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The site of Aquileia (northeastern Italy): example of fluvial geoarchaeology in a Mediterranean deltaic plain / Le site d'Aquilée (Italie nord-orientale) : exemple de géoarchéologie fluviale dans une plaine deltaïque méditerranéenne

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Résumé

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The site of Aquileia (northeastern Italy): example of fluvial geoarchaeology in a Mediterranean deltaic plain

Le site d'Aquilée (Italie nord-orientale) : exemple de géoarchéologie fluviale dans une plaine deltaïque méditerranéenne

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Abstract

Archaeological and historical data show that Aquileia was one of the most important fluvial harbours of the Roman Empire. Recent databases, derived from several disciplines, highlight the presence of important waterways in the Aquileia deltaic plain during antiquity. The core deposits record the presence of high-energy river channels, at least north and east of the town. At the beginning, these courses had a generally N-S direction and probably fed the hut village of the 9th-7th centuries B.C., recently discovered in the city. Subsequently, the waterways had a NE-SW trend. The reason of this hydrographical change is linked to natural and/or artificial causes. Interaction of palaeohydrography and palaeohydrology with urban development is clearly demonstrated. People are affected by river dynamics: river flooding provides "natural" hydrological constraints in the deltaic plain, to which Roman communities responded by channelising rivers to guarantee good conditions of navigability and implementing flood protection measures and reducing hazards in these hydromorphous environments.

Key words: delta, palaeoenvironments, palaeohydrography, palaeohydrology, geoarchaeology, Roman antiquity, Aquileia, Italy.

Résumé

Les données archéologiques et historiques montrent que le site d'Aquilée fut l'un des plus importants ports fluviaux de l'Empire romain. Les recherches multidisciplinaires récentes insistent sur l'importance des voies fluviales dans la plaine deltaïque d'Aquilée au cours de l'Antiquité. Les résultats apportés par les paléoenvironnementalistes attestent la présence de paléochenaux fluviatiles de haute énergie, au moins au nord et à l'est du site. Initialement (IXe-VIIe s. av. J.-C.), le tracé des paléochenaux a suivi une direction de composante principalement N-S, avant d'adopter une direction NE-SW. Les facteurs à l'origine de cette évolution hydrographique sont d'ordre naturel et/ou anthropique. L'interaction entre la paléohydrographie du site, la paléohydrologie des cours d'eau et l'aménagement de la ville romaine est clairement démontrée. Les stratégies de développement urbain évoluent en fonction de la dynamique fluviale. En même temps qu'elle s'adapte aux contraintes hydrologiques "naturelles" de la plaine deltaïque, la société romaine contrôle l'extension des environnements hydromorphes ainsi que la géométrie et l'hydraulicité des cours d'eau afin de maintenir de bonnes conditions de navigabilité.

Mots clés *: delta, paléoenvironnements, paléohydrographie, paléohydrologie, géoarchéologie, Antiquité romaine, Aquilée, Italie.*

Version française abrégée

Récemment inclus dans le patrimoine de l'UNESCO, le site d'Aquilée est situé à une cinquantaine de kilomètres à l'ouest de Trieste, dans un delta de la frange côtière nord-adriatique. La "plaine deltaïque d'Aquilée" (~ 400 km^2 ; alt. < 10 m) correspond à la partie orientale de la plaine littorale frioulane ; elle est bordée à l'est par les massifs et les plateaux calcaires

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du Karst et au nord par les Alpes Juliennes et Carniques et leur piémont (fig. 1). Cette plaine s'inscrit au sommet d'un remblaiement fluvio-marin mis en place depuis la fin du Pléistocène. Son évolution géomorphologique (fig. 2) est contrôlée par deux principaux facteurs, l'alluvionnement et le glacio-eustatisme (fig. 4), et, dans une moindre mesure, ou localement, par l'activité néo-tectonique et les actions anthropiques. Actuellement, le delta est drainé par quelques cours d'eau de résurgence karstique (Ausa, Terzo, Natissa, Tiel) et par un fleuve allochtone, l'Isonzo (module ~ 230 m^3/s), dont la source est située dans les Alpes Juliennes.

Les données archéologiques et historiques montrent que le site d'Aquilée fut l'un des plus importants ports fluviaux de l'Empire romain. Les recherches multidisciplinaires récentes, associant la géomorphologie, la sédimentologie, la paléontologie, la géophysique et l'archéologie, insistent sur l'importance des voies fluviales dans la plaine deltaïque d'Aquilée au cours de l'Antiquité. En particulier, les géomorphologues postulent que le réseau hydrographique actuel n'est pas conforme à celui de l'Antiquité. Deux mécanismes (capture, défluviation) pourraient confirmer cette hypothèse de travail, dans un contexte où 1) le relief et la pente des lits fluviaux, très faibles dans la plaine, sont propices aux débordements et aux changements de tracé et/ou 2) des phénomènes de subsidence peuvent, au fil du temps, avoir augmenté, dans la partie orientale de la plaine, l'espace d'accommodation. L'objectif de cet article est 1) de définir les grandes caractéristiques paléoenvironnementales et paléohydrographiques du site d'Aquilée, 2) de quantifier la variabilité hydro-sédimentaire des cours d'eau et 3) de discuter des interactions possibles entre la paléohydrographie, la paléohydrologie et le développement de la ville romaine.

*L'étude paléoenvironnementale montre que le site d'Aquilée s'inscrit dans une plaine deltaïque où se juxtaposent des micro-reliefs (*i.e.*, paléo-bourrelets alluviaux) et des dépressions (*i.e.*, anciens marais d'eau douce ou lagunes saumâtres ; fig. 3 et fig. 5). La partie nord-orientale de la plaine est plus élevée (~ 6,5 m) que la partie sud-occidentale (~ 3 m ; fig. 5). Ce dénivelé s'explique par une vitesse d'aggradation accrue de la plaine au nord-est, liée aux apports solides du paléo-Isonzo, du paléo-Natisone et du paléo-Torre. La position dominante du site d'Aquilée (alt. 3-4 m) par rapport à son environnement immédiat s'explique avant tout par la surélévation artificielle de la topographie, provoquée par l'empilement des niveaux d'occupation romains, paléo-chrétiens et médiévaux. La topographie de la ville romaine, contrastée, est située entre -1 m et -2 m sous le sol actuel. Dans la mesure où il a été montré que le sous-sol au droit d'Aquilée était néo-tectoniquement stable, l'enfouissement de ces paléosols d'occupation est attribué à des phénomènes d'alluvionnement, renforcés par les remblaiements artificiels post-romains. Au sud de la ville fortifiée, une vaste zone déprimée est prolongée par une succession de reliefs sableux (*i.e.*, "Dunes du Belvédère et de San Marco" ; fig. 1) orientés nord-est—sud-ouest et nord-nord-est—sud-sud-ouest ; les données géomorphologiques, sédimentologiques et chronologiques récemment obtenues montrent qu'il s'agit de dunes éoliennes remaniant les sables fluviatiles d'un paléochenal.*

*Les sources historiques et épigraphiques révèlent que le site d'Aquilée a été édifié dans des zones humides insalubres. Les légendes indiquent que l'essor de la ville romaine n'a pu se faire qu'au prix d'un lourd travail de drainage des terrains hydromorphes. Les données paléoenvironnementales acquises lors de fouilles géoarchéologiques, confortées par des carottages profonds (campagnes S.A.R.A. ; fig. 6) et par la prospection géophysique du sous-sol, ont permis de confirmer ce point de vue. En particulier, la reconstitution d'un transect ouest-sud-ouest—est-nord-est (fig. 7) indique que le sous-sol d'Aquilée est caractérisé par la présence de dépôts fluviatiles (*i.e.*, banc de chenal ou plaine d'inondation) depuis la fin du Pléistocène. Des conditions plus humides sont décelées par la micro-paléontologie des dépôts fins à partir de 3500 av. J.-C. C'est très certainement dans cette ambiance humide que se développe le réseau hydrographique autour de la ville antique.*

Concernant la reconstitution du système hydrographique, on sait par les données historiques qu'un cours d'eau résultant de la confluence entre le paléo-Natisone et le paléo-Torre s'écoule non loin d'Aquilée au Ier siècle ap. J.-C. ; il s'agit très certainement du paléo-Isonzo. Les résultats apportés par les paléoenvironnementalistes attestent la présence de paléochenaux fluviatiles de haute énergie, au moins au nord et à l'est du site (fig. 8 et fig. 9). Initialement (IXe-VIIe s. av. J.-C.), le tracé des paléochenaux a suivi une direction de composante principalement N-S, avant d'adopter une direction nord-est—sud-ouest. Cette dernière est très certainement celle des paléochenaux actifs au début de la fondation d'Aquilée, en 181 av. J.-C. Les embouchures des paléochenaux mis en évidence sont localisées au sud de la ville fortifiée, en mer, au-delà de l'actuelle lagune de Grado. La connexion entre la mer et le port fluvial d'Aquilée est assurée par des chenaux fluviaux navigables, naturels ou artificiels (Canal Anfora). La direction nord-est—sud-ouest des chenaux artificiels ou de certains chenaux dits naturels (Terzo, Ausa) apparaît globalement conforme à l'orientation de la centuriation romaine.

*Du point de vue de la caractérisation hydro-sédimentaire des cours d'eau et de leur géométrie, l'étude litho-stratigraphique des remblaiements alluviaux atteste une continuité de la sédimentation grossière de l'âge du fer à l'époque impériale (fig. 7 et fig. 9). Dans le secteur central de la ville (fig. 7), le sous-sol enregistre la présence de trois paléochenaux emboîtés, mis en place entre 5615 av. J.-C. et 150 ap. J.-C. Le paléochenal le plus récent (*i.e.*, paléochenal dit n° 3 ; fig. 7) présente la compétence la plus élevée. La largeur de sa bande active est estimée à 300-400 m, pour une profondeur maximale de 9 m. Ses caractéristiques géométriques permettent de le comparer à l'actuel Isonzo, en aval de la confluence avec le Torre, dont le style fluvial s'apparente à du tressage. Les calculs hydrauliques, celui de la puissance spécifique en particulier, confirment cette hypothèse. Ils attestent l'existence, au début de l'Antiquité, d'une plaine alluviale à chenaux multiples, sur laquelle la migration des drains est rendue possible par la progradation des bancs de chenal, dans un contexte d'excédent de charge favorisant l'exhaussement du plancher alluvial.*

Pour finir, l'étude aborde l'interaction entre la paléohydrographie du site, la paléohydrologie des cours d'eau et l'aménagement de la ville romaine. Ainsi, il est montré que certains paléochenaux ont été artificiellement remblayés durant la phase finale de leur activité, afin d'accroître la surface des zones urbanisables. D'autres travaux hydrauliques ont été effectués afin de chenaliser les cours d'eau de haute énergie, comme le montre la découverte des quais du port fluvial, construits sur la berge du fleuve Natissa (photo 1). En même temps qu'elle s'adapte aux contraintes hydrologiques "naturelles" de la plaine deltaïque, la société romaine contrôle l'extension des environnements hydromorphes ainsi que la géométrie et l'hydraulicité des cours d'eau afin de maintenir de bonnes conditions de navigabilité.

Introduction

In the areas surrounding the Mediterranean coast, Holocene deltaic systems present geomorphological features which have been controlled by numerous factors including sea-level variations, alluviation, structure, and human activities (Stanley and Warne, 1993; Dubar and Anthony, 1995). If natural factors played an important role during the first part of the Holocene, human influence has been great since 6000 years and increased enormously during the last 2000 years (Kay, 1993; Cencini, 1998). Studies focusing on interaction among people and environment in the deltaic plains were particularly developed since the last decade (Jeftic *et al.*, 1992; Ibanez *et al.*, 1997; Stanley and Warne, 1998). In particular, current scientific research poses the question about relations between societies installed in the wetlands and flood risk. In the Mediterranean area, management of wetlands by human communities begins early. The consideration of flood risk linked to flooding, avulsion-switching processes and/or crevassing is not restricted to Modern societies. The flood risk has been taken into account early, in particular by the antic societies. Recent work in the Rhône Delta has shown that societies tried to control river-channel geometry since the beginning of Antiquity (1st century B.C.) in order to minimise the hydro-geomorphological impact of flood events (Arnaud-Fassetta, 2000). In addition, the Romans modified locally the distribution of fluvial waters in the deltaic plain by digging artificial channels and drainage/irrigation ditches (Arnaud-Fassetta and Landuré, 2003).

In Italy, most fluvio-deltaic studies concern the Tyrrhenian coast (Bartolini *et al.*, 1984; Pranzini, 1989; Canuti, 1994; Romano *et al.*, 1994; Bellotti *et al.*, 1995). Paradoxically, little is published about the palaeohydrography and palaeohydrology of the northern Adriatic deltas during Antiquity except rare studies such as those concerning the Pô delta (Cencini, 1998) or the Marche region (Coltorti, 1997). Previous studies have concentrated on marine palaeoenvironments and on coastline evolution (Mathers *et al.*, 1999; Fouache *et al.*, 2000 and 2001). Moreover, most studies concern the late Middle Ages and Modern times. As many other Mediterranean deltas, the Aquileia deltaic plain, located along the northern Adriatic coast about 50 km west of Trieste (fig. 1), was occupied early by human societies. Therefore, its study fosters a better understanding of the interaction between anthropogenic factors and the hydrographic network in the deltas. At Aquileia, human settlements have been built in many deltaic plain settings considered safe from flood risk, including possible floodplain submersion and river channel shifts. Therefore, we postulate that interaction between population, the floodplain and river channels was particularly developed in the study area. Thus, it should be possible to explore how Roman society adapted to fluvio-deltaic environment change, in a context of strong fluvial constraints.

To date, few studies have described the functioning of the early rivers and/or hydrographical networks and channel patterns of the Aquileia deltaic plain. Aspects of the site are of the reconstruction of river courses in the deltaic plain and the characterisation of hydrological regime of rivers in antiquity. If we observe the map of the present hydrographical network (fig. 1), we note that only little rivers (Ausa, Terzo, Natissa and Tiel) drain the deltaic plain around Aquileia. Their basin area, which does not exceed ten to fifty km^2, is strictly part of the Aquileia plain. Only the Isonzo River and its main tributaries (Torre, Natisone and Judrio) constitute, to the east, the only important river basin (3452 km^2). Here we take into account the key elements we have at our disposal, particularly the archaeological remains at the site of Aquileia, ancient texts and archaeological excavations. These have shown that this was a big Roman fluvial harbour and geomorphologists postulate that the present-day hydrographic network is not at the same place as the ancient one. Two mechanisms (stream capture, channel shift or switch) would confirm this working hypothesis, in the context where 1) both the relief and water slope energy are low in the deltaic plain, and 2) subsidence process over time may increase depositional accommodation in the eastern part of the deltaic plain.

The aim of this paper is to 1) define the main characteristics of the hydrographical network and its historical context, 2) characterise fluvial dynamics at the site of Aquileia, and 3) consider some man-river relationships (*i.e.*, between hydrography, channel river dynamics and urban development) in the city during Roman antiquity.

Morphostructural context, late Quaternary delta plain development, and human settlement

Aquileia deltaic plain (~ 400 km^2; alt. < 10 m) corresponds to the eastern part of the Frioulian coastal plain. It is bordered to the east by massive limestones of the Karst plateaux and massifs, and to the north by the Alpine massifs and their piedmont (fig. 1).

The Alpine massifs may be divided into two sub-units: the Carnic Alps to the NW, constituted mainly by limestone, and the Julian Alps to the NE, where compact limestone is associated with dolomite. Elevations range from 950 m to 2780 m (Mt Coglians: Carnic Alps) and 2677 m (Mt Mangari: Julian Alps). Geomorphological features linked to Quaternary glaciations (rocky glacial knobs, moraines) have been preserved in the landscapes of the two massifs. In the Julian Alps, numerous faults present two distinct traces:

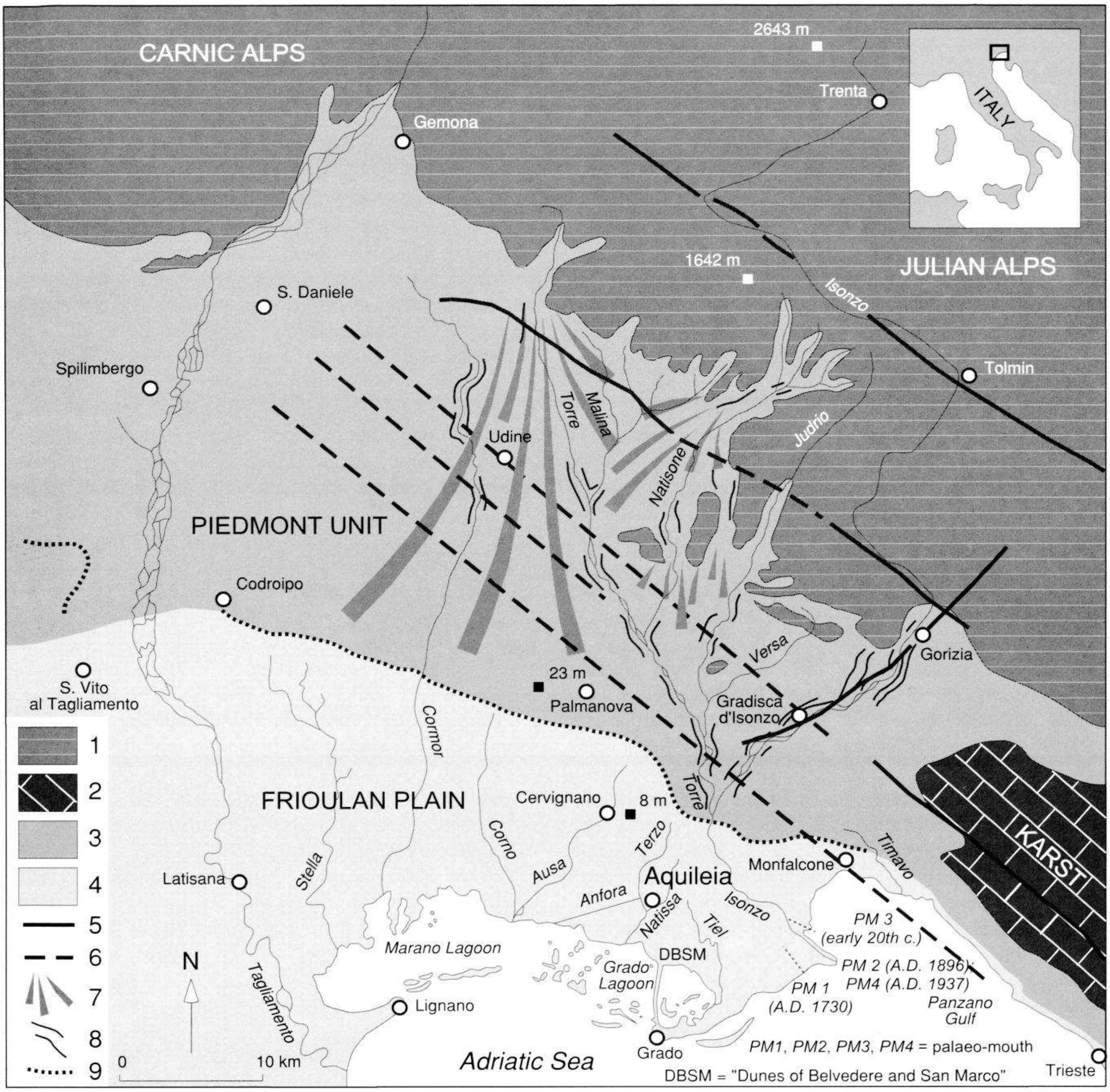


Fig. 1 – **Map of the Aquileia deltaic plain and its region.** 1: mountainous massifs (limestone, dolomite); 2: Karst plateau and massifs (limestone); 3: piedmont (calcareous marl, marly limestone, marly calcareous flysch); 4: plain unit (Quaternary fluvio-marine infill); 5: major fault; 6: possible fault (hypothetical trend); 7: alluvial fan; 8: enclosed valley (not represented in the mountainous units); 9: springs boundary.

*Fig. 1 – **Carte de la plaine deltaïque d'Aquilée et de sa région**. 1 : massifs montagneux calcaires et dolomitiques ; 2 : plateaux et massifs calcaires du Karst ; 3 : piémont (marnes calcaires, calcaires marneux, flyschs marno-calcaires) ; 4 : plaine (remblaiement fluvio-marin quaternaire) ; 5 : faille principale ; 6 : faille supposée (tracé hypothétique) ; 7 : cône alluvial ; 8 : vallée encaissée (non représentée dans les unités montagneuses) ; 9 : ligne de résurgence karstique.*

NW-SE (Alpine trace) or NE-SW (Dinaric trace). These faults involve active tectonics which have continued until now, since the present-day uplift of the Julian Alps is estimated to be 0.1 mm/yr (Carulli *et al.*, 1980). It is probable that faults have influenced the hydrographical network pattern. In particular, the fault-line valley of the Isonzo River presents a typical rectangular pattern (type D from the classification of Howard, 1967), with faults and/or joints at right angles ("bayonet trace"). Moreover, the localised presence of tectonised soft rocks (slaty marl) and friable superficial deposits (till, alluvium, colluvium), associated with steep gradients and possible occurrence of seismic events, induce frequent mass movements and gullying in the basin area. Therefore, the mountainous unit produces a large amount of debris that accumulates further downstream, and initially on the piedmont.

On the piedmont, the substrate is characterised by calcareous marl, marly limestone and marly calcareous flysch. Here, as in the mountainous unit, the lithological context favours mass movements (failures, landslides) and gullying (badlands) on slopes. Moreover, most of the piedmont surface is covered by alluvial fans formed during the late Quaternary. Steep river-channel gradients and high sediment loads have caused course changes of the rivers Torre, Natisone and Judrio on the fans. In addition, the area is crossed by several faults (fig. 1) linked to Plio-Quaternary tilting of the Karst plateaux and massifs that dip gently to the NW; the main fault corresponds to the Palmanova line. In agreement with G.B. Carulli *et al.* (1980), tilting may be related to increasing weight of the external front of the southern Alps and the external Dinarides. Faulting also appears to affect the eastern part of Aquileia deltaic plain.

Aquileia deltaic plain corresponds to the top of a fluvio-marine infilling deposited since the late Quaternary (Marocco, 1991a). Drainage is affected by two types of river: 1) several little rivers (Ausa, Terzo, Natissa, Tiel), which lie downstream of a karstic spring boundary (this latter constitutes the contact between the deltaic plain and piedmont), and 2) allochthonous rivers, particularly the Isonzo River (mean annual water discharge ~ 230 m^3/s; mean annual sediment discharge ~ 0.76 x 10^6 m^3), which starts in the mountainous area (Julian Alps) at about 1610-m elevation. This river is characterised by a network of laterally unstable, braided, high-gradient channels. High stream powers allow to transport a coarse bed-material load (gravels and coarse sands) down to ~ 10 km upstream from the river mouth (Bresson, 2000 and 2001; Siché, 2002). Further downstream, the gradient decreases and the single channel of the Isonzo River tends to become deeper and sinuous. Here, bed material is characterised by silt and sand. The large amount of sediment deposited at the river mouth for a long period has built a vast deltaic system with a complex history.

During the last Glacial Maximum (23-18 ka B.P.), the Gulf of Trieste was an alluvial plain covered by a Gramineae steppe connected to the palaeo-Isonzo-Torre-Natisone system to the east and to the palaeo-Tagliamento to the west (Bortolami *et al.*, 1977; Marocco, 1991a). During the post-glacial transgression, the sea first submerged the Istrian coast (~ 10 ka B.P.), then the Karst coastline of Trieste (~ 7 ka B.P.), then the Frioulian coastal plain. The geomorphology of the Holocene Aquileia deltaic plain has been widely studied by A. Brambati (1970, 1985) and R. Marocco (1989, 1991a, 1991b). Focusing on the coastline evolution, R. Marocco (1991a) used historic, archaeological and geological data to postulate four palaeogeographical scenarios at 4 ka B.P., 2 ka B.P., 1 ka B.P. and 0.5 ka B.P. (fig. 2).

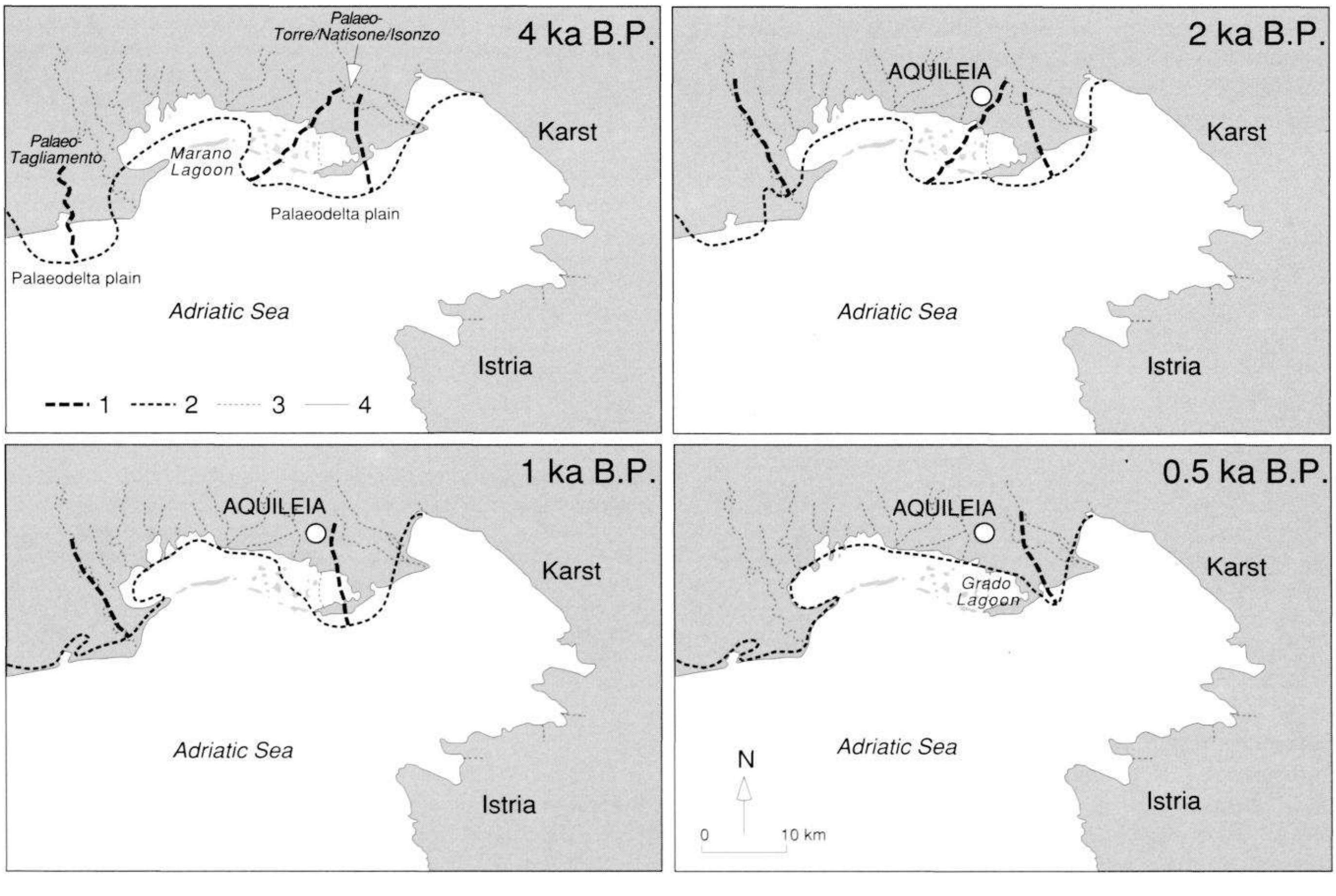


Fig. 2 – **Palaeogeography of the Aquileia deltaic plain at various time intervals (modified after Marocco, 1991).** 1: distributary palaeochannel; 2: palaeocoastline; 3: present river; 4: present coastline.

*Fig. 2 – **Paléogéographie de la plaine deltaïque d'Aquilée à différentes époques de son évolution (d'après Marocco, 1991 modifié)**. 1 : paléochenal fluviatile ; 2 : ancienne ligne de rivage ; 3 : cours d'eau actuel ; 4 : ligne de rivage actuelle.*

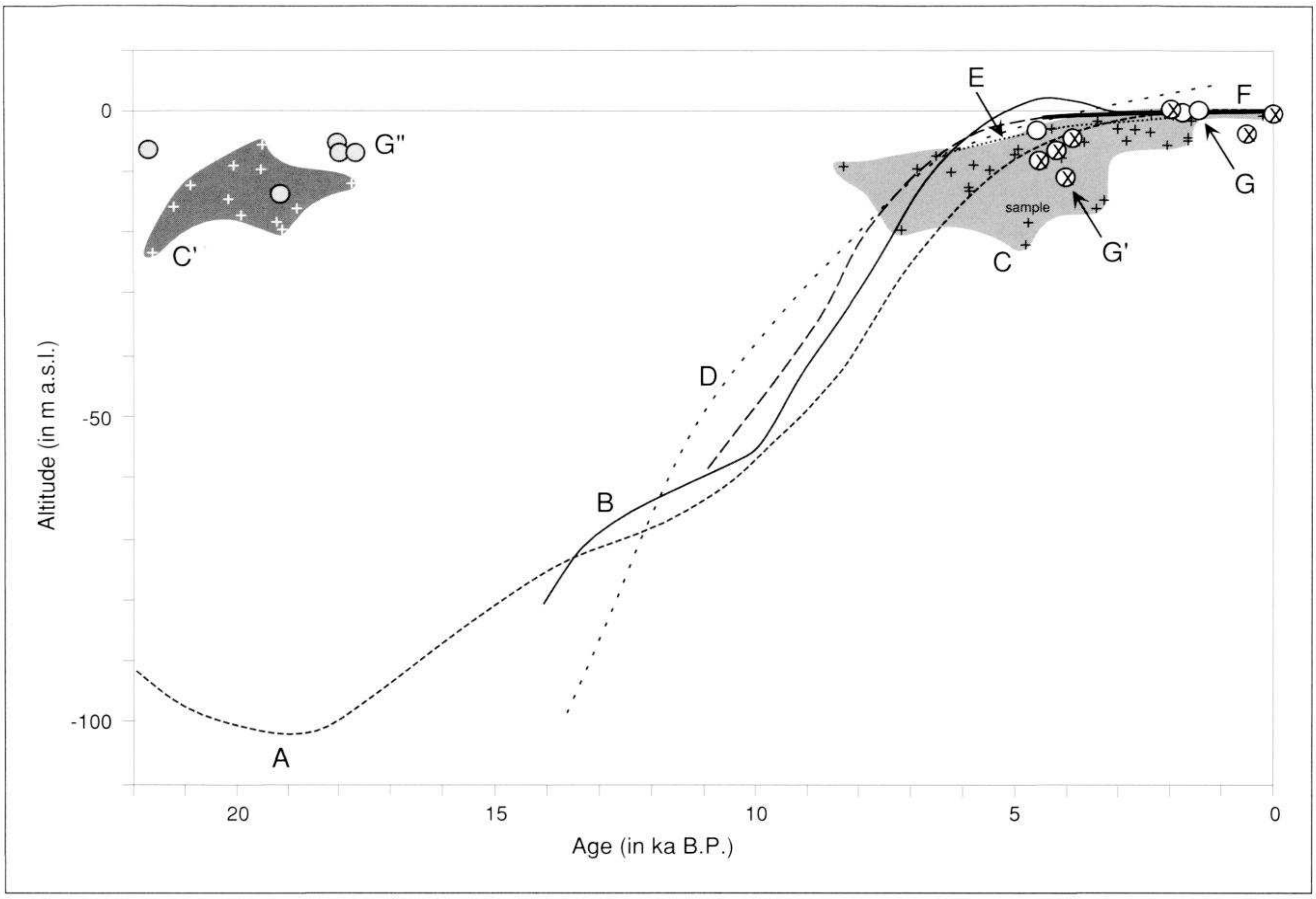


Fig. 3 – **Relative sea-level changes in northwestern Mediterranean since the last Glacial Maximum**. A: Roussillon, France (Labeyrie *et al.*, 1976); B: SW France (Aloïsi *et al.*, 1978); C: Venice plain and lower Pô valley, Holocene deposits (Bortolami *et al.*, 1977); C': Venice plain and lower Pô valley, Pleistocene deposits (Bortolami *et al.*, 1977); D: French Riviera (Dubar and Anthony, 1995); E: Fos Gulf, France (Vella and Bourcier, 1998); F: rocky coasts of Provence, France (Laborel *et al.*, 1994); G: Aquileia deltaic plain, Holocene peat deposits (Marocco, 1991a; S.A.R.A. project); G': Aquileia deltaic plain, Holocene marine deposits (Marocco, 1991a; S.A.R.A. project); G": Aquileia deltaic plain, Pleistocene peat deposits (Marocco, 1991a; S.A.R.A. project).

*Fig. 3 – **Variations du niveau marin relatif en Méditerranée nord-occidentale depuis le dernier maximum glaciaire**. A : Roussillon, France (Labeyrie* et al., *1976) ; B : France du SW (Aloïsi* et al., *1978) ; C : plaine de Venise et basse vallée du Pô, dépôts holocènes (Bortolami* et al., *1977) ; C' : plaine de Venise et basse vallée du Pô, dépôts pléistocènes (Bortolami* et al., *1977) ; D : Riviera française (Dubar et Anthony, 1995) ; E : Golfe de Fos, France (Vella et Bourcier, 1998) ; F : côtes rocheuses du Sud-Est français (Laborel* et al., *1994) ; G : plaine deltaïque d'Aquilée, tourbes holocènes (Marocco, 1991a ; S.A.R.A. project) ; G' : plaine deltaïque d'Aquilée, dépôts marins holocènes (Marocco, 1991a ; S.A.R.A. project) ; G" : plaine deltaïque d'Aquilée, tourbes pléistocènes (Marocco, 1991a ; S.A.R.A. project).*

Three main events are identified in the deltaic area: 1) Marano Lagoon is older than the one at Grado, since their formation can be ascribed to ~ 5.5 ka B.P. and post-Roman age, respectively; 2) the present Aquileia area has not recently been reached by the sea; and 3) the main rivers of the area have been affected by generally continuous avulsion processes that, at least in the case of the Isonzo River, have continued until now.

Four main factors control the geomorphological evolution of the Aquileia deltaic plain: 1) alluviation, 2) eustatic fluctuations, 3) subsidence process, and 4) anthropogenic factors.

1) The Aquileia deltaic plain was formed mainly by sediment supplies of the palaeo-Isonzo-Torre-Natisone. Large amounts of sediment discharged by these rivers and redistributed by waves are important factors controlling geomorphological evolution of the deltaic plain, at least during the past 5000 years.

2) With regards to sea-level fluctuations, the available first order data (peat radiocarbon ages *versus* sample depths) show a consistent relationship between Aquileia deltaic plain and numerous sites of the northwestern Mediterranean (fig. 4). Second order data (organic silt or mollusc shell radiocarbon ages *versus* sample depths) do not give precise information concerning the vertical position of the relative sea level. However, distribution of these latter on the "age/depth" diagram (fig. 3), below the peat radiocarbon ages of Aquileia deltaic plain and northwestern Mediterranean "reference curves", would confirm the hypothesis of negative movements of the geologic substrate linked to subsidence processes. Finally, all the curves (fig. 4) show that relative sea-level rise was rapid between 17 ka B.P. and 7 ka B.P. (Pirazolli, 1998). Rates of relative sea-level change

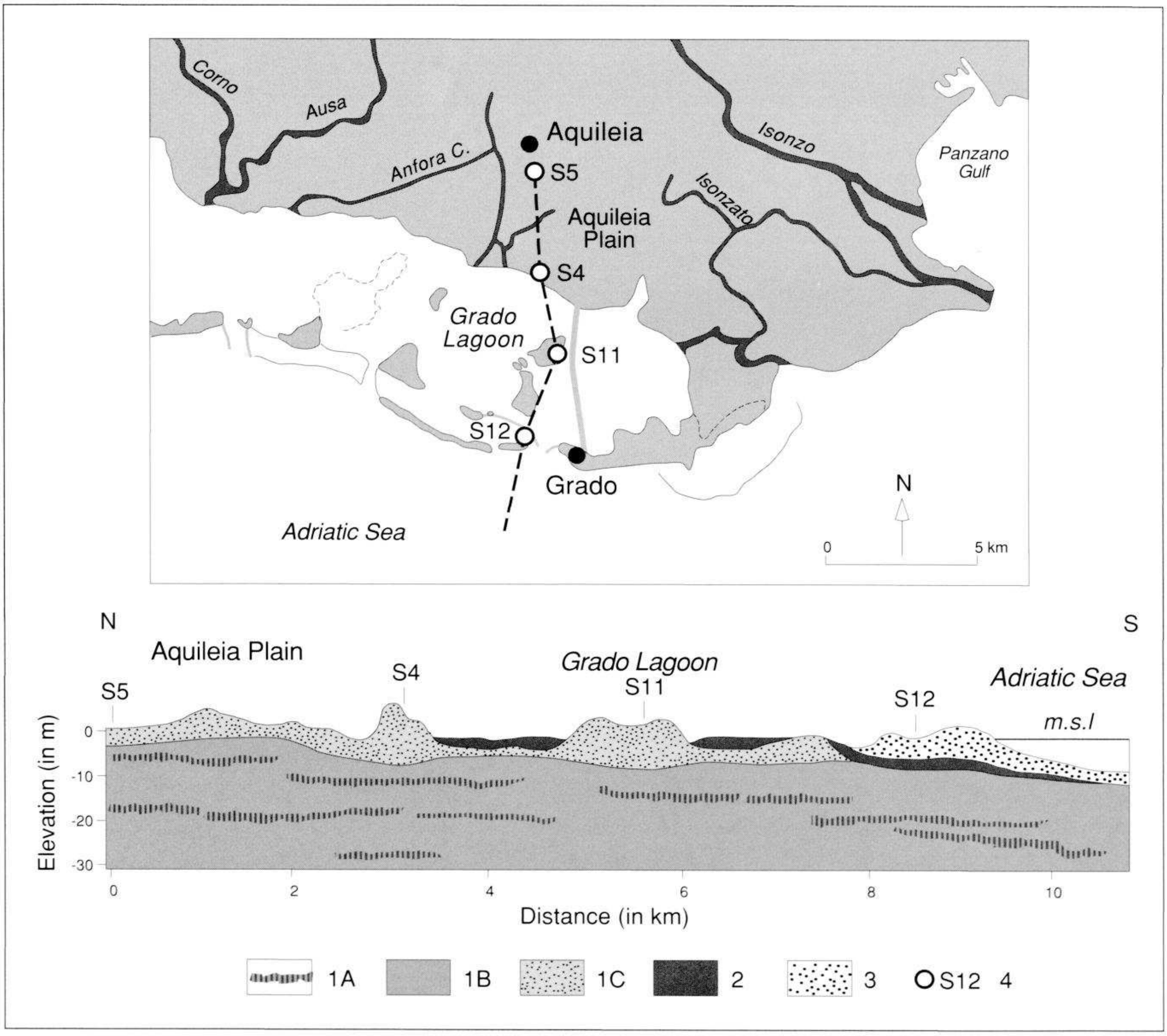
decelerated considerably since ~ 7 ka B.P. and sea level approached its present stand by ~ 5 ka B.P., allowing the progradation of the deltaic systems (Stanley and Warne, 1994).

3) Moreover, neotectonics is expressed by subsidence process. Natural subsidence rates are low (0.1-0.2 mm/yr on average; Bondesan *et al.*, 1995). However, higher rates have been reported near river channels (~ 2.2 mm/yr near the Isonzo River). Whatever the evidences, subsidence rates in Aquileia deltaic plain are lower than those estimated in other sectors of the Adriatic coast. In particular, the work of S. Mathers *et al.* (1999) reveals very high subsidence rates (2.5-10 mm/yr) along the Adriatic coast of Albania. Here, subsidence is the main factor controlling the rapid geomorphological evolution of the deltas; that is not the case in the Aquileia deltaic plain where alluviation and eustatism play the leading role in geomorphological evolution of the delta.

4) In the Aquileia deltaic plain, the first settlement phase is dated between the 9th and 8th centuries B.C.; afterwards, it seems to have continued, despite the absence of preserved structures (Maselli Scotti, 1998a). The territory is occupied for a short period in the 2nd century B.C. by Transalpine Gauls, and then more consistently by the Romans who in 181 B.C. founded a colony in order to meet various political, military and economic needs (Bandelli, 1999). Located at the southernmost part of the Amber Road, a commercial route linking the Baltic region and the Adriatic (Maselli Scotti, 1996), Aquileia was one of the most important fluvial harbours of the Roman Empire. The Aquileia deltaic plain

Fig. 4 – **Depositional palaeoenvironments in the Aquileia deltaic plain (modified after Marocco *et al.*, 1984)**. 1: continental deposits (1A = peat; 1B = silt; 1C = sand); 2: lagoonal deposits; 3: marine deposits; 4: borehole.

*Fig. 4 – **Les paléo-milieux de sédimentation autour d'Aquilée (d'après Marocco** et al.**, 1984 modifié)**. 1 : sédiments continentaux (1A = tourbe ; 1B = limons ; 1C = sables) ; 2 : sédiments lagunaires ; 3 : sédiments marins ; 4 : carotte sédimentaire.*



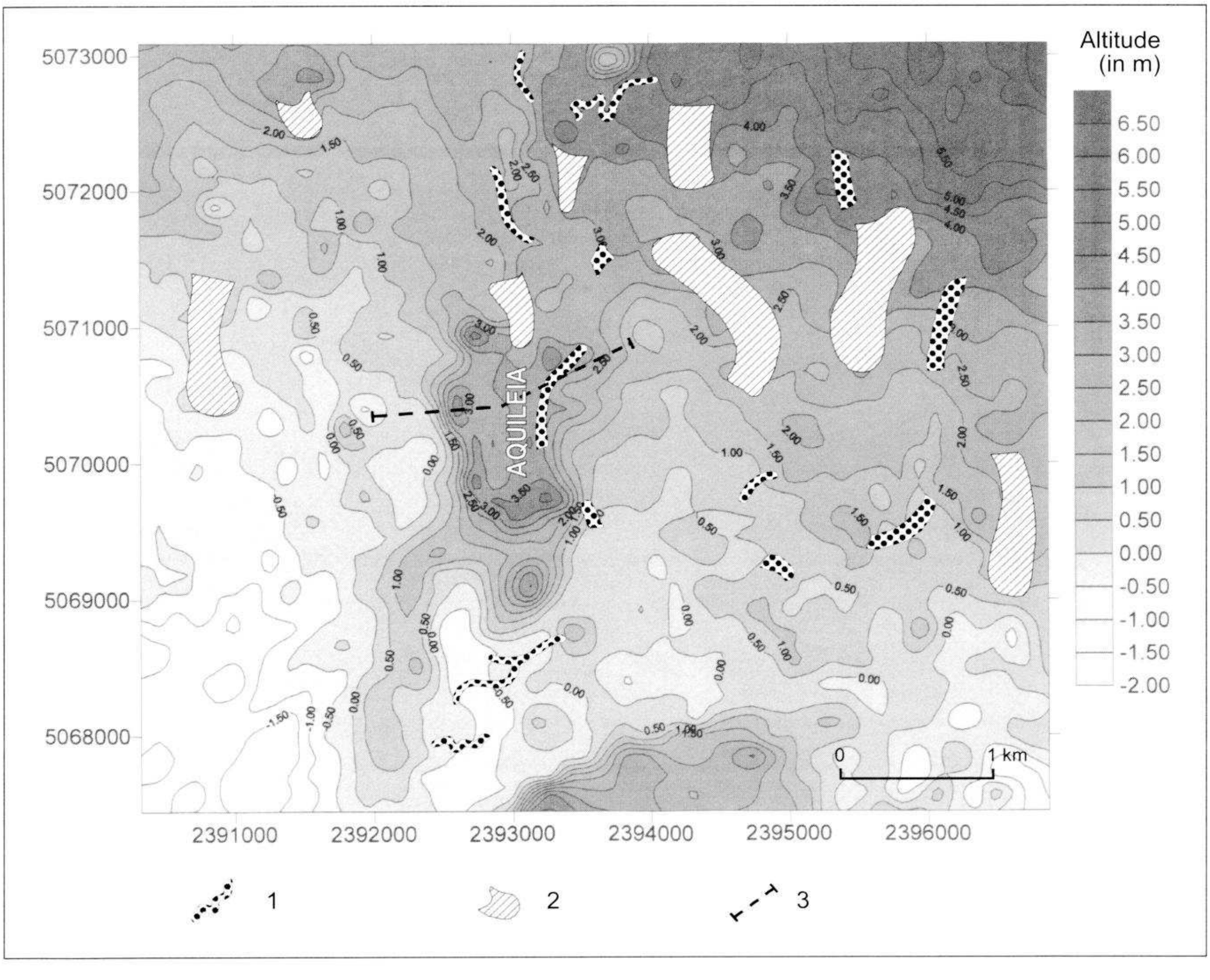
was exposed to coastal limitations, which caused the Romans to settle inland, along a river navigable from its mouth. Important coastline shifts precluded installation of a maritime harbour.

Palaeoenvironmental features at the site of Aquileia

The historic town of Aquileia is located on an alluvial plain delimited to the east by the Isonzo River, to the west by the spring-fed river Ausa, to the north by a relief resulting from fluvial changes of the Isonzo-Natisone-Torre system, and to the south by the so-called "Dunes of Belvedere and San Marco", which are major relief features surrounding present Grado Lagoon (fig. 1 and fig. 4). The palaeophysiography of the Aquileia territory was determined by analysis of the present microrelief and identification of geomorphological features (palaeo-ridges, ancient riverbeds and dunes). A microsurvey around Aquileia using the Surfer[1] program (kriging interpolation system) (fig. 5), which details 2102 quoted points on the Carta Tecnica Regionale (scale 1:5000; equidistance 0.5 m) shows that the deltaic plain is characterised by a series of relief features and depressions, with a N-S slope. Within these reliefs are observed a series of sedimentary bodies in palaeo-ridges, that correspond to abandoned beds of pluvio-nival rivers that developed by natural avulsion. These ridges are particularly evident northeast and just behind the town of Aquileia, thus recording the eastward diversion of rivers characterised by a large sedimentary load. The photogrammatic survey confirms microtopographic data, and identifies a series of fluvial courses located in the substrate as indicated by strongly impermeable deposits. Such courses appear of modest size and near-continuously meandering as related to spring-fed rivers. Other fluvial courses are identified in the substrate by means of geophysi-

Fig. 5 – **Microtopography map (equidistance 0.5 m) of the Aquileia region**. 1: abandoned river channel; 2: fluvial ridge; 3: stratigraphic cross-section (see fig. 6). The numbers indicate the kilometre grid of the Carta Tecnica Regionale of the Friuli-Venezia Giulia. Altitude in m, above and below m.s.l.

*Fig. 5 – **Carte topographique détaillée (équidistance 0,5 m) autour d'Aquilée**. 1 : paléochenal ; 2 : bourrelet alluvial ; 3 : tracé de la coupe stratigraphique (fig. 6). Les numéros reprennent la grille kilométrique de la Carte Technique Régionale du Frioul-Vénétie julienne. Altitude en m au-dessus ou au-dessous du niveau moyen de la mer.*



cal methods: these appear to be gravel and coarse sand bodies in the subsoil (Vaia *et al.*, 1985).

Moreover, relief and low zones are present north-northeastwards, southwards and southeastwards, respectively. It appears that the northeastern part of Aquileia is higher (~ 6.5 m) than the southwestern area (~ 3 m). The altitude difference between the extremities of the area is related to plain aggradation (*i.e.*, alluvial palaeo-ridges) from the action of the Isonzo, Natisone and Torre rivers, which have flowed here at different times. West of the Roman town, the depressions are probably due to limited fluvial sediment input (distal flooding), as also indicated by the presence of swamp and peat-bog deposits which have been continuously reclaimed since Roman time. In this area, localised subsidence phenomena occur. In the central part of the area, Aquileia rises to 3-4 m a.s.l., and is delimited by fortification walls. In addition, it is higher, with the presence of Roman, palaeo-Christian and mediaeval buildings (tell), than the surrounding plain. The anthropogenic soils of the Roman town are between 1 m and 2 m, down from the present-day ground level. Since the area is considered stable with regards to subsidence, this phenomenon is linked to normal deltaic plain aggradation, and to anthropogenically related relief features such as embankments.

In addition, south of the fortified town, a depressed zone is extended by NE-SW and NNE-SSW relief features (*i.e.*, "Dunes of Belvedere and San Marco"; fig. 1), that extend to the Grado Lagoon. These relief features comprise alluvial sands, which include soils ending with pan horizons. The dunes have been previously attributed to littoral processes related to proximity of the sea and interpreted as an ancient shoreline of Versilian sea ingression (Segre, 1969). Recently, geomorphological, sedimentological and chronological data exclude this hypothesis and suggest an aeolian origin in continental settings in which alluvial deposits have been modified (Marocco, 1991b; Lenardon and Marocco, 1994). This interpretation, however, should be further confirmed by the additional chronological and palynological research now in progress.

Concerning the palaeoenvironmental characteristics, historical sources and epigraphic evidence reveal that the site of Aquileia was built on marshlands that, overall, were salubrious (Vitruvius, *De Arch.* I, 4,11-12; Traina, 1988; Strazzulla, 1989). Legends indicate that the territory of Aquileia was a humid environment, developed at an early stage due to efficient drainage and canals. The memory of ancient drainage systems helps explain the importance of the Diomedes myth in this region. Diomedes embodied the civilizing hero: legends credited him with the drainage of Daunia and the construction of a canal linking inland centres to the sea (Strazzulla, 1989; D'Ercole, 2000). During the historical period, a group of *aquatores Ferorienses* (Inscriptiones Aquileiae, 1991-1993; 201 and 202), was no doubt still in charge of the city's hydraulic system. Their name is derived from *Feronia*, a goddess of dominating nature who is often mentioned in Aquileia (*Inscriptiones Aquileiae*, 1991-1993; 199 and 200) and particularly worshipped in the Pontine marshes (Fontana, 1997). It is no coincidence that *M. Cornelius Cethegus*, who initiated the drainage projects in this marshy area in 160 B.C., was one of the *triumviri* in charge of proceeding with the second renewal of the Aquileia colony in 169 B.C. (Strazzulla, 1989).

Moreover, investigations on the stratigraphic sequences of both the archaeological excavations [Essiccatoio (Maselli Scotti *et al.*, 1995); Roman harbour zone (Carre and Zaccaria, 2001)] and S.A.R.A. (*Subacqueous Archaeology Roman Aquileia*) boreholes yield useful data concerning palaeoenvironments of the Aquileia region during prehistoric, protohistoric and Roman time (fig. 6). The S.A.R.A. borehole sections were studied from lithological, biostratigraphic, chronostratigraphic (^{14}C dating) and archaeological analyses. Subsoil investigations were completed by recent geoelectric soundings at least to 12 m from ground level. To date, the results have been published by N. Pugliese *et al.* (1999), F. Maselli Scotti *et al.* (1999) and M.-B. Carre and F. Maselli Scotti (2001). The WSW-ENE transect reconstruction (fig. 7) that crosses the northern part of the Roman town indicates that the Aquileia subsoil was characterised by fluvial deposits (*i.e.*, river channel or floodplain) since uppermost Pleistocene time. In addition, the floodplain deposits also provide evidence of a change in environmental settings (swamp, peat-bog, emerged setting). These settings often appear as fining-upward sequences (sand to mud deposits, to peat; fig. 7). In some instances, these deposits contain a biogenic fraction, thus allowing a refined reconstruction of past conditions. In particular, fine deposits have a richer organic fraction than coarser ones, and consist of fresh water and pulmonate molluscs, ostracods and vegetal fragments indicative of swamps to peat-bogs. In addition, sea-level rise and subsidence processes, linked to fluvial changes and a decrease of solid river input, produced ingression of the sea. This produced brackish-water wetlands, as recorded by deposits containing brackish water molluscs, ostracods and foraminifers. These brackish water conditions began at ~ 3500 B.C., as indicated by borehole and excavation data (Essiccatoio, Ca' Baredi ; fig. 6). Moreover, brackish water conditions are indicated by very recent core-deposits (boreholes 5/1995, 6/1995 and 7/1995), and excavations (Roman harbour zone) where there are rare occurrences of low salinity ostracods. Finally, alluvial deposits, including pseudogley soils, continue in Aquileia subsoil (to 2.5-2.0 m from the ground soil) where they are then substituted by archaeological (Roman and mediaeval) and recent anthropogenic levels. It is in this palaeoenvironmental context that hydrographic network developed in the Aquileia area.

Hydrographic network and channel hydraulics at Aquileia during Roman time

Reconstruction of the hydrographic system

Historical sources, together with microtopographic, photogrammetric and palaeoenvironmental data, serve to make an initial interpretation of the hydrographic network at Aquileia during antiquity. Early documentation provides

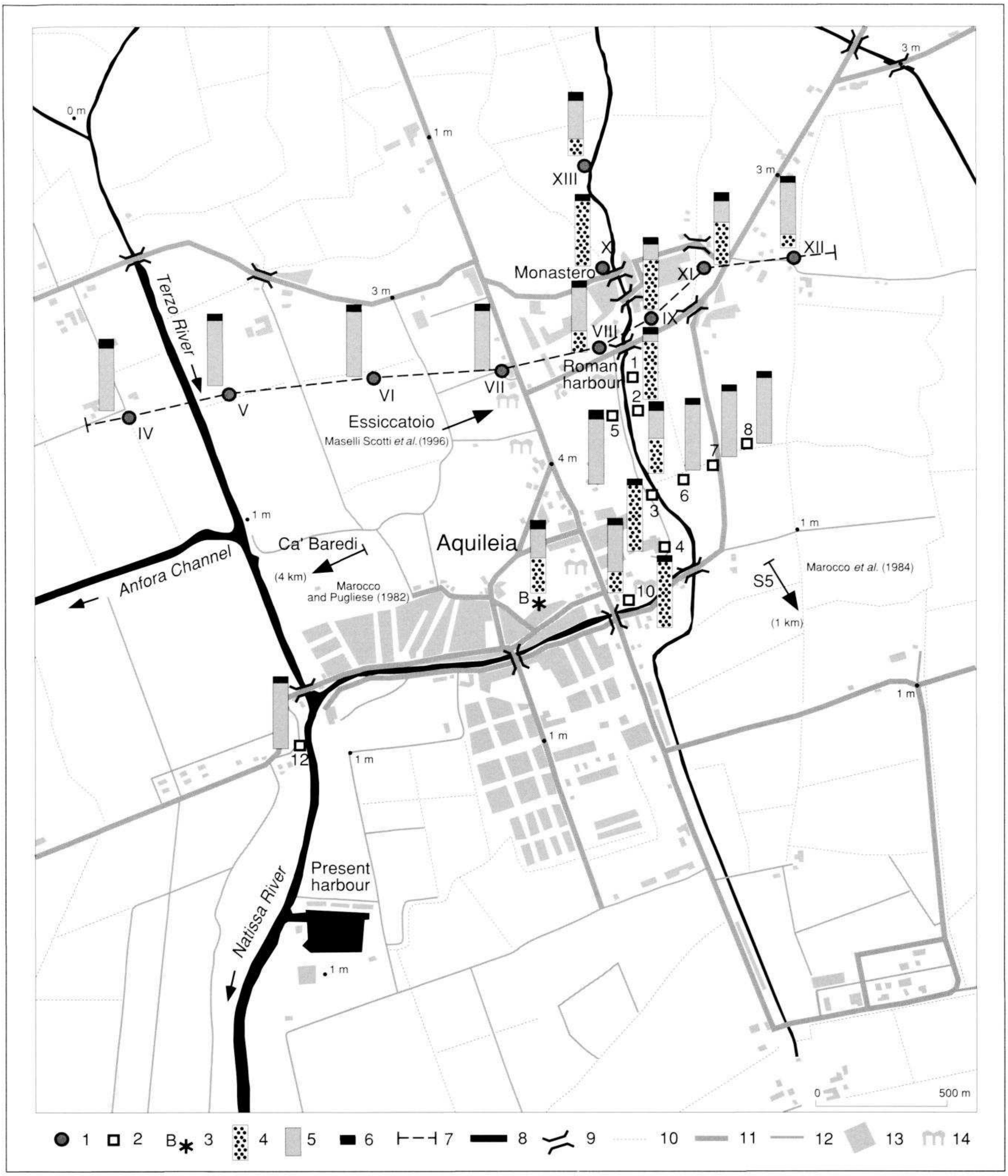


Fig. 6 – **Depositional environments deduced from sediment cores (S.A.R.A. and Brünner).** 1: S.A.R.A. borehole (1994); 2: S.A.R.A. borehole (1995); 3: "Brünner" borehole; 4: coarse river channel deposits (gravel with sand matrix); 5: flood plain deposits (sand, silt and/or clay); 6: reworked material; 7: stratigraphic cross-section (see fig. 7); 8: present river; 9: present bridge; 10: present drainage ditch; 11: present main road; 12: present secondary road; 13: present settlement; 14: Roman vestiges.

Fig. 6 – ***Interprétation des environnements de dépôt à partir des carottes S.A.R.A. et Brünner****. 1 : carotte S.A.R.A. (année 1994) ; 2 : carotte S.A.R.A. (année 1995) ; 3 : carotte "Brünner"; 4 : dépôts grossiers de chenal (graviers dans matrice sableuse) ; 5 : dépôts alluviaux fins (sables, limons et/ou argiles); 6 : matériel remanié ; 7 : tracé de la coupe stratigraphique (fig. 7); 8 : cours d'eau actuel ; 9 : pont actuel ; 10 : fossé de drainage actuel ; 11 : route actuelle ; 12 : chemin actuel ; 13 : installations humaines actuelles ; 14 : vestiges romains.*

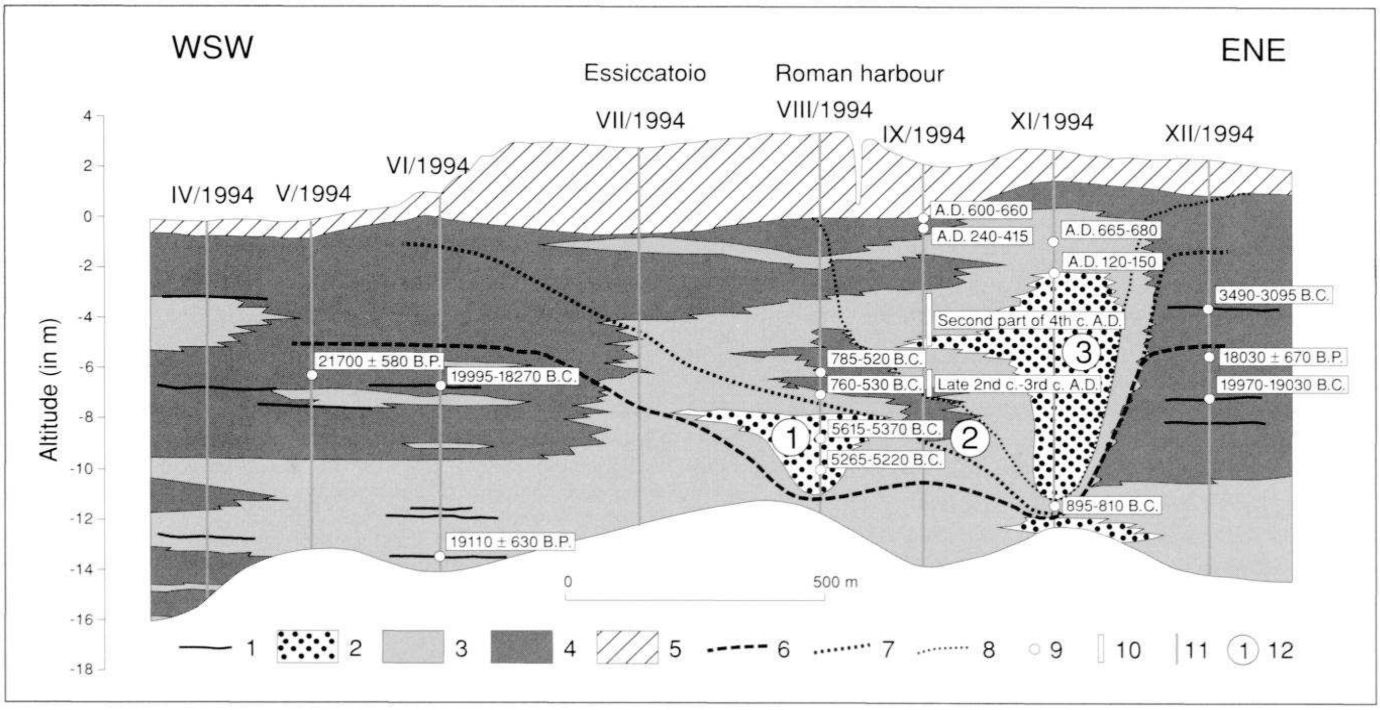
some information about the main hydrography of Aquileia region (Vedaldi Iasbez, 1994). Pliny (1st century A.D.) notes that a river resulting from the confluence of the Natisone and the Torre flowed not far from Aquileia. Two votive dedications, dating from the 2nd century A.D. and found in the current bed of the Isonzo (Inscr. Aq. 96; Vedaldi Iasbez, 1996), refer to this river as a fluvial divinity with the name of *Aesontius*. Later literary sources also mention the *Frigidus* (associated with the Vipacco/Vipava) and the Isonzo, written with the graphical variations *Isontius* and *Sontius*. Finally, we call attention to the existence of a low relief surface where a divinity with a beard and horns (following the classic iconography of rivers), holding a reed in his hand, is lying on a riverbank at the foot of the *Tyche* of Aquileia with a cornucopia. This latter symbolises the prosperity of the city, of which the river is the source (Bertacchi, 1994b).

Moreover, palaeoenvironmental data show that, during Antiquity, the Aquileia area was cut by two pluvio-nival rivers, which flowed adjacent to the east of the town (fig. 8). One river (*i.e.*, "palaeochannel 2" in fig. 7, so-called "north channel" in fig. 8) flowed from the north and probably was used by those in the hut village of the 9th-7th centuries B.C., recently described in the locality (Maselli Scotti *et al.*, 1996). In time, this palaeochannel became progressively less important and deviated eastwards. Subsequently, it was filled by fine overbank deposits and anthropogenic debris. A second protohistoric and historic palaeochannel (*i.e.*, "palaeochannel 3" in fig. 7, so-called "NNE channel" in fig. 8) flowed from the NNE and lapped the eastern Aquileia area. It probably was important during the period of Aquileia foundation. The buried palaeobed deposits indicate continuity of coarse sedimentation from Iron Age to Roman Imperial time. These riverbeds are believed to continue southward, but there is no information about this, except for some gravel lenses identified in the subsoil by means of geophysical investigations (Stefanini and Cucchi, 1976). These lenses record various fluvial course changes. Their mouths were located to the south, beyond the present Grado Lagoon. The connection between the sea and the Roman harbour of Aquileia was maintained by a series of natural and artificial waterways. These waterways connected this famous *emporium* to Marano Lagoon (to the southwest), and presumably to San Canziano call (to the east).

In addition, the present spring rivers are characterised by N-S trending typical incised beds (Terzo and Tiel) at the western and eastern parts of the site. West of the urbanized area, the Ausa River is NE-SW directed, thus along the trend of the artificial and navigable Anfora channel. The orientation of these rivers seems to parallel the territorial arrangement of the Romans for the *secundum naturam*-made centuriation of the Aquileia area and, subsequently, to those of Maria Theresa's reclamation (18th century A.D.). This is particularly true for the Terzo and Ausa rivers that flow parallel to fortification walls and the Anfora channel, respectively (Marocco, 1991a). The Natissa spring-fed river, which rises

Fig. 7 – **WSW-ENE lithostratigraphic section at Aquileia (see fig. 5 for location of the boreholes)**. 1: peat; 2: gravel; 3: sand; 4: pelite; 5: reworked material; 6: alluvial floor *post* 18030 ± 0.670 ka B.P. (speculative trace); 7: alluvial floor *post* 3490-3095 B.C. (speculative trace); 8: alluvial floor *post* 785-520 B.C. (speculative trace); 9: radiocarbon date (cal.); 10: archaeological date; 11: S.A.R.A borehole (1994); 12: number of palaeochannel.

Fig. 7 – ***Coupe lithostratigraphique WSW-ENE du site d'Aquilée (localisation des carottes sur la fig. 5)****. 1 : tourbe ; 2 : graviers ; 3 : sables ; 4 : pélites ; 5 : matériel remanié ; 6 : plancher alluvial post 18 030 ± 0,670 ka B.P. (tracé hypothétique) ; 7 : plancher alluvial post 3490-3095 B.C. (tracé hypothétique) ; 8 : plancher alluvial post 785-520 B.C. (tracé hypothétique) ; 9 : datation radiocarbone (cal.) ; 10 : datation archéologique ; 11 : carotte S.A.R.A (année 1994) ; 12 : paléochenal numéroté.*



NNE of Aquileia and flows to the SSW, towards Grado Lagoon, crosses Aquileia following a course along the historic centre. This Aquileia-to-sea (Morgo) course reveals several remnants of buildings and other archaeological evidence. They may indicate this course as the remains of the river that once flowed east of town (Carre *et al.*, in press).

Characterisation of channel geometry and hydraulics

Aquileia deltaic plain, at least since the Bronze Age, was crossed by rivers (*i.e.*, torrent-like and/or spring-fed rivers) characterised by a consistent solid load transport. The reaches flowed on fluvial ridges, and their flooding produced aggradation of the deltaic plain. In the central sector of the WSW-ENE transect (*i.e.*, Essiccatoio, fluvial harbour, Monastero locality; fig. 7), the subsoil records a deep incision and subsequent sedimentation of three superimposed and separate channel deposits ranging from 5615 B.C. to A.D. 150. The three palaeochannels are clearly different, on the basis of channel geometry, petrology and grain size of the deposits. In particular, two superimposed riverbeds are present near the fluvial harbour (borehole VIII/1994) (fig. 7). The first one (so-called "palaeochannel 1"; fig. 7) is radiocarbon dated (calibrated age) at 5615-5220 B.C. It preserves almost 3 m of thick gravel-sand bars, and is capped by overbank deposits. The second one ("palaeochannel 2"; fig. 7) is surely pre-Roman in age, since it cuts the previous bed and contains protohistoric pottery fragments (895-810 B.C. in calibrated radiocarbon age). It is characterised by sands and laminated pelites (overbank), and its top is buried by an Iron Age soil. Eastward (Monastero area, boreholes IX/1994 and XI/1994, in proximity of Roman bridge) another erosion phase, which affects the underlying deposits down to 14 m from the ground soil, precedes the accumulation of a channel bar. This latter does not record evident differences from the Iron Age to the foundation of Aquileia, and has a thickness ranging from 4 m (borehole VIII/1994) to 9-10 m (borehole XI/1994); it is composed of coarse gravel and sand. It is associated with "palaeochannel 3" (fig. 7), and its course was recognized in the substrate near the Monastero locality with a trend towards the fluvial harbour. The top few metres of this large buried palaeobed comprise anthropogenic infill and reworking, particularly evident from the 2nd century to the 4th century A.D. Above these materials, the area experienced near-continuous flooding and deposition of tardi- and post-Roman swamp sediment (4th-7th centuries A.D.).

In conclusion, the younger channel (*i.e.*, "palaeochannel 3") was of high competence, and one much higher than that recorded by deposits of previous rivers (*i.e.*, "palaeochannels 1 and 2"). It shows a considerable active-channel width (w = 300-400 m) and maximal channel depth (d_{max} = 9 m; fig. 7). This channel geometry presents characteristics similar to the present channel of the Isonzo River, just after its confluence with the Torre River (d_{max} = 8 m; w = 240 m) and, subsequently, before flowing to the lower deltaic plain (d_{max} = 8-12 m; w = 120 m). Moreover, the provenance direction of these deposits (N-S, palaeo-Torre River; NNE-SSW, palaeo-Isonzo River) corresponds to the direction of ridges recorded by microtopography (fig. 5), thus confirming this hypothesis. Both palaeochannels indicate considerable solid bottom-transport, and a braided fluvial bed type.

Hydraulic calculations, including those of stream power, confirm this hypothesis. Using the equation of R.A. Bagnold (1966), the specific stream power (w) of the younger channel (*i.e.*, "palaeochannel 3") has been estimated to have a maximal value of 160-170 W/m^2, with w = 400 m (fig. 7), mean channel depth (d) = 2 m, cross-sectional area (A) = 842 m^2, channel slope (s) = 0.002, and Manning resistance coefficient (n) = 0.025. Comparison with specific stream power (w) of the present Isonzo River one kilometre downstream of the Torre confluence (*i.e.*, 17 km upstream the river mouth) records a comparable value: 270-280 W/m^2 at bankfull discharge, with w = 287 m, d = 3.6 m, A = 802 m^2, s = 0.002, and n = 0.025 (Siché, 2002). According to the classification from G.C. Nanson and J.C. Croke (1992), these values may characterise a braided river flood plain, where the dominant process is lateral point-bar or braid-channel accretion.

Palaeohydrography, palaeohydrology and urban development

Human settings in Aquileia deltaic plain have been present since the Iron Age, as demonstrated in the extensive archaeological literature. Populations were affected by river dynamics: river flooding provided "natural", hydrological constraints, and the Roman communities responded by channelising rivers to guarantee good navigational conditions, constructing flood protection measures, and reducing the extension of water-logged environments.

Roman city versus hydrological constraints and water-logged environments

Roman colonisation was characterised by radical territorial planning using orthogonal geometric forms of centuriation, where limits were defined by roads and canals which were oriented relative to the antique waterways (Prenc, 2000). Farming and exploitation of the land distributed to the settlers must also have been subject to important hydraulic drainage and deforestation (Bandelli, 1984). The course of a navigable canal (*i.e.*, Anfora canal), which linked the city to the current

Fig. 8 – **Interpretation of the palaeohydrographic network near Aquileia during antiquity**. 1: Roman palaeochannel; 2: Roman bridge; 3: Roman road; 4: Roman city. See caption of fig. 6 for details of the sediment cores, and present topography, hydrography and management (in grey on the map).

*Fig. 8 – **Reconstitution du réseau hydrographique autour d'Aquilée, durant l'Antiquité**. 1 : paléochenal romain ; 2 : pont romain ; 3 : voie romaine ; 4 : cité romaine. Se reporter à la légende de la fig. 6 pour tout ce qui concerne le contenu des carottes sédimentaires et le détail de la topographie, de l'hydrographie et des aménagements actuels (en gris sur la carte).*

lagoon of Marano, must have been part of the original project (Strazzulla, 1989): the canal is paved with stone from Istria and has a constant slope, thereby guaranteeing efficient evacuation of water (Canale Anfora, 2000).

Moreover, selection of a humid zone for the settlement required the use of adapted construction techniques. Excavations have revealed that certain structures (*i.e.*, especially in the area around the fluvial harbour) were built on a dense network of wooden stakes, or on mounds of brick and amphora debris (Brusin, 1934). Traces of a drainage system, using horizontal and vertical rows of amphorae underneath the streets and the buildings were also discovered (Maselli Scotti, 1998b). Moreover, urban planning began shortly after, imposed when the fluvial harbour functioned properly. Some adaptations clearly had to be made because of specific constraints of the site: to the east, an adequate distance

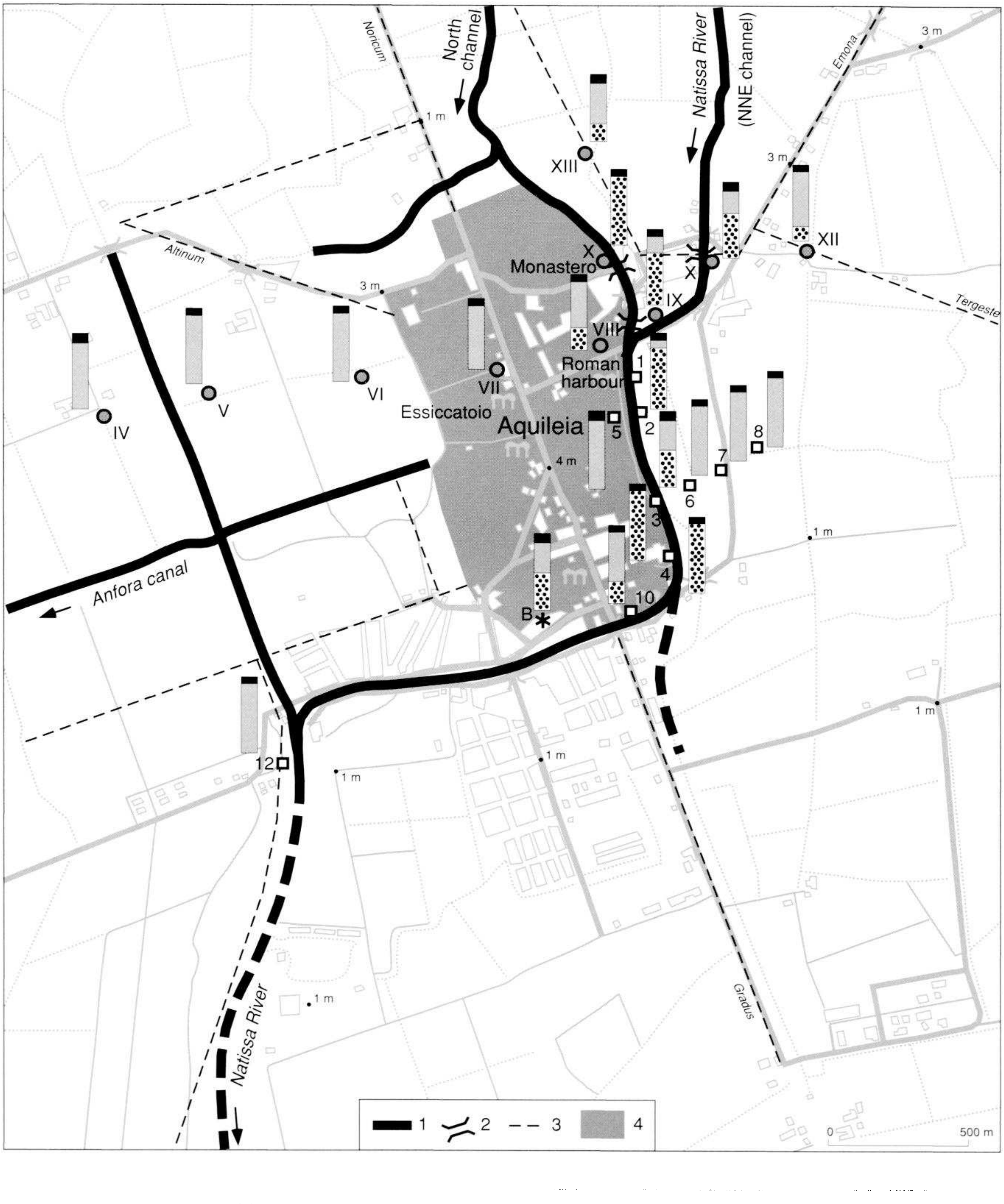


Photo 1 – **Portion of the quay discovered along the Roman fluvial harbour of Aquileia (photo by G. Brusin)**. The structure is situated on the right bank of the Natissa palaeochannel.

*Photo 1 – **Portion du quai découvert le long du port fluvial romain d'Aquilée (cliché G. Brusin)**. La structure délimite la rive droite du paléochenal du fleuve Natissa.*

from the river – and therefore the fluvial harbour – had to be maintained, so that the harbour was linked to the town centre (the *forum*) by three parallel streets. At first, the area west of the city was not built up, and only later was used for the theatre, amphitheatre and circus, which took advantage of a natural depression in this area (Strazzulla, 1989).

As long as Roman administration remained efficient, urban construction, communication network, and trade developed in Aquileia and its territory. Then, during the last two decades of the 2nd century A.D., and especially in the 3rd century A.D., progressive destructuring of the Roman state had repercussions on the city's infrastructures. The fragile environmental equilibrium, which had been one of the essential factors of development of the city, became compromised. We have some evidence of this change: four epigraphic documents which can be dated back to A.D. 238 show that the emperor Maximinus the Thrace had two roads leaving the city toward the north restored and consolidated (*Inscriptiones Aquileiae*, 1991-1993; 2892a, 2892b, 2893a and 2893b), as they had degraded due to long-term action of water. Later, probably in the first decades of the 4th century A.D., the *via Annia* was rehabilitated, because this road had become unusable due to a lack of upkeep and invasion by marsh water (*Inscriptiones Aquileiae*, 1991-1993; 2894a and 2894b). We also note the hydrological degradation in the northeastern suburb of Aquileia (the area of "Necropoli di Levante" between Colombara and S. Egidio), where many funerary walls were disrupted by effects of water infiltration (Brusin, 1934). Finally, at the end of the antique period, the role of the city in Adriatic trade exchange decreased considerably (Sotinel, 2001), most likely due to problems arising from the military situation, and probably also because of difficulties in navigation resulting from the increased infill of the river channel.

Artificially infilled low energy riverbeds

Avulsion processes normally lead to abandonment of channel sections and, downstream of the avulsion point, decreasing channel competence results in gradual, fine infilled channel sections. From the moment that hydrodynamics are reduced, river channels may be artificially infilled to increase the size of the urban area. Such a situation occurred near the site of Monastero (X/1994), with an artificial channel infill depth to 4 m, and near the Roman *forum* (locality: North Essiccatoio). Here, a complex archaeological stratigraphy records the phases of site occupation: hut remains (9th-8th centuries B.C.); at least four centuries of decay; and renewal of building activity (2nd century B.C.), immediately following foundation of the Roman colony (181 B.C.; Maselli Scotti *et al.*, 1996). During excavation activity, sedimentology and palaeontology served to recognise that site colonisation took place in marsh settings, sometimes influenced by brackish water input.

Moreover, one sediment borehole (VII/1994; fig. 6) collected northwest of the *forum*, in the ambulacra behind the colonnade that borders this place, is of note. The lower part (20-17.66 m) of the stratigraphic log records the presence in this zone of an ancient riverbed, as indicated by coarse sediments including gravel and coarse sand. This river channel phase is followed by an interval (17.66-2.38 m) of rhythmic alluvial plain deposits (sand, silt, mud and peat). The earlier deposits (sand and silt) contain foraminifers indicative of high-energy brackish and fluvial environments (*Trochammina inflata*, *Protelphidium anglicum*, *Ammonia tepida*, *Cribroelphidium sp.*); the later ones (mud and peat) contain the ostracod *Ilyocypris gr. gibba*, recording a depressed area subject to periodic exundation, with entrapment of fluvial water (swamp). The top of the borehole (2.38-0 m) corresponds to an artificial infill of the river channel, which began in the Republican epoch, following natural infill of riverbed as a result of low-energy hydrodynamics. Geophysical investigations (Ground Penetrating Radar, resistivity) confirm this and provide some details on the 2D and 3D geometry of the artificial channel infill.

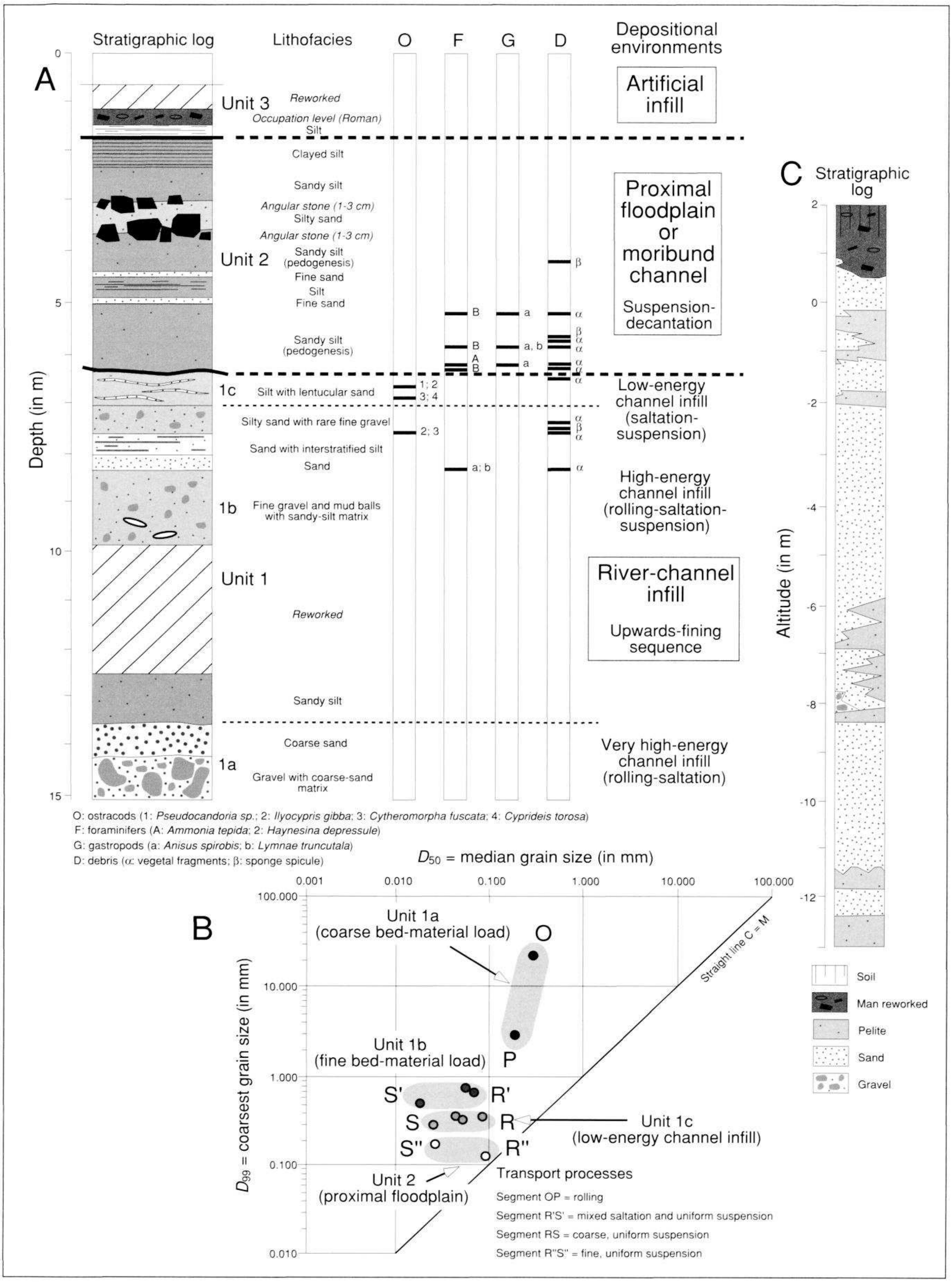
Management of high-energy river channels

Four boreholes have been drilled along the fluvial harbour on the Roman path, close to the remains of two bridges, situated upstream of the harbour structures (boreholes XI/1994 and IX/1994), and within the harbour basin proper, delimited by the remains of quays (boreholes 1/1995 and 2/1995) (fig. 6). The four boreholes show the same basic stratigraphic features, starting from the base: coarse sediment of fluvial origin, not yet dated; coarse deposits, to 4 m thick, containing remains of archaeological debris and dated mainly to Roman imperial age; swampy silty sands and muds, radiocarbon dated to ~ 7th century A.D.; recent flood silts and modern artificial deposits at depths to above 2.5 metres from ground surface. The rare archaeological finds tend to confirm the local presence, at least since protohistoric time, of a river channel characterised by both high bedload transport capacity and competence. However, this high-energy river channel was a managed one. Hydraulic work which begun from the time of the town's foundation, at the beginning of the 2nd century B.C., is indicated by some bank embankments discovered along the harbour channel (photo 1). Most of this construction channelised the riverbed along several kilometres (Carre *et al.*, in press). During the 1st century A.D., the channelised river had a width of ~ 48 m (Carre and Maselli Scotti, 2001). The bottom of infill deposits (boreholes 1/1995 and 2/1995) contain shards older than the earlier Imperial epoch, thus indicating that 1) dredging channel operations were made during channelisation, and/or 2) hydraulic conditions leading to infill processes occurred since that period. Evidence of artificial channel narrowing is provided by the evolution of successive ramparts, built on the river embankments so as to protect the city in the 3rd century A.D., and then built partly in the river channel onward from the 4th century A.D.

The site of the amphitheatre is located in the southwest corner of the town, within the Imperial Great Wall (Bertacchi, 1994a), and north of an antique palaeochannel. The subsidence noted in the amphitheatre centre may indicate that this structure was built in a naturally depressed zone. A drainage system made of six rows of superposed amphorae, discovered close to the building and along the *cardo maximus*, is interpreted as the fill of this depression (Maselli Scotti, 1998b). One borehole was collected near the "Brünner" structure with the purpose of interpreting the hydrographic network and caracterising fluvial dynamics (fig. 6). Here, we recognise an upwards-fining sequence of alluvial infill composed by three main sedimentary units, described here from the base to the top (Bresson, 2001) (fig. 9A). Unit 1 (between 15.00 m and 6.35 m) corresponds to an upwards-fining sequence of a channel fill. It is, in turn, subdivided in three secondary units. The first (1a: 15.00-13.90 m) is composed of mixed gravel (axis a: 3.0-0.3 cm) and sand transported by rolling/saltation (fig. 9B). This deposit is interpreted as bedload of a very high-energy river channel. The second (1b: 13.90-7.30 m) is composed of mixed sand and rare pebble (rolling-saltation), with interstratified silt (suspension), corresponding to bed-material load of a high-energy riverbed (fig. 9B). Sponge spicules and brackish foraminifers in this deposit (fig. 9A) record river-mouth proximity, with possible incursion of a salt-wedge in the palaeochannel. Numerous mud balls indicate that bank-erosion processes likely occurred, as related to active channel widening. The third (1c; 7.30-6.35 m) is lenticular sand and silt (suspension) deposited in a low energy palaeochannel (fig. 9A and 9B). Unit 2 (between 6.35 m and 1.85 m) is represented by a mix of silt and sand deposited by suspension process in a proximal floodplain or in a moribund river channel (fig. 9A and 9B). Unit 3 (between 1.85 m and the top) comprises reworked silt with abundant archaeological (Roman) material (fig. 9A). In conclusion, the "Brünner" borehole serves to identify a high-energy palaeochannel near the Roman amphitheatre. The relationship between the "Brünner" palaeochannel and the one recorded in borehole 10/1995 (fig. 6) remains to be determined. Comparative analysis of alluvial deposits (fig. 9A and 9C) shows that the "Brünner" palaeochannel, dominated by a gravel-sand bedload, was more powerful than the second one characterised by a dominant sandy, or occasionally sand-gravel, bedload. Precise datation of channel infills is needed to determine whether (or not) the two palaeochannels were active simultaneously.

Conclusions

Geoachaeological data, derived from several disciplines, record the presence of important waterways in the Aquileia plain, primarily to the east of the site. The rivers that flowed on the Aquileia deltaic plain in former time are far more important than the rivers that are present here today. Core deposits record the presence of at least two rivers, to the north and east of Aquileia. The older river had a North to South course. Subsequently, the waterways had a NE to SW flow direction. The reason for this change may be linked to natural and/or artificial causes. However, eustatism (*i.e.*, resulting in decreased channel slope) and neotectonics, linked to activity along dislocation lines presented here, may explain changes of the fluvial hydrodynamics (Marocco, 1989). Both rivers transported coarse (gravel) deposits, which do not occur south and west of Aquileia. Thus, there is uncertainty in defining the intermediate tracts of waterways that flowed seawards and towards the present Grado Lagoon. Uncertainty also remains with regards to identifying ancient river mouths, which are probably located in marine areas. In summary, the present study increases knowledge about the Roman Aquileia area, providing information on both the inner margin of the lagoon and relief bet-


A
Stratigraphic log
Lithofacies
O
F
G
D
Depositional environments
Depth (in m)
0
5
10
15
Unit 3
Reworked
Occupation level (Roman)
Silt
Artificial infill
Clayed silt
Sandy silt
Angular stone (1-3 cm)
Silty sand
Angular stone (1-3 cm)
Unit 2
Sandy silt (pedogenesis)
Fine sand
Silt
Fine sand
Sandy silt (pedogenesis)
Proximal floodplain or moribund channel
Suspension-decantation
β
B
a
α
B
a, b
β α α
A B
a
α α α
1c
Silt with lentucular sand
1; 2
3; 4
Low-energy channel infill (saltation-suspension)
Silty sand with rare fine gravel
2; 3
α β α
Sand with interstratified silt
Sand
a; b
α
High-energy channel infill (rolling-saltation-suspension)
1b
Fine gravel and mud balls with sandy-silt matrix
Unit 1
Reworked
River-channel infill
Upwards-fining sequence
Sandy silt
Coarse sand
1a
Gravel with coarse-sand matrix
Very high-energy channel infill (rolling-saltation)
O: ostracods (1: *Pseudocandoria sp.*; 2: *Ilyocypris gibba*; 3: *Cytheromorpha fuscata*; 4: *Cyprideis torosa*)
F: foraminifers (A: *Ammonia tepida*; 2: *Haynesina depressule*)
G: gastropods (a: *Anisus spirobis*; b: *Lymnae truncutala*)
D: debris (α: vegetal fragments; β: sponge spicule)
B
D_{50} = median grain size (in mm)
0.001
0.010
0.100
1.000
10.000
100.000
D_{99} = coarsest grain size (in mm)
100.000
10.000
1.000
0.100
0.010
Unit 1a (coarse bed-material load)
O
P
Straight line C = M
Unit 1b (fine bed-material load)
S'
R'
S
R
S''
R''
Unit 1c (low-energy channel infill)
Unit 2 (proximal floodplain)
Transport processes
Segment OP = rolling
Segment R'S' = mixed saltation and uniform suspension
Segment RS = coarse, uniform suspension
Segment R''S'' = fine, uniform suspension
C
Stratigraphic log
Altitude (in m)
2
0
-2
-4
-6
-8
-10
-12
Soil
Man reworked
Pelite
Sand
Gravel

ween Aquileia and Grado Lagoon. The relation between the evolutionary history of the area surrounding the Roman town and the substrate of Grado Lagoon and Adriatic Sea needs to be interpreted by means of additional boreholes and excavations so as to complete the reconstruction of the Roman hydrographic system.

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Fig. 9 – **Petrology and fauna in the "Brünner" and 10/1995 boreholes**. A: stratigraphic log, sedimentary units, palaeontological analysis and depositional environments interpreted from the "Brünner" borehole; B: CM diagram (Passega, 1957; Arnaud-Fassetta, 2000) of the sediments of the "Brünner" borehole; C: stratigraphic log and sedimentary units of the 10/1995 borehole.

*Fig. 9 – **Analyses sédimentaires et faunistique des carottes "Brünner" et 10/1995**. A : log stratigraphique, unités sédimentaires, analyse paléontologique et milieux de sédimentation déduits de la carotte "Brünner" ; B : diagramme CM (Passega, 1957 ; Arnaud-Fassetta, 2000) des sédiments de la carotte "Brünner" ; C : log stratigraphique et unités sédimentaires de la carotte 10/1995.*

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