Eclogae geol. Helv. 90 (1997) 143–150
0012-9402/97/010143-08 $1.50 + 0.20/0

Eclogae Geologicae Helvetiae

Lacustrine ooidal sands in Lake Geneva (Switzerland): Sedimentological evidence for high-energy conditions and lake-level rise in the Late Bronze Age. Climatic implications and constraints on the location of lake-dwellings

ANDREA MOSCARIELLO[1]

Key words: ooidal sand, transgression, palaeoclimatology, archaeology, lake-dwelling, Late Bronze Age

ABSTRACT

Sedimentological investigations on the western shore and lake-bottom of the Geneva Bay have revealed the presence of unconsolidated surface sediments mainly consisting of homogeneous ooidal sands. Their nature suggests deposition on a shoreface during a wave-dominated transgression phase reaching about 375 m a.s.l.. Sedimentological evidence indicates that this lake-level rise was strictly related to a climate modification characterized by persistent strong storm winds. Moreover, deposits interpreted as mud flows suggest that high magnitude rainfalls must have occurred frequently. Chronological data from both ooidal sands and archaeological remains indicate a Late-Bronze Age for these event, about 2800 ^{14}C yr. BP. Such unfavourable natural conditions finally forced the prehistorical lake-dwellers to move landwards to higher ground.

RESUME

L'étude sédimentologique de dépôts superficiels dans la zone centrale et la bordure ouest de la Rade de Genève (Lac Léman), montre l'existence d'une couche de sables homogènes à oöides (4 m d'épaisseur au maximum). La nature de ces sables indique des phases d'accumulation diachrones en milieu littoral pendant une transgression lacustre qui aurait atteint environ 375 m au-dessus du niveau de la mer. Les évidences sédimentologiques suggèrent que, pendant la montée du niveau du lac, le milieu lacustre était dominé par l'action des vagues associée à de fréquentes tempêtes. Des dépôts interprétés comme des coulées de boue, indiquent que d'intenses précipitations se produisaient fréquemment. Les données chronologiques obtenues à partir des sables à oöides et de restes archéologiques permettent d'attribuer à cette phase de transgression un âge du Bronze Final (environ 2800 ^{14}C ans BP). Ces conditions naturelles défavorables, probablement liées à une déterioration climatique générale, conditionnèrent le déplacement de sites lacustres littoraux (Pâquis et Plonjon) vers des zones topographiques plus élevées (Parc de la Grange).

Introduction

Pioneering studies on the Neolithic and Bronze Age lake-dwelling along Lake Geneva (Gosse 1881; Blondel 1923) document the occurrence of numerous settlements at different topographical levels, ranging between -4 and +3 m with respect to the present-day lake-level (Gallay & Kaenel 1981). The position was strongly influenced by natural (geological, climatic and ecological) and cultural factors (Magny 1993). Among the former, long term lake-level fluctuations seem to have often played a dominant role (Sauter 1976; Gallay & Kaenel 1981).

The sedimentary record of many French and Swiss Jura and subalpine lakes (Brochier & Joos 1982; Joos 1982; Magny & Mouthon 1990; Gaillard 1985; Magny & Richard 1985, 1987, 1988a, b, c, Moulin 1991; Wohlfarth & Schneider 1991) show several synchronous lake-level fluctuations during the Holocene period. Such fluctuations, observed also in other European lakes, have generally been correlated to plurisecular climate-induced palaeohydrological changes (Ammann 1982; Street-Perrot & Harrison 1985; Digerfeldt 1986, 1988; Harrison et al. 1991). However, the lack of sedimentological evidence directly linked with temperature (e.g. desiccation cracks) or precipitation (e.g. colluvial deposits) makes it usually quite difficult to reconstruct the local meteorological conditions and to understand the effective role played by climatic parameters during the different rising and lowering phases.

This paper intends therefore 1) to document, with a sedimentological and geomorphological approach, a depositional event that occurred in the south-western part of Lake Geneva, related to a high-energy rising phase of the lake-level; 2) to specify the prevalent meteorological parameters demonstrating that such an event was strictly related to a climate dominated by strong precipitation and storm conditions; 3) to emphasise that the latter forced the Late Bronze Age prehistorical people to move.

[1] Section des Sciences de la Terre, Université de Genève, 13, rue des Maraîchers, CH-1211 Genève 4
Present address: Institut F.A. Forel, 10 route de Suisse, CH-1290 Versoix

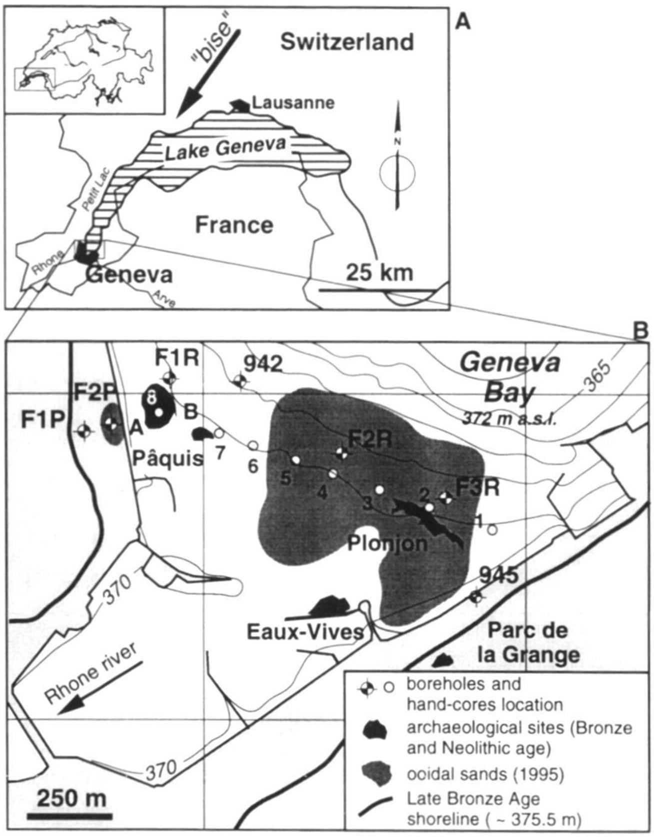

Fig. 1. A: geographical outline of the study area with the direction of the NE wind („bise") affecting Geneva Bay. B: geotechnical boreholes, hand cores and archaeological sites location (modified after Corboud 1985) with the distribution of ooidal sands (summer 1995).

Geographical and geological setting of the ooidal sands

Geneva Bay

Geotechnical boreholes drilled in spring 1993 in Geneva Bay and on the lake shore (Moscariello & Wildi 1994) allowed us to collect the whole preserved Quaternary stratigraphical record. Particular attention was paid to the topmost sediments in cores F2R and F3R (Fig. 1), consisting of well-sorted homogenous ooidal sands overlying Holocene laminated lacustrine deposits. The palynological content of the latter indicates the occurrence of diachronous depositional events since Late Glacial to Boreal time (A.M. Schneider, written communication).

Previous detailed petrographical investigations on these ooidal sands were carried out by Girardclos (1993).

The subaqueous distribution of the sands was reconstructed by means of further investigations carried out with piston hand-cores and diving observations. These data, together with previous indications given by Lombard & Cuénod (1965) (core 942, Fig. 1) and Corboud (1985), point out that the sands form an irregularly shaped body, about 500 m wide, located in the central and the eastern part of the Bay (Fig. 1) between 1.5 and about 6 m water depth, next to the outlet of the Rhône river.

The sand body shows a strongly variable thickness (1.05 m maximum in core F2R) and generally has a lenticular cross section (Fig. 2B). A geological profile across the Bay (Fig. 2C) indicates that the base of the sand is located at about 369 m a.s.l.

Strong bottom currents linked to the outlet vicinity (Bétant & Perrenoud 1932) and periodic dredgings in the Bay cause erosional processes still contributing to the superficial reworking of the sands and, in places, to their removal. The present-day distribution shown in Fig. 1 disagrees with the sediment facies map outlined by Vernet *et al.* (1972) based, in this region, only on a few samples.

Fine sands are found at the same altitude also on the eastern shore (core 945, Fig. 1) alternating with organic-rich layers (Lombard & Cuénod 1965). Unfortunately, the sedimentological description is not sufficiently detailed to define a genetic correlation with the sediments found in the Bay.

Geneva Bay western shore

The lithostratigraphic succession cored in the lake is also present on the western shore (core F2P in Fig. 1). Sands reach about 4 m in thickness ranging from 373 m a.s.l. (1 m above the present lake-level) to 369 m a.s.l. (i.e. the same altitude of the sand base found in cores F2R and F3R) (Fig. 2). The western shore topography and the general geological setting (Fig. 2) point out that such deposits form a sedimentary wedge leaning against an inclined surface cut into silty lacustrine sediments and open-work coarse gravel (Ruchat 1985). This surface seems to be genetically related to the terrace surface located at about 375 m a.s.l. westward.

A detailed sedimentological study was carried out in the uppermost 9 m of core F2P (373.5 m a.s.l.). Microstratigraphic investigations were performed on thin sections of undisturbed samples and by electron-microscope observations.

The stratigraphic record of core F2P (Fig. 3) consists in the following units (from the top):

0.00–0.50 m	anthropogenic embankment consisting of sandy gravel with brick fragments.
0.50–0.88 m	brown structureless and homogeneous, well-sorted medium sand mostly consisting of coated grains (ooids) with brecciated shells of molluscs and gastropods. From 0.78 m downward scattered little pebbles with rounded clast of marly silt.
0.88–1.20 m	chaotic facies assemblage of brown massive sandy muds with abundant, randomly scattered or rare crudely aligned rounded and subangular very small clast and pebbles.
1.20–1.50 m	sand (same as 0.50–0.88 m).

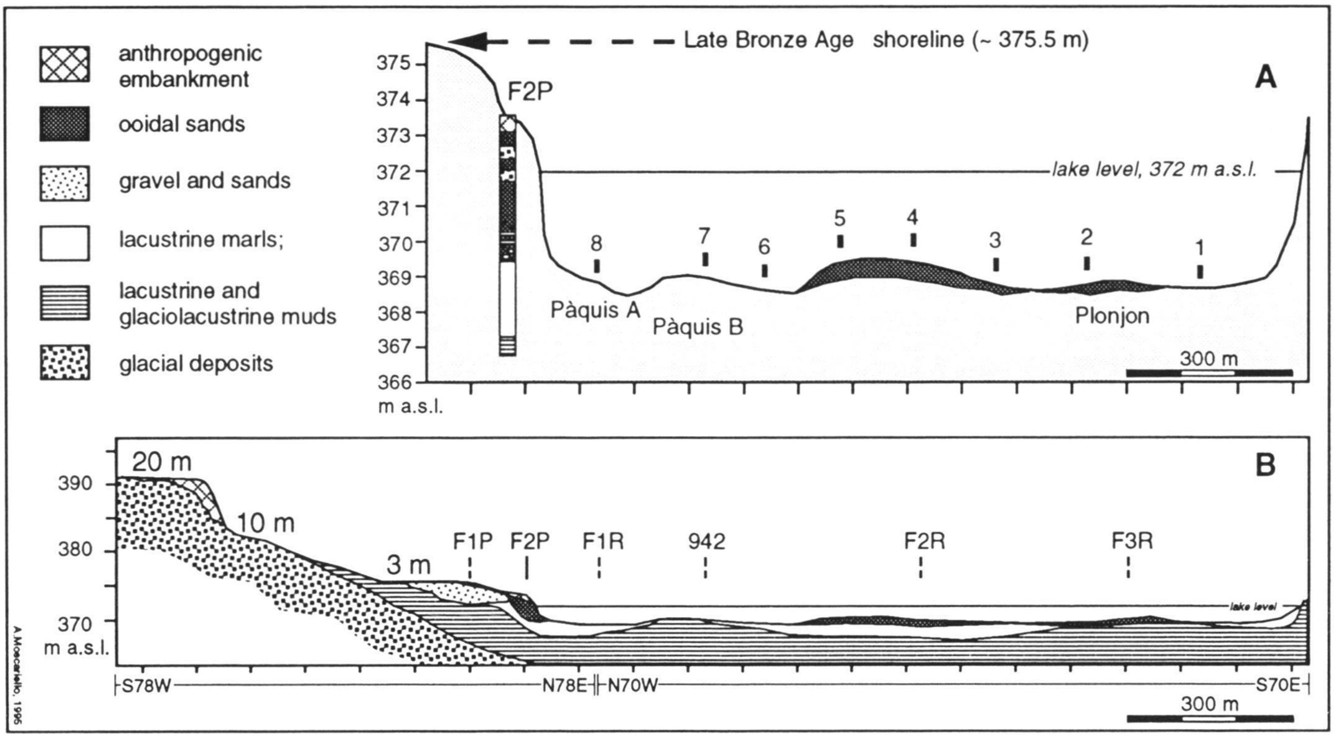

Fig. 2. A: profile across the Geneva Bay with location of submerged ooidal sands and core F2P (sublacustrine profile modified after Corboud 1985); B: geological cross-section across Geneva Bay (data from Ruchat 1985) with projected boreholes locations. Refer to Fig. 1 for cores and archaeological sites location.

1.50–1.74 m chaotic facies assemblage (same as 0.88–1.20 m).

1.74–2.50 m sand (same as 0.50–0.88 m).

2.50–4.00 m sand (same as 0.50–0.88 m) with thin intercalations of grey laminated marly silts (60–70% of $CaCO_3$), alternating with dark grey clay/organic-rich layers; primary lamination within the silts is often obscured near the erosional contact at the top of each marly intercalation. Well-rounded silty clasts are abundant within the sands; their amount and sizes increase toward the bottom of the unit.

4.00–6,35 m olive grey laminated marly silts with mm-thick intercalations of fine sands and dark grey clay/organic-rich levels; scattered whole shells of molluscs occur.

6,35–9.00 m apparently massive grey clay-rich silt with thin intercalations of fine sand; scattered little pebbles, in places forming layers („stone lines"), are abundant. The amount and sizes of the clasts increase downward.

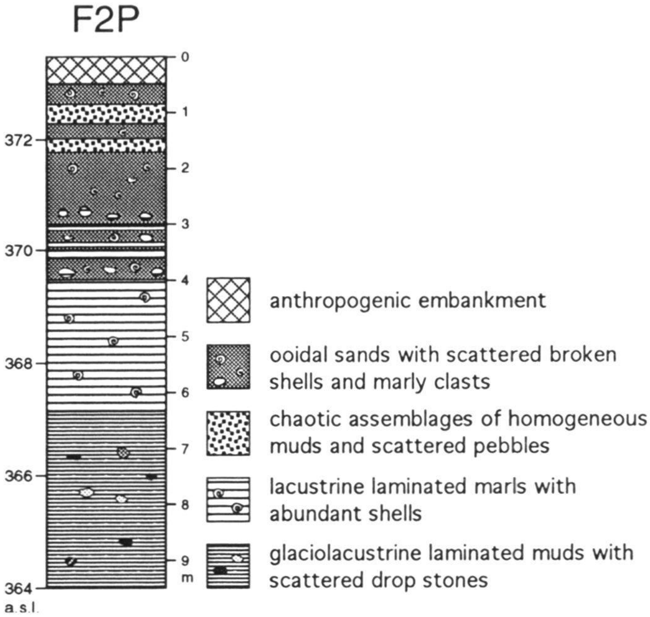

Fig. 3. Stratigraphical log of the core F2P (see Fig. 1 and 2 for location).

Grain-size analysis of the ooidal sands shows that medium sand (0.125–0.25 mm) is most abundant, reaching 91.5% of the whole sediment. The fraction > 0.25 mm in diameter is less than 3.6%. About 95% of the grains consist of calcitic coated grains (Fig. 4). Two types of ooidal sand grains have mainly been observed: well rounded grains with quite a smooth and uniform external surface (oolites) and non-symmetric irregularly shaped grains with a non-uniform and wrinkled surface (oncoids) (Richter 1983). The grain coatings consist either of

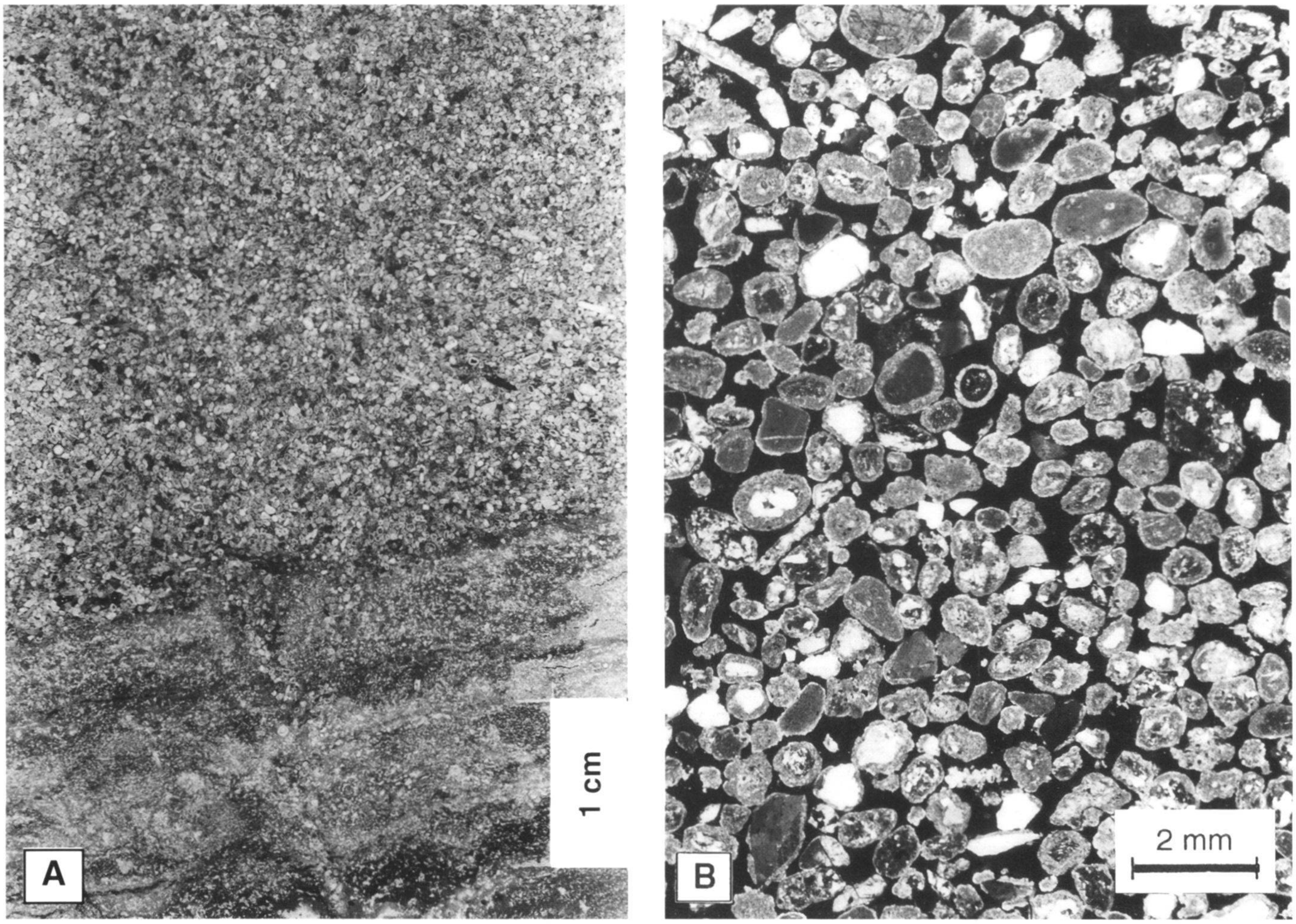

Fig. 4. A: homogeneous ooidal sand overlying laminated lacustrine marls showing local bioturbations; B: microphotograph of ooidal grains; note the occurrence of well rounded grains mingled with other, differently shaped coated grains.

structureless concretions of micrite (random ooid) or of concentric sparitic laminations. Both types suggest an important role of micro-organisms (bacteria) in the coating processes. Nuclei mainly consist of angular and rounded grains of quartz, K-feldspar, plagioclase and calcite; metamorphic (micaschist and quartzite especially) and sedimentary (sandstone and limestone) rock fragments are also present.

Coarser fractions, larger than 0.63 mm in diameter, are usually formed by plant and shell debris mixed with resedimented carbonate concretions of biochemical origin. They consist of irregularly shaped coated grains (oncolites) and encrustations of charophyte stems, forming both cauliflower-like forms (about 45% of the size fraction) and tube-like forms (less than 5%) (Magny 1987).

A thin ooidal outer cortex collected at the core F2R base was dated by radiocarbon AMS technique (Girardclos 1993). It yielded an age of 2805±60 ^{14}C years BP, corresponding to the upper Subboreal time period (Ammann & Lotter 1989), i.e. the Late Bronze Age (Bintz et al. 1991). Calibrated age for this value ranges between 1186 and 811 years BC (Stuiver & Becker 1993).

Interpretation

The lower part of the lithostratigraphic succession found in F2P site clearly shows the transition from a cold, distal proglacial to a temperate lacustrine environment. The former was dominated by clastic sedimentation with alternations of freeze and thaw periods (dropstones), the latter characterized by endogenic carbonate precipitation (Moscariello et al. 1995). Fine sediments (silts and clays) have settled in a calm environment since the glacier retreat for a long time period during the Late glacial - Holocene time interval (Moscariello 1996). On the contrary, the overlying ooidal sands represent the product of a high-energy depositional event, the only one recorded in the lacustrine sedimentary succession preserved in Geneva Bay (Moscariello & Wildi 1994; Moscariello 1996).

A first indication of a change in hydrodynamic conditions is suggested by the nature of the ooid nuclei. The accumulation of abundant clastic grains indicates a wave-induced erosional phase affecting the bedrock (Tertiary Molasse) and the glacial deposits. The good sorting indicates further washing and sieving processes.

Intercalations of laminated marly silts in the lower part of the sandy unit (Fig. 3) suggest that short, high-energy events were initially alternating with fine-grained endogenic deposition. The facies association argues for a lower shoreface environment and interbedded sand and silts reflect alternations of storm and fairweather conditions (Elliot 1986).

The sand homogeneity in the upper part of the unit indicates persisting storm conditions strong enough to rework all previous fairweather deposits. Redeposition of the upper shoreface sands on the lower beach must have occurred as a result of shoaling-storm-waves, wind-driven currents and surge currents, thus explaining the great thickness found in core F2P. Such reworking processes could have been further emphasized by subaerial exposition following the lake-level lowering (Fig. 5).

Well-oxygenated waters related to high dinamicity favoured supersaturation in $CaCO_3$ which, combined with phytoplankton activity, allowed the calcite precipitation and the formation of coated grains. The abundance of oolitic grains together with oncoids and cauliflower-like forms confirm a high-energy depositional environment in nearshore shallow waters (Magny 1992).

The two interstratified chaotic assemblages, separated from the sands by sharp erosional surfaces, are interpreted as gravitational slumps which removed glacial and glaciolacustrine deposits. They were probably caused by abundant and persistent rainfalls and by diversion of flowing water onto the landward slope. They took place as mudflows (Varnes 1978), reaching the shoreface and possibly entering the lake. The lack of ooidal sands within the fine-grained matrix indicates that these processes did not result from wave-induced shore erosion during storms. Rather, they represent singular events in the absence of storm waves.

Deposition of the sands took place at least 1.5–3 m above present lake-level during a transgression event that shaped the upper terrace surface at about 375 m a.s.l. (+3 m above present lake-level). The present location (western shore), about 1.5 m above the terrace, therefore suggests a subsequent erosion and a reshaping of the terrace profile (Fig. 5) caused by successive lake-level fluctuations. Actually, historical data concerning the period before the lake-level regularization (Forel 1892–1901) indicate that extreme annual variations could reach 2.5 m in amplitude. Such short-period fluctuations could easily reshape the terrace edges through the mobilization and the lakeward redeposition of the sands. Nevertheless, former lake-level fluctuations associated with intense wave activity are demonstrated by the presence of gravels (Fig. 2) forming narrow strips

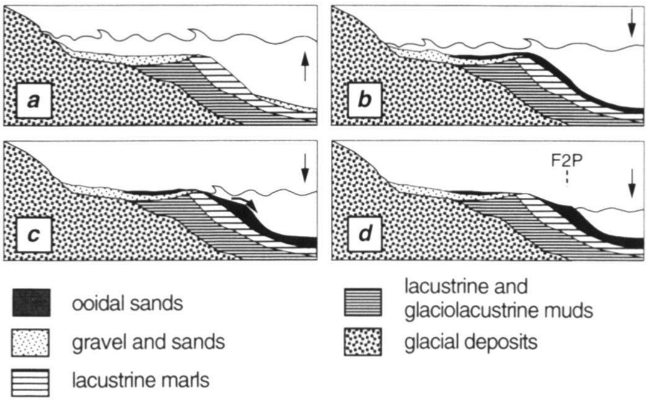

Fig. 5. Schematic drawing of depositional and reworking processes related to the lake-level fluctuations near the shoreline. a) High lake levels allow the washing out of glacial and glaciolacustrine deposits and the formation of an open-work gravel beach; sands are deposited lakeward at the base of the slope. b) lake-level lowering and wave action combined with calcite precipitation allow ooid formation and their accumulation on the upper and lower shoreface. c) continued lake-level lowering induces the erosion of the terrace edge and the resedimentation of the beach sands in the lower shoreface. d) during lake-level low stand, subaerial exposure of the terrace edge accentuates the reshaping and smoothing of the terrace profile; reworking and resedimentation of the beach sands still occur.

along the eastern and western Geneva Bay shores (Ruchat 1985). They can be the result of wash-out from glacial and glaciolacustrine sediments outcropping landward (Fig. 5).

The altimetrical correlation between the basal surface of submerged sands and F2P core, together with the occurrence of similar sedimentological features at the base of the thickest sequences (rounded lacustrine marly clasts both in F2P and F2R core), provide some information about the original distribution of the ooidal sands. The present-day submerged sands could represent the relict of a thicker (particularly toward the shore) and wider ancient body occupying the Bay. However, natural erosion (running water, lake-level fluctuations) combined with anthropogenic reworking, makes it difficult to precisely reconstruct their original extension.

Hydrodynamic processes and climatic implications

The formation of ooidal sands is the result of the intermittent motion of bottom sediments in the shallow and turbulent water of a wind and wave dominated lacustrine environment. At present, these conditions occur in the Bay when a high hydrodynamic regime persists and produces waves deep enough to rework the bottom sediments.

The water depth in the middle of the Bay was about 7 m during the Late Bronze Age high stand. Previous works on wave features in Lake Geneva (Bruschin & Falvey 1975; Bruschin & Schneiter 1978; Girardclos 1993) estimated that waves 0.5-1 m in height are characterized by a wave base easily reaching the lake bottom at 5–7 m water depth. At present such

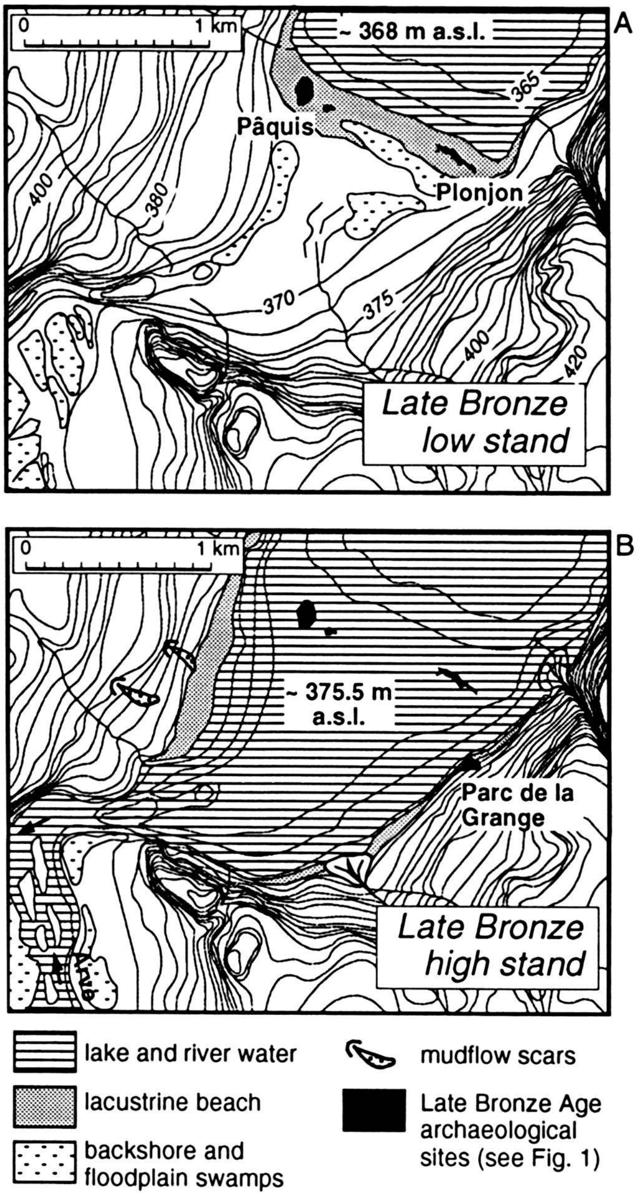

Fig. 6. Schematic drawing of the paleogeographical situations A) before and B) during the Late Bronze Age lake-level rise in the Geneva Bay (reconstituted topography modified after Corboud 1994).

waves are generated by a high-velocity wind (average 8–10 m/s) blowing from NE, with a high effective fetch (about 30 km). Actually this wind, (locally called „bise"), often affects the Geneva Bay, located at the extreme southwestern part of the Petit Lac (Fig. 1). This implies that Late Bronze Age ooidal sands could be reworked also in the centre of the Bay during the high-stand phase. However, they must not be considered related to an exceptional depositional event. Recent observations confirm in fact that ooidal formation is still active . The peculiarity of the Late Bronze Age ooid sands formation therefore consists just in the persistence of climate-induced sedimentary processes.

The Geneva lake-level variations have been related essentially to climatic (precipitation and temperature: Magny & Olive 1981) and geological factors (outflow damming by the flood deposits of the Arve river or by the sliding of the Rhône banks: Amberger 1976; Wildi 1994).

Demonstrating which factor determined the lake-level rise during the Late Bronze Age is controversial, particularly because the time span was relatively short (a few hundreds years for the Late Bronze Age event). However, the synchroneity of lake-level rises and glacier advances in the Swiss and Austrian Alps and in northern Sweden (see Magny 1992 for references) seems to argue for a climatic control of Holocene lake-level fluctuations (Ammann 1982; Street-Perrot & Harrison 1985; Digerfeldt 1986, 1988; Harrison et al. 1991).

Moreover, the occurrence of ooidal sands combined with mud-flow deposits suggests that the lake-level rise was related to an increase in precipitation and to strong and persistent storm winds. Any contributions from geological factors operating at the same time, however, cannot be excluded.

Archaeological evidence

The presence of submerged prehistorical sites in Geneva Bay (Gosse 1870; Blondel 1923; Sauter 1959; Corboud 1985) documents that the area was occupied on several occasions by lake-dwellings since Neolithic to Late Bronze Age. Wood remains of pile-work structures (Blondel 1923; Corboud 1985) lying about 3 m under the present-day lake-level (about 369 m a.s.l.) in Pâquis and Plonjon sites (Fig. 1), are generally attributed to the Late Bronze Age (Blondel 1923). Hundreds of these remains distributed over a large surface suggest the presence of a village during a lake-level low stand (Blondel 1923). Excavations in Plonjon site (Corboud 1985) have recently brought to light pieces of pottery and bronze tools, confirming former chronological indications. Wood structures are driven into the marly silts and in places buried by ooidal sands.

The Parc de la Grange site, about 200 m from the lake shore (Fig. 1), was also attributed to the Late Bronze Age (David-Elbiali 1995). It is located on the eastern shore at about 375.5 m a.s.l., 6 m higher than the apparently synchronous submerged sites (Pâquis and Plonjon). The particular interest of this site is due to two parallel rough stone walls turned lakeward and built between the lake and handicraft structures (combustion sites). They were interpreted as rudimentary dams protecting against the wave action (David-Elbiali 1995). The age of the site is confirmed by the radiometric dating of an oak charcoal giving 2785±70 ^{14}C years BP. It corresponds, after calibration (Stuiver & Beck 1993), to the interval of 1186-800 years BC (David-Elbiali 1995).

Conclusion

The ooidal sands of Geneva Bay were deposited on a littoral zone during a lacustrine transgression dominated by high waves. This process induced a diachronous thick ooid sand accumulation toward higher topographic levels (Fig. 2). On the western shore deposition reached at least 373 m a.s.l.. Geomorphological evidence suggests that the shaping of the higher terrace at about 375.5 m a.s.l. is associated to this transgression. This hypothesis is supported by Late Bronze Age archaeological findings in Parc de la Grange site where artificial dams at about 375 m a.s.l. indicate the height reached by the waves (Fig. 6). More precisely, the chronological data imply that this abrupt rise of the lake level and the sand deposition occurred at the end of the Late Bronze Age (about 2800 ^{14}C yr. BP).

Wave action caused the partial erosion, the reworking of the ancient lake bottom, and consequently the damage of the anthropogenic structures built near the shore (Pâquis and Plonjon sites). The persistence of such processes induced the prehistoric lake-dwellers to move to higher areas, far from the storm-wave action. The Parc de la Grange site might represent one of these safer sites, where favourable conditions persisted for a while, before the building of artificial protections against the wave action was necessary.

A correlation between lake-level rise and climatic factors has been established on the base of sedimentological evidence. The occurrence of fairweather conditions alternating with abundant rainfall and storms has been demonstrated. Storm winds were particularly frequent and persistent. Such meteorological conditions can be related to the climatic degradation which occurred in Central Europe at the end of the Subboreal time period and which is well documented in the Alps by glacier advances (Röthlisberger 1986) and in the Jura and French subalpine range by synchronous lake-level fluctuations (see Magny 1992 for reviews). Such conditions induced the definitive desertion of the Geneva Bay littoral lake-dwellings

These data suggest that previous interpretations have to be reviewed indicating for the same interval of time a lower lake level, at 367.5 m a.s.l. (Gallay & Kaenel 1981, pag. 155).

Further sedimentological and archaeological investigations on littoral deposits supported by new chronological data (radiocarbon dating, dendrochronology) are however necessary to improve the knowledge of lake-level fluctuations and to estimate more precisely their timing.

Acknowledgements:

This study forms part of my PhD research undertaken at the University of Geneva and financed by the Swiss National Science Foundation (Grant n° 4031-033204 - PNR 31).

I am grateful to P. Corboud, E. Davaud and W. Wildi for discussions and comments that provided helpful and constructive criticism. I thank S. Girardclos and M.L. Filippi for assistance in underwater sampling, and the Institute F.A. Forel, University of Geneva, for technical support and access to the core lab facility. I also gratefully acknowledge A. Strasser and H.C. Jenkyins for their comments and suggestions on an earlier version of this work.

I also wish to acknowledge the help of V. McCormack and B. Ujetz who improved the English version of the manuscript.

REFERENCES

AMBERGER, G. 1976: Origine et géologie. In: Le Léman un lac à découvrir (Ed. by AMBERGER G. et al.). Office du livre S.A., Fribourg; 11–34.

AMMANN, B 1982: Säkulare Seespiegelschwankungen: wo, wie, wann, warum ? Mitt. natf. Ges. Bern N.F. 39, 97–106.

AMMANN, B. & LOTTER, A.F. 1989: Late-glacial radiocarbon and palynostratigraphy on the Swiss Plateau.Boreas. 18, 109–126

BÉTANT, A. & PERRENOUD, G. 1932: Etudes sur la partie occidentale du Lac de Genève. Courants et températures. Mém. Soc. Phys. et Hist. nat. Genève 41(2), 225–293.

BINTZ, P., BOCQUET, A., BOREL, J.-L., OLIVE, Ph. 1991: Tableau diachronique. In: Paleo-environnement holocène et archéologie dans les alpes françaises du nord et leur piemont (Ed. by VIVIAN R. et al). Com. Trav. Hist. et Scient., Paris, 150–163.

BLONDEL, L. 1923: Relevé des stations lacustres de Genève. Genava 1, 88–112.

BROCHIER, J.L. & JOOS M. 1982: Un élément important du cadre de vie des Néolithiques d'Auvernier-Port: le lac. Approche sédimentologique, Cahiers d'Archéol. Romande 25, 43–67.

BRUSCHIN, J. & FALVEY, H., 1975: Vagues de vent sur un plan d'eau confiné, considérations générales et application au Léman (Petit Lac). Bull. Techn. Suisse Romande, Ecole polytech. féd. Lausanne, 14–16.

BRUSCHIN, J. & SCHNEITER, L. 1978: Caractéristiques des vagues dans les lacs profonds, vagues de bise sur le Léman (Petit-Lac), campagnes de mesures 1974–1978. Bull. Techn. Suisse Romande, Ecole polytech. féd. Lausanne, 19.

CORBOUD, P.1985: Rapport préliminaire sur les recherches réalisées en 1985. Rade de Genève, stations de la Belotte et de la Pointe-à-la-Bise. in G.R.A.P.: Inventaire et étude archéologique des sites préhistoriques immergés du Léman. Dépt. d'Anthropol., Univ. Genève. 1–7.

– 1994: Les occupations préhistoriques de la Rade de Genève: niveaux du Léman et villages littoraux. In: Genève sur l'eau (Ed. by BROILLET PH.) Dépt. trav. publ. et énergie; Genève 19–31.

DAVID-ELBIALI, M. 1995: Genève-Parc de la Grange-Tente Botta: vestiges de la fin du Bronze final. Ann. Soc. Suisse Préhist. et Arch. 78, 164–168.

DIGERFELDT, G. 1986: Studies on past lake-level fluctuation. In: Handbook of Holocene Palaeoecology and Palaeohydrology (Ed. by BERGLUND B.E.) 5, 127–143

– 1988: Reconstruction and regional correlation of Holocene lake-level fluctuations in Lake Bysjön, South Sweden. Boreas 17, 165–182

ELLIOTT, T. 1986: Siliciclastic shorelines. In: Sedimentary environments and facies (Ed. by READING H.G.). Blackwell Sc. Publ. 155–188.

FOREL, F.-A. 1892–1901: Le Léman. Monographie limnologique. Lausanne, Rouge et C. 3 vol. 1905 pp. Slatkine reprint, Genève, 1969.

GAILLARD, M.-J. 1985: Postglacial palaeoclimatic changes in Scandinavia and Central Europe. A tentative correlation based on studies of lake-level fluctuations. Ecologia Mediterranea 11, 159–175.

GALLAY, A. & KAENEL, G. 1981: Repères archéologiques pour une histoire des terrasses du Léman. Arch. suisses antropol. gén. 45 (2), 129–157.

GIRARDCLOS, S. 1993: Enregistrement des événements de haute énergie et formation d'ooïdes dans des sédiments littoraux du Léman (Petit Lac) Trav. dipl. Univ. Genève, non publié.

GOSSE, H.J. 1881: Plan de la Rade de Genève. Archives d'Etat de Genève.

HARRISON, S.P., SAARSE, L. & DIGERFELDT, G. 1991: Holocene changes in lake levels as climate proxy data in Europe. In: Evaluation of climate proxy data in relation to the European Holocene (Ed. by FRENZEL, B., PONS, A. & GLÄSER, B.). 159–169, Akadem. der Wissensch. und der Lit., Palaeoclim. Res. 6

JOOS, M. 1982: Swiss Midland-lakes and climatic changes. In: Climatic change in later prehistory (Ed. by HARDING A.F.). Edinburgh University Press, 44–51.

LOMBARD, A. & CUÉNOD, Y. 1965: Sondages et profils dans la Rade de Genève. Arch. Sci. phys. nat. 18, 305–320.

MAGNY, M. 1987: Esquisse d'un modele pour une approche sédimentologique de séquences holocènes en milieu lacustre carbonaté. Documents du Cent. Etud. Rech. Lacs, Anciens Lacs et Tourbières, Mém. 1, 181–211.

– 1992: Holocene lake-level fluctuations in Jura and the northern subalpine

ranges, France: regional pattern and climatic implications. Boreas 21, 319–334.
– 1993: Un cadre climatique pour les habitats lacustres préhistoriques? C.R. Acad. Sci. Paris 316, 1619–1625.
MAGNY, M. & MOUTHON, J. 1990: Interprétation paléolimnimétrique d'une coupe stratigraphique de la station 2 de Chalain (Jura): comparaison des approches sédimentologique et malacologique. Arch. Sci. Genève 43, 99–115.
MAGNY, M. & OLIVE, Ph. 1981: Origine climatique des variations du niveau du Lac Léman au cours de l'Holocène. La crise de 1700 à 700 ans BC. Arch. suisses antropol. gén. 45 (2), 159–169.
MAGNY, M. & RICHARD, H. 1985: Contribution à l'histoire holocène du Lac de Bourget: recherches sédimentologiques et palynologiques sur le site de Conjux-la-Chatière (Savoie, France). Rev. Paléobiol. 4, 253–277.
– 1987: Contribution à l'histoire holocène du Lac des Rousses (Jura, France): recherches sédimentologiques et palynologiques. Rev. Paléobiol. 6, 89–103.
– 1988a: Nouvelle contribution à l'histoire des lacs du Jura français: recherches sédimentologiques et palynologiques sur les lacs de Chalain, de Clairvaux et de l'Abbaye. Rev. Paléobiol. 7, 11–23.
– 1988b: Contribution à l'histoire postglaciaire de deux lacs de Clairvaux (Jura, France): recherches sedimentologiques et palynologiques. In: Lake, mire and river environments during the last 15000 years (Ed. by LANG, G. & SCHLÜCHTER, C.), Balkema, Rotterdam, 23–29.
– 1988c: Fluctuations du Lac de Narlay (Jura, France) au subboreal et au subatlantique. Bull. Ass. franç. EtudeQuatern. 1, 17–24.
MOSCARIELLO, A. 1995: Late Pleistocene and Holocene depositional processes in the Geneva Bay (Lake Geneva, Switzerland). Terra Nostra - abstr. INQUA - XIV Congress Berlin, 2/95, 194.
– 1996: Quaternary geology of the Geneva Bay (Lake Geneva, Switzerland): Sedimentary record, Palaeoenvironmental and Palaeoclimatic Reconstruction since the Last Glacial Cycle. PhD thesis, Univ. de Genève, Terre & Environnement, 4, 230 pp.
MOSCARIELLO, A. & WILDI, W. 1994: Sedimentological features of glacial and late-glacial deposits in the southwestern part of the Lake Léman (Geneva roadstead, Switzerland). Abstract 15th IAS Regional Meeting Ischia, 298–299.
MOSCARIELLO, A., SCHNEIDER, A.M. & FILIPPI, A.M. 1995: Late Glacial - Holocene transition in lake sediments of Geneva Bay (Lake Geneva, Switzerland). In: Abstr. of the 1st. ILIC Congress Copenhagen (Ed. by NOE-NYGAARD, N. & CHRISTENSEN, U.W.), 88.
MOULIN, B. 1991: La dynamique sédimentaire et lacustre durant le Tardiglaciaire et le Postglaciaire. Arch. Neuchât., 9.f.
RICHTER, D.K. 1983: Calcareous oöids: a synopsis. In: Coated grains (Ed. by PERYT, T.M.). Springer-Verlag, Berlin, 71–99.
RÖTHLISBERGER, F. 1986: 10.000 Jahre Gletschergeschichte der Erde. Verlag Sauerländer, Aarau.
RUCHAT, C. 1985: Carte géologique et géothecnique du Canton de Genève 1:5000. République et Canton de Genève.
SAUTER, M.-R. 1959: Quelques réflexions à propos du problème des palafittes. Genava, NS 7, 35–56.
– 1976: Les premiers millénaires de vie humaine autour du lac. In: Le Léman, un lac à découvrir (Ed. by AMBERGER G. et al.). Fribourg, Office du Livre 6, 161–189.
STREET-PERROT, F.A. & Harrison ,S.P. 1985: Lake levels and climate reconstruction. In: Paleoclimate analysis and modeling (Ed. by HECHT A.D.). Wiley, New York, 291–340.
STUIVER, M & BECKER, B. 1993: Radiocarbon calibration program rev. 3.0. Radiocarbon 35, 35–65.
VARNES, D.J. 1978: Slope movements types and proceses. In: Landslides analysis and control (Ed. by SCHUSTER, R.J. & KRIZEK, R.J.). Transportation Research Board. Spec rep. 176, National Academy of Sciences, Washington D.C., 11–33.
VERNET, J.-P., THOMAS, R.L., JAQUET, J.-M. & FRIEDLI, R. 1972: Texture of the sediment of the Petit Lac (Western Lake Geneva). Eclogae geol. Helv. 65, 591–610.
WOHLFARTH, B. & SCHNEIDER, A.M. 1991: Late glacial and Holocene lake level fluctuations in Lake Biel, western Switzerland. J. Quat. Sc. 6(4), 293–302.
WILDI, W. 1994: Le site naturel de Genève. In: La Genève sur l'eau (Ed. by BROILLET PH.). Dépt. trav. publ. et énergie: Genève. 19–31.

Manuscript received December 28, 1995
Revision accepted July 2, 1996