, terrains (BENDER, 1974) accounting for the weathering and erosion of the basement itself (cf. AVIGAD et alii, 2005 cum bibl.). The local stratigraphic succession (cf. QUENNEL, 1951; BENDER, 1974) starts with the thin (locally less than 50 m in thickness) Salih Arkose arenitic formation, overlain by a thick (locally more than 500 m in thickness) suite of both paralic and shallow-water (e.g. SELLEY, 1972; AMIREH et alii, 1994), massive and/or poorly stratified Cambrian-Ordovician quartzarenites belonging to the Umm Ishrin and Disi formations (BENDER, 1974 cum bibl.; FRANCHI, 2002). An important - although hardly detectable at the outcrop in the Petra-Beida area - regional unconformity separates the latter from the overlying, entirely fluvial (AMIREH, 1997), quartzarenites of the Early Cretaceous Kurnub formation. The local succession is closed by the Ajlun Group (QUENNEL, 1951), consisting of marly-calcareous platform formations (SCHULZE et alii, 2005 cum bibl.) over 500 m thick.

The hand-carved rock monuments of Petra and Beida (cf. figures 6B, 10, 16) are entirely cut in the sandstones of Umm Ishrin and Disi formations (AMIREH et alii, 2001; FRANCHI, 2002); moreover, many quarries in use in different historical period attest to the fact that the same sandstones were employed as construction material (FRANCHI, 2002). Since the rock characters largely account for weathering-related conservation problems, it is worth emphasizing some lithologic and petrographic attributes of the two formations above (fig. 2). The Umm Ishrin formation is mostly composed of medium-coarse grained, well-sorted quartz (in percentage as high as 80%) combined with highly variable proportions of cements consisting (cf. AMIREH, 1991) of authigenic kaolinite, hematite, goethite and subordinate poikilotopic calcite (FRANCHI & PALLECCHI, 1995). Cementation by both quartz overgrowths and pressure solutions is rather frequent. Quite common are needle-shaped, not always identifiable, mineral inclusions. The most common detrital grains recognised under optical microscope are zircon, tourmaline, titanite and occasional crandallite (FRANCHI & PALLECCHI, 1995). The occurrence of several 10-15 cm-tick arenaceous lenses/layers with amounts of hematite cement as high as 50%, is a peculiarity of the Umm Ishrin formation. Dioclases filled with fibrous-radial hematite have also been observed. The first occurrence of whitish, thin-bedded arenites marks the rather uncertain boundary between the sandstones of the Umm Ishrin formation and those of the overlying Disi formation. This latter consists entirely of light grey, fine to medium-coarse grained quartzarenites, characterised by recurrent lenses of well
rounded centimetric quartz pebbles. From a petrographic standpoint, the sandstones of the Umm Ishrin and Disi formations are quite similar, except for a considerable decrease of both iron oxides and hydroxides cements. The Disi accessory minerals are the same as for the Umm Ishrin and are generally found with the same frequency.

The geomorphology of the Petra and Beida territory strongly reflects both differential erosion and recent tectonics. Several distinct landforms, such as sharp stream deflections and alignments of scarps, canyons and ridges, account for recent displacement along the structural fault-system affecting the area. On the contrary, a large number of examples in which the control on landforms by the tectonic structures must be regarded as passive -i.e. simply produced by differential erosion processes independent (or quite independent) from the recent deformation history of the region- are apparent. At a large scale, a c.ca N-S trending, high escarpment (fig. 3) accounts for a marked eastward erosional retreat of the western margin of the carbonate plateau, favoured by the thick weak layer represented by the arenites of the Kur-nub formation and the marls of the Naur formation (base of the Ailun Group, figures 2, 3). The escarpment faces a wide terrace-like area accounting for the resistant top of the Palaeozoic quartzarenites (i.e. Umm Ishrin and Disi formations), deeply dissected by an complex net of canyons and narrow throughs concealing the sites of Petra and Beida. Indeed, in such rocks the tectonics related to the Dead Sea-Wadi Araba transform system has produced steep, high rock-relieves, spaced out by fault-bordered narrow troughs as the “Petra Valley” (fig. 4) (cf. BARJOUS & MIKBEL, 1990; FRANCHI, 2002). Since the arenites are always intensely faulted and fractured (cf. figs. 3, 4), streams trenching in deep, narrow gorges as well as weathering, aeolian, and runoff processes shaped such area in a tangle of cliffs, pillars and passages to form an imposing “town of rocks” (FRANCHI et alii, 2004). The intricate system of canyons and passages that characterise the area includes both the Siq, the c.ca 4-km narrow (in places less than 4 m wide and more than 60 m high), hidden way to Petra (cf. PANIZZA & PIACENTE, 2003; FRANCHI et alii, 2004) and the cramped canyon where the
monumental area of Beida is placed (fig. 5). Such canyons belong to a riddled minor stream-net, controlled by the complex fault-fracture systems affecting the Palaeozoic quartzarenites and joining the Seil Wadi Musa main stream.

Weathering is certainly one of the most effective processes in the Petra-Beida area, able both to mould landforms and to deteriorate the monumental heritage (fig. 6). The weathering effectiveness on natural landforms is underlined by a large abundance of niches, honeycomb-structures and tafoni, and by rounded and spheroidal rock-surfaces as well (cf. figs. 3, 6A). On both monuments and natural surfaces, hardening of external rock-surfaces is a usual phenomenon.Likened generated oxalates, at least in the documented examples (case hardening, DORN, 2004) are responsible for such weathering-related biological action, able to exert a partial protection of the rock-surface itself from further degradation,
so often allowing tafoni-like forms to develop. With respect to the historical and artistic heritage conservation, the principal causes of degradation depend on complex interactions of mechanical, chemical, and in part anthropical processes (cf. Alouby et alii, 1993; Franchi & Pallecchi, 1995; Franchi et alii, 1999; Paradise, 2005). Indeed, the principal—or in any case a primary—mechanism of weathering depends on the thermal stresses (i.e. thermoclastism) suffered by sandstone grains (quartz above all) for insolation changes, night drops in temperature, etc. The loosened grains can be removed from the rock-surface by gravity, wind, rain-splash, runoff, etc. In this concern, it is worth emphasizing that both in Petra and Baida, running waters coming from higher areas usually flow all over the facades of the monuments, largely contributing to the decaying of the architectural elements (e.g. Franchi, 2002; Wedekind, 2005). A second important cause of weathering processes/monument decay peculiar to the area of Petra-Baida (e.g. Ed Dehir, Petra) is related to salts of varying chemism, abundant all along sandstone fractures and/or faults, and the origin of which is still matter of working hypothesis. Such salts, besides producing—also owing to the presence of iron sulphate hydrate (acid hydrolysis with pH 2)—a chemical corrosion on many sandstone cements, are responsible for mechanical aloclastic processes related to cycles of salt dissolution-precipitation (fig. 7). Chemical and mineralogical analyses carried out

Fig. 6 – Weathering effects on the Paleozoic sandstones: A – tafoni, Umm Ishrin formation, Petra; B – facade of the Obelisk Tomb, Disi formation, Petra.

– Effetti dell’alterazione delle arenarie paleozoiche: A – tafoni, Formazione dell’Umm Ishrin, Petra; B – facciata della Tomba degli Obelischi, Formazione del Disi, Petra.

Fig. 7 – Microcrystals of chlorides and sulphates from weathered sandstones on the inside of a Nabatean tomb.

– Microcristalli di cloruri e di solfati prodotti dall’alterazione delle arenarie nella parte interna di una tomba Nabatea.
on a large number of samples has established (FRANCHI et alii, 1999) the presence in varying proportions of sodium chloride (predominant) together with potassium chloride, nitrates (deriving from the anthropisation of the tombs) and calcium sulphate. Although largely controlled by the tectonic structure and lithology, the Petra-Beida area also shows a significant association of landforms (mainly depositional ones) related to climatic causes. The occurrence of aeolian products and landforms deriving from weathering processes typical of arid and semi-arid regions is rather obvious. Nevertheless, less obvious depositional landforms -often relic and related to past climatic conditions- are recognisable all over the Petra-Beida territory. In this connection, it is worth reporting several terrace-alluvium patches scattered on the hilltops and along the hillsides of the Petra Valley tectonic depression and partially correlatable with the remnants of ancient pedimentary surfaces. These latter are covered by more or less thick alluvial-fan deposits, sometimes deeply dissected and terraced, sometimes well preserved or only partially dissected (e.g. the piedmont area of Beida), anyhow likely to be related to upper Pleistocene relatively cold and humid depositional stages (FRANCHI, 2002).

3. – PHYSICAL ENVIRONMENT CONSTRAINTS AND CULTURAL OUTCOMES

The territory of Petra and Beida bears the remainders of very ancient cultures (cf. CLARK, 1987), every so often substantiated by important archaeological remains. Here, the remains of archaic cultures definitely co-exist and overlap with relatively recent vestiges, e.g. Crusader and Islamic. Petra is the crucial site of the Nabatean culture, known above all for a huge concentration of monumental tombs of Hellenistic inspiration (cf. fig. 16). Beida, in turn, is well known among archaeologists for its masonry architecture and other attributes of agricultural-farming settled village (fig. 8) dating back as long as the 9th millennium B.C., with older hunting occupations from about the 12th millennium B.C. (COMER, 2003).

The geomorphologic setting of the Petra-Beida territory has acted as an ideal background for the inhabitants to evolve from nomadic to resident conditions (e.g. BiENKUWSKI, 1995). This very change brought about the deep anthropogenic modifications which made this site unique. As a matter of fact, the prehistorical-protohistorical cultures –including the Edomite one– took advantage of landforms without significantly modifying them (e.g. KIRKBRIDE, 1985). Indeed, their settlement, mainly on the foothills, has been probably favoured by the vicinity of wadies and springs, although other morphologic factors such as good drainage conditions, positions out of both flash flooding and rock fall hazard must have been important in the ultimate settlement choice (cf. COMER, 2003). In this concern, it is worth emphasizing that Baida protohistorical settlement exploits an alluvial terrace (fig. 8), and still in its zenith (7th-6th millennium B.C.), the nearby stream has been its major water source. The Nabateans themselves –who gradually supplanted the Edomites between the 6th and the 4th century B.C.– got an undoubted advantage from the tangled geomorphology of the Petra-Beida area (e.g. PANIZZA AND PIACENTE, 2003; FRANCHI et alii, 2004). Indeed, the built Petra town is placed into a deep tectonic depression, out-of-the-way and easy to defend because flanked by cliffs (fig 4) and reachable without difficulty only through a narrow and
hidden passage through the mountain (the “Siq”, i.e. crack in the rock); it is worth emphasizing that the geomorphology of the area hindered in some degree also the Roman conquest of the town (cf. Parker, 1987), dating to 106 A.D. The monumental Nabatean Beida, in turn, is set in a narrow, hidden canyon (fig. 5) cutting a steep rock relief riddled by canyons and crevices. Besides being an ideal place to live in because of its geomorphologic setting, the Petra-Beida area benefits from a favourable climate, since its mountains protect it from both north-eastern cold winds and south-western warm ones. Being water the primary need, both the first Nabatean settlement and the earlier stages of town development, were certainly favoured by springs fit to supply water to both the local community and caravans. The growth of Petra as a big caravan town (e.g. Zayadine, 1985) got the Nabateans, innately skilled at water exploitation (they came from the arid Arabian lands), to achieve an impressive system of watering, suitable for over 30.000 inhabitants living there in the 1st century B.C.-2nd century A.D. On the contrary, the neighbouring Beida valley, reproducing and emphasizing Petra’s geomorphologic characteristics on a small scale, became the heartland of both Nabatean religion and politics.

The watering-system construction, the necessity to maintain the Siq passage free from debris as well as the development of a monumental “town of deads” obtained by chiselling a multitude of tombs out of the maze of rock walls all around the built-up town, are just the main reasons for the manifold landscape modifications which make the Petra-Beida site such an unique place. Nevertheless, the necessity to prevent natural hazards, as floods or the decay of in-use architectonic elements, compelled the Nabateans to implement flood-control works as well as to equip the majority of architectural structures with drainage systems (e.g. Franchi, 2002; Wedekind, 2005). In conclusion, although different geomorphologic processes (e.g. mass movements, weathering, aeolian activity) and tectonic factors (earthquakes) influenced the Nabatean culture, water was the primary one. Hence, the fascinating subject of water exploitation and water related hazard—an issue still today able to exert a great appeal on both scholars and tourists— is what we will focus on in the next pages.

4. – THE ANCIENT WATER SYSTEM OF PETRA AND BEIDA: THE AL HABIS SITE

Umm al Biyara – the name of which means “Mother of the Cisterns” – is the first example (probably Edomite) of large cisterns chiselled out of rock to collect rain water. Later on, Nabateans developed impressive water supply systems based on channels and cisterns. Specifically, the Nabatean water-system, inherited in a second time by Romans, consists of imposing cisterns, dams and hierarchized channel nets (figs. 9, 10). Indeed, taking advantage from both the topographic and lithologic characteristics of the area, the construction of a dense net of channels has delivered the scarce rainfall water into a multitude of cisterns chiselled
out of sandstone slopes. Such complex hydraulic engineering works both ensured an adequate water supply for the local population and mitigated the effects of monument degradation produced by rainwater runoff down their facades (FRANCHI, 2002; LUBICK, 2004; WEDEKIND, 2005). Today, the drainage system is no longer operational, as it has been filled up with debris and broken up by landslides. Nevertheless, the elements constituting the water-supply system, often carved in rock, maintain even nowadays monumental characteristics and display an unquestionable skill both in hydraulics and in exploiting an unfavourable environment.

Taken into account the importance of the water providing system in both archaeological and geologic-geomorphologic studies, a detailed survey of the water collection system of Petra and Beida archaeological sites has been started in 2004 in order to ascertain the precise function of each single part of the system. Field work has been started in the sample-site of Al Habis (fig. 11), the choice of which accounts for both its small size and its effectiveness as a model system for testing an appropriate field surveying method. The most important water collection channels -chiselled out of the rocky slopes (Umm-Ishrin sandstones) and still visible today- run all around the Al Habis site, along the so-called “third bench” (fig. 11). Since the inaccessible nature of the site prevents the use of a GPS system, to rapidly acquire a cinematic view of the points, measurements were made using the Total Station Trimble 5600 (FRANCHI et alii, 2005). The employment of this equipment allowed both a quick survey of their course and mapping of their position on a 3-D model of the Al Habis rock-spur. 3-D reconstructions of the geometric shape of each single section of the channels was instead obtained by photogrammetry (DRAP et alii, 2001). The result of this operation is an extremely detailed and measurable 3-D model of the channels (fig. 12) that can be used both for classification and study purposes as well as for virtual tests and simulations on the flow of the waters.

The creation of such a detailed model allowed us to extract information on sections along the course of a channel and to estimate the degree of deterioration of the side walls of the water channel. A forthcoming development of this analyses is the spatial and functional survey of the water channeling system in order to gain an correct un-
derstanding of the complex network of cisterns and channels. The model can be used for channel classification, flow simulation, virtual tests, and other scientific objectives as well as for to develop projects of restoration of parts of the water providing system with a consequent mitigation of runoff damages to the facades of the monuments. An exploitation in touristic and educational frameworks is also a natural development of scientific results and flow simulations.

5. – EVIDENCE OF HISTORICAL ALLUVIAL EVENTS IN PETRA

The Nabatean dependence on water is sanctioned in their rituals, thus mirroring its sacredness; such cultural trait is testified by the large number and size of cisterns and pools connected with sanctuaries and sacred places (fig. 10). Neither the more ephemeral and aesthetic forms of water employment were disregarded by the Nabateans; indeed they built up pools, fountains and gardens both in the urban area and in its neighbourhood (an aspect emphasised after 106 A.D. by the Romans). However, to Petra, water didn’t mean just survival, aesthetics and rituality: it represented a natural hazard as well. It is well known how the Nabateans were obliged to divert the course of Wadi Musa stream (fig. 13), in order to prevent the recurrent flooding of the Siq, their main way to Petra (e.g. AL-WESHAH & EL-KHOURY, 1999; LUBICK, 2004; PANIZZA & PIACENTE, 2003, p. 289). A dam was built by Nabateans just downstream the deviation to prevent flood overflow (fig. 13); later, not only the Romans maintained the dam and the same tunnel, but they also enlarged this latter, 88 m long and 6 m wide at present time.

Since Pleistocene times, the Petra Valley and the topographically low areas around Beida underwent repeated stages of alluvial accumulation and dissection because of climatic and perhaps tectonic control (FRANCHI, 2002). Nevertheless, also in historical times, when such areas experimented a generalised downcutting—or at least a vertical stability-stage of streams, several alluvial events occurred, perhaps in connection with late Holocene climatic fluctuations (cf. ENZEL et alii, 2003, cum bibl.) and/or...
exceptional meteorological events (cf. AL-WESHAH & EL-KHOURY, 1999). Actually, terrace alluvium containing fragments of pottery, monuments completely or partly buried by alluvium as well as alluvial patches on the canyon rock-walls of the Siq (fig. 14), highlight flooding events spanning from Nabatean to post-Roman age. Several architectural elements (i.e. tombs) have been probably buried before the construction of the dam: in this respect, some of the highest alluvial patches in the Siq (i.e. ca 3.5-4 m above the Roman paving), although “Nabatean” in age -as shown by included pottery fragments- could indicate flood events pre-dating the dam. Nevertheless, since the most part of both Nabatean and younger alluvial deposits hints at repeated flooding events of the Siq-Petra Valley, temporary inefficiencies of the upstream dam and/or overflow episodes can be stressed. It is worth emphasizing that some important alluvial stages burying Nabatean artefacts are recognisable both far downstream the channel diversion and along nearby wadies, thus hinting at rather generalized events, perhaps related to climatic changes or important storms. It is therefore possible that the dam constructions has mitigated the flood impact without completely removing the problem of floods, as indirectly indicated also by an extensive flooding event of the Siq occurred in January 2004. Anyhow, in Nabatean/Roman times important alluvial-fill episodes raised several metres the Siq valley floor burying entire monuments, as demonstrated by recent excavations beneath Al Khazneh (i.e. the Treasure), the most famous Petra’s monument, and other tombs (figs. 15-16). Other important alluvial-fill episodes clearly post-date the town decline which followed 551 A.D. destructive earthquake and the 663 A.D. Arab conquest. Such decay produced hydraulic system and dam deterioration: floodwater entered again the Siq and both the Roman paving and several architectonic elements were definitively buried by alluvium (fig. 15).

Besides being a geomorphologic hazard for an area with high touristic impact (AL-WESHAH & EL-
Khoury, 1999), the repeated occurrence of flood events is an intriguing matter scientific research and can be also of some concern in both educational and touristic purposes. Since a detailed reconstruction of the alluvial top-surfaces is needed, in order both to decipher at least a relative chronology of the events and to reconstruct the alluvial bodies, similarly to the Al Habis site, detailed surveys by means of laser scanning and GPS systems have been taken up, starting from the Siq, where the relationship between alluvium and architectural elements is clear enough. Preliminary surveys have allowed the reconstruction of two of the main historical alluvial top-surfaces, including the one shown in figure 15. Buried monuments and alluvial patches can be thus combined in 3-D reconstructions and explicative panels for both the popularisation of geomorphologic topics and their integration into the better-known archaeological context, also fostering new educational paths. Indeed, whatever the causes, timing and extension of the historical alluvial events, their evidence is so striking and so closely related to architectural elements of the monumental areas that both educated tourists and scholars cannot help wandering about such issue.

6. – CONCLUDING REMARKS

Petra and Beida (Jordan), UNESCO sites, are two important adjacent archaeological areas deeply integrated in a striking geomorphologic landscape. The impressive historical, archaeological and monumental heritage as well as a somewhat “exotic” collocation of these sites, are unquestionably the main factors contributing to attract a huge number of tourists in such places. However, several geologic and geomorphologic features blending with monumental elements and appealing to both tourists and scholars are part of the overall indivisible heritage of these sites and suitable for being improved and popularised.

Both Nabatean water exploitation and flow...
control are fascinating issues and, what’s more, they are primary links between archaeological-monumental topics and geomorphologic ones. In this connection, ongoing researches about two topics directly related to both water and geomorphology of the Petra-Beida area—viz. water system reconstruction and historical alluvial-fill assessment—are suitable to promote a “geomorphologic culture” among both tourists and scholars. The analysis of both problems has been started by means of laser scanning and GPS systems, in order to obtain detailed measurements and reconstructions. The collected data make it possible to obtain 3D digital reconstruction and interactive models, flow models, alluvial fill modellisations etc., which are all appropriate for being improved as both educational and divulgation tools. Actually, they are suitable for being used in education rooms, employed as illustrative materials in guides, leaflets and explicative-panels and so on. Moreover, the singling out of additional topics could encourage the realization of new thematic touristic paths, able to lighten an overpressure along the usual touristic paths of an area the heritage of which is known to be at risk of decaying.

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