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The stones of the Sanctuary of Delphi – Northern shore of the Corinth Gulf – Greece

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Abstract – The choice of stones by the ancient Greeks to build edifices remains an open question. If the use of local materials seems generalized, allochthonous stones are usually also present but lead to obvious extra costs. The current work aims to have an exhaustive view of the origins of the stones used in the Sanctuary of Delphi. Located on the Parnassus zone, on the hanging wall of a large normal fault related to the Corinth Rift, this Apollo Sanctuary is mainly built of limestones, breccia, marbles, as well as more recent poorly consolidated sediments generally called *pôros* in the literature. To overpass this global view, the different lithologies employed in the archaeological site have been identified, as well as the local quarries, in order to find their origins. The different limestones are autochthons and come from the Upper Jurassic – Cretaceous carbonate platform of the Tethys Ocean involved in the Hellenides orogen. Those limestones of the Parnassus Massif constitute the majority of the rock volume in the site; a specific facies of Maastrichtian limestone called "Profitis Ilias limestone" has been used for the more prestigious edifices such as the Apollo Temple. The corresponding ancient quarry is located few kilometers west of the sanctuary. Then, slope breccia has been largely used in the sanctuary: it crops out in and around the site and is laying on top of the carbonates. Finally, the *pôros* appear to be very variable and seven different facies have been documented, including travertine, oolitic grainstone, marine carbonates and coarse-grained sandstones. All these recent facies exist in the south-east shore of the Gulf of Corinth, although – except for the grainstone – the quarries are not yet known.

Keywords: Delphi / Gulf of Corinth / archaeology / building materials

Résumé – Les pierres du sanctuaire de Delphes, Marge nord du Golfe de Corinthe, Grèce. Le choix des pierres de construction par les anciens Grecs reste à ce jour une question ouverte. Si l'emploi de matériaux locaux semble dominer, les faciès allochtones sont aussi présents. Ce travail propose une vue exhaustive des pierres mises en œuvre dans le sanctuaire de Delphes. Situé dans la zone du Parnasse, au pied d'une faille normale liée à l'ouverture du Golfe de Corinthe, le sanctuaire d'Apollon est majoritairement construit en calcaires, brèches et marbres. Des sédiments peu consolidés, récents, d'origine et de faciès variés appelés *pôros* dans les sources textuelles antiques, appellation souvent reprise dans la littérature moderne, sont également utilisés. L'identification des différents faciès a été menée sur le site, ainsi que dans les carrières locales, dans le but de retrouver la provenance des différents matériaux. Les calcaires sont clairement locaux et proviennent de la plate-forme carbonatée, d'âge Jurassique Supérieur à Crétacé, de la Téthys, reprise en compression lors de la formation de la chaîne des Hellénides. Ces calcaires du Massif du Parnasse correspondent à la majeure partie du volume de roche mis en œuvre ; un faciès spécifique de calcaire maastrichtien, appelé le calcaire de Saint-Élie, a été utilisé pour les édifices les plus prestigieux tels

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que le temple d'Apollon. La carrière antique correspondante se trouve à quelques kilomètres à l'ouest du site. Les brèches de pente ont été aussi largement employées : elles affleurent autour et dans le site archéologique et recouvrent les carbonates mésozoïques. Enfin, les roches appelées *pôros* correspondent à des faciès très variés ; sept types ont pu être reconnus dont du travertin, des grainstones à oolites, des carbonates marins et des grès grossiers. Tous ces faciès récents sont présents sur les côtes sud-est du Golfe de Corinthe, mais à l'exception des *grainstones* à oolites, les carrières d'origine n'ont pas encore été précisément localisées.

Mots clés : Delphes / Golfe de Corinthe / archéologie / matériaux de construction

1 Introduction

1.1 Context of the study

The study of monumental architecture in Greek Antiquity is usually approached with an historical, archaeological and architectural points of view, in order to better understand the building techniques and the socio-economic environment of the construction sites. In this study, the approach is focused on the building materials, which must have been one of the first and key question for the ancient craftsmen as for their sponsors. Wood, soil, terracotta and rock are the main materials employed; however, from the 7th century BC, stones became predominant in monumental construction (Martin, 1965; Lawrence, 1996). The question of the rock's origin has been the center of many studies, in Greece and all around the world; but in the case of Greece, those studies usually focused on materials today considered to be prestigious, such as marbles (Waelkens *et al.*, 1992; Attanasio *et al.*, 2000; Jockey *et al.*, 2011; Antonelli and Lazzarini, 2015).

This paper aims for a more global approach to the question of the building materials in ancient Greece, taking into account the immediate environment and regional geology in our reflection. The fact that local lithologies are predominant and were clearly favored in ancient constructions has already been noticed by many authors (Martin, 1965), the transport for long distance presented obvious difficulties and expensive costs (Hansen, 2000).

This research project is part of the program "The Stones in Delos and Delphi" launched by the French School at Athens. It aims to better define this global scheme by achieving an exhaustive overview of the different stones used in those two large sanctuaries of Apollo. The current paper presents the results of this ongoing study in the case of Delphi. After a short geological setting of the Gulf of Corinth area and a small overview of the historical context of the Sanctuary, the various stones found will be described from a macro- and microscopic points of view. When already known, the provenance of the stones will be discussed. The relative use of stones will be synthetized through a global lithological map of the Apollo sanctuary.

The marbles will not be mentioned in that study; they are anyway all imported, the closest marble outcrop being located in Livadia, 50 kilometers away from Delphi (Déroche *et al.*, 1989); this marble is black. The main ancient white marble quarries are located in the Athens area or the Cycladic Islands (Maniatis *et al.*, 1988; Palagia and Herz, 2002). The focus is here on the other stones, that were clearly not selected and used randomly by the builders in Delphi.

In the archaeological literature, the Greek word *pôros* refers to many facies with a high porosity, in opposition to the already compacted rocks, such as low porosity limestones, magmatic rocks and marbles (Martin, 1965). However, it does not correspond to a specific facies: there is no homogeneity in terms of depositional environment, lithology or age. *Pôros* is also the name of an island in the Saronic Gulf where calcarenite and eolianite are present – these rocks are called de facto *pôros* by the archeologists – but depending on the location, it may correspond to completely different facies. One of the results is the list and characteristics of the various *pôros* of Delphi in order to overpass this imprecise terminology.

1.2 Geological setting

The geodynamic history of the eastern Mediterranean region has been dominated by the convergence of Africa and Eurasia since the Mesozoic, inducing subduction, collision and obduction processes (Sengör and Yilmaz, 1981; Dercourt *et al.*, 1986; Ricou *et al.*, 1986; Ricou, 1994; Menant *et al.*, 2016). In this context, the Mount Parnassus, standing 2457 meters above Delphi, has been formed during the Hellenides orogen, since the Late Cretaceous, by thrusting Mesozoic limestone platforms of the Thetys margin. Three different structural domains are present near Delphi: the Parnassus Nappe which overlaps the Pindos Nappe to the West and is overthrusted by the Pelagonian Nappe of the Internal Hellenides eastward (Fleury, 1980; Doutsos *et al.*, 2006; Jolivet and Brun, 2010; Royden and Papanikolaou, 2011; Menant *et al.*, 2016) (Fig. 1).

Due to the clockwise rotations of the region between 15 and 8 Ma (Kissel and Laj, 1988; Morris and Anderson, 1996; van Hinsbergen *et al.*, 2005; Brun and Sokoutis, 2007; Jolivet *et al.*, 2015), the Hellenides are now oriented in a close to north-south direction. Since the Miocene, in consequence of the migration of the subduction toward the south and the westward propagation of the North Anatolian Fault, the Hellenides are affected by north-south extension localized in the active grabens of Corinth, Evia, and within the Central Hellenic Shear Zone (Armijo *et al.*, 1996; Papanikolaou and Royden, 2007) (Fig. 1).

The Parnassus Nappe is composed of: (1) neritic limestones from the Trias to the Upper Cretaceous; (2) pelagic limestones from the Campanian to the Maastrichtian; (3) a red pelite of the Paleocene and flysch (Eocene). Four bauxite horizons correspond to emersion of the carbonate plate-form and hiatus (Fleury, 1980; Mettos *et al.*, 2009) (Fig. 2A).

The Corinth area is one of the fastest rifts in Europe with an opening rate of ca. 1.5 cm/year (Moretti *et al.*, 2003). Its

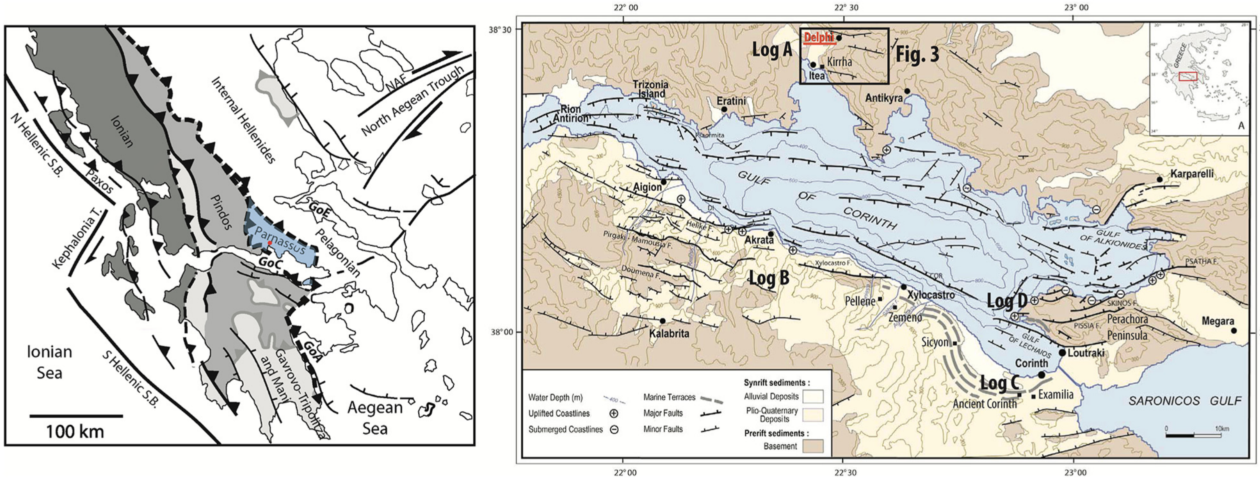

Fig. 1. Left: global map of Greece showing the geodynamic setting of the Gulf of Corinth (GoC) with the different nappes composing the external (shades of grey) and internal (white) Hellenides. The blue corresponds to the Parnassus Nappe. GoA: Gulf of Argolikos; GoE: Gulf of Evia; SB: subduction boundary; NAF: North Anatolian Fault (modified from Rohais and Moretti, 2017). Right: zoom on the Gulf of Corinth, showing the main locations mentioned in the text, and the areas corresponding to the stratigraphic columns (Log A, B, C and D) presented in Figure 2 (modified from Moretti *et al.*, 2003).

evolution is rather well constrained (Ori, 1989; Taylor *et al.*, 2011; Ford *et al.*, 2013; Nixon *et al.*, 2016; Ford *et al.*, 2017; Rohais and Moretti, 2017; Gawthorpe *et al.*, 2018) and could be divided in three phases: (1) an initiation phase dominated by small-extension continental and lacustrine sedimentation called the Lower Group; (2) an increase of the fault activity associated with a connection of the basins leads to a deep-water lacustrine to marine sedimentation referred as the Middle Group; (3) since 1 Ma the uplift of the Peloponnesus exhumed the syn-rift deposits on the southern shore and the deltaic systems shifted northward (Fig. 2B). Marine terraces of the Upper Pleistocene have been exposed (Fig. 2C) and, locally, Quaternary stromatolitic deposits in the Perachora Peninsula (Fig. 2D). On the northern shore of the Gulf, Oligo-Miocene sedimentation is mainly missing and Quaternary slope breccia lays in discordant contact on top of the Mesozoic limestones and Eocene flyschs in most part of the region (Pomoni-Papaioannou, 1994; Gregou *et al.*, 1994; Solakius *et al.*, 1998; Solakius and Kati, 2001).

The Sanctuary of Delphi is located on the northern margin of the Corinth Gulf, about 600 meters above the sea level and 10 kilometers from the coast. It lays on the hanging wall of the major normal fault dipping southward, the Arachora – Delphi – Amphissa Fault. Another large normal fault dipping northward, borders the Pleistos Valley, south of Delphi (Piccardi, 2000; Piccardi *et al.*, 2008; Valkaniotis *et al.*, 2011) (Fig. 3).

1.3 The Apollo Sanctuary of Delphi

Most of the archaeological site of Delphi was excavated during the period called “la Grande Fouille” between 1892 and 1903 by the French School of Archaeology at Athens. It released an exceptional complex composed of the Apollo Sanctuary, the Athena Sanctuary, two monumental fountains – Castalia and Kerna –, a stadium, a gymnasium and parts of the ancient city (Fig. 3).

Activities linked to the Apollo Sanctuary are attested since the 7th century BC and until the 4th century AD, but the panhellenic sanctuary became particularly important between the 6th and the 4th century BC. Greek cities, mediterranean kingdoms, illustrious families or prominent individuals came to consult the Oracle, dedicate offerings and build treasuries in honor of Apollo (Jacquemin, 2000). The panhellenic games, the *Pythian Games*, took place in Delphi every four years since the Archaic Period, bringing together people from all the Hellenic World as well as riches for the city (Bommelaer and Laroche, 2016).

The sanctuary underwent a lot of transformation and enlargement during its existence (de La Coste-Messelière, 1969). The Apollo Sanctuary was laid out on several terraces and has been modified and enlarged, especially during both important reconstruction phases of the Temple, following its accidental destruction (Amandry and Hansen, 2010; Perrier, 2019). The Apollo Temple burnt down in 548/7 BC and has to be reconstructed and the peribolos, the wall surrounding the sacred area, was enlarged. In 373/2 BC, the temple was destroyed by a landslide. The latest temple (of which the remains are still visible today, and called the New Temple by opposition to the Old Temple) was reconstructed with a local limestone of high quality, the Profitis Ilias limestone, which has been extracted for the first time on this occasion (Amandry and Hansen, 2010; Bommelaer and Laroche, 2016).

2 Material and method

2.1 Inside the archaeological site

The main goal of this paper is to present an exhaustive list of the lithologies that could be observed in the archaeological site of Delphi – the Apollo Sanctuary, the stadium and the Athena Pronaia Sanctuary (Fig. 3). The Gymnasium, as well as the Castalian fountains, were not accessible during the fieldwork for security reasons, and the antique city which has not been excavated and mapped precisely yet.

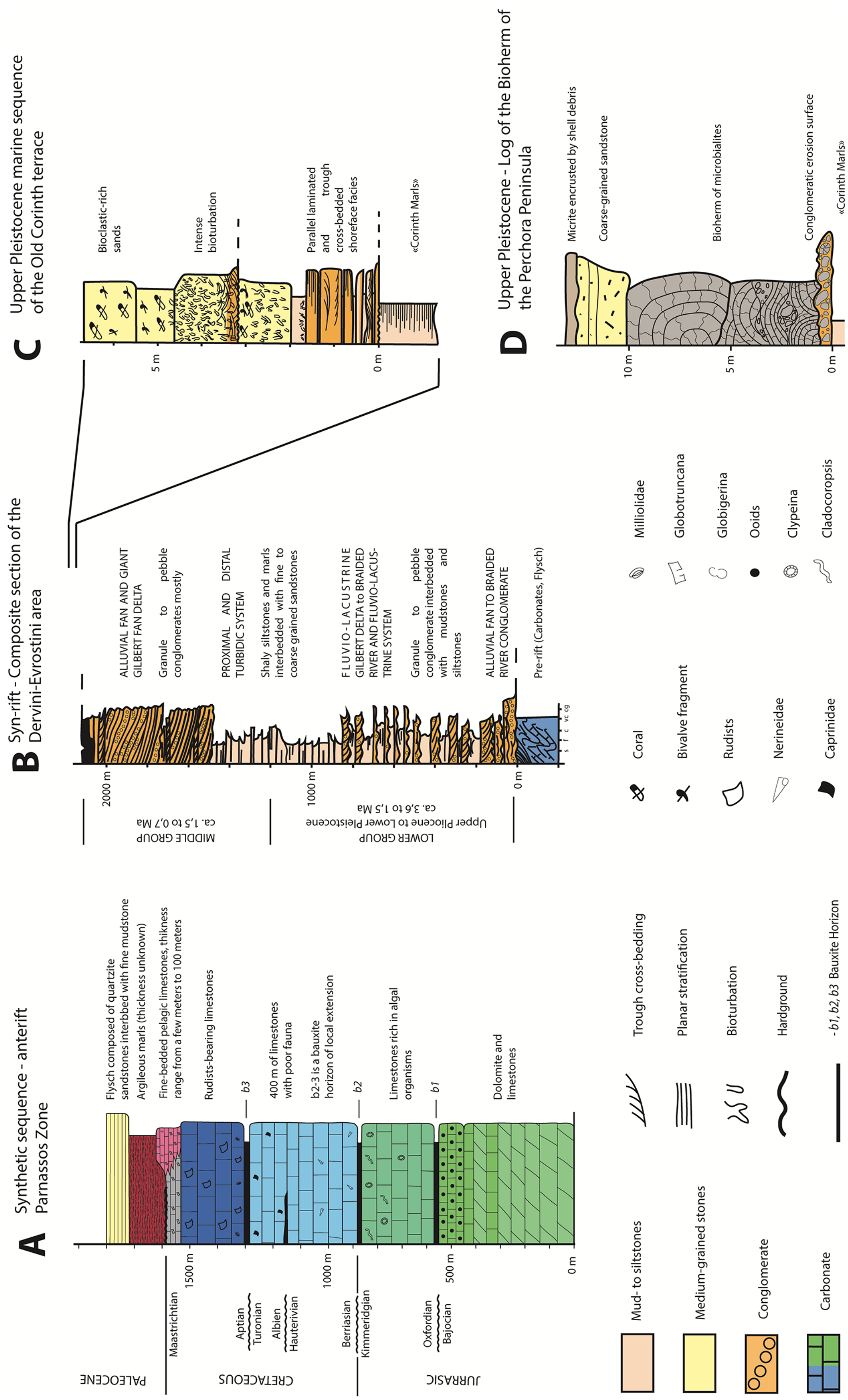

Fig. 2. A. Synthetic stratigraphic column of the Parnassus Nappe in the region of Delphi (modified from Fleury, 1980; Gielisch, 1993; Carras, 1995; Nirta *et al.*, 2018). Recent sedimentary formations located on the south coast of the Gulf of Corinth. B. Composite section of the Dervini-Evrostini area (Rohais *et al.*, 2007). C. Sedimentary log of the Old Corinth terrace (Collier and Thompson, 1991; Armijo *et al.*, 1996). D. Synthetic section of the Perachora Peninsula (D) (Bouleugon, 2016). See Figure 1 for locations.

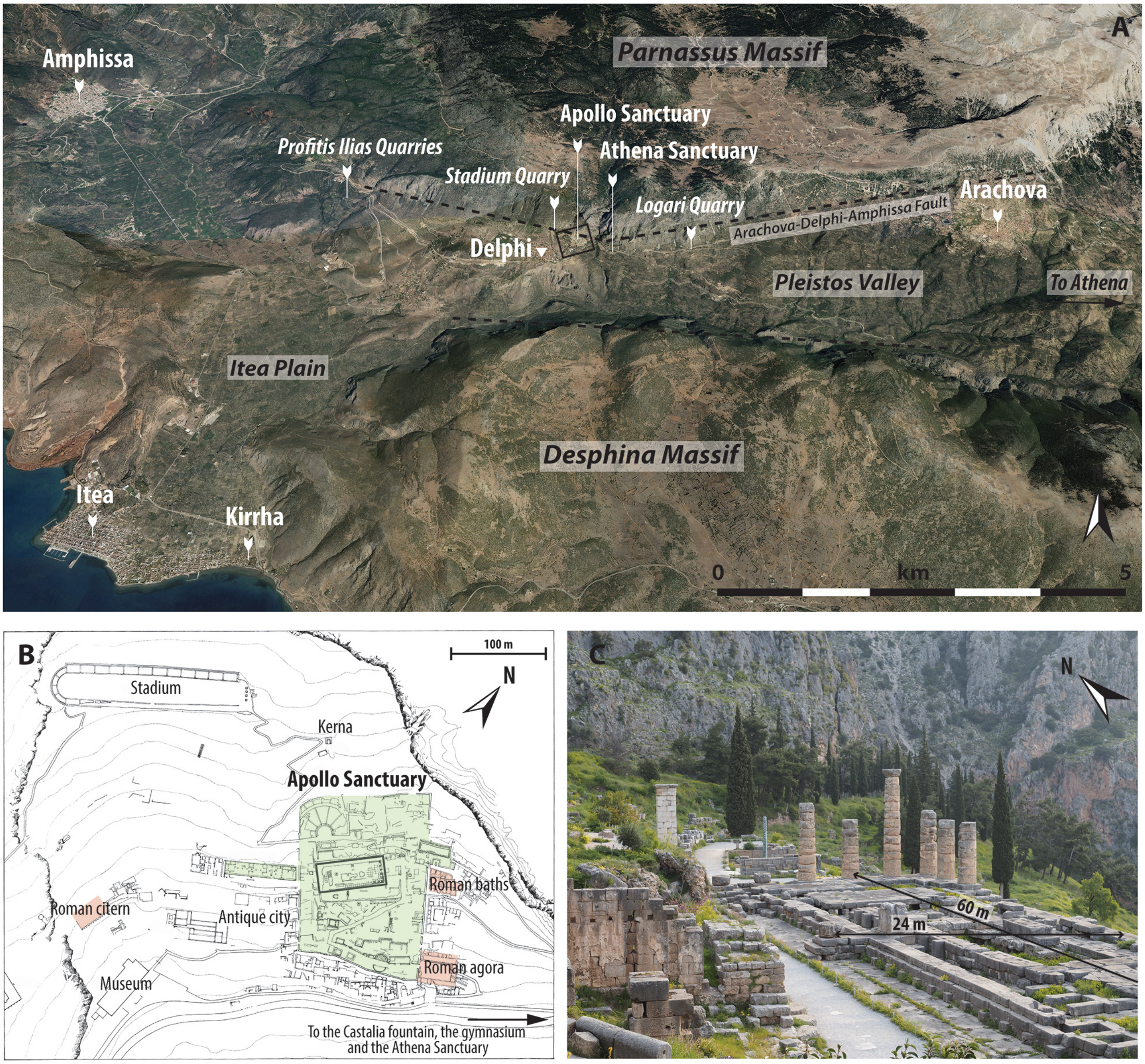

Fig. 3. The archaeological site of Delphi. A. Aerial view of the Pleistos Valley where Delphi stand, with the main cities, quarries and toponyms, and the two mains faults (Google Earth). B. Map of the archaeological complex with the Apollo Sanctuary in green, and the Roman vestiges in red; 5 meters between the contour lines (modified from Bommelaer and Laroche, 2016). C. Picture of the Apollo Temple on the Sanctuary, standing at the hanging wall of the Arachova-Delphi-Amphissa Fault.

The description of building materials differs from the ones applied on outcrops since destructive sampling is forbidden in protected archeological sites. Systematic macroscopic descriptions were first completed, taking into account geological characteristics (fossil content, sedimentary petrology, sedimentary structures), with the use of a portable digital microscope (Dino-Lite®). This method allows to distinguish between different types of *pôros* but has not been sufficient to differentiate between different types of limestone. These first order descriptions and the knowledge of the regional geology of Delphi allowed us to discriminate between materials which have been extracted from the region, and materials which were imported from elsewhere (facies that were not observed in the Parnassus nappe). For allochthonous materials, the microscopic description of the sedimentary facies allowed us to make assumption on their provenance.

2.2 Outside the archaeological site

Samplings were proceeded in the surrounding of the archaeological site to add more information on local facies. Two different cases were encountered: (1) the exact provenance of the facies is known (ancient quarries); or (2) the exact provenance is unknown. In the first case, samples were taken near the antique quarry. In the second case, samples were taken the closest to the archaeological site, on outcrops suspected to have been exploited in ancient times but that do not show any evidences. In total, fifteen thin sections of the

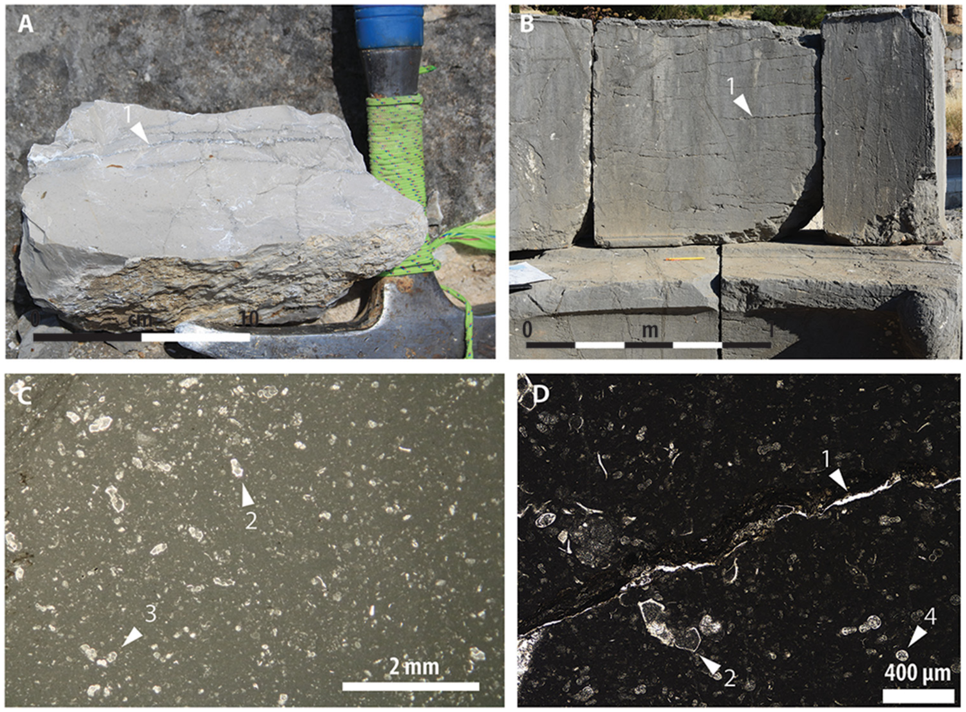

Fig. 4. Profitis Ilias limestone. A. Sample of limestone from the Profitis Ilias quarry, presenting its natural color light grey and stylolitic joints (1). B. Blocks of Profitis Ilias limestone employed in the Apollo Sanctuary. Stylolitic joints are still visible despite its dark grey patina. C. Microscopic view showing *Globotruncana arca* (Cushman, 1926) (2) and Globigerina (3) in a micritic cement. D. Specimen of *Globotruncana arca* (Cushman, 1926) (2), a stylolitic joint (1), a calcisphere (4).

samples were made as well as some basic petrophysical measurements: density and porosity were measured using an automatic gas pycnometer (AccuPyc II 1340) at the laboratory GeoRessources of the University of Lorraine. One sample of each facies of carbonate were analyzed.

3 Results: the stones of the sanctuary

3.1 Petrological description of the stones

3.1.1 The limestones

Profitis Ilias limestone (Fig. 4)

This facies has been sampled near the ancient quarries of Profitis Ilias, 5 km west of Delphi (see Fig. 3 for the location of the quarry), after which the stone is named. The Profitis Ilias limestone is a massive wackestone with thick beds up to 2 meters and presents many stylolitic joints parallel to the bedding (Fig. 4A), straight calcitic veins, generally perpendicular to the joints, and few centimetric nodule of cherts. The facies color is light grey and appears dark grey or dark blue in surface due to the alteration, which make it easily recognizable (Fig. 4B).

Thin sections document a marine fossiliferous assemblage composed of calcispheres and pelagic foraminifera, which represent 15 to 20% of the grains, in a micritic matrix. We identified: Globigerinas, *Globotruncana stuarformis* (Dalbiez, 1955), and *Globotruncana arca* (Cushman, 1926), which is, with only one keel, attributed to the Early Maastrichtian (Figs. 4C and 4D). This facies has a density of 2.65 g.cm^{-3} and a very low porosity of 1.15%.

Pink limestone (Fig. 5)

The reference outcrop used for the description of this facies is in a modern quarry, 12 kilometers eastward of Delphi, near the modern town of Arachova (Fig. 3). The outcrop has a thickness of max. 10 meters and a length of ca. 100 meters with beds of 1 or 2 meters in thickness. It displays many small stylolitic joints, interrelated and parallels to the bedding, and calcitic veins up to 2 centimeters without general orientation (Fig. 5A). Its characteristic color varies from dark pink to grey, and its alteration color is grayish (Fig. 5B).

The Pink limestone is a wackestone with more than 40% of grains in a micritic matrix. The thin sections show a grain composition of planktonic foraminifera: *Rugoglobigerina rugosa* (Plummer, 1927) (Fig. 5C), *Globotruncanella pschadae* (Keller, 1946) (Fig. 5D), *Abathomphalus mayaroensis* (Bolli, 1951) (Fig. 5E). These foraminifera date the formation of the Maastrichtian. Gasteropods and multi-chamber uniaxial foraminifera are observed (Fig. 5C). Petrophysics properties show a density of 2.68 g.cm^{-3} and a very low porosity of 0.84%.

Rudist limestone (Fig. 6)

A massive dark limestone with beds up to 1 meter crops out just west and south of the archaeological site, under the modern road leading to the modern town of Delphi (Fig. 3). Two main end-members can be observed: a floatstone composed of fragmentary rudists in a micritic matrix, and a boundstone built of rudists reefs, that are easily recognizable in employed blocks (Fig. 6A). Some rudists observed on the outcrops are parts of the *Hippuritidae* and *Radiolitidae* families (Fig. 6B).

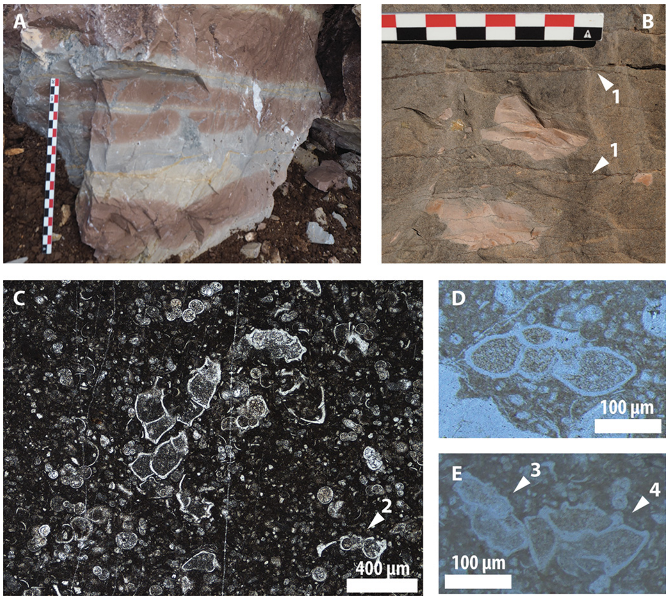

Fig. 5. Pink limestone. A. Outcrop at the modern quarry of Arachova, 12 km east of Delphi (Fig. 3 for location), showing the color's variation of the rock; stylolitic joints are also present but not visible on this photo. B. Block of Pink limestone used in the Apollo Sanctuary showing several stylolitic joints (1). C. Microscopic view showing the numerous foraminifera in micrite. *Rugoglobigerina rugosa* (Plummer, 1927) (2). D. *Globotruncanella pschadae* (Keller, 1946). E: *Abathomphalus mayaroensis* (Bolli, 1951) (3); *Globotruncana ventricosa* (White, 1928) (4). Red, white and black rectangles on the scale represents 1 cm.

Thin sections show a highly fractured floatstone with calcitic veins: fragments of rudists, recrystallized bioclasts and unidentified algae in micritic matrix, partly recrystallized into sparite (Fig. 6C). Very few multi-chamber benthic foraminifera from the *Miliolidae* family and planktonic biserial foraminifera have been observed (Fig. 6D). This facies has a density of 2.68 g.cm^{-3} and a porosity less than 1%.

Parnassus limestones (Fig. 7)

This limestone's outcrop presents beds up to 2 meters and an important rate of karstification highlighted by small surfaces and large-scale dissolution features: lapiez, micro-karsts, karsts (Figs. 7A–7C). Samples are taken near the Stadium Quarry, located hundred meters just above the sanctuary, at the foot of the cliff (Fig. 3).

Two subfacies are identified: one subfacies is a grainstone composed exclusively of ooïds (less than 0.5 mm in size) cemented by sparite (Fig. 7D). The other subfacies is a very heterogeneous and fractured wackestone (60% of grains) composed of pellets, algae, crinoids and others biological remains (Fig. 7E). Centimetric oncoids, with irregular cortex, are also observed in the outcrop (Fig. 7A). The wackstone has a density of 2.68 g.cm^{-3} and a low porosity of 0.8%.

3.1.2 The breccia

The slope breccia crops out in the immediate surrounding of the sanctuary. This facies is defined by angular polygenic limestone clasts ranging from gravel to boulder cemented by a reddish clay matrix (Fig. 8A). The limestone composing the breccia shows two different sub-facies which correspond to the Parnassus limestone (Fig. 8B).

Fault breccias are also present in the surroundings of Delphi, around the core of the Amphissa Fault (see for instance Fig. 3D in Moretti *et al.*, 2003). However, fault breccia is not observed in the sanctuary as building material: the lack of available volume in comparison to the large mass of slope breccia may be an explanation.

3.1.3 The *pôros*

As already mentioned, this study did not aim to create a new definition of the generic term *pôros*, but to present a list of stones called *pôros* within the archaeological site of Delphi. In that case, seven types of stones have been distinguished, numbered from P1 to P7 (Fig. 9). Due to the restriction of sampling on the site, only macroscopical observations were carried out, on building stone out of their geological context, using a portable microscope. It cannot be excluded that the list is incomplete or that two facies have roughly the same geographical origin; on the opposite, two blocks of stone with similar facies can also come from two different quarries.

P1: Oolitic grainstone

The stone presents a grain-supported fabric built by well-sorted and very fine-grained ooids (Fig. 9, P1, B, 1). Some blocks show stratification. This facies appears yellow and its altered color is yellowish-grey.

P2: Bioclastic grainstone

This facies shows grain-supported fabric composed of small calcitic bioclasts. Those fragments are tubular and some sections of crinoids (Fig. 9, P2, B, 2) have been observed; their size varies from 0.2 to 1 mm.

P3: Coarse-grained sandstone

This poorly-sorted detrital rock shows millimetric to centimetric limestone pebbles and centimetric gastropods shells (Fig. 9, P3, A, 3 and 4) embedded in a medium to coarse-grained sand. The color is orange to yellow but the alteration leaves orange deposits on the surface – it may indicate the presence of oxides.

P4: Sandstone

A poorly-sorted detrital sand shows angular grains of mostly quartz and few feldspars without matrix (Fig. 9, P4). The stone is massive and the grain size varies from fine to medium-grained.

P5: Travertine

A white calcareous travertine shows tubular structures, carbonates tubes formed by concretion around plant are also observed. A shard has been observed, caught in the concretion (Fig. 9, P5, A): it must be a recent freshwater deposit (less than 10 000 years, when pottery started to be produced in Greece) formed near a place with human activities.

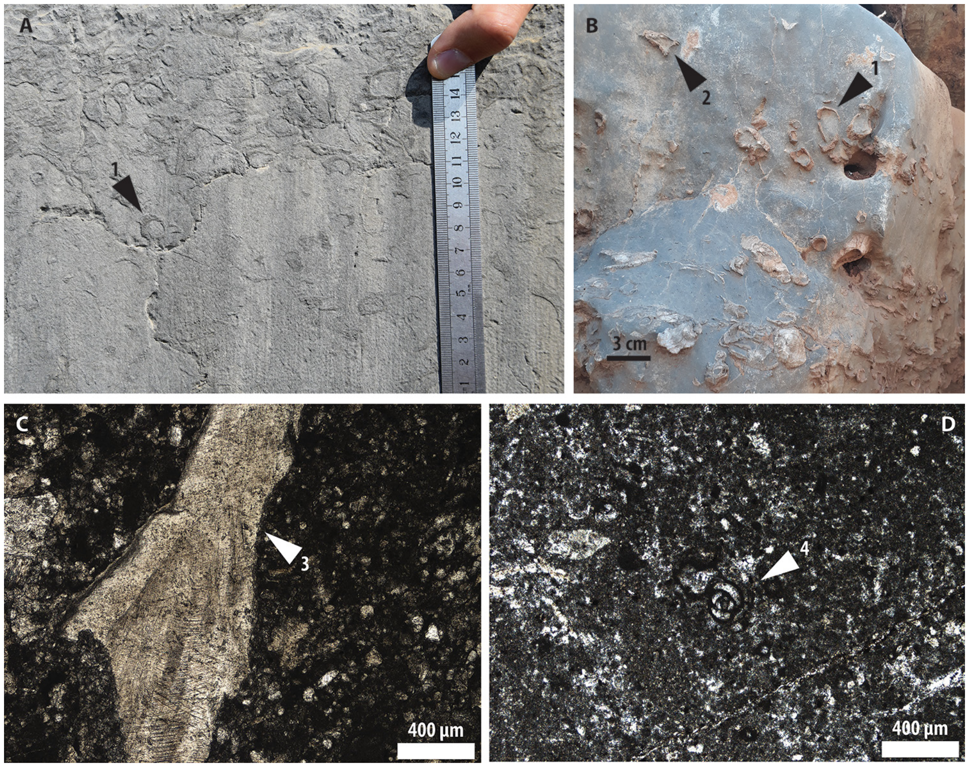

Fig. 6. Rudist limestone. A. Block of Rudist limestone (1) used in the sanctuary of Delphi. B. Outcrop of massive limestone with whole rudist shells (1) and specimen of the Hippurite family (2). C. Microscopic view showing a recrystallized fragment of rudist (3) in a micritic cement. D. Microscopic view showing a specimen of Miliolidae (4).

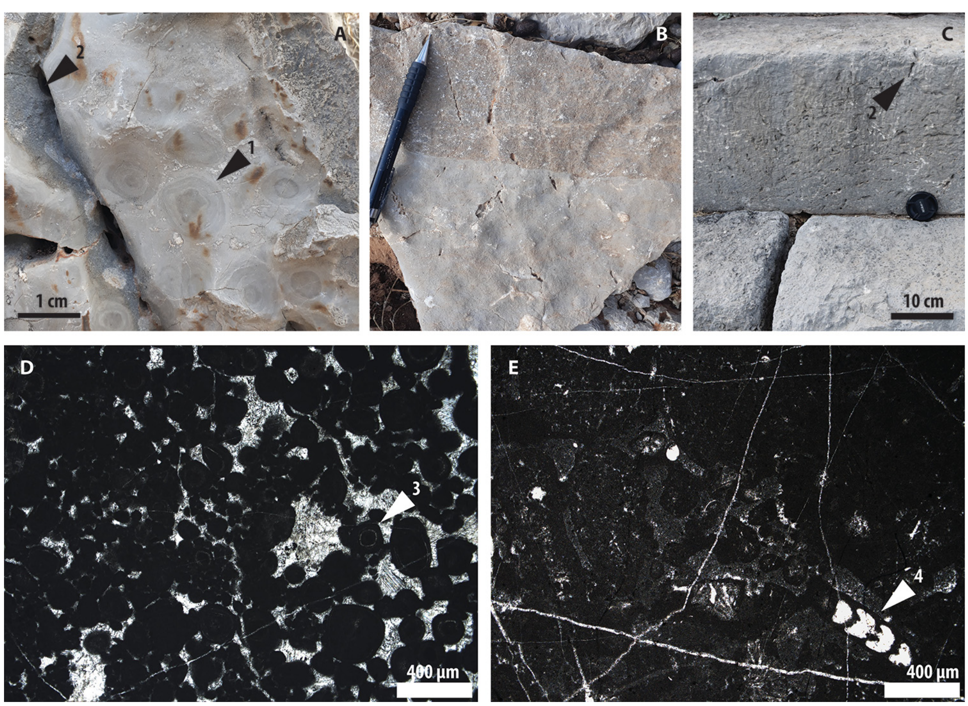

Fig. 7. Parnassus limestones. A. Outcrop observed near the Stadium Quarry showing centimetric oncoïds (1) and microkarsts (2). B. Sample observed near the Stadium Quarry showing the two subfacies observed in the Parnassus Massif. The pen is 12 cm long. C. Block of Parnassus limestone employed in the Apollo Sanctuary showing a high degree of karstification with microkarsts (2). D. Microscopic view showing a subfacies of the Parnassus limestones: an oolitic grainstone (3). E. Microscopic view of a subfacies of Parnassus limestones: a wackestone composed of pellets and biological remains in a micritic cement (4).

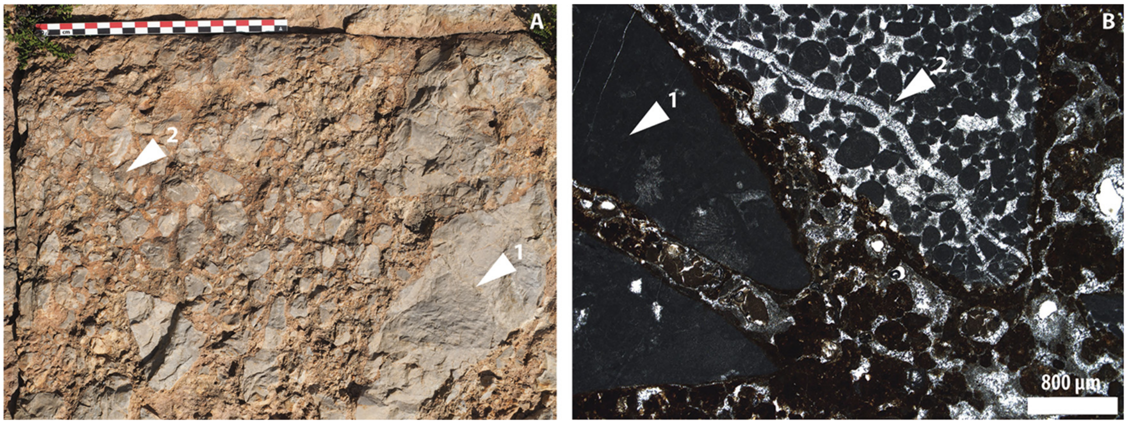

Fig. 8. Breccia. A. Block of breccia used in the Apollo Sanctuary; the clasts sizes ranges from a few centimeters to 30 centimeters; clasts of the two subfacies of the Parnassus limestones can be observed (1 for the wackestone, 2 for the oolitic grainstone). B. Microscopic view showing the limestone clasts (1 for the wackestone, 2 for the oolitic grainstone) in a clay matrix. Red, white and black rectangles on the scale represents 1 cm.

P6: Red boundstone

This red calcareous rock shows branching and tubular structures showing thin layers (Fig. 9, P6) and forming large-scale concentric laminations. This fabric is consistent with the typical characteristic of bioconstucted rock, probably build by stromatolite.

P7: Marine floatstone

This stone is composed of centimetric and intact bivalves (almost 50% of the stone) in a micritic matrix. It is easily recognizable in monuments by the numerous shells (Fig. 9, P7, A, 5 and 6). The stone is still not yet consolidated, so it did not undergo a strong burial and/or diagenesis.

3.2 Provenance of the stones

3.2.1 Local exploitation

Local stones were extracted in different ways in and around the sanctuary. In the interest of saving and practicality, the workers used the rocks directly available, mainly the Parnassus limestones. Falling blocks of the cliff show extraction marks on top of them (Fig. 10B). At the eastern extremity of the Stadium, above the Apollon Sanctuary, stairs were built directly from the Parnassus limestones outcrop. They took advantage of the geology and topography of the site.

Then, extraction tool marks have been observed east and west of the site, alongside the cliff; it suggests that the workers punctually extracted blocks from local outcrops, up to hundred meters from the site (Fig. 10A). Mesozoic limestones were extracted – the Parnassus limestones mostly, however no proof of extraction has been observed for the Rudist limestone. No large ancient quarry of Pink limestones has been located, but modern quarries have been observed in the surroundings of Delphi, near Arachova. Closer to the sanctuary, this facies outcrops on a branch of the main fault, 1500 meters eastward of the archaeological site (just before the Logari Quarry, see Fig. 3): the extraction is clear but cannot be dated yet, and the extracted volume is small.

Quarries in the region are known to have been exploited in antique times (see Fig. 3 for locations). Small quarries, a few meters wide, that could have been used to build one or two monuments, are located directly in and all around the site. Two of them have been localized (Amandry, 1981). The first one is known as the Stadium Quarry, located just above the sanctuary, at the foot of the cliff (Fig. 10C); it seems that it was used to build the Stadium: the material match as the Stadium was built in Parnassus limestones and slope breccia. The second one is called the Logari Quarry (2 km East of Delphi), where the Mesozoic limestones from the Parnassus Massif was also exploited. Then, the biggest quarries are the Profitis Ilias quarries, where the limestones used for the Apollo Temple of the 4th century BC were extracted (Fig. 10D) (Amandry 1981; Papageorgakis and Kolaiti 1992; Zambetakis-Lekkas *et al.*, 2001; Amandry and Hansen, 2010). Located 5 km to the west of the archaeological site, the high quality of the stone can justify the required work to transport the blocs.

3.2.2 Regional exploitation

Provenance of allochthonous materials are not yet fully defined. However, the identification and characterization of seven of the so-called *pôros* allow us to make assumption on their origins. One conclusion can be elicited from the petrological description of each facies: they all show a medium to high porosity, which could mean that they did not undergo strong burial, advanced diagenesis, or that they are very young formations. Recent sedimentary formations, such as the synrift ones – the marine terraces, fluvial and lacustrine deposits – exposed by the uplift of the Peloponnese, have to be prospected (see Figs. 1 and 2 for location).

Before this study, only one facies origin had been clearly identified by ancient and modern authors. In the buildings accounts of the Apollo Temple of the 4th century BC, written on limestones or marble plaques found within the Sanctuary, was written that stones from Corinth were employed for its construction (Bousquet, 1942; Roux, 1966). It corresponds to the oolitic grainstone facies used for the column drum of the actual Temple; this facies is also used in a lot of other monuments in Delphi: a hypothesis is that all this material comes from roughly the same place. The grainstone facies have been also clearly identified and observed in the archaeological site of Ancient Corinth (Fig. 11A) and

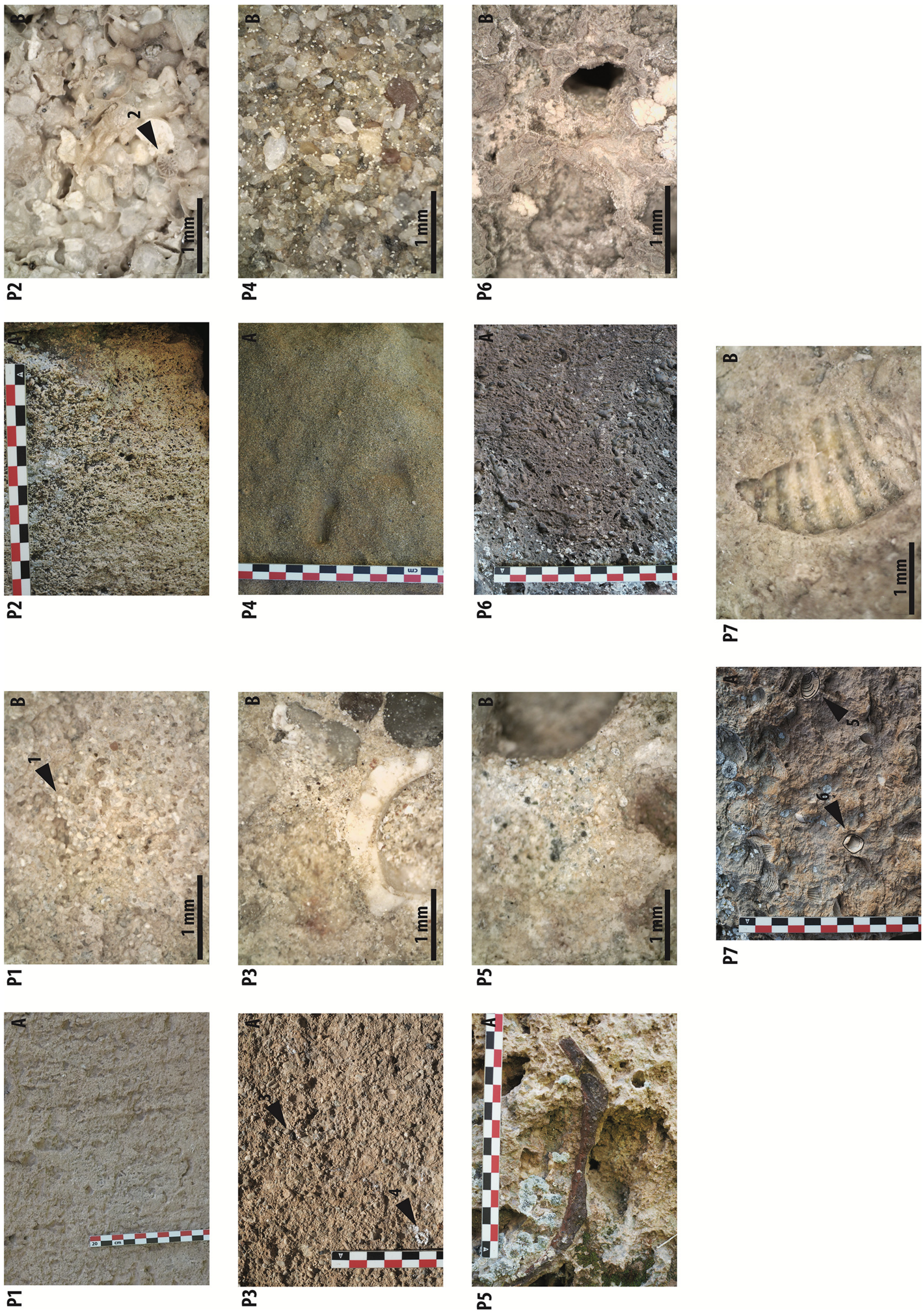

Fig. 9. Macroscopic (A) and microscopic (B) views of the different pôros observed in the archaeological site of Delphi. Microscopic views (B) were obtained with the help of the portable microscope. Red, white and black rectangles in scale is 1 cm. P1: oolitic grainstone composed of micrometric oolites (1); P2: bioclastic grainstone with section of crinoid (2); P3: coarse-grained sandstone with pebbles (3) and shell fragments (4); P4: sandstone showing angular quartz and feldspar; P5: modern travertine and its encrusted shard; P6: red boundstone; P7: marine floatstone with shells impressions (5) and bivalves shells (6).

Fig. 10. A local exploitation. A. Extraction marks observed at the top of a rock that fell of the cliff above Delphi. B. Extraction tool mark observed at the foot of the main fault, hundred meters west of the Apollo Sanctuary. C. Stadium Quarry, located just above the stadium. D. The ancient Profitis Ilias quarries, 5 km west of Delphi. E. Location of the extraction sites.

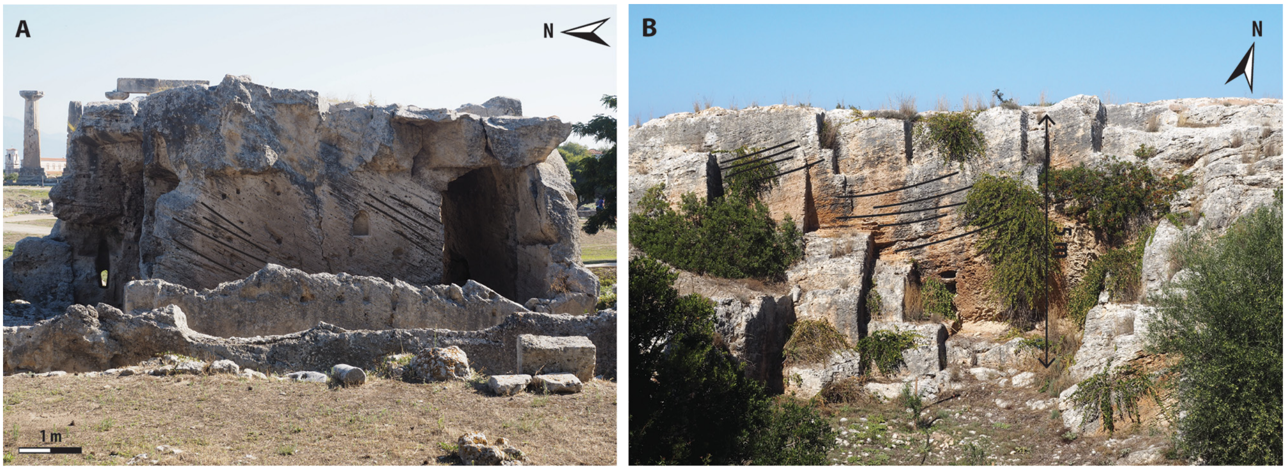

Fig. 11. Regional exploitation. A. Fountain of Glauke, at the Ancient Corinth, build directly in the oolitic dune (5 meters high); the oblique stratification can be observed; behind is standing a column of the Apollo Temple of Ancient Corinth, which is a monolith also build in oolitic dune. B. Quarry of Examilia, East of Corinth, showing extraction tool marks and known to have been exploited in antique times; the facies is similar to the one observed in the archaeological site of Ancient Corinth, the stratification is also clearly marked. See Figure 1 for location.

corresponds to the lithology exploited in the Examilia quarries (Collier and Thompson, 1991; Hayward, 1996, 2003, 2013) (Fig. 11B) (see Fig. 1 for the location of Examilia, to the east of Corinth). In addition, a column shaft in oolitic grainstone has been found at Kirrha, the harbor of Delphi (Fig. 1). This block seems to be intended for the Apollo Temple – it shows that stones transited by sea and by land. It is well known that the region between Corinth and Sicyon exported a lot of materials to different construction sites (Hellmann, 1999; Hansen, 2000; Lolos, 2002).

For the other facies, only assumptions can be made. The north margin of the Corinth Gulf corresponds to a deep carbonate platform, whose limestones underwent during the alpine orogeny an advanced diagenesis; our porous facies do not match with this depositional environment. Moreover, the northern margin is actually in subsidence; in opposition to the Peloponnese, which is raising (Armijo *et al.*, 1996; Bell *et al.*, 2009; Rohais and Moretti, 2017). Thus, recent sedimentary deposits of the Corinth Gulf are only exposed to without, east and south of the Gulf. The observed porous facies – the different sandstones and the marine floatstone – could come from this region. As stone trade has already been proved with the oolitic grainstone facies, other materials could be transported by ship. However, no evidence has been provided to this date; more extensive study of the sedimentary deposits must be carried out.

Finally, the only stromatolitic deposit known in the region is observed along the coast of the Perachora Peninsula, in the Isthmus of Corinth. The hypothesis is that the sedimentary facies observed in the Sanctuary of Delphi then may come from this location. Local deposits of travertine are also located in the surrounding of Pellene and Zemeno, on the southern border of the Corinth Gulf (Gawthorpe *et al.*, 2018); Pellene is located on land but it has an ancient harbor on the coast (see Fig. 1 for locations of the different places mentioned).

3.3 Use

Based on the macro- and microscopical descriptions of the building materials, a lithological map of the Apollo Sanctuary has been produced (Fig. 12). It displays the building stones remaining in place – time damages, destructions, or re-investment have impacted this snapshot, and most of the stone volume is missing, that being the main limit of the document. This map is of relatively low resolution, as only the main lithology used in each building is presented. For example, the Apollo Temple here is shown as composed only of Profitis Ilias limestone; in reality, the foundations are in slope breccia, marble and oolitic grainstone, the floor in the Profitis Ilias limestone, the columns in oolitic grainstone – showing its complex history.

All the monuments mentioned in the following description, to the exception of the Stadium that lays outside the Apollo Sanctuary, are located in the Figure 12.

The Parnassus limestones corresponds to 25% of the building materials in the archaeological site: it was mainly used to build the Stadium and the Theater. These two monuments are some of the biggest in the complex, so they represent a very large volume of materials. Moreover, a few foundations of Parnassus limestones are scattered in the Sanctuary, such as the Treasury of Siphnos. Then, the Pink limestone represents the second main stone facies with a proportion of also 25%. It has been used in a lot of different circumstances: for the peribolos – the sacred enclosure of the Apollo Sanctuary –, or the polygonal wall. The Profitis Ilias limestone represents 15% of the Delphi stones and is used extensively in the Apollo Temple of the 4th century BC, the Niche of the Argos Kings, and several statue bases. Finally, the Rudist limestone facies represents 5% of the remaining stones and it was employed to build the south exterior of the peribolos and two massive statue bases.

Some lithologies are almost exclusively associated to one monument, and they correspond most of the time to the allochthonous facies. The coarse-grained sandstone (P3) is used only in the Treasury of the Beotians, and the bioclastic sandstone (P2) in the Treasury X and the so-called Bouleuterion, two monuments that had nothing in common originally. The modern travertine (P5) is observed in the foundations of the Treasury of Thebes, and the red travertine

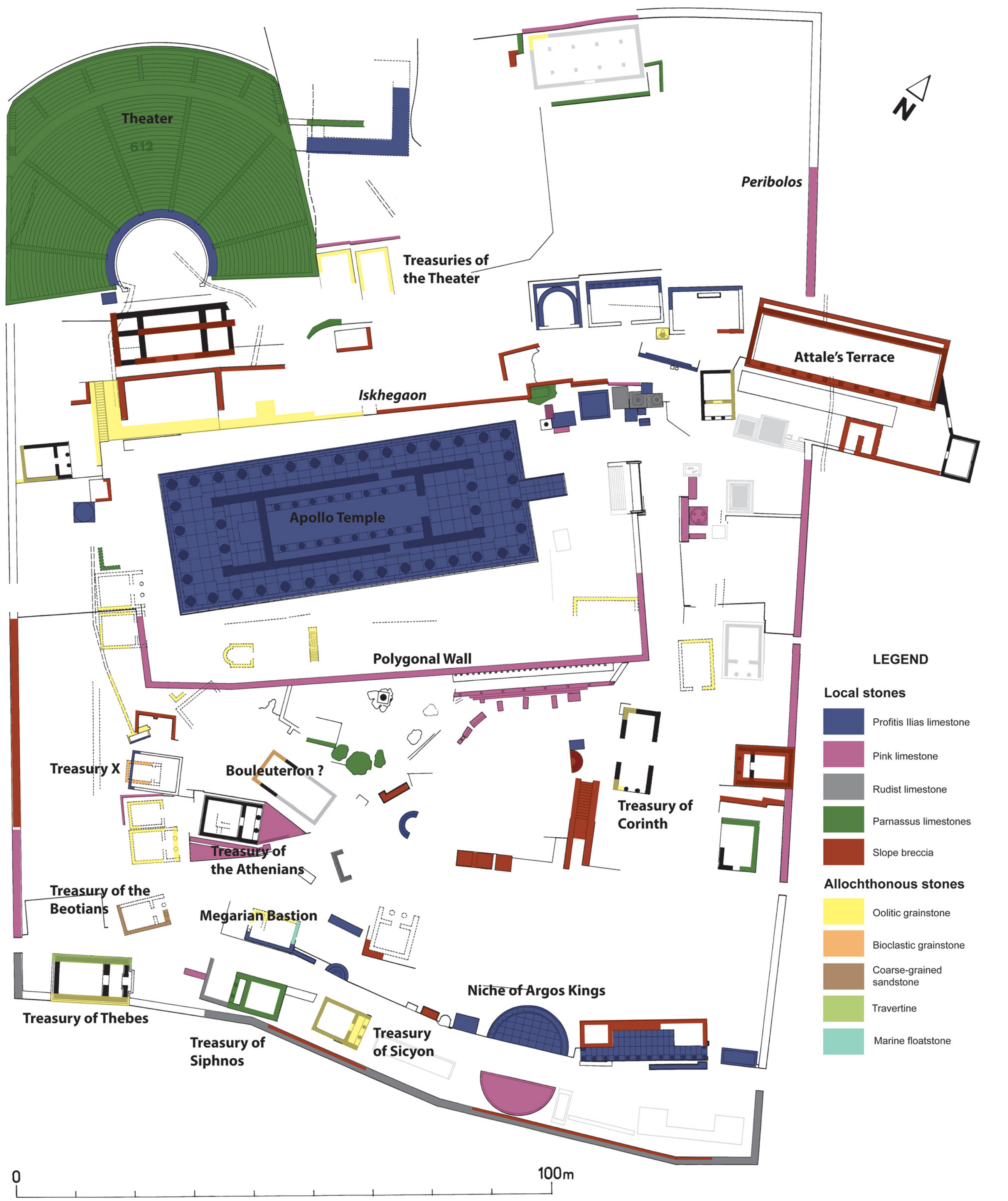

Fig. 12. Lithological map of the Apollo Sanctuary of Delphi; each color represents one of the facies described in this article, with the exception of the red boundstone which was not employed in the Apollo Sanctuary but only in the Athena Sanctuary. Base map modified from Bommelaer and Laroche, 1991.

(P6) only in the Athena Sanctuary (not represented on the lithological map). Finally, the marine floatstone (P7) is observed in the Megarians Bastion (as well as some lonely blocks scattered in the sanctuary), and sandstone (P4) in the foundations of the Treasury of Sicyon, as reemployed blocks.

4 Discussion

The choice of building materials has evolved over time: the transition from wood to stone in the 7–6th centuries BC is one of the greatest achievements for monumental construction (Lawrence, 1996). But the utilization of a precise type of stones in construction is looked based on a lot of different factors that still need to be better understood. In addition, the same stone was not used the same way all through the centuries. It is well known that it evolved during times, as new quarries were discovered and open, or advanced technologies allowed transport on greater distances; but the political context and the financial situation – the social environment – also had their part in the choice of building materials. Finally, the geotechnics aspect of stones – their hardness, their capillary properties, the capacity to being polished, to resist to compression, or weathering – seemed to be known by ancient builders.

In the case of the Sanctuary of Delphi, the discussion will shortly address some of those aspects, confront the new geological data with the history of Delphi, and raise questions and hypotheses from those observations. They seem relevant for the Apollo Sanctuary as sponsors came from all Greece to build offerings and treasuries in one of the most important sanctuary at the time; one may anticipate that economic limitations were not the only factor in the choice of stone.

The oldest unknown treasuries – or *oikos* – in the Apollo Sanctuary are surprisingly built in oolitic grainstone. They correspond to the small structures cut by the polygonal wall (which was constructed at the end of the 6th century), the Treasuries of the Theater, as well as the Treasury of Corinth (see Fig. 12 for locations) (Laroche and Nenna, 1993). They are very similar to the facies used in the Apollo Temple of the 4th century BC – so they may also come from Corinth. In any case, they are not local. Only small remains of those *oikos*' foundations were conserved, and almost no information about the elevation. One hypothesis is then that the stones of Corinth were used before the 6th century BC, very early in the history of Delphi.

After the construction of the Old Apollo Temple, its destruction and the reinvestment of its building stones for the New Temple, the wall terrace above it (the *iskhegaon*), and some other monuments, during the 4th century, the oolitic grainstone facies was clearly less employed. Thus, a new trend has been noted: the use of slope breccia became more predominant, as it was not use at all, or in very small quantity, before. For example, the Attale's Terrace was built during the 2nd century BC almost entirely in slope breccia. It seems that, imported stones where first used, then local stones. It is also contradictory with the idea that the Ancient probably had to extract the slope breccia to create terraces during the 5th century BC, but its use in construction appears later.

Concerning the geotechnical aspect, the density is a crucial characteristic for the transport but also for the construction – intuitively, one may expect lighter stones in the second floor of a building. However, in the case of the limestones in Delphi, they have all a very similar density – between 2.65 and 2.68 g/cm^{-3}. It seems that the choice was based on other characteristics that must be evaluated.

In general, there is no clear link between the nature of the building stone and the dedicator of the monument: the *pôros* may all come from the south border of the Corinth Gulf, but the dedicator does not. But some *pôros* were employed in just one building (*e.g.* the coarse-grained sandstone, P3, in the Treasury of the Beotians): the more rational explanation is that the builders have brought this specific stone for the construction, as it was the case for marbles (Martin, 1965).

Finally, the observations in the site support the hypothesis that the Profitis Ilias quarries were opened for the construction of the New Apollo Temple (Amandry, 1981). It seems that this limestone was only used in monuments build in the same time or after the beginning of the construction of the Apollo Temple (see Fig. 12 for the lithological plan of the sanctuary: the blue represents the Profitis Ilias limestone).

5 Conclusion

This study has enabled us to point out an unexpected diversity of building materials used in the Sanctuary of Delphi. In total, twelve different sedimentary facies have been described: four limestones of the Parnassus Nappe, recent slope breccia, and seven facies of so called *pôros*, that can be defined as recent porous sedimentary deposits. The recognition of the various lithologies allowed us to draw conclusions and hypotheses on their use in the archaeological site and their provenance.

The majority of the building stones were extracted locally but Delphi shows an unusual quantity of imported material (around 15%). Precise provenances are still under investigation, but the porous facies can be linked with the Pleistocene sedimentary deposits of the south-east margin of the Corinth Gulf were the same lithologies have been observed: oolitic grainstone at Corinth; stromatolites formation in Perachora; travertine in Pellene. Other criteria should be analyzed to validate or invalidate those hypotheses, using non-intrusive and portable analytical methods for example. Knowing the stones origin can be important for the restauration and conservation processes of the monuments.

The first steps of this study support the hypothesis that stones, even those that are more common and accessible than marbles, must have been chosen for precise reasons by the builders, even if the exact purpose is still unclear – the influence of the cost, the politics and the geotechnics aspects have to be evaluated.

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