Reports

Early Holocene Oöids in Modern Littoral Sands Reworked from a Coastal Terrace, Southern Tunisia

Abstract. *Locally, Early Holocene (Atlanticum) oöids, dated with carbon-14, form the major compound in the Recent near-shore sediments of the Gulf of Gabes (southern Tunisia, Mediterranean Sea). They are reworked from coastal oölites and are not forming today. The Holocene oölites crop out at the seaward side of a coastal terrace, while the oölitic rocks from the inland side give a straightforward carbon-14 age of 20,000 to 30,000 years before the present. The entire terrace was formerly dated as Tyrrhenian III (= last interglacial time).*

Today oöids are known to form in tropical shallow waters. In striking contrast to this are the oöids of the Gulf of Gabes (Tunisia, southern Mediterranean Sea), which form a main component of the Recent marine near-shore sediments. However, there is the question of whether these oöids do in fact form under the climatic conditions of the Mediterranean Sea proper. It is, therefore, of special interest, with respect to the sedimentology of carbonates, to clarify this problem.

The results of the radiocarbon dating presented here prove that the oöids from the Gulf of Gabes are not forming today. Evidence from field studies and sedimentological examinations show also that the oöids are reworked from submarine and onshore oölites (*1*). The age of these rocks, formerly placed in the last interglacial (Tyrrhenian III) time had to be revised, too. At least a rim near the present-day shoreline is of Holocene age. Samples from localities situated more to the inland side of this elongated oölitic zone give C^{14} dates of approximately late Pleistocene age. The entire oölite belt belongs to the worldwide system of marine coastal terraces formed during Late Quaternary time.

The oölitic facies of this Quaternary terrace frames a large part of the Gulf of Gabes, from southern Tunisia (*2*) to western Libya. On Djerba Island (Tunisia) and the adjacent African mainland, this terrace often begins with a basal conglomerate. The mollusk fauna, reported from here (*3*), indicates a normal marine environment and probably an elevation of sea level at that time of about 5 to 7 m above the present level. This sequence is covered by less fossiliferous, cross-stratified oölitic rocks that are thought to be fossil dunes. In Tunisia the entire oölitic sequence measures 3 to 10 m; in Libya it is up to 30 m thick (*4*).

Lucas (*5*) was the first to study the offshore sands of Djerba. From one sample with an oöid content of about 75 percent, and two others with a lower oöid content, he concluded that oöids are forming there at the present time. Furthermore, he compared the sediments and the oceanographic setting off Djerba with the high-carbonate environment of the Great Bahama Bank (*6*). However, there is more difference than resemblance between the Gulf of Gabes and the regions of modern oöid formation—for example, epicontinental banks such as the Great Bahama Bank, marginal lagoons such as the the La-

Table 1. Carbon-14 ages of oölites and oölitic sands from southern Tunisia. N-ratio is the ratio of quartz to calcareous nuclei (*21*). The C^{14} content, expressed in percentage of standard initial C^{14} content of surface ocean carbonate (*18*), is given in parentheses. For locations see Fig. 1.

Location	Total sediment	Dated sample	Average of C^{14} age (years B.P.)	Remarks
		Sample KS 8		
Ras Tourgueness, Djerba; rock cliff; 4 to 5 m above sea level	Oölite slightly lithified; content: oöids (aragonitic), 54% by volume; cement (calcitic), $<<5\%$ by volume (estimated); $CaCO_3$, 68% by weight; N-ratio, 1:5.3	Same as for total sediment	Total carbonate: 9,230 ± 70 (31.7 ± 0.3)	Younger calcitic cement makes the oölite appear slightly younger (*11*), while the presence of calcareous nuclei goes in the opposite direction
		Sample KS 19 (I)		
Zarzis, southern Tunisia; terrace about 7 m above sea level	Oölite slightly lithified (Fig. 2A); content: oöids (aragonitic), 66 to 74% by volume; cement (calcitic), $<<5\%$ by volume (estimated); $CaCO_3$, 88 to 91% by weight; N-ratio, 1:3.4	Same as for total sediment	Total carbonate: 7,060 ± 60 (41.5 ± 0.3)	Same as above
		Sample KS 30		
NE off Djerba Island, Gulf of Gabes, southern Tunisia (33°58'N, 10°56.5'E); water depth, −13 m	Recent marine sand (Fig. 2B) content: oöids (aragonite), 71% by volume; Recent skeletal material, 18% by volume; calcareous pellets, 5% by volume; free quartz, 5% by volume; undetermined, 1% by volume	Enriched oöid content of the marine sand: skeletal material reduced to $<1\%$ by volume; $CaCO_3$, 56% by weight; N-ratio, 1:1.5; grain size, 500 to 250 μm. Differential leaching in four successive steps	Step 1: 6,010 ± 90 (47.3 ± 0.5) Step 2: 6,540 ± 100 (44.3 ± 0.5) Step 3: 7,770 ± 110 (38.0 ± 0.5) Step 4: 10,370 ± 125 (27.5 ± 0.5)	Outermost layers of the oöids Layers nearer to the nucleus and an increasing amount of calcitic nucleus material Remainder: $CaCO_3$ ≈20% by weight

guna Madre in the Gulf of Mexico (*7, 8*), or in continental salt lakes such as the Great Salt Lake, Utah (*9*). They are all situated in a subtropical to tropical or arid climate, or both, often close to regions where reef corals grow, and are known to have a high precipitation rate of calcium carbonate, mainly aragonite. In contrast with these, the Gulf of Gabes has only moderately warm water coming from the North Atlantic. As this water enters through the Strait of Gibraltar it follows the coast of North Africa. During the winter, especially, the Mediterranean climate is not warm enough to increase the temperature of the water so that reef corals can grow and precipitate aragonite.

The new investigations around Djerba (Fig. 1) do not support the theory of present-day formation of the oöids. The oöids of the modern marine offshore sands, examined in 53 samples, show mechanical abrasion and boring by organisms. If these so-called "Recent" oöids are compared with the well-formed oöids from the elevated terraces (Fig. 2), one notes that the oöid layers are much thinner and more irregular within the Recent sands. Often parts of the oöid shells are broken away, exposing the nucleus. Skeletal grains, derived from Recent marine organisms and detrital grains, such as pellets, rock fragments, or eolian quartz, do not show any coating by carbonate. The oölitic envelopes of "Recent" and of fossil oöids are still aragonite.

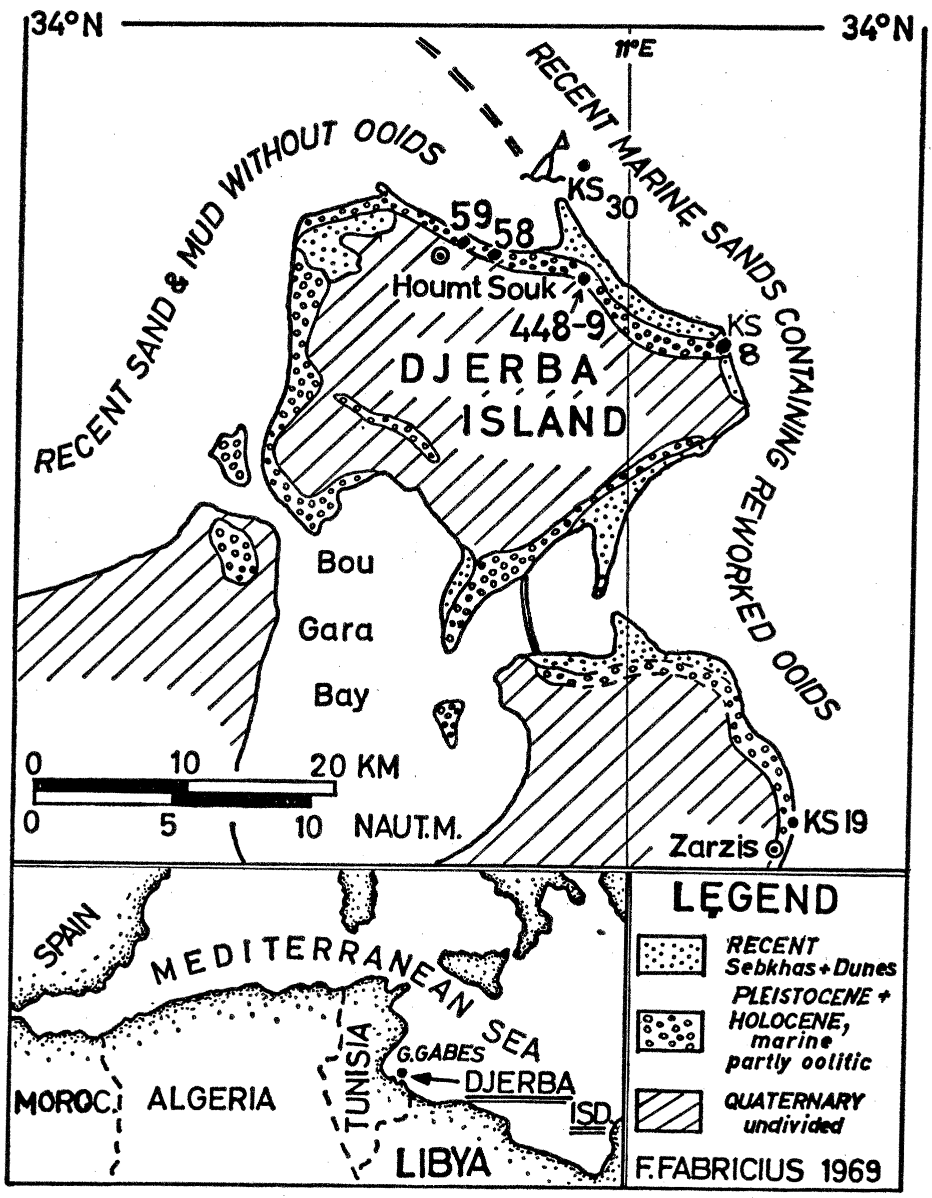

Fig. 1. Index map and geological sketch of Djerba Island, with the location of the dated samples. The modern marine sediments off Djerba are divided into two facies: east of the dashed line, containing reworked oöids; west of the line, without oöids.

Samples with the highest oöid content were selected for dating the formation of the fossil oölite of the subaerial terrace and the oöids in the modern marine sands by the C^{14} method (Table 1). The oöids of sample KS 30 of the sublittoral sands were separated from other constituents by letting them roll downward on a slightly inclined chute (*10*). The fraction containing grains with diameters from 500 to 250 μm was selected for differential dating with C^{14}. The calcareous coatings of the oöids were dissolved, in four successive steps, with dilute hydrochloric acid. On the average, about 7 μm of the envelopes were dissolved in each leaching step. After the fourth step the remaining fraction consisted of about 20 percent $CaCO_3$ and 80 percent quartz. The differential leaching was controlled by the amount of acid applied in the successive steps.

In order to minimize inhomogeneous dissolution by the acid while it was being added to the sample, the acid was cooled to 0°C before application. In this way the reaction needs about 1 minute to be 90 percent complete, leaving sufficient time for thorough mixing by shaking or stirring. Nevertheless, the leaching may have attacked inhomogeneously the carbonate coating of the individual grains because of intrinsic differences in local reactivity. Therefore, as a result of the contributions of older layers, the true age-to-depth relation may have been smoothed considerably more than was to be expected theoretically by a true layer-by-layer leaching. The age difference between the individual leaching fractions (Table 1) must be taken, therefore, as minimum values.

Rock samples. If one considers all possible sources of contamination, it does not seem likely that the minor alterations of the aragonitic oöids have changed the original C^{14} content to a great extent. Even if all the younger calcitic cement in samples KS 8 and KS 19 (which is certainly much less than 10 percent of the total carbonate) had been precipitated only very recently this would not explain the C^{14} content, which ranges between 31 and 42 percent of modern carbon (*11*). Therefore, the measured age should be reasonably correct, particularly since there is also carbonate from nuclei which shifts the results to the opposite direction (Table 1). The influence of meteoric water and of weathering apparently did not reach much below the

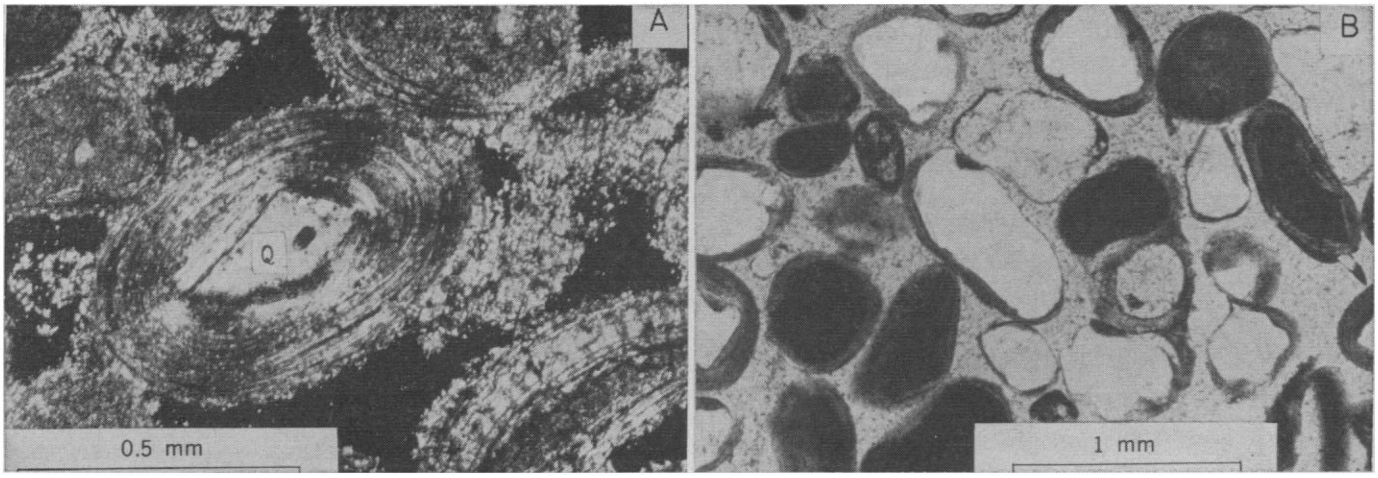

Fig. 2. (A) Early Holocene oölites from the cliff rock north of Zarzis. The aragonite coating around the calcareous or quartz (*Q*) nuclei is well preserved. The grains are cemented by a thin veneer of calcite. Thin section; polarized light with crossed Nicols. (B) Reworked early Holocene oöids in modern marine sand northeast of Djerba. The nuclei consist of quartz (light) and lime (dark). On many grains the oölitic coating is damaged by abrasion or algal boring, or both. Thin section of grains embedded in polyester resin; normal light.

encrusted surface of the outcrops, which is about 20 cm thick.

Sand samples. The radiocarbon determination of the oöids from modern sands might be slightly affected by traces of Recent skeletal material and calcareous rock fragments (less than 1 percent), and by the calcareous nuclei of the oöids. The two latter constituents can be considerably older than the coating of the oöids.

Even if the leaching did not work strictly layer by layer, as discussed above, it is unreasonable to assume that the carbonate coating is actually still forming today. It is also unlikely that the apparent age of approximately 6000 years B.P. obtained from the first leaching fraction is due simply to old carbonate that was leached from more central (that is, older) parts of the oöids. One must conclude that the oöids ceased to grow several thousand years ago, probably not much later than 6000 years B.P. They certainly are much older than the oöids from the Bahama banks, which range in age from modern to about 2700 years B.P. (*10*). If we compare the straightforward C^{14} age of the Recent sand oöids with that of the fossil oölite rock, they appear to be roughly the same. This, together with the geological evidence, leads to the conclusion that the oöids in the modern marine sands are reworked from the fossil oölitic rocks. This reworking is due to a combined biological and wave action of the submarine outcrops and to the action of breakers on the cliff rocks.

Until now the terrace (+5 to +7 m) of southern Tunisia has been thought to be of Tyrrhenian III (or Monastirian II) age. This is the time equivalent to the Eemium (or Sangamon stage of North America), the interglacial period between the two last main glaciations [Riss and Würm (*12, 13*)]. In the area of the Gulf of Gabes, the new C^{14} dates place at least the seaward parts of this terrace in the Holocene. The dates coincide with the Holocene "climatic optimum," which ranges from about 7000 to 4000 years B.P. and has its maximum at about 5000 years B.P. (Atlantic time).

The fauna that is known from many localities (*3*), for example, *Strombus bubonius* Lamark, indicates a warm climate. This gastropod is now endemic in the tropical waters off the Senegal coast and the Canary Islands, but not in the present Mediterranean. Undoubtedly, the climatic situation in the Mediterranean Sea was much better suited for the genesis of oöids during the postglacial climatic optimum than it is at the present time. In accordance with our data, the oöid growth ceased when the temperature dropped and the sea level began to fall again after its probable maximum at about 5000 years B.P.

Data concerning terraces that show evidence of a worldwide early Holocene transgression from the Mediterranean area and the coasts of the oceans were compiled by Guilcher (*14*). These terraces range in altitude from + 2 to + 5 m above the present sea level (*13–17*).

A number of aragonitic oölite samples, which belong to the inland side of the oölitic belt, have been dated as well. The ages given below are straightforward ages of the total samples, with the C^{14} content (*18*) given in parentheses.

Sample No.	Age (years B.P.)	C^{14} content (%)
KS 58a	21,475 ± 260	(6.9 ± 0.3)
KS 59	20,490 ± 230	(7.8 ± .2)
448	29,960 ± 650	(2.4 ± .2)
449	27,400 ± 500	(3.2 ± .2)

Since these outcrops do not contribute to the modern littoral sediments, the data are not discussed here in detail. However, the straightforward ages indicate (i) that there was an earlier oölite formation and (ii) that these older sediments are also piled up in dunes at about the same altitude as the younger ones. Although a Tyrrhenian (III) age cannot be excluded for these four samples, because of possible contaminations by younger carbon, there are two points which favor an age younger than the last main glaciation (Würm, Weichsel, Wisconsin). (i) The oöids and other aragonitic compounds have not yet transformed to calcite, which usually is the case for Pleistocene carbonates; and (ii) we have no hint of a stagnation of the oölite formation between the older one from the inland side and the younger one from the seaside part of this oölitic zone. It seems, therefore, more likely that we are dealing with one sucessive sequence of oölitic formation. This does not exclude interruptions by minor climatic changes during the late glacial and postglacial time. On the other hand, it is difficult to discriminate, by means other than physical dating, two identical facies at the same elevation but of Holocene and of late Pleistocene ages.

Terraces of Tyrrhenian III age (= Ouljium or Monastirian II) are also known to exist on many coasts of all oceans (*14, 19*).

With further investigation by means of radiocarbon, more marine terraces now considered to be of last interglacial age might also turn out to be of postglacial age.

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References and Notes

1. "Oölite" is a rock, composed predominantly of "oöids," which are more or less spherical, sand-sized grains with a concentrically layered, mainly calcareous coating around a nucleus of various origin.
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4. A recent field study (Fabricius, June 1969) of the "Tyrrhenian" Gargaresh Limestone west of Tripoli, Libya, could prove for the first time the same oölitic facies. This sediment, partly fossil coastal dunes, is excavated in many quarries which show facies up to 30 m high.
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11. If the oöids of sample KS 19, for example, were older than 40,000 years and 5 percent of cement were Recent, the apparent age would be 24,000 years B.P. (see also samples KS 58 and KS 59). In our samples, 5 percent of Recent calcitic cement can be responsible for an apparent age, which is about 1000 years too young.
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18. The measured C^{14} contents, after normalization to $\delta\ C^{13} = 0$ per mil deviation from the Chicago PDB (Pee Dee belemnite) standard, are expressed in percent of 0.95 NBS (National Bureau of Standards) oxalic acid. Allowance is also made for isotope fractioning between plants and ocean carbonates as well as for C^{14} pileup at the air-sea interface (*20*).
19. It is not the aim of this report to discuss the still pending problem of "Quaternary Sea Level Rise" (*13, 17*) from this local point of view. Recently, this question was critically reviewed by Guilcher (*14*).
20. K. O. Münnich, *Naturwissenschaften* **6**, 211 (1963).
21. Nucleus (N)-ratio: the proportion of quartz nuclei to calcareous nuclei of oöids.
22. The field work was carried out in March 1967 by F.H.F. in cooperation with R. Hesse.
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A Possible Bedrock Source for Obsidian Found in Archeological Sites in Northwestern Alaska

Abstract. *Recently discovered deposits of obsidian in the Koyukuk valley may be the long-sought-for source of obsidian found in archeological sites in northwestern Alaska. Obsidian from these deposits compares favorably in physical characteristics and sodium-manganese ratio with the archeological obsidian, and there is evidence that the deposits have been "mined" in the past.*

Artifacts and chippings of obsidian have been found at a number of archeological sites in northwestern Alaska, including the well-known excavations at Onion Portage and Cape Denbigh (*1–3*) (Fig. 1). These materials are commonly mixed with other cultural materials composed of chert and slate. However, although sources for the chert and slate are widely distributed in the bedrock terrane of northwestern Alaska, no natural occurrence of obsidian has been reported anywhere in the vast region that lies north and west of the Yukon River. Some archeologists have even suggested that the archeological obsidian was carried in from natural sources as far away as the Aleutian Islands or Wrangell Mountains.

Locating the source of the artifact obsidian clearly is of great importance to archeologists, as it would provide

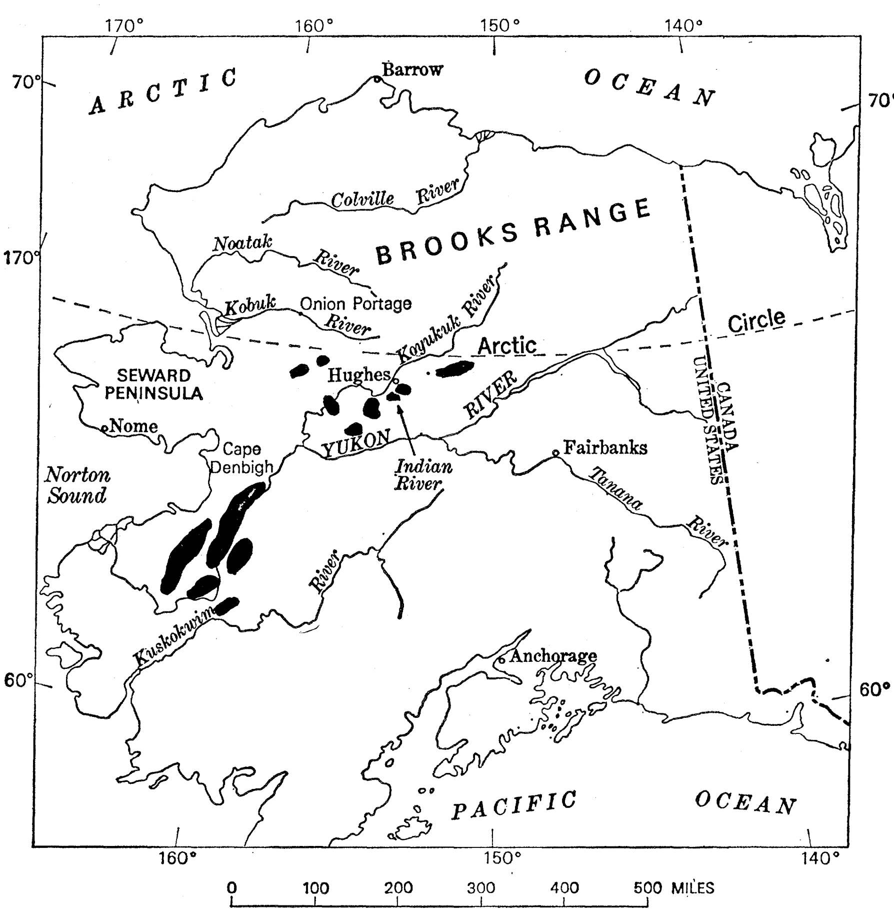

Fig. 1. Map of Alaska showing location of Indian River obsidian deposits and other Upper Cretaceous and Tertiary volcanic rock occurrences (shaded) along lower Yukon and Koyukuk rivers.