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Extracting wealth from a land of starvation by creating social complexity: A dialogue between archaeology and climate?

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Abstract

Arid areas are often considered as places where the emergence of complex societies and economies is unlikely to happen, due to the environmental restrictions they impose on land use, food production and settlement patterns. Archaeological data collected during 30 years in the Oman peninsula are used to analyze the relationship between human societies and climate change during the Early Bronze Age (3rd millennium BC/5th millennium BP). It is suggested that establishing a direct chronological correlation between indicators of climatic change and social evolution is unrewarding and a deterministic approach irrelevant. Societies perceive climatic change and react to it according to their representations of nature and to their history. Modeling social evolution in conjunction with environmental changes by using non-linear multi-agent models is a much more fruitful way to understand the relationship between Man and climate. ***To cite this article: S. Cleuziou, C. R. Geoscience 341 (2009).***

Résumé

La complexité sociale comme moyen de produire de la richesse dans une terre de pénurie : un dialogue entre archéologie et climat ? On considère souvent que l'émergence de sociétés et d'économies complexes est impossible dans les zones arides, du fait des restrictions qu'elles imposent à l'usage des terroirs, la production de nourriture et le type d'habitat. On utilise les données archéologiques recueillies dans la péninsule d'Oman depuis une trentaine d'années, pour analyser la relation entre sociétés humaines et changement climatique durant l'âge du Bronze ancien (3^{e} mill. av. J.-C./5^{e} mill. BP). La méthode qui consiste à rechercher selon une approche déterministe un synchronisme entre les indicateurs du changement climatique et l'évolution des sociétés est considérée comme peu pertinente et improductive. Les sociétés perçoivent le changement climatique et y réagissent selon leur histoire et les représentations qu'elles se font de la nature. La modélisation de l'évolution des sociétés en relation avec les changements de l'environnement à l'aide de modèles multi-agents non linéaires est proposée comme une méthode plus appropriée pour comprendre les relations entre Homme et climat. ***Pour citer cet article : S. Cleuziou, C. R. Geoscience 341 (2009).***

Keywords: Holocene; Bronze Age; Oman; Arabia; Climate; Modeling; Society

Mots clés : Holocène ; Âge du Bronze ; Oman ; Arabie ; Climat ; Modélisation ; Société

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The difference between Desert and Garden is not water: it's man (Tuareg proverb)

1. Introduction

Arid areas are often considered as places where the emergence of new types of societies and economies is unlikely to take place, due to the environmental restrictions they impose on land use, food production and settlement patterns. This has not always been the case, and aridification of climate was for long accepted as a factor in the development of food production. This is the scenario known as the *oasis theory* suggested in 1929 by Vere Gordon Childe, one of the most preeminent prehistorians of the 20th century, for the beginning of the Neolithic in the Near East. According to him, plants, animals and among them Man concentrated around the places where water was still available [7]. Men would have observed plants and animals and selected those that were easy to tame and/or domesticate. The theory was replaced by Braidwood's nuclear zones scenario according to which domestication of plants and animals occurred in areas where both resources were naturally abundant after the Last Ice Age. This led human societies to grow in size, settle less favorable areas by transferring wild plants and animals, protecting useful fields and herds and inducing genetic mutations and eventually selecting ''useful'' ones.

Desertification of vast areas that once could have been flourishing, such as the Sahara, then became a popular topic. Theories linking the collapse of the earliest complex societies to human action on soils appeared later and replaced older theories of barbarian invasions. Other paths of research were investigating socioeconomic causalities [46], until abrupt climate change emerged as a heated argument under the pressure of the fears bred by the growing concern for global warming at the end of the 2nd millennium of the Christian era. The collapse of the Akkadian empire in Mesopotamia interpreted by Weiss et al. [51] in coincidence with severe aridity in North Africa and western Asia became a common topic among specialists of climate change, the 4.2 kyr BP event, (among others: [17,18]), whose consequences were accepted as a firmly established fact of archaeological research despite the reserve of many archaeologists and assyriologists [10,26]. A mega ''historic-climatic'' event was later suggested by adding to Mesopotamia the end of the Egyptian old kingdom and of the Indus Valley civilization, the three great urban cultures of the second part of the 3rd millennium BC in the ancient World [49]. Rapid progress in climate studies but also growing threats about abrupt climatic change, and especially that induced by human action have made such studies among the most debated topics in recent archaeological literature [4,34,40,50].

2. Some questions about methodology

The methodology primarily consists in establishing synchronisms between historical and climatic data. An often hidden problem behind this approach is that timescales between historians and specialists of ancient climates, even those working on the Holocene, are rather different. The difference between the BP (before 1950 AD) of geosciences and the BC (before Christian era) of historians is a good example. This is even a burden when specialists of both disciplines write a paper together and is well-illustrated for instance by the 15 lines that Brooks [4,29] felt necessary to put in the introduction of his synthetic paper. Archaeological chronologies at the beginning of Middle East history, the second part of the Middle Holocene, are extremely debated and far from being fixed. They all rely, to some extent, on the *Ægyptiaca,* the thirty volumes about the chronology of Egyptian dynasties written in Greek by the Egyptian priest Manethon of Sebennytos (3rd century BC), constantly revised since the beginning of Egyptology according to new epigraphic data. It has been extended step by step towards Europe according to imports and typological similarities between archaeological items and to the Middle East, adding to the former historical events known from textual evidence, like the famous battle of Qadesh in Syria which opposed Ramesses II to the Hittite empire, at a date generally accepted as 1274 BC. This led in the Middle East to three different historical chronologies plus some more local ones, whose use is not always specified in archaeological literature. The low chronology for Palestine directly drawn from the Egyptian one was predominant until the 1950s against a high chronology that had a difference of almost two centuries. A general agreement for a middle chronology has been prevalent since the 1960s. Such chronologies are not at all constructed by radiocarbon, which was little used until 25 years ago, so that our dating of some most important periods in the Middle East is based on a handful of more or less reliable ^{14}C ages. Radiocarbon in Europe was reluctantly accepted by many archaeologists. It made most dates younger than those accepted by the traditional ''step by step from Egypt'' chronology drawn by Childe, until the use of calibrated dates made them older [41]. The same is true for the Middle East and radiocarbon is almost excluded from Egyptology. Only areas without written texts used to rely on a large number of ^{14}C ages, and matching together both areas is extremely difficult. Two centuries may be little at geological scale but seven or eight generations are a very long period in history, and the poor resolution of the historian's calendar is certainly a major obstacle to such a strategy.

Moreover, ancient and traditional societies react to climate change through various cultural filters. Each society has its own perception of these changes and its own way to react. Ethnography provides many examples of how societies perceive these changes and react to them [19,20]. It is also important to know that reactions occur at many levels in the same society and may differ considerably. Processions against the advance of glaciers were organized during the Little Ice Age in the Alps, dances or prayers for rain may have been performed, witches burnt. Political power may have promoted some different agricultural practices or cultivars, ordered the construction of hydraulic works, but one should not ignore the importance of decisions taken at various individual levels [48]. Human societies are highly complex machineries and simply matching the dates of climatic events and documented political changes is obviously bound to fail.

3. Adaptation of humans to environmental changes: Early Bronze age oases of inner Oman

In order to figure out what could be the best strategy to shift from guessing games to scientific demonstration, it may be of interest to briefly expose the results of a work carried out since 30 years in the Oman Peninsula (Fig. 1). The region was for long ignored by archaeologists, being considered as a place where, due to hyper arid conditions, no complex societies could have flourish in Antiquity. In 1958, a Danish archaeological team made the first excavations in the coastal island of Umm an-Nar near Abu Dhabi on the Persian Gulf coast, uncovering a 3rd millennium BC necropolis of collective burials and the associated settlement. The tombs contained rich items displaying affinities with the already (although poorly) known cultures of south-eastern Iran, from where some were obviously imported. This led Geoffrey Bibby, the expedition's director, to think that: "*Perhaps the site was populated by migrants from the Iranian side of the Gulf who left after a few generations without any contact with the people of the Interior, if there was anybody in the Interior*". Cultures of the interior of Oman were found two years later by the same expedition and the main explanation sought in climate: "*The community we were excavating was one which was geared to a*

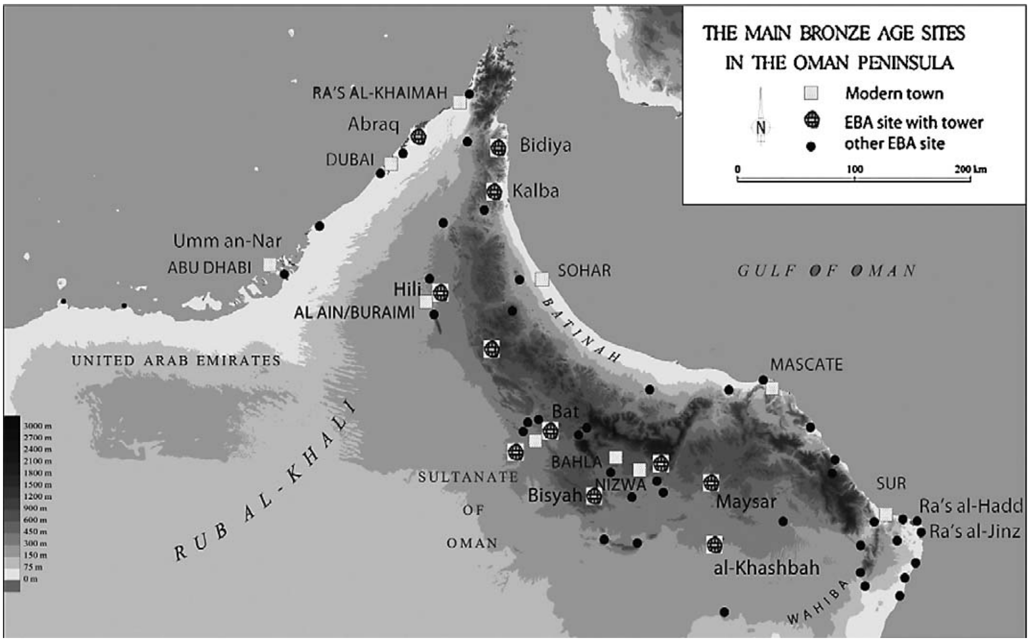

Fig. 1. Map of the Oman peninsula, with main Early Bronze Age sites.

Fig. 1. Carte de la péninsule d'Oman avec les principaux sites de l'Âge du Bronze.

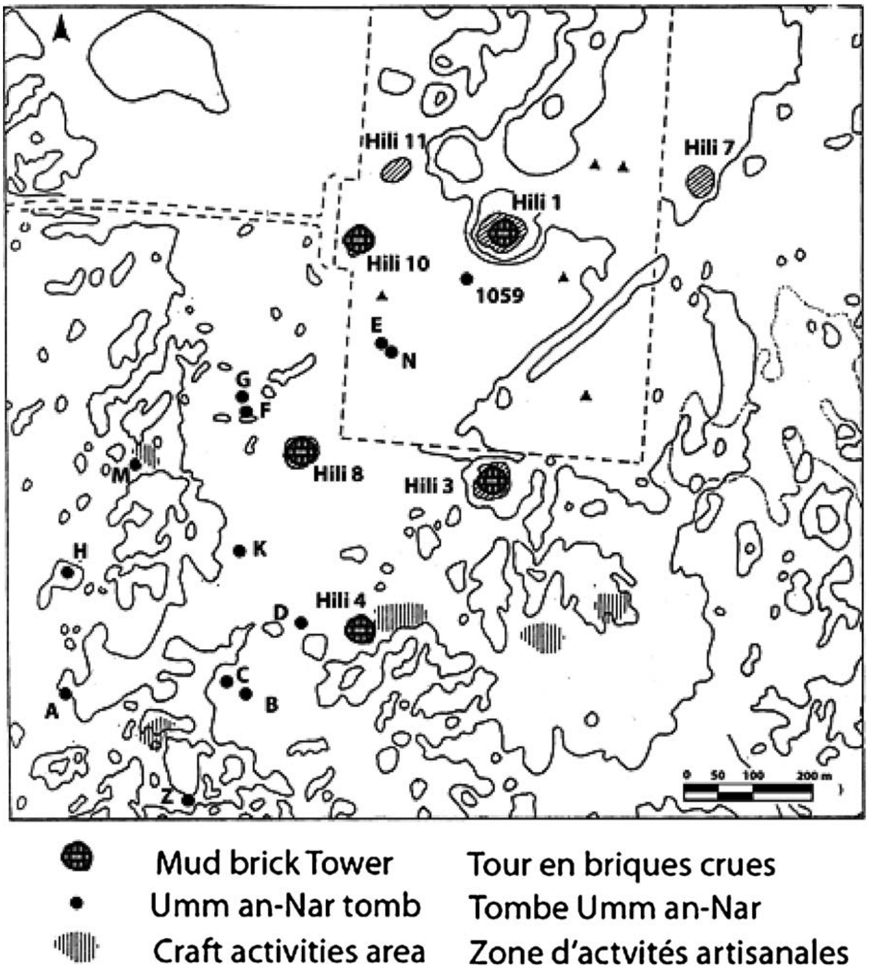

Fig. 2. General map of the Early Bronze Age site at Hili.

Fig. 2. Plan général du site de Hili à l'Âge du Bronze ancien.

different climate, in particular a greater rainfall that of the present day'' ([2]: p. 329).

Excavations were carried out yearly between 1977 and 1984 at Hili in the Emirate of Abu Dhabi, between the al-Khattam sand dunes, a northern extension of the Rub' al-Khali, and the al-Hajjar mountain range of Oman [8,9]. The site had already been explored by the Danish team [21,22] and was known to have been settled in the Early Bronze Age, during the 3rd BC/5th BP millennium. It consists of several large mud brick towers (at least 5) and of some 15 collective burials similar to those of Umm an-Nar, scattered on an area of ca. 30 hectares (Fig. 2). The modern landscape is a degraded wooden steppe (*Acacia tortilis*. and *Prosopis cineraria*) extending on some 4 km in width between the al-Khattam sand dunes and the first Jurassic limestone ridges of the Omani mountains, eastwards of the traditional oasis gardens of Hili. The Danish team had already excavated a megalithic collective burial (tomb 1059) dated around 2300 BC, contemporaneous with a large round mud brick tower (Hili 1). The area selected for excavations, Hili 8, is located 250 m southwest of it. The aims were to uncover a chronological sequence for the occupation of the site and to establish the subsistence economy and its possible evolution. Three superimposed mud brick towers and adjacent buildings were found, ranging between ca. 3000 and 2000 calBC. Two dates at 3320–2908 calBC (Mc 2266 and 2267) were obtained on burnt brushwood for the construction of the tower. These were the solid base of buildings ranging from 20 to 26 m in diameter and including a well in the centre (Fig. 3). The largest tower on the site, excavated around 1990 by the Department of Antiquities of al-Aïn is ca. 35 m in

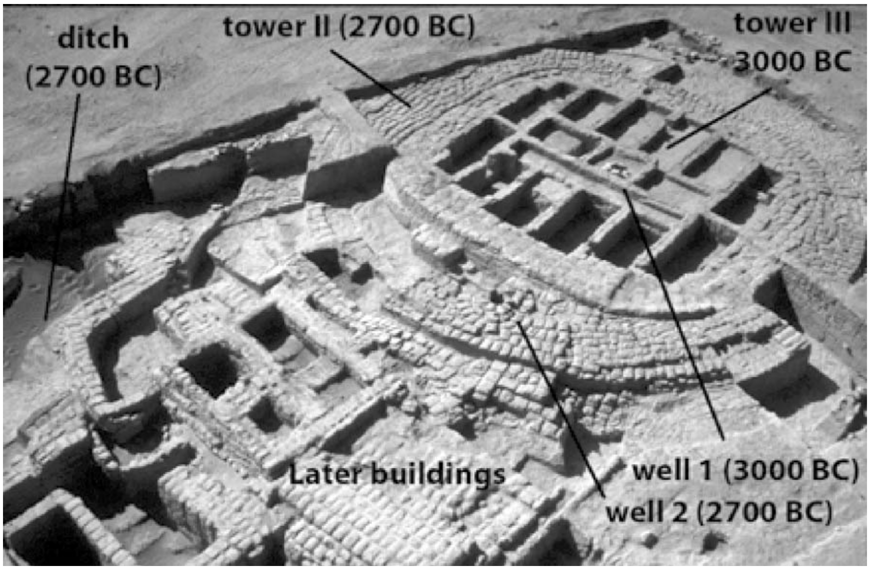

Fig. 3. Aerial view of site Hili 8, from the northeast.

Fig. 3. Vue aérienne du site de Hili 8, du nord-est.

diameter. Similar buildings made of mud bricks, stones or a combination of both, are known on other Early Bronze Age sites in the Peninsula such as al-Abraq, Bidiyah, Kalba, Bat, Bisyah and Maysar, to quote only excavated ones. The lowest part is a solid base and the height can be estimated to over 10 m, there is no entrance at ground level and it is supposed that the living quarters in the upper part could only be accessed by a door at some height in the wall. Tower 1545 at Bat was preserved on 7 m high, and this height was still that of the solid base, and no entrance system was found [23]. They are surrounded by a ditch that had at some time been filled with water, and are usually interpreted as forts or temporary refuge areas belonging to the high-ranking families of the community, who dwelled in smaller houses nearby. Archaeobotanical evidence indicates an oasis economy with palm trees, some fruits and legumes cultivated under their protecting shadow, and winter cereals grown in irrigated surrounding fields [15]. Cattle, sheep, goat and donkey were domesticated, cattle being the main source of animal proteins [47]. Rain fed agriculture is excluded whatever the precise climatic conditions around 3000 BC/5000 BP and the techniques of water procurement became a priority of research.

Two wells were found at the site, associated with the towers (Fig. 4). The earliest one was dug around 3000 BC when building the first tower, and abandoned after a few centuries, by 2700 BC at last. The second one may have been dug shortly after while building the second tower and remained in use for almost one millennium with the third tower and even later, until 1800 BC. The first well was 3.85 m deep below the surface of the plain at that time while the second one reached a depth of 8.5 m, showing evidence that it was deepened several times. A fall of the water table by 4.5 m in one millennium can therefore be hypothesized. The shallow depth of the water table around 3000 BC is confirmed by the presence all around the earliest tower of a narrow ditch, 2.5 m deep and 0.40 m wide at the bottom, which according to its filling can be considered as a drainage dish dug in the loamy silt of the substratum. It was quickly covered by adjacent constructions after less than a century of occupation. Later on, all the area east of the tower was dug down to ca. 80 cm, in order to reach a layer of ophiolite gravels in the soil, a huge work interpreted as a way of deepening the fields in order to facilitate watering. Eventually, by 2700/2600 BC, the second tower was built surrounded by a U shaped moat, 5 m wide and some 2 m deep. Excavations east of it have uncovered a sequence of four intersecting trenches (Fig. 5) that were driving water to the moat, usually through a small basin used for domestic or artisanal purposes. These ca. 40 cm wide trenches vary between 10–15 cm (T5) and 90 cm in depth (T7), with intermediate values at 30–35 cm (T4) and 35–40 cm (T8). Their sequence of use ranges from the shallowest to the deepest, suggesting that their catchment level had itself lowered of ca 80 cm within a two-century period according to the general stratigraphy. It has been

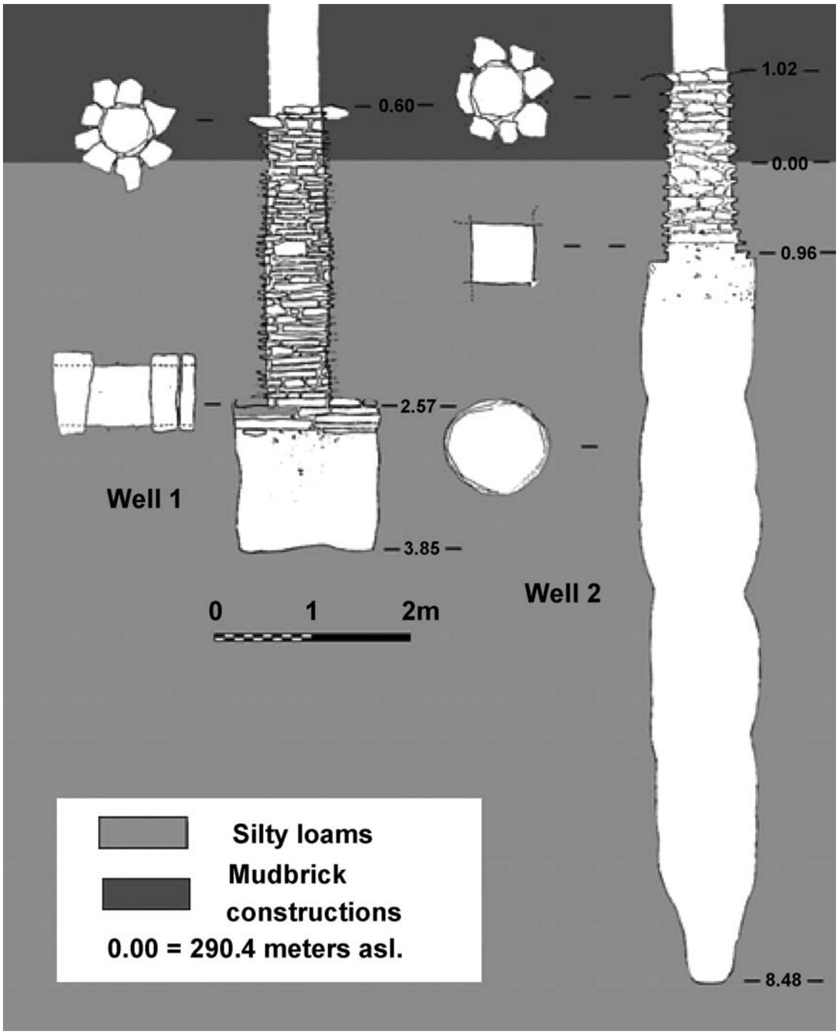

Fig. 4. Section through the wells of Hili 8. Note the successive deepenings of well 2.

Fig. 4. Section des puits de Hili 8. Noter les recreusements successifs du puits 2.

advocated elsewhere that these trenches were connected to a gravity irrigation system similar to the underground galleries tapering water in the aquifers of the temporary riverbeds (wāds) or at the foot of the mountains, known as *kārez* in Afghanistan, *Qanats* in Iran, *Falaj* in Oman or *Foghara* in the Saharan belt [11,13]. Such an early date for this system is still rejected by most historians and archaeologists but has been recently confirmed by stratigraphy and radiocarbon dating at Ghubrat Bahla in Oman ([36]: p.150) It may therefore be concluded that the Early Bronze Age communities of Oman were well-equipped to face aridity and drought starting from 3000 BC. Lowering the fields when the level of water catchment lowers for instance is still today common practice in Omani oases.

Excavations at Hili and other settlements such as Bat, Bisyah or Maysar indicate that this Early Bronze Age culture, which was formed rather quickly at the end of the 4th millennium BC, knew a continuous growth throughout the 3rd millennium BC and culminated during in its last centuries (2300–2000 BC). Its advent is also marked by a new type of graves. The dead that were before buried in the settlements [44] are now placed in tower-like monuments uncovering a funerary chamber with multiple burials, up to 30 in a single tomb ([43]: 70–71), located on crests and rocky ridges overlooking the newly established oases. These are later replaced by the multichambered graves of Umm an-Nar type, which could accommodate several hundred corpses and were the place of complex rituals and bone manipulations.

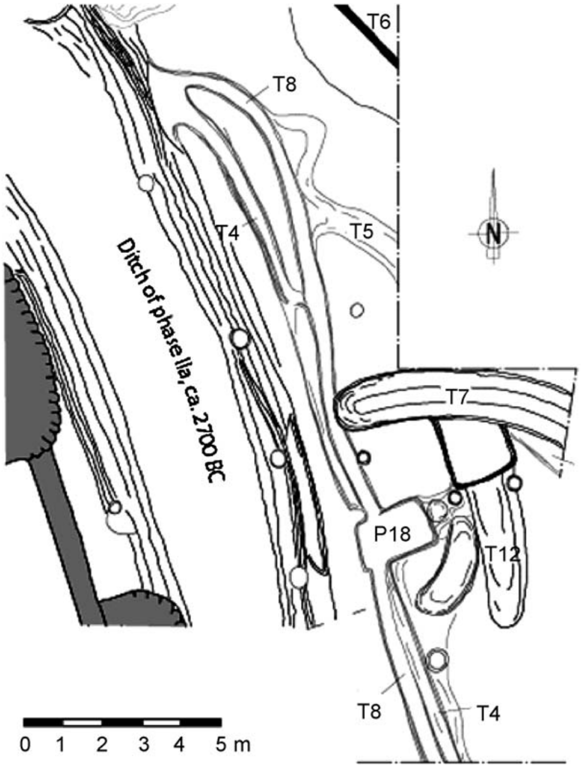

Fig. 5. Hili8, water channels east of the main ditch. T5 and T12 are the same channel. The three earlier ones cross a deeper rectangular basin before reaching the ditch. The last one, T7, brings water near the tower, but not anymore inside the ditch (ca. 2700–2500 BC).

Fig. 5. Hili 8, canaux à l'est du fossé principal. T5 et T12 sont le même canal. Les trois plus anciens traversent un bassin rectangulaire avant d'atteindre le fossé. Le dernier, T7, conduit l'eau près de la tour, mais plus dans le fossé (2700–2500 av. J.-C. environ).

They are again located near the settlements and become more and more monumental towards the end of the 3rd millennium. A striking aspect is that at a time when royal cemeteries such as Ur are known in Mesopotamia, all the more the pyramids of Egypt, there are no exceptional burials in Oman and everyone ends in these collective burials, enhancing community membership rather than personal status. In combination with what is known of settlements, this leads to hypothesize a kin based society where alliance between groups and families is more important than hierarchy, what is usually known as heterarchy or tribal system. Such a society is more flexible than the hierarchies that had developed at the same time in Mesopotamia and Egypt, and well-equipped to face periods of crises such as those created by the vagaries of a hyper arid climate [12].

Profound changes occurred rather abruptly around 2000 BC with a drastic culture change. Material culture became different, new types of graves appear both including single burials and still some collective burials with less sophisticated rituals. Most sites are abandoned or at least differently settled; leading most archaeologists to hypothesize a collapse followed by almost a millennium of ''dark ages''. Settlement patterns became different, less visible in archaeological data, and the possibility of a shift towards a more nomadic way of life is entertained. Some authors looked at economic causes such as a collapse of trade with India and Mesopotamia until abrupt climate change fell from the north as a result of the end of Akkadian empire supposedly caused by the 4.2 kyr BP event [51]. The latter was strengthened by deep-sea evidence of core M5-422 in the Gulf of Oman ([17,37]: 129).

4. Adaptation of humans to environmental changes: a regional study in eastern Oman

Since 1985, the joint Hadd Project under the direction of the author and Prof. Maurizio Tosi (University of Bologna) has been carrying out excavations and intensive surveys not far from there, in the eastern part of the Ja'alan, the easternmost region of the Sultanate of Oman. The study area encompasses some 3000 sq km. It is limited to the west by a north-south oriented limestone range reaching an altitude of 1200 m, the Jebel Khamis, to the north and to the east by the sea and to the south by the lowermost course of a large seasonal river, the Wād al-Batha, where large modern oases are found (Fig. 6). The northern part of this study is a large limestone terrace of Miocene age that was eroded by high sea levels during the Late Pleistocene some 120,000 years ago at ca. 30/40 m asl, that forms along the sea a continuous vertical cliff only cut by a few wād beds. At the hinge between the Gulf of Oman and the Arabian Sea, a mid-Holocene sandbar delimitates the lagoon of Ra's al-Hadd, while south of the terrace, the large lagoon of Khor al-Jaramah is in permanent communication with the sea through a deep canyon cut across the terrace. Southwards, the flat eastern coast presents a series of filled-in Holocene lagoons, while the interior consists of gravel terraces intersected by large shallow wād beds that still occasionally feed the lagoons. A mid-Holocene, north-south fault system lifted the eastern coast and the lagoons by a few meters, inducing significant changes at the junction of the wāds and the lagoons. Large mangrove swamps and reed belts populated the lagoons until the early 3rd millennium BC, but they appear to have been more open and brackish by the middle of the 3rd millennium BC [1,32].

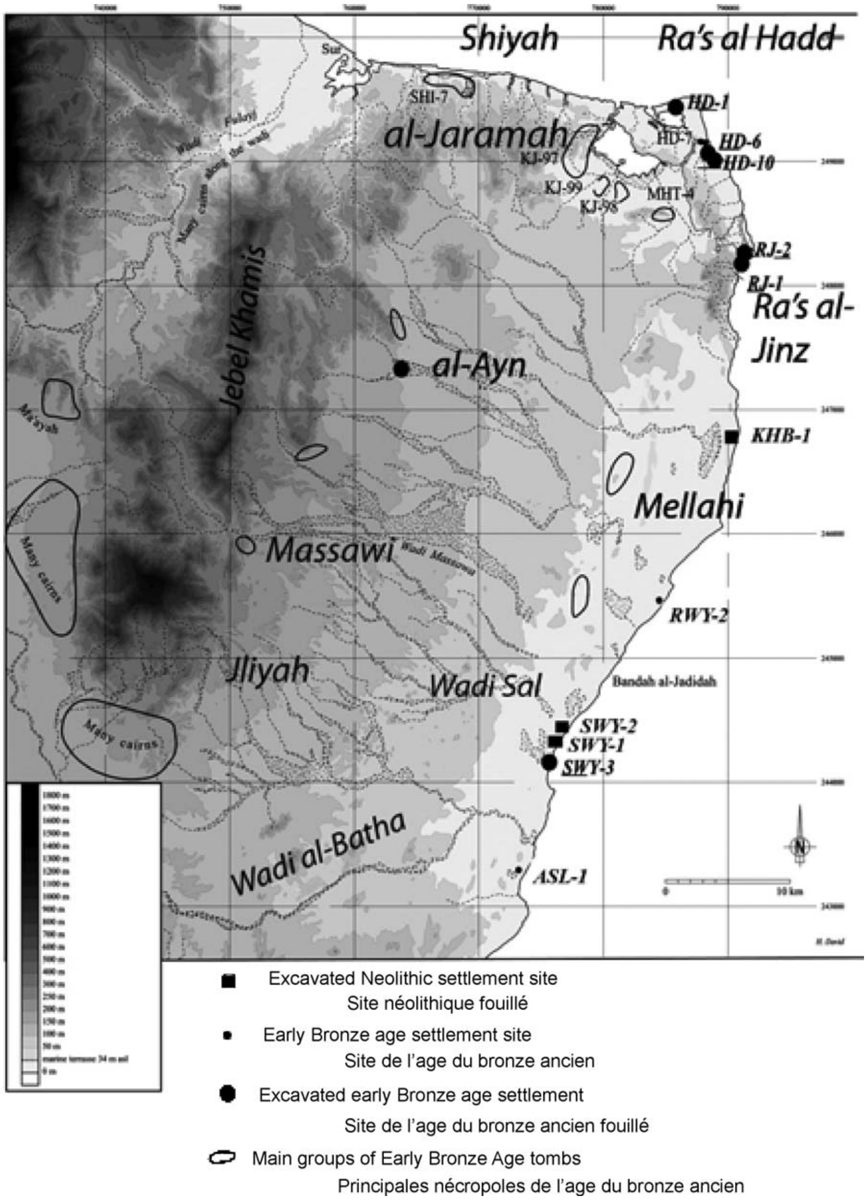

Fig. 6. Archaeological map of the Ja'alan, eastern Oman.

Fig. 6. Carte archéologique du Ja'alan, Oman oriental.

The eastern Ja'alan is a superb palimpsest of ancient settlements and graveyards, with particular emphasis on the mid-Holocene. Dozens of settlements of fishermen communities pinpoint the inner coasts of the lagoons and the sandbars, such as as-Suwayh SWY-1 and 2 or Ra's al-Khabbah KHB-1 to quote only excavated sites [5,6] while flint scatters are omnipresent in the interior. Over 3000 Early Bronze Age tombs have been located and plotted in a GIS and three major sites excavated: Ra's al-Hadd HD-6, dated ca. 3100–2600 BC (Azzara, forth.) (Fig. 9), Ra's al-Jinz RJ-2 dated ca. 2500–2000 BC [16] and Ra's al-Jinz RJ-1, which was in use until ca. 1750 BC during the Wād Sūq period [35] 25 years of work allow reconstructing the cultural evolution of the area and its environmental changes. The rapid shift to Early Bronze Age is well documented at Ra's al-Hadd HD-6 and the related cemeteries (HD-7, HD-10). Major sites also existed at Shiya and Ra's al-Jinz on the coast

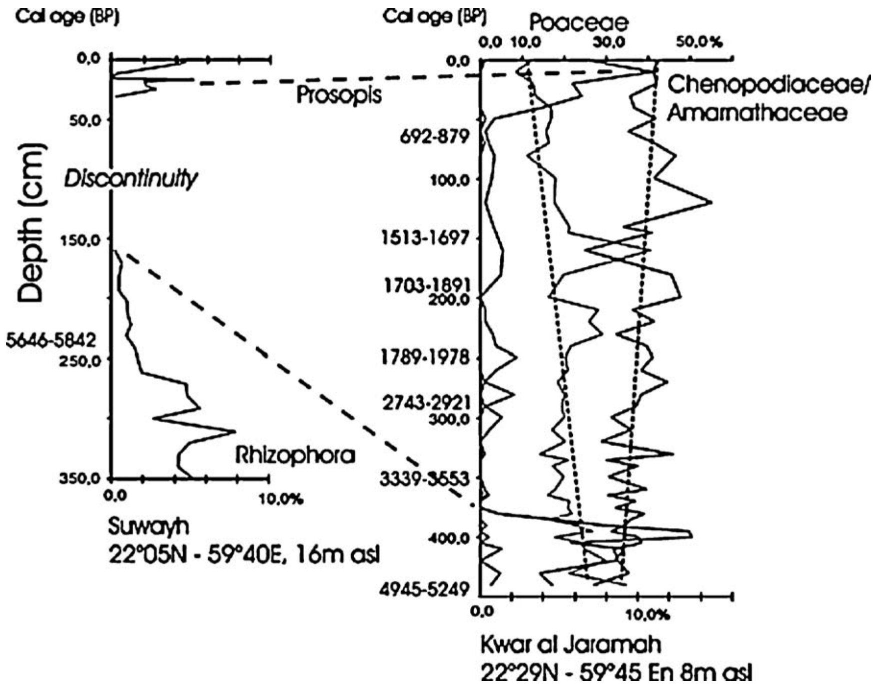

Fig. 7. Pollen diagrams in Suwayh and Khawr al- Jarama lagoons, Oman. It indicates the continuous fall of poacea and raise of Chenopodiaceae-Amaranthaceae, the fall and disappearance of *Rhizophora* sp. and the appearance and raise of *Prosopis cineraria*.

Fig. 7. Diagramme pollinique des lagunes de Suwayh et Khor al-Jarama, Oman, montrant la baisse des poacées et la montée des chénopodiacées-amaranthacées, la baisse et la disparition des *Rhizophora* sp. et l'apparition et la montée du *Prosopis cineraria*.

(Fig. 8), al-Jaramah, Mellahi and probably Wād Sa'l inside the lagoons, and smaller ones along the piedmont of the Jebel Khamis such as al-Ayn, Massawi or Jliyah. Most of these sites are not known but can be assumed by the distribution of Hafit type tombs, usually at the geographical gravity centre of the necropoles. Surveys and excavations at one of them, i.e. al-Ayn, have uncovered a type of settlement, made of several scattered houses and palm tree gardens, which was unknown until now [3], neglected by archaeologists as they are much smaller and less visible than oases with large towers. House ALA-2 yielded seashells from the coast and evidence of animal husbandry and date cultivation. Waiting for ^{14}C ages, it can be provisionally dated of the early 3rd millennium BC according to similarities between its flint industry and that of Ra's al-Hadd HD-6, but the presence of Umm an-Nar tombs nearby indicates that the site was settled during the whole 3rd millennium BC. This discovery is important for understanding settlement patterns in Oman during the Early Bronze Age. Small groups of Hafit type graves are known in remote valleys everywhere. They can now be considered as indicating small palm tree gardens usually not visible to archaeologists, tapering springs or wād gravels at some distance, which would have played a major role in the overall subsistence economy.

By the mid-3rd millennium, spatial analyses ([25], see also this volume) demonstrate a shift of settlement networks towards the interior (mainly al-Ayn and Jliyah) with the exception of Shiya and to a lesser extent Ra's al-Jinz. This may be interpreted as a result of lowering resources in the lagoonal areas due to penetration by seawater and ensuing filling by continental sediments ([1]: pp. 57–59). Palynological studies (Fig. 7) (Lézine, this volume) also indicate a continuous aridification of climate, with the disappearance of *Rhizophora* sp. in the mangroves, notably at Khor al-Jaramah, and advent of *Prosopis cineraria* in the steppe.

A large site appears around 2500 BC at Ra's al-Hadd that does not fit into this picture. Site HD-1 is located on the sandbar delimitating the tidal lagoon of Khor al-Hajjar which was as a major port of call in Medieval times and already during the second part of the 3rd millennium BC [39]. The site is however very different from all others e.g., (there are no tombs nearby), and may be excluded from speculations at local level, although it played an important role at regional and international one (Figs. 8 and 9).

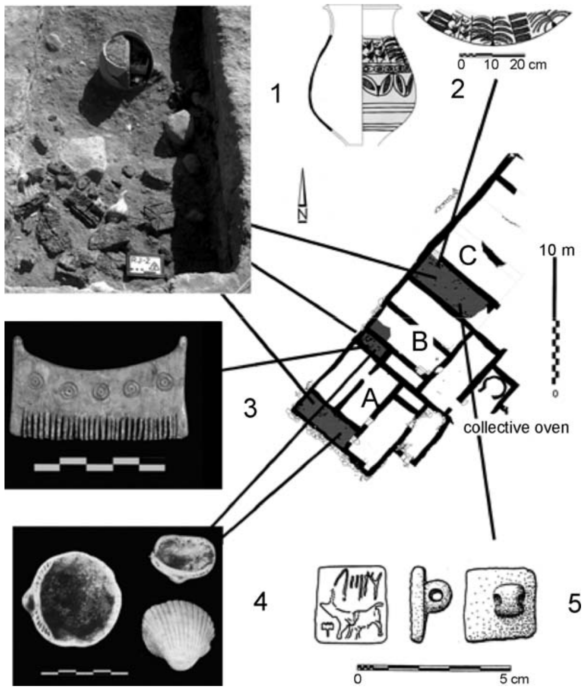

Fig. 8. Identification of agents at Ras'al-Jinz RJ-2 (ca. 2400–2300 BC). A, B and C are three residential units. Each of them has its own storage of bitumen for boat repairs (1) associated with imported material such as a painted jar (2) and a stamp seal from the Indus valley (5) in unit C, an Indian elephant ivory comb (3) in unit B or material for export: a mixture of pyrolusite and lime packed in valves of *Anadara* shells (4) or *Fasciolaria trapezium* shells (visible on 1) in units A and B.

Fig. 8. Identification des agents à Ra's al-Jinz RJ- 2 (vers 2400–2300 av. J.-C.). A, B et C sont trois unités résidentielles. Chacune a une provision de bitume pour la réparation des embarcations (1) associée à du matériel importé, une jarre peinte (2) et un cachet de la vallée de l'Indus (5) en C, un peigne en ivoire d'éléphant de l'Indus (3) en B ou du matériel prêt à être exporté: un mélange de pyrolusite et de chaux, conditionné dans des valises de coquilles d'*Anadara* (4) ou de *Fasciolaria trapezium* (visibles sur 1) en A et B.

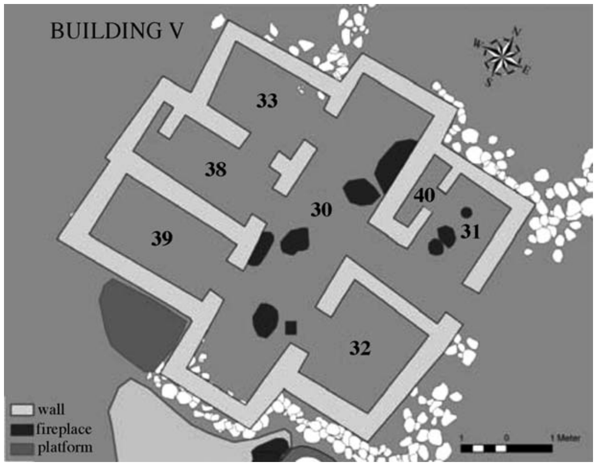

Fig. 9. Two living units at Ra's al-Hadd HD-6 (ca. 3000–2800 BC). The two buildings with multiple small rooms may correspond to units in Fig. 8. They may share the same domestic oven.

Fig. 9. Deux unités résidentielles à Ra's al-Hadd HD-6 (vers 3000–2800 av. J.-C.). Les deux bâtiments à multiples petites pièces peuvent correspondre aux unités de la Fig. 8. Ils partagent le même four domestique.

5. Discussion and conclusions

Interpretation of these data has to be related to various time and spatial scales, from local to global level. Two major cultural events are documented: the shift from coastal to inner environments by mid 3rd millennium BC and the apparent depopulation of the area by 2000 BC. The first one seems mainly due to the fact that lagoons on the eastern coast are less productive, being invaded by sea water and then filled, inducing a complete change in resources management. It enhanced the role of piedmontane oasis gardens, and that of exchanges with more specialized production (cured fish) on the coast, possibly also extending the network of exchanges with the al-Batha oases. Moreover, evidence from Ra's al-Hadd indicates a growing dependence on international trade for supply of basic food such as fat in the shape of clarified butter. Fat is essential in desert environments [45]. The coastal sites were probably producing it from fish, reptiles (turtles) and sea mammals (dolphins), but extra supply of land mammals fat in the shape of clarified butter (*ghee*) or cheese was probably also important, as indicated by the wide distribution all across Oman of a particular type of large jars made in the Indus [33] that are likely to have contained dairy products [27]. We also know from cuneiform textual sources that vegetal oil (sesame) was imported from Mesopotamia [28]. This induced more complexity in the social system, around the control of the products of trade and their circulation but also around its means of transport: building and equipping boats, organizing the crew and cargo, etc. The role of high ranking or rich families would have been enhanced, coming into conflict with the theoretical equality among members of a tribal society. Most social anthropologists will consider with interest the possibility that such factors caused the collapse of the system by 2000 BC [14], with no or little attention to climatic factors. By 4.5 kyr BP, the aridity with an absence of winter rains is already the same than by 4.2 kyr BP or by 4 kyr BP/2000 calBC when the region appears almost depopulated during the Wād Sūq period. We are simply at this stage facing competing explanations by competing schools of thought. Piling up arguments in favor of one or another approach is simply sterile and certainly against the aim of this conference.

Although a purely deterministic approach is clearly irrelevant, it would be unrealistic not to consider climatic change, both in short and long term, as an important factor in the development of human societies. At a time when models are used to integrate climatic data and to reconstruct environmental changes induced by climate change, it is proposed here to incorporate models of social change with the models used by geosciences in order to understand relations between human societies and climates. As a matter of fact, thoughts on the use of models or simulation in archaeology have been going on since they were developed by computer science [39,42]. However, proper modelling work remained restricted until the possibility became available to use powerful computing methods and adequate tools, such as Multi Agent Systems or Agent-Based Modeling [24,38]. Several attempts have already been made in that direction about various levels of social complexity in various places and at various timescales. These include the end of Anasazi communities of northern Arizona around 1200 AD [30], in which climatic factors have often been reckoned, or Bronze Age northern Mesopotamia [52], the place where the 4.2 kyr event was first advocated. Creating artificial societies through such methods is an attempt to approximate the complexity of human societies, giving each agent, who or whatever it is, some degree of freedom within a defined range. It allows testing the stability or instability of its response to change of given parameters, for instance environmental ones. Whoever looks at the state of the art will obviously consider that most of the work is ahead of us. Many archaeologists already complain about oversimplification of data involved by such attempts while it is likely that many geoscience specialists may be reluctant about the obvious high amount of hypotheses required by the use of such models in human and social sciences.

The way ahead is long. It necessitates creating and maintaining a comprehensive GIS database including archaeological and environmental data, and to run heuristically the model many times. The amount of potential parameters is high, including social, economical and environmental ones. The work done in the Ja'alan, although less advanced that the two experiments quoted above, can now rely on a large amount of data on settlements and land use, paleodemography, and of course environment. The study area was small and the society at an intermediate level of complexity between Anasazi and northern Mesopotamia. The timescale is long but is supposed to encompass a society which has experienced less social and political transformations than Mesopotamia. Additional problems are likely to be expected for instance in the way to account for mobility of population between various areas, well documented by archaeology and ethnography. It is known for instance that Ra's al-Jinz was only settled in winter, when fishing was possible during the winter monsoon [31].

A further and last question is how to relate this evolution to global change. Palynological evidence from Khor al-Jaramah clearly dates the disappearance of *Rhizophora* sp. from the mangroves at 4.5 kyr BP. This disappearance is obviously linked to increased aridity but does not indicate alone an abrupt change in rains at the same period. It simply means that aridity had reached such a level that the *Rhizophora* population could not maintain anymore. We have to draw the full implications of this event for the productivity of the mangroves in general, before incorporating it in our model of change in land use. On the other hand, if the 4.2 kyr BP abrupt event is not visible at present in the archaeological model, should we conclude that either it did not exist, or that the society's resilience was high enough to erase it from what is known of the archaeological record? Moreover, to what extent can this scenario be generalized to the Oman Peninsula as a whole? It has been since long argued that the Early Bronze Age society of Oman was a highly integrated aggregation of farmers, fishermen and nomadic herders. However, although all components of the aggregation are present, the Ja'alan site is only one instance of this combination and we reckon that several others have to be tested before reaching a more general model, such as a piedmontane region of interior Oman, a wād valley in the mountains, a segment of the coastal plain of the Gulf of Oman (the Batinah plain) and probably a coastal area of the Persian Gulf. Of course, the general design of the model can apply to both areas, but archaeologists have collected and processed a huge amount of data collection before reaching a general understanding. This probably means that answers to our questions about the relationships between man and climate in the recent past are quite far away in time and may not meet the expectations of the media. However, if archaeology using such research strategies is better able to take its part in the dialogue with geosciences, as proposed during this meeting, a giant step ahead would have been made.

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