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The Syrian Coast: A Model of Holocene Coastal Evolution

P. Sanlaville†, R. Dalongeville†, P. Bernier‡ and J. Evin‡

†GREMMO-UMR 149,
Université Lumière
Lyon 2 -C.N.R.S.,
Maison de l'Orient,
7 rue Raulin,
F 69007 Lyon, France

‡URA 11,
Université Claude-Bernard
Lyon 1 -C.N.R.S.,
Centre de Paléontologie
stratigraphique
et de Paléoécologie,
43 Bd du 11 novembre 1918,
F 69622 Villeurbanne Cédex,
France

ABSTRACT

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On the calcareous Syrian coast, rocky but low for the most part, three different processes alternated several times during the Holocene: heavy sedimentation with prograding beaches; mechanical erosion with the receding of the coast and the formation of beach-rock; organogenic construction (vermetids) and biocorrosion. No less than three main aggradational phases occurred (during the 4th millenium BC, the 2nd millenium BC and the medieval period); each of them can be correlated with an important alluvial discharge from the Lebanese and Syrian wadis and rivers, carried by the South-North coastal drift and built into huge beaches. Only the last fluvial terrace (the medieval one) could be C-14 dated so far, but the oldest terrace, rich in Neolithic sherds, cannot be older than the 5th millenium BC, and the second one contains Bronze Age (2nd millenium BC) artifacts. So the aggradation beaches are clearly in phase with fluviatile discharges controlled by climatic oscillations or anthropic factors. When the alluvial discharge diminished, former beach deposits were eroded by the waves and currents, the coast receded and beach-rock formed. The unconsolidated beach sediments were, to a large extent, carried away, and biological and biochemical processes developed on the bedrock and beach-rock (vermetids settled down and corrosion benches developed). Then whenever a new alluvial phase occurred, the vermetids were eroded or disappeared; fossilized under beaches, the biological and biochemical processes stopped, and a new cycle began with an aggradation beach stage. So during the Holocene on the Syrian coast, several geomorphic processes successively occurred, mainly controlled by climatic oscillations but also probably by anthropic factors. According to numerous C-14 datings, the duration of each phase was about a millenium.

ADDITIONAL INDEX WORDS: *Syria, Holocene, shorelines, coastal erosion, bioconstruction, beach-rock, tectonics.*

INTRODUCTION

The Holocene Eastern Mediterranean coastal evolution has been studied either on rocky coasts with plunging cliffs where the corrosion notches and vermetid bioherms (FÉVRET and SANLAVILLE, 1966; FÉVRET *et al.*, 1967; LABOREL, 1986; PIRAZZOLI, 1986; PIRAZZOLI *et al.*, 1991; LABOREL and LABOREL-DEGUEN, 1994) attested to sudden tectonic-controlled sea level changes, or in deltaic areas with thick alluvial deposits indicating a huge accretion rate (Western Turkey, Peloponnese). Elsewhere, authors have generally been satisfied with noting the presence of Holocene fossil beaches and beach-rocks, without trying to retrace the precise evolution of the whole area during the Holocene.

DALONGEVILLE *et al.* (1993) emphasized the fact that various processes interfered on the Syrian coast during the middle and late Holocene: sedimentation, carbonate diagenesis, organogenic constructions, corrosion. Now, new field observations and numerous C-14 dates (Table 1) allow us to understand the coastal evolution much better.

In spite of the proximity of the mountains, the Syrian coast is generally low, though often rocky, and mainly developed in clayey limestones. The tide range is small (20 to 40 cm). Westerly and especially southwest winds are dominant and the coast receives strong wave action, with a longshore drifting to the north. The sea surface temperatures range from 17 °C in March to more than 28 °C in August. The mountains are nearby, receiving from 1,000 to more than 1,200 mm of precipitation concentrated during the cold season (October to April), and wadis flow down rapidly to the sea. Lastly, this area has been densely inhabited for a long time.

The Syrian coast is subject today to severe mechanical erosion. For some decades, considerable transformations, linked to the development but anarchic and dangerous have affected the coastal area. Not only are some archaeological sites in danger or already partly destroyed (for instance Tabet el-Hammam), but also beach sands or gravels, dune sands and even beach-rock slabs are being taken away. The coast re-

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Table 1. *14C age of Syrian and Lebanese samples.*

1—Beach and beach-rock shells

Code Ref.	Lab. Ref.	^{14}C BP (1σ)	Location	Shells	^{14}C Cal. B.C./A.D. (2σ)	Maximum Probability
1	Ly-5630	5,960 ± 60	Arab el-Malek, beach 1	*Glycymeris*	4538–4308 B.C.	4419 B.C.
2	Ly-6140	5,570 ± 210	W. Borghol, south	*Conus*	4342–3449 B.C.	3991 B.C.
3	Ly-5632	5,155 ± 65	Arab el-Malek, beach 2	*Murex*	3683–3376 B.C.	3590 B.C.
4	Ly-6144	4,480 ± 60	Maksar, lower coastal dune	*Cerithium*	2868–2532 B.C.	2845 B.C.
5	Ly-6282	4,380 ± 65	Hraiché (Akkar)	*Glycymeris*	2758–2395 B.C.	2495 B.C.
6	Ly-6271	4,180 ± 85	Ibn Hani, north	*Glycymeris, Cerastoderma*	2502-2036 B.C.	2269 B.C.
7	Ly-6142	4,105 ± 50	Maksar, upper coastal dune	*Cerithium*	2341–2027 B.C.	2133 B.C.
8	Ly-6275	4,015 ± 65	Tahat al-Khizan (Maksar)	*Cerastoderma, Glycymeris*	2262–1880 B.C.	2005 B.C.
9	Ly-6276	3,790 ± 75	Nahr el-Arab	*Mitra, Fusinus*	1953–1583 B.C.	1730 B.C.
10	Ly-6277	3,955 ± 65	N. el-Abrach	*Conus, Glycymeris*	2164–1789 B.C.	1901 B.C.
11	Ly-6268	3,945 ± 60	Kharab, north	*Conus, Glycymeris*	2131–1793 B.C.	1886 B.C.
12	Ly-6133	3,770 ± 50	Tabet al-Hammam	*Glycymeris, Cerastoderma*	1875–1607 B.C.	1679 B.C.
13	Ly-6138	3,750 ± 70	Kharab inf.	*Glycymeris, Cerastoderma*	1889–1524 B.C.	1672 B.C.
14	Ly-6701	3,740 ± 65	Cheikh Zennad, Lebanon	shelly sand	1878–1525 B.C.	1618 B.C.
15	Gif-AMS	3,590 ± 70	Guverdjine Kaya	shelly sand	1683–1376 B.C.	1509 B.C.
16	Ly-6279	3,440 ± 70	Kharab, beach-rock 2	*Cerastoderma*	1503–1171 B.C.	1313 B.C.
17	Ly-6141	3,165 ± 40	W. Borghol, north	*Glycymeris, Conus*	1112–877 B.C.	911 B.C.
18	Gif-AMS	2,945 ± 55	Guverdjine Kaya	shelly sand	845–670 B.C.	774 B.C.
19	Ly-6696	2,800 ± 115	Kharab, P.B.	*Glycymeris*	818–321 B.C.	469 B.C.
20	Ly-6280	2,615 ± 65	Kharab, beach-rock 3	shelly sand	469–171 B.C.	255 B.C.
21	Ly-6264	2,610 ± 55	Maksar, beach-rock 1	Cerithids	416–177 B.C.	289 B.C.
22	Ly-6263	2,365 ± 50	Maksar, BR2	Cerithids	155 B.C.–96 A.D.	24 A.D.
23	Ly-5627	1,970 ± 55	Ras Ibn Hani, lower layer	Cerithids	315–566 A.D.	437 A.D.
24	Ly-5626	1,920 ± 55	Ras Ibn Hani, upper layer	Cerithids	373–629 A.D.	492 A.D.
25	Ly-6137	1,640 ± 45	Kharab, upper	*Conus*	673–874 A.D.	776 A.D.
26	Ly-6134	1,575 ± 65	Arab el-Malek, upper	*Murex, Glycymeris*	691–988 A.D.	882 A.D.
27	Ly-6139	1,305 ± 45	W. Borghol	*Glycymeris*	1019–1223 A.D.	1068 A.D.
28	Ly-6265	1,227 ± 52	Ras el-Bassit	*Conus*	1061–1292 A.D.	1222 A.D.

2—Vermetids and bioconstructions

Code Ref.	Lab. Ref.	^{14}C BP (1σ)	Location	Remarks	^{14}C Cal. B.C./A.D. (2σ)	Maximum Probability
29	Ly-5624	5,595 ± 85	Guverdjine Kaya	+1,20 m	4095–3718 B.C.	3997 B.C.
30	Ly-5631	5,275 ± 65	Arab el-Malek	beach 2	3800–3549 B.C.	3692 B.C.
31	MC-145	3,490 ± 80	Tripoli, Lebanon	+1.20 m	1596–1220 B.C.	1399 B.C.
32	Ly-5636	3,225 ± 55	Ras Ibn Hani, bioconstruction	>0,80 m	1233–912 B.C.	994 B.C.
33	Ly-5637	2,915 ± 50	Ras Ibn Hani, bioconstruction	>0,80 m	811–589 B.C.	767 B.C.
34	Ly-6274	2,745 ± 65	Tahat el-Khizan (Maksar)	+0.40 m, fossilized	744–350 B.C.	399 B.C.
35	Ly-5621	2,590 ± 45	Ras Ibn Hani	+0.45 m, mole	389–183 B.C.	349 B.C.
36	Ly-6272	2,360 ± 70	Maksar	+0.60 m, fossilized	183 B.C.–139 A.D.	45 A.D.
37	MC-63	2,035 ± 130	Tabarja, Lebanon	+0.60 m	66–653 A.D.	414 A.D.
38	Gif-AMS	2,010 ± 60	Arab el-Malek	+0.60 m, fossilized	250–544 A.D.	425 A.D.
		1,900 ± 50			411–635 A.D.	561 A.D.
		1,890 ± 60			402–657 A.D.	580 A.D.
39	MC-64	1,960 ± 140	Tabarja, Lebanon	+0.60 m	120–711 A.D.	530 A.D.
40	Ly-6262	1,960 ± 50	Tell Soukas	+0.90–1.10 m	337–577 A.D.	465 A.D.
41	Ly-6273	1,925 ± 70	Maksar	+0.90 m	339–644 A.D.	546 A.D.
42	Ly-5623	1,890 ± 55	Guverdjine Kaya	+0.60 m, fossilized	416–650 A.D.	573 A.D.
43	MC-146	1,880 ± 50	Tripoli, Lebanon	+0.60 m	427–651 A.D.	596 A.D.
44	Gif-AMS	1,880 ± 70	Arab el-Malek	+0.60 m, fossilized	392–674 A.D.	596 A.D.
		1,820 ± 60			459–698 A.D.	637 A.D.
45	Ly-6283	1,705 ± 65	Ras el-Karm (Ibn Hani)	+0.50 m	594–838 A.D.	679 A.D.
46	Ly-5625	1,675 ± 55	Ras Ibn Hani	± 0 m, causeway	647–841 A.D.	747 A.D.
47	Ly-6267	1,485 ± 50	Ras el-Bassit	+0.66 m	813–1026 A.D.	971 A.D.
48	Gif-AMS	1,450 ± 60	Ras el-Bassit	+0.60 m	830–1063 A.D.	981 A.D.
49	Gif-AMS	1,400 ± 70	Ras el-Bassit	+0.60 m	877–1171 A.D.	1020 A.D.
50	Ly-6266	1,395 ± 100	Ras el-Bassit	+0.76 m	921–1109 A.D.	1019 A.D.
51	Gif-AMS	1,335 ± 50	Ras el-Bassit	+0.60 m	993–1199 A.D.	1059 A.D.
52	Ly-5622	1,335 ± 50	Ras el-Bassit	+0.60 m	993–1199 A.D.	1106 A.D.

Table 1. *Continued.*

3—Continental shells

Code Ref.	Lab. Ref.	^{14}C BP (1σ)	Location	Fauna	Remarks	^{14}C Cal. B.C./A.D. (2σ)	Maximum Probability
53	Ly-6143	5,160 ± 55	Maksar	*Helix*	reddish layer	3991–3781 B.C.	3829 B.C.
54	Ly-6281	3,435 ± 92	Amrit	*Helix*	coastal dune	1958–1524 B.C.	1724 B.C.
55	Ly-6135	1,885 ± 50	N el-Abrach	*Melanopsis, Melanoides*	lowest terrace	29–250 A.D.	109 A.D.
56	Ly-6136	1,860 ± 55	W. Syano (Jableh)	*Melanopsis, Melanoides*	lowest terrace	42–316 A.D.	174 A.D.
57	Ly-5156	1,860 ± 75	N. el-Abrach	*Melanopsis, Melanoides*	lowest terrace	23–337 A.D.	165 A.D.
58	Ly-5157	1,830 ± 55	N. el-Abrach	*Melanopsis, Melanoides*	lowest terrace	83–348 A.D.	186 A.D.
59	Gif-93232	3,210 ± 60	N. el-Abrach	*Melanopsis, Melanoides*	lower terrace	1614-1323 B.C.	1486 B.C.

4—Samples collected from bioconstructed rims on the Hatay coast (Pirazzoli *et al.* 1991)

Code Ref.	Lab. Ref.	^{14}C BP (1σ)	Corrected 14C (reservoir effect)	Fauna	Location According to the Orontes Delta	^{14}C Cal. B.C./A.D. (2σ)	Maximum Probability
60	Pa-775	2,595 ± 100	2,995 ± 100	vermetids	north	1018–543 B.C.	799 B.C.
61	Pa-779	4,800 ± 80	5,200 ± 80	vermetids	north	3765–3388 B.C.	3620 B.C.
62	Pa-823	2,050 ± 60	2,450 ± 60	vermetids, oysters	north	321 B.C.–25 A.D.	130 B.C.
63	Pa-782	2,040 ± 80	2,440 ± 80	vermetids	north	345 B.C.–82 A.D.	115 B.C.
64	Pa-781	1,710 ± 100	2,110 ± 100	vermetids, algae, oysters	north	47–516 A.D.	265 A.D.
65	Pa-776	2,410 ± 60	2,810 ± 60	vermetids	north	769–392 B.C.	581 B.C.
66	Pa-774	2,830 ± 60	3,230 ± 60	oysters	north	1255–906 B.C.	1074 B.C.
67	Pa-822	2,315 ± 80	2,715 ± 80	vermetids	north	788–250 B.C.	408 B.C.
68	Pa-771	1,345 ± 70	1,745 ± 70	oysters	north	544–795 A.D.	699 A.D.
69	Pa-769	2,290 ± 95	2,690 ± 95	vermetids	south	741–393 B.C.	181 B.C.
70	Pa-778	2,685 ± 100	3,085 ± 100	oysters	south	1158–887 B.C.	742 B.C.
71	Pa-773	5,170 ± 190	5,570 ± 190	algae, vermetids	south	4402–3615 B.C.	3981 B.C.
72	Pa-780	2,910 ± 95	3,310 ± 95	algae, vermetids	south	1415–916 B.C.	1196 B.C.

cedes considerably and is badly modified as a consequence of the almost total disappearance of sand. However, retreat of the beaches has made observation easier over the last several years (Figure 1).

FIELD AND LABORATORY DATA

Radiocarbon Date

Most of the radiocarbon measurements were performed by liquid scintillation counting in the Radiocarbon Laboratory of the Claude-Bernard University in Lyon. When samples were too small (less than 0.5 g), we asked for measurements using the AMS technique by the Tandétron machine of the Gif-sur-Yvette Laboratory (Dalongeville *et al.,* 1993). Table 1 also includes four datings on samples coming from Lebanon and measured by gas counting in the (now closed) Monaco Laboratory (Thommeret and Thommeret 1966, 1969) and, by comparison, 13 radiocarbon datings performed at Paris VI University on organic samples collected along the Hatay coast, at the mouth of the Orontes by Pirazzoli *et al.* (1991).

Conventional radiocarbon dates are written BP according to international rules, taking into account the isotopic fractionation. For all the measurements on carbonate samples by the counting technique, this isotopic fractionation was assumed to be *circa* 0‰ P.D.B. for the marine samples and *circa* 10‰ P.D.B. for the lacustrian or continental sediments, while precise δC-13 were obtained in the AMS analyses.

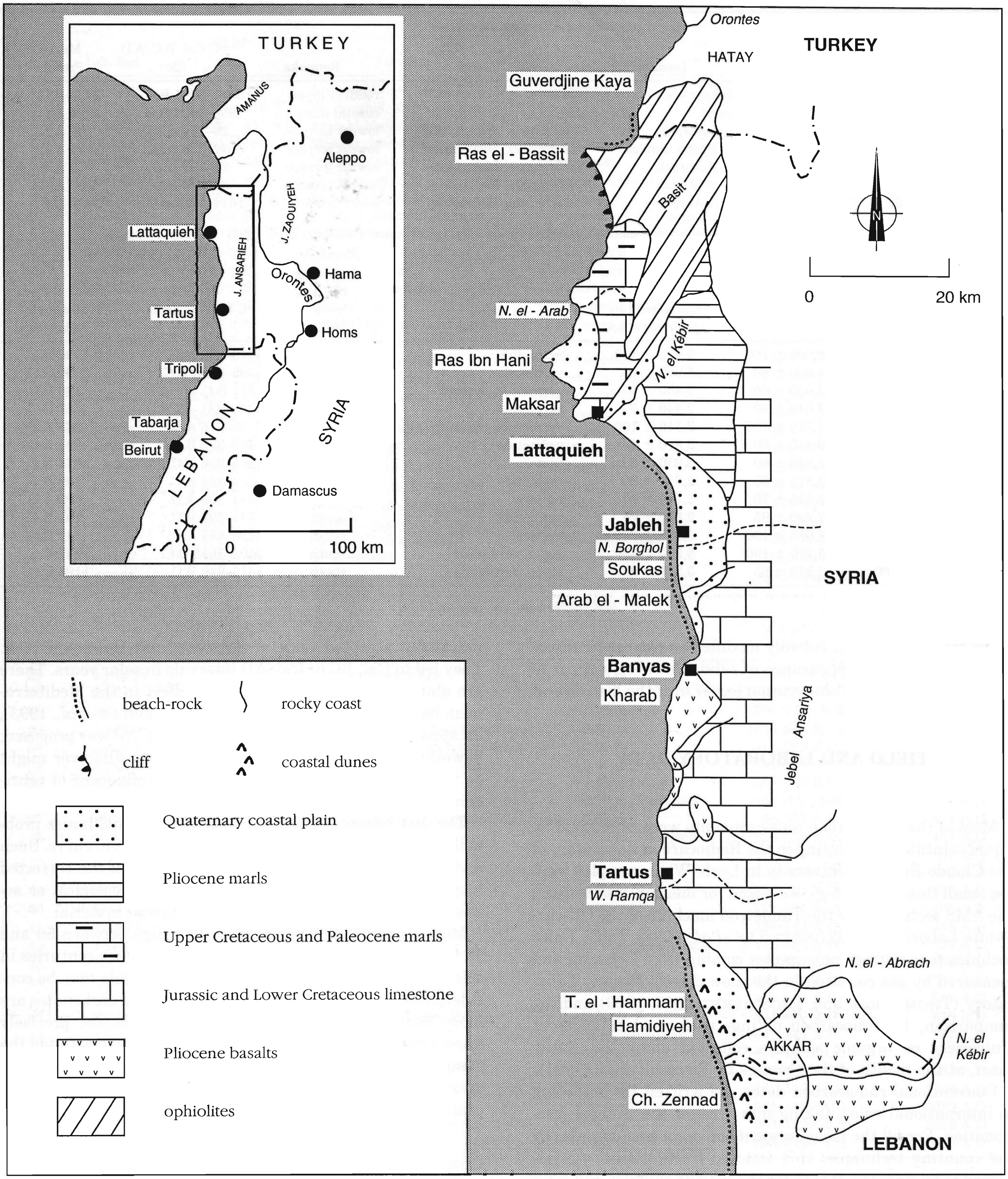
Calibration of the BP dates in the calendar scale were made (with a 2σ standard deviation) according to the internationally accepted data of Stuiver and Reimer (1993). They led to Cal. BC or Cal. AD intervals in solar years. There are almost no data on the reservoir effect in the Mediterranean basin. In a previous paper (Dalongeville *et al.,* 1993), an apparent age of 320 yr (*i.e.* ΔR = −80 ± 25) was proposed; however, a 400 yr value in the whole area whatever might be the shoreline shape and the possible influences of continental or deep-sea waters is now assumed.

The last column in Table 1 indicates the maximum probability obtained from the atmospheric calibration curve. Such a value generally differs from the mid-point of the corrected interval. It allows better comparisons with geological or archaeological dates obtained from continental material.

Most of the BP statistical margins range between 50 and 70 C-14 yr leading to intervals (2σ) of about two centuries in solar years. Dates taken from marine materials may be considered as reliable, but those from continental carbonates are more doubtful; the original C-14 content is not precisely known and some secondary carbonates may have polluted the samples. Therefore, the indicated dates of those samples are maximum ages and their real age may be younger by several centuries.

Coastal Deposits

Two sections are particularly significant. The first one is located at Maksar, some kilometers north of Lattaquieh, south of the rocky Cape of Afamia (Figure 2). Some distance from the Lattaquieh harbour, the freeway linking Lattaquieh



DAO : Y. MONTMESSIN, Maison de l'Orient (CNRS)

Figure 1. Location map.

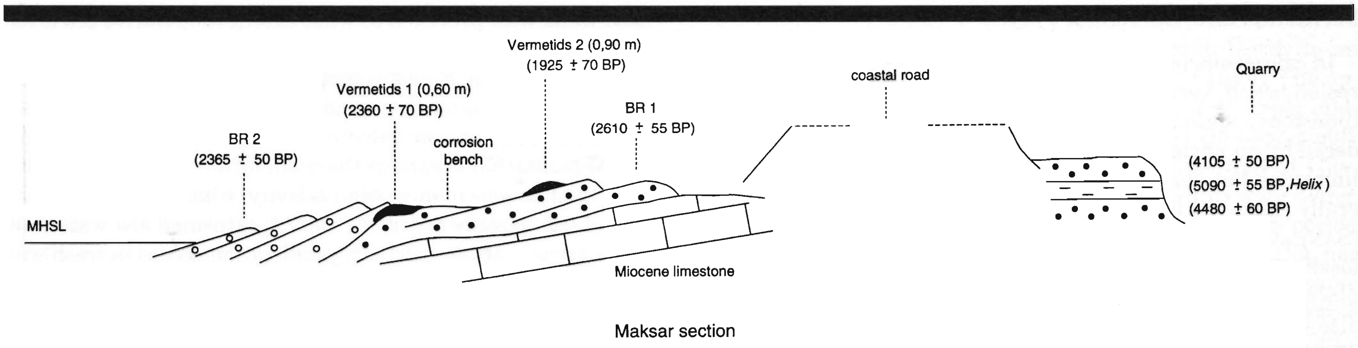


Figure 2. Maksar section.

to Ibn Hani (a seaside resort close to the Ras Shamra-Ugarit archaeological site) runs along a small cove developed into a fishing port. Upper beach-rock slabs are to be found at 1.80 m above the high water level, resting on the Pliocene marls. Radiocarbon datings of marine shells (Cerithids) gave 2,610 ± 55 yr BP (Ly-6264) for the lower beach-rock and 2,365 ± 50 yr BP (Ly-6263) for the more recent one. The lower beach-rock was cut into a corrosion bench (trottoir) at about +0.60 m and shows veneers of vermetids. The vermetids at +0.90 m have been dated to 1,925 ± 70 yr BP (Ly-6273). The vermetids at +0.60 m, dating 2,360 ± 70 yr BP (Ly-6272), underlie the upper beach-rock. East of the road, a sand pit displays another section; a coarse bioclastic marine but wind-blown (Helix) sand gave, on marine shells, a date of 4,105 ± 50 yr BP (Ly-6142). At the bottom of the section a similar deposit has been dated to 4,480 ± 60 yr BP (Ly-6144). Between these two eolian deposits, continental shells of red (2,5 YR 3/6) silty sands have been dated 5,090 ± 55 yr BP (Ly-6143); they are somewhat older than the underlying sands, but continental gastropods generally seem older than normal.

Another interesting section, located at Arab el-Malek in the southern part of the Jableh plain, has already been published (DALONGEVILLE *et al.,* 1993) but new information has been brought to light (Figure 3). The Miocene marly bedrock outcrops locally but is generally covered by layers of two successive generations of beach-rocks. The lower part of the older one corresponds to a reddish silty sand, strongly cemented and resting on the Miocene. The upper beach-rock fossilizes stone-pits. It also overlies vermetid rims, which are mainly concentrated at about +0.60 m and settled on an older beach-rock. Two AMS (Gif-sur-Yvette) samples gave dates of 2,010 ± 60, 1,900 ± 50 and 1,890 ± 60 yr BP for the first one, and 1,880 ± 70 and 1,820 ± 60 yr BP for the second one (DALONGEVILLE *et al.,* 1993). About 30 m east, three uncemented beach deposits outcrop up to ±2.50 m. The lowest beach which overlies a red silty sand is as old as 5,960 ± 60 yr BP (Ly-5630). In strong unconformity to it, there is a younger beach outcrop, rich in marine shells and vermetid boulders. The vermetids are 5,275 pm 65 yr old (Ly-5631) and the shells are dated to 5,155 ± 65 yr BP (Ly-5632). Underlying a sand dune, the third beach fossilizes a cliff cutting the two older beaches. Marine shells gave a date of 1,575 ± 65 yr BP (Ly-6134). This younger beach was then cemented into beach-rock and overlies the +0.60 m vermetids.

The Maksar and Arab el-Malek sections show how complex the Holocene coastal processes have been. Numerous other sections bring fuller information. For instance at Kharab, south of Banyas city, on a Pliocene volcanic bedrock, several (probably three) unconformable beach-rocks give way laterally to a thick beach, outcropping up to +5.50 m and apparently single and homogeneous. The marine shells of two coarse levels at the base and the top of this beach have been dated to 3,750 ± 70 yr BP (Ly-6138) and 1,640 ± 45 yr BP (Ly-6137), and the two youngest beach-rocks have been dated to 3,440 ± 70 yr BP (Ly-6279) and 2,615 ± 65 yr BP (Ly-6280). Lastly, on both sides of the Wadi Borghol mouth, three beaches have been respectively dated to 5,570 ± 210 (Ly-6140), 3,165 ± 40 (Ly-6141) and 1,305 ± 45 (Ly-6139) yr BP.

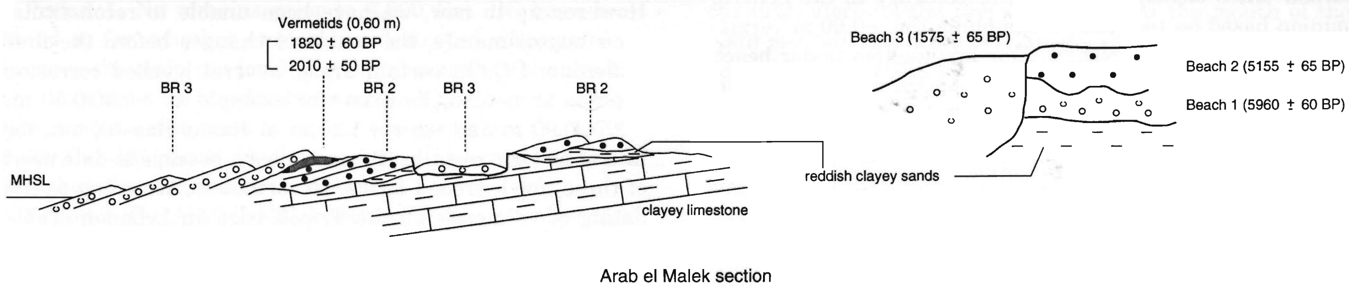


Figure 3. Arab el-Malek section.

Vermetids and Corrosion Forms

In calcareous plunging cliffs, the present-day vermetid corrosion bench, very regular and rather narrow (0.50 to 1 m on limestone, appreciably wider on calcarenite), is often bordered by an ancient corrosion bench, more than 1 m wide on limestone but very rare on calcarenite. This fossil form generally exists in Lebanon too, where it is 0.60 m to 0.80 m high (SANLAVILLE, 1977). Some higher (for example at +1.20 m) fossil rims, notches or corrosion benches are visible in various places (at Ras el-Bassit, Tell Soukas, Guverdjine Kaya and also on the small islands off Tripoli, in Lebanon), but generally they are badly preserved and vermetids are absent.

On the coast of Syria and Lebanon, vermetids are the sublittoral fixed gastropods, *Dendropoma (Novastoa) petraeum* Monterosato, generally living in association with the coralline rhodophyte, *Neogoniolithon notarisii* (Dufour) SETCHELL and MASON. Both species are important biological sea-level indicators ((FÉVRET and SANLAVILLE, 1966). Vermetids only develop on a hard substratum. When they are to be found on a beach-rock, we can be sure that the sediment had already been cemented into beach-rock before the vermetids settled on it. Vermetids only live where waves do not carry sand or gravels, because vermetids cannot withstand erosion, muddiness or burial under beach deposits.

Observation of living vermetids has shown that on an exposed coast, they mark the sea level with a precision of only 0.25 m versus 0.10 m on a sheltered shore. It is difficult to know what the hydrodynamic conditions were when fossil vermetids lived, and thus to know the exact sea level. More especially, parts of these vermetids may have been eroded, providing only an imprecise height. On the contrary, the altimetric significance of vermetids is clear and precise when they form thick and continuous rims associated with notches or forms of corrosion. But, of course, altimetric differences can be due to tectonics.

Finally, the radiocarbon dates of fossil vermetids indicate when the vermetids died. Death can be due to a sudden uplift which took away from their biotopes, or to a fossilization under beach deposits. This last occurrence is clearly the most frequent on the Syrian coast. Most of the observed fossil vermetids look fresh, but this apparent freshness is frequently due to a rapid fossilization under marine or eolian deposits (Guverdjine Kaya, eastern part of the Ras el-Bassit headland, Arab el-Malek). Thus, vermetids give information on the coastal evolution: alternating phases of biocorrosion and bioconstruction, of alluviation, or of mechanical erosion. Radiocarbon dates clearly show that, in contrary to the general opinion based on too small a sampling, the +0.60 m vermetids did not die all together; their fossilization under beach sediments occurred at various periods according to the coastal area.

Sea Level Changes and Tectonics

It is not easy to know at what relative sea level and coastline each phase of the really complex evolution of the Syrian coast corresponded. Beaches often provide only imprecise data: thus, in the Arab el-Malek area the ancient beaches are clearly higher than the present beach, but it is difficult to determine with precision to what extent the relative sea level has changed.

Analysis of beach-rock cements makes it possible to determine the position of the ancient shoreline. Where crystallization is aragonitic or calcitic, the soaking agent is marine and cementation occurs in the mediolittoral zone, under the combined actions of microbian activity, which stabilizes sand, and of the movements of the $CaCO_3$ saturated sea water; on the contrary, drusic calcite crystallization occurs in fresh water (LONGMAN, 1980; HECKEL, 1983; BERNIER and DALONGEVILLE, *forthcoming*). Thus, at Hamidiyeh, in the farthest south of the Syrian coast, beach-rock formed in coastal dune sand cemented with drusic calcite in fresh water, which means that, in this area, the coastline has retreated since the diagenesis.

Due to bad conditions of observation (mainly a strong hydrocarbon pollution), beach deposit analysis provided very little information on possible changes of the sea level. However, a comparison between the present and the cemented keystone-vugs can prove the existence of a relative sea level variation. Keystone-vugs are the internal structures of air vacuoles trapped in the beach sand at the upper limit of the mediolittoral zone and controlled by water/air exchanges in a porous sediment, between ebb-tide and flood-tide (BEAUDOIN, 1954, 1971; DUNHAM, 1970). Since the mean range of the tide does not exceed 0.25 m in Syria (at Maksar, keystone-vugs were found at +1.80 m), the relative sea level was even much higher than today, probably higher than 0.60 m.

Vermetids give some more precise data. The frequent existence on limestones of two levelled corrosion benches proves that the sea level was stable quite a long time to allow the shaping of these benches, but also that the uplift up to +0.60 m was rapid enough (although not necessarily instantaneous) to allow the +0.60 m corrosion bench to be preserved. The +0.60 m corrosion platform, very frequent in Syria and in Lebanon, was first attributed mainly to eustasy (SANLAVILLE, 1977) and then, more rightly, to tectonics (PIRAZZOLI, 1986; PIRAZZOLI *et al.*, 1991; EROL and PIRAZZOLI, 1992). But was the movement brutal? When did it exactly occur (DALONGEVILLE *et al.*, 1993)?

First, even if the Syrian coast seems to have evolved rather homogeneously, regional disparities may have occurred. So, it is difficult to say if vermetids at +1.20 m at Guverdjine Kaya, *circa* 5,600 yr BP, have a general or only a local significance. When the marine biogenic cement of an ancient roadway formed at Ibn Hani between 1,200 and 600 Cal. BC, the sea level was at least 0.80 m higher than the present one. However up to now, we have been unable to reconstitute, even approximately, the sea level changes before the first millenium BC. In certain areas, several levelled corrosion benches or notches do exist (for example at +0.40/0.50 m, +0.70/0.90 m and *circa* +1.30 m at Ras el-Bassit), but, for lack of biologic remains, it has not been possible to date most of these much eroded forms. Nevertheless, according to the dating of vermetids on the Tripoli islet, in Lebanon (Table 1.2), it is probably after the middle of the second millenium BC that the rise which brought about their death began.

Since about 500 Cal. BC, interpretation seems to be easier, because numerous remains of vermetid rims supply both precise heights and plenty of dates. If the +0.60 m vermetid rims are frequent, even at Ras el-Bassit and at Guverdjine Kaya, vermetids have been observed also at rather different heights: at about +0.40 m (and also ±0 m) at Ibn Hani, at about +0.70 m at Ras el-Bassit and also at about +0.90 m at Maksar (where vermetids also occur at +0.60 m), and even at +1 m at Soukas. These data are rather contradictory, unless they can be attributed to weak but complex tectonics: firstly a slow subsidence, then a more rapid uplift. The +0.60 m corrosion bench has been interpreted (PIRAZZOLI, 1986) as a brutal uplift which must have caused the death of the vermetids and allowed a perfect conservation of the bench. It is true in areas with deep water cliffs, but elsewhere vermetids have very often been fossilized under a beach, and radiocarbon data clearly mark the date of fossilization more than the date of the uplift. Moreover, the age of vermetids varies extremely from one place to another: between 250 and 698 Cal. AD at Arab el-Malek and between 810 and 1,200 Cal. AD at Ras el-Bassit (Table 1), which raises a problem of interpretation. It is only at Tabarja and in islets off Tripoli, in Lebanon, and at Ras el-Bassit (except nearby the archaeological site) in northern Syria, that we can be sure that the dated vermetids were not fossilized under sediments. So, the uplift may not have been synchronous everywhere; it should have occurred during the fifth or the sixth century AD in Lebanon, but *circa* the year one thousand at Ras el-Bassit, in other words much later than the tectonic paroxysm reported by PIRAZZOLI (1986) as taking place at the beginning of the Byzantine period. It has been impossible to trace the existence of fossil vermetids, associated or not with a corrosion bench, that lived after the beginning of the 2nd millenium AD; then, the present vermetid bench was already forming so we can consider that the process of bench formation is rather long.

THE MAIN PHASES OF THE EVOLUTION OF THE SYRIAN COAST AND THEIR SIGNIFICANCE

Interpretation: The Main Evolution Phases

The detailed study of the coast, the various indicators of evolution available (vermetid rims, beaches, beach-rocks) and radiocarbon dates allow us to determine the Holocene evolution of the Syrian coast (Figures 4 and 5). Several main periods that must be interpreted become evident (Figure 4). In order that observations can be correlated to archaeological data, calibrated dates expressed in years BC or AD are used here (STUIVER and REIMER, 1993; Table I).

Period 1. No remains prior to 4,600 Cal. BC have been found so far, whether erosion has destroyed all remains or because the main sea level was then lower than the present one; on a coast such as the Syrian coast that is being uplifted this second assumption is not so convincing for the 6,000–4,600 Cal. BC period which is supposed to correspond to the postglacial transgressive maximum.

Period 2. The Arab el-Malek section (Figure 3) proves that, between 4,600 and 3,500 Cal. BC two clearly distinct beaches formed. Before the second one appeared (also attested at the mouth of Wadi Borghol), the first one was eroded enough to allow the appearance of a beach-rock or the clearing of the substratum on which vermetids then settled and prospered (vermetid bioherms found in the second beach testify to an intermediate period during which water was limpid). The upper beach at about +2 m presents the facies of an upper mid-littoral deposit which corresponds to a sea level appreciably higher than the present one; it is at that time that at Guverdjine Kaya in the north, the +1.20 m vermetids were living.

Period 3 (3,500–2,800 Cal. BC). No remains of this period have been dated so far: neither beach, nor vermetid, nor beach-rock (even on the Hatay coast (Turkey) if the same reservoir effect of 400 yr value is taken into account (Table 1.4) for the dated samples collected by PIRAZZOLI *et al.*, 1991). That seems very curious. It may be that, during this period, there were no river deposits and the waves progressively eroded the previous deposits which must have been very large since remains still exist today. Vermetids probably settled somewhere in the most favourable places; why have none of them been identified so far? Was the sea level then lower than the present one?

Period 4 (2,800–800 Cal. BC). Except at Arab el-Malek, numerous remains of beaches and coastal dunes exist, indicating that the shoreline prograded everywhere, mainly between 2,800 and 1,500 Cal. BC. At Maksar, only coastal dune sands outcrop now, but their facies prove that the beach was very near. Beach deposits are important at Kharab and in the whole of southern Syria. At Guverdjine Kaya, they have been preserved as veneers against the cliff; so, on this much exposed coast, an important part of the cliff was fossilized. At Ibn Hani, an ancient causeway was overlaid by sea water and biogenic cementation developed, proving that the mean relative sea level at this place was no less than +0.80 m. Lastly, the death of the vermetids of the Tripoli islets and on Hatay seems to prove that the coast was uplifted *circa* 1,400 Cal. BC; this uplift must not have exceeded 0.40 m *circa* 1,000 Cal. BC, given the biogenic cement of an ancient causeway at Ibn Hani (DALONGEVILLE *et al.*, 1993).

Period 5 (from 800 Cal. BC to 500 Cal. AD). Except in some particular areas, no new beach formed at that period, but the previous beaches receded and exhumed beach-rocks on which vermetids settled (especially at Maksar). A +0.60 m corrosion bench was shaped everywhere. During this period, the great development of vermetid rims appears similar to the one we can observe today, with a corrosion bench and vermetid rims on beach-rocks.

Period 6 (from 500 to 1,200 Cal. AD). A new beach formed which as a consequence of erosion or fossilization produced the death of the vermetids that had resisted so far the mechanical effects of the previous period. At the mouth of the Nahr el-Arab, this beach is transgressive on a Byzantine site. An uplift must have occurred between 400 and 600 Cal. AD in Lebanon and *circa* 1,000 AD in northern Syria, raising the vermetid bench up to +0.60/0.80 m.

Period 7. After 1,200 Cal. BC, the last beach in its turn was strongly attacked by the sea and receded, leaving beach-rocks. For a few decades anthropic action has accelerated the retreat process so that all Holocene beaches or coastal dunes will probably disappear shortly. At the same time, the present vermetid bench has been developing in the plunging cliff areas.

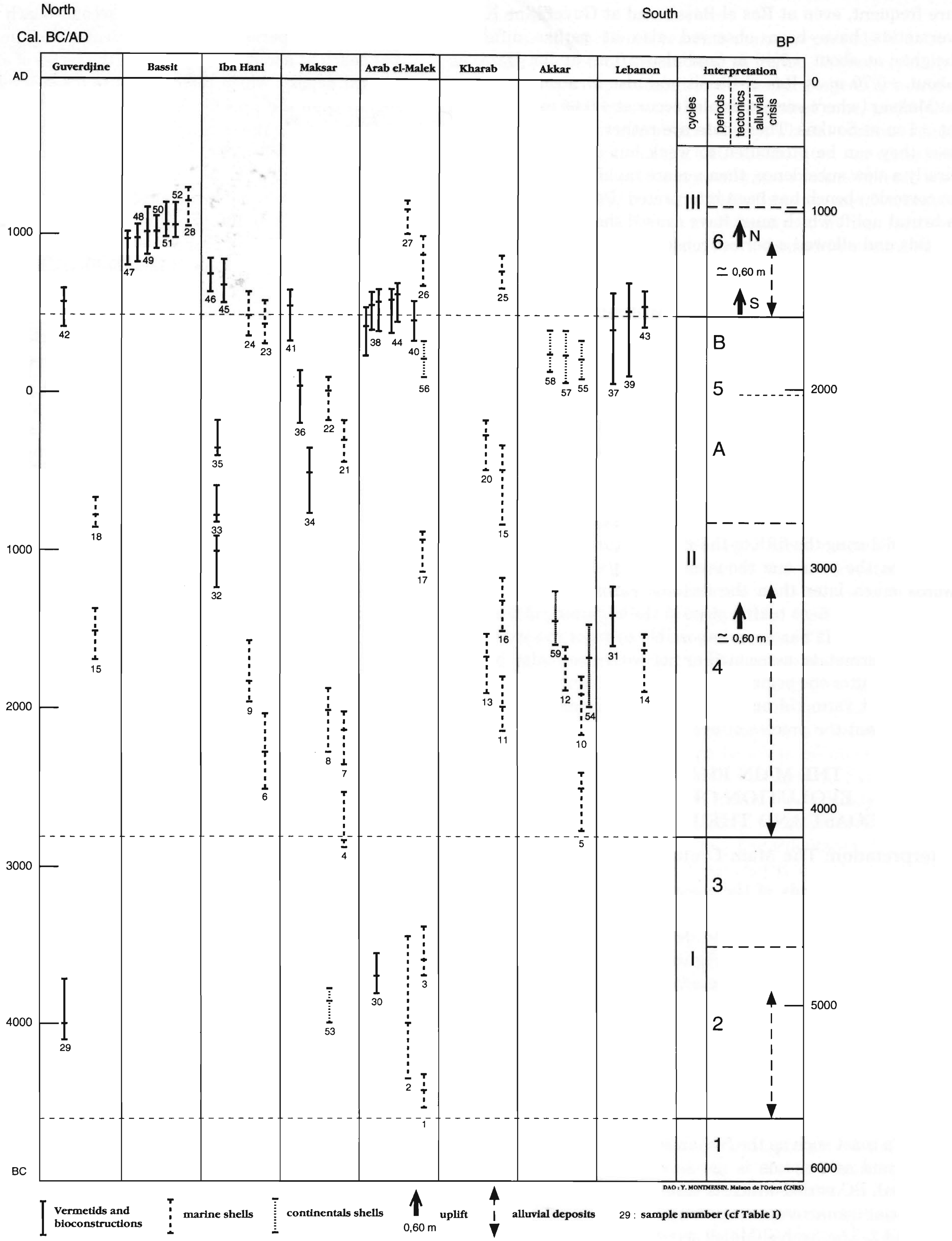


Figure 4. Regional evolution and chronology of the Syrian coast. Explanation in the text.

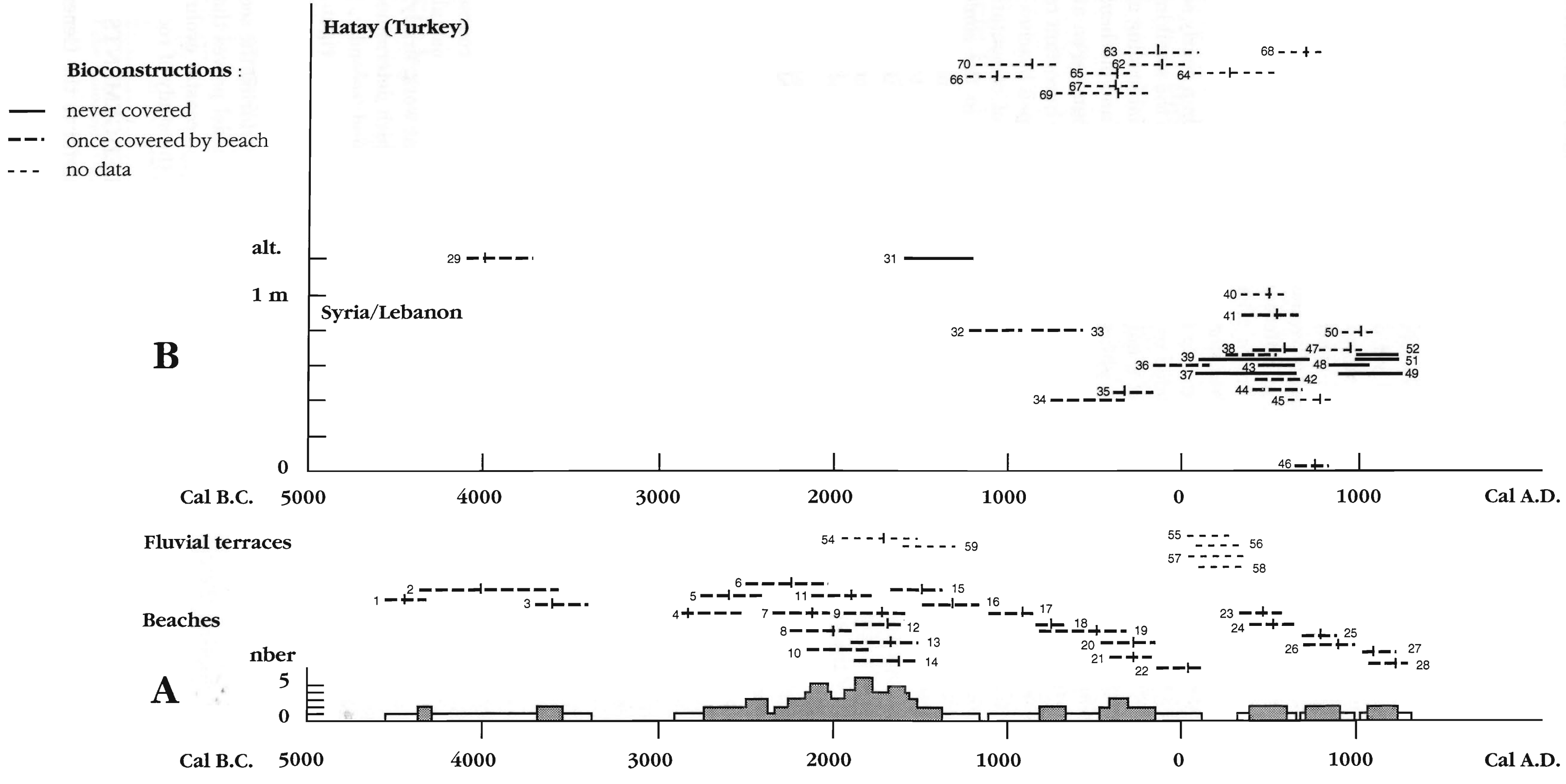


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Figure 5. Comparison between coastal aggradation phases and fossil vermetids associated to corrosion beaches or notches along the coast of Syria and the adjacent areas. Sample numbers of Table 1. Ages, in solar years, correspond to a 95% probability (two sigmas). A, histogram showing occurrences of dated beach sediments (whatever the present altitude of these deposits). B, bioconstruction occurrences. For the Hatay samples, the present day altitude has not been taken into account.

Discussion: The Syrian Model of Coastal Evolution

On the flat coastal areas where accumulation and erosion phases alternated, the general evolution model is the following one (Figure 6): the cycle (Cycle I) begins with a prograding sand, gravel or pebble beach (Phase 1); this beach is then consolidated into a beach-rock that mechanical erosion uncovers (Phase 2); if erosion stops, vermetids settle on the beach-rock and even a corrosion bench can begin to form eroding the beach-rock (Phase 3) when the period of stability is long enough. Then a new cycle (Cycle II) may start, with its three more or less complete and long phases: beach fossilizing vermetids (Phase 1), beach-rock formation (Phase 2) and the fixing of vermetids. However, vermetids never could settle in areas where shore drifts (sand or pebbles) are very abundant (in the Kharab area or the farthest south).

Thus, the Syrian coast has undergone, for more than six millenia and rather uniformly all along the coastline, an original and complex evolution. A very precise stratigraphical analysis and a study of the coast as a whole (not the rocky area) is required to understand this evolution. It seems that no less than three aggradational periods of unequal duration occurred (Figures 4 and 5): the first one *circa* the end of the 5th and the beginning of the 4th millenium BC; the second one *circa* the end of the 3rd and the beginning of the 2nd millenium BC; and the last one during the medieval period. Very probably, these aggradational phases are to be related to a huge discharge by rivers and wadis of sediments that were then carried away along the coast by the south-north beach drift and accumulated into beaches. Unfortunately, it has not been possible to establish a stratigraphic relationship between the beaches and the fluvial terraces, or to get C-14 dates for the terraces, except for the last one; in the southern part of the region, the youngest terrace was dated to 1,800 ± 50 yr BP (on fresh water gastropods; Table 1.3, Samples 55 to 58). Two other Holocene terraces have been identified, mainly on the Wadi Ramqa which flows into the sea south of Tartus city. Epipalaeolithic and Neolithic artefacts have been found in the oldest one of these which should be contemporaneous with (or just posterior to) the Pottery Neolithic (*circa* the 5th millenium BC). The second one, which also exists in the Euphrates Valley (GEYER and SANLAVILLE, 1991) provided Bronze age sherds of pottery (2nd millenium BC) and was dated on fresh water gastropods to 3,210 ± 60 yr BP (Table 1.3, Sample 59). Thus, the aggradational phases of the Syrian coast may well be in step with the periods of great river and wadi load (Figures 4 and 5), but we do not know if this load was controlled by climatic, anthropic or, more probably, mixed factors.

It is after the second sedimentary crisis (Figure 4, Period 4) that we can best retrace the subsequent evolution. When supply of detrital deposits diminished or stopped, the coast began to recede and beach-rocks appeared. According to the intensity and the direction of the swell, beach deposits were reworked, redistributed and eroded again, allowing the formation of inset beaches and beach-rocks (Period 5A). When the alluvial deposits, the load transported all along the coastline and the uncemented sedimentary stock on the strand zone were greatly reduced, the mechanical processes were replaced by biological and biochemical processes; vermetids settled and a corrosion bench formed (Period 5B). This stage of relative stability came to an end when a new alluvial crisis occurred; then a new cycle started (Figure 4, Cycle III).

The process described here concerning the Holocene evolution of the Syrian coast occurred of course during other Quaternary periods. The so-called corrosion benches were generally formed through complex and multiple processes, as pointed out on the Lebanese coast for the Last Interglacial, during which there alternated in the same area mechanical erosion, beach forming, cementation into beach-rock and the shaping of vermetid benches (SANLAVILLE, 1977).

So, at different time scales and for a sea level supposed stable (*circa* ±1 m), the coast underwent more or less important transformations on a small width—some tens of meters—due to a weak tidal range. On a yearly scale, the beach prograded or receded according to the swell intensity; on the scale of a millenium, strong alluvial loading and mechanical erosion alternated with corrosion and biochemical processes, especially according to climatic changes; on an intermediate scale (the scale of a century), some important reworkings may have interfered, for instance stepped beaches (sometimes in apparent concordance with lack of cementation, as can be seen at Kharab) or beach-rocks, in the same sedimentary stock, mainly according to hydrodynamism. Relative sea-level variations controlled by eustatism or tectonics also occurred, without altering the general scheme; the resultant uplift has mainly contributed to the preservation of the beaches or of the corrosional or constructional forms.

CONCLUSION

In low and not too resistant clayey limestone areas, the Syrian coast underwent an original Holocene evolution with an alternation of: heavy sedimentation (prograding beaches); erosion, receding coast and beach-rock formation; and, lastly, corrosion processes and vermetid bioconstruction, which finally affected a rather narrow sector (only ten to a hundred meters wide) on this coast where the tide range is very small. In fact, series of cycles alternated, each phase lasting about a millenium, but with quite a variable duration and intensity. On the Syrian coast, the eustasy and even the tectonics brought only small disturbances, but of course the resultant uplift favoured the preservation of the coastal deposits. Two main forces seem to have been at work: firstly, a climatically controlled alluvial discharge which determined the load and efficacy of the coastal drift; and secondly, hydrodynamic changes, of climatic or meteorological origin. It seems that this model operated during other periods of high sea level, notably during the Tyrrhenian period, as proved in Lebanon. Man probably interfered greatly during the second half of the Holocene. Nevertheless, this model proves that, however interesting, the complexity of the coastal evolution cannot be adequately accounted for by the study of rocky coasts alone.

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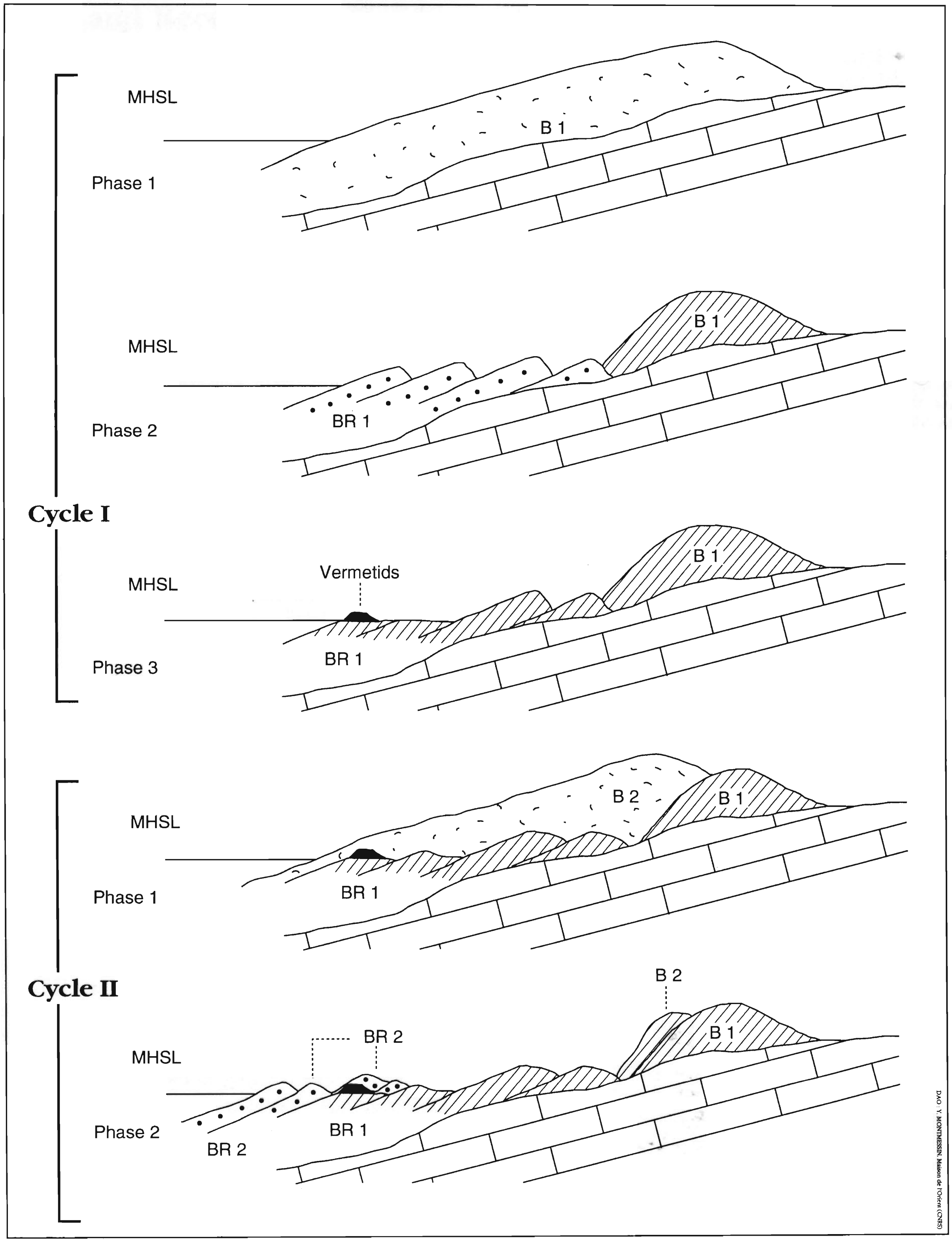

Figure 6. Model of the Holocene evolution of the Syrian coast. (B) Beach; (BR) beach-rock. Explanation in the text.

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