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No indication of increased temperatures around 2200 BC in the south-west Mediterranean derived from oxygen isotope ratios in marine clams (*Glycymeris* sp.) from the El Argar settlement of Gatas, south-east Iberia

Martin Kölling, Vicente Lull, Rafael Micó, Cristina Rihuete Herrada, and Roberto Risch

Zusammenfassung

Keine Hinweise auf höhere Temperaturen im südwestlichen Mittelmeer um 2200 v. Chr. aufgrund von Sauerstoffisotopendaten von Meeresmuscheln (*Glycimeris* sp.) aus der El Argar-Siedlung Gatas, Südostspanien

Die Analyse einer Reihe von Muschelschalen der Gattung Glycymeris *unterschiedlichen Alters aus der gut datierten Fundstelle Gatas ergab* $\delta^{18}O$ *Isotopenverhältnisse, die eine allmähliche Abnahme der mittleren Oberflächenwassertemperaturen zwischen 2700 v. Chr. und 1200 v. Chr. anzeigt. Die Saisonalität der Oberflächenwassertemperaturen, die in den Isotopensignalen der Molluskenschalen erhalten sind, betrug 7,0 °C. Während die absoluten Temperaturen, die sich für diese Änderung ergeben, von der Qualität der Kalibrationsbeziehung zwischen Isotopendaten der Muschelschalen der Gattung* Glycymeris *und den Temperaturen abhängt, scheint das Signal selbst und seine relative Intensität robust zu sein. Proben von 2750 v. Chr. zeigen eine mittlere Temperatur über 19,0 °C, die zu den jüngsten Proben des Profils von 1200 v. Chr. graduell auf rezente Mitteltemperaturen um 17.5 °C abnehmen. Während wir Hinweise auf eine wärmere Phase vor 2500 v. Chr. und ein kühleres Holozän nach 1500 v. Chr. finden, zeigen die marinen Muscheln kein Temperaturmaximum um 2200 v. Chr., wie dies in hochauflösenden Proben aus dem North Greenland Ice Core Project (NGRIP) gezeigt werden konnte.*

Summary

Sampling a series of Glycymeris *species shells from an age transect in the well-dated Gatas excavation site, we found* $\delta^{18}O$ *isotope ratios that indicate a small gradual decrease in mean sea surface temperatures between 2700 BC and 1200 BC. The sea surface temperature seasonality recorded in the mollusk shells during this period was 7.0 °C. While the absolute temperatures are subject to the quality of the calibration used for converting* Glycymeris *species isotope data to temperatures, the signal itself and its relative magnitude seem to be robust. Samples from 2750 BC show mean temperatures above 19.0 °C decreasing to recent values around 17.5 °C in the youngest samples from the record at 1200 BC. While we find indications for a transition from a warmer phase before 2500 BC to a colder Holocene after 1500 BC, the marine clams do not show a temperature peak around 2200 BC as it was recorded in high-resolution samples from the North Greenland Ice Core Project (NGRIP).*

Introduction

The prehistoric settlement of Gatas (Fig. 1) is located 5.0 km from the Mediterranean coast, in the foothills of the Sierra Cabrera, on the southern edge of the Tertiary basin of Vera, Prov. Almería (south-east Spain). The hill on which the largest part of the settlement is located occupies an area of about 1.5 ha, and is naturally defended by vertical slopes on all but one side. It was discovered in 1886 by Louis and Henri Siret and excavated systematically between 1986 and 2001[1]. A stratigraphic sequence of settlement structures and deposits, including burials, confirms a practically continuous occupation of the hilltop site between c. 2900 cal BC and 1000 cal BC. With more than 70 radiocarbon dates, Gatas presents probably the most firmly dated archaeological sequence in the western Mediterranean. The interdisciplinary research conducted on the site has been crucial to the understanding of the environmental, economic and social changes occurring in the most arid region of Europe during the Copper and the Bronze Ages.

Dog cockle shells (*Glycymeris* sp.) were found throughout the archaeological sequence and must have been collected at the nearby coast, where they are still found today (Fig. 2).

Material and methods

Eight specimens of dog cockles from acceleration mass spectrometer (AMS) and archaeologically dated layers, and several recent dog cockle samples were micro-sampled for stable oxygen isotope analysis. It is important to note that for each chrono-stratigraphic phase, whenever possible, at least two

1 Castro et al. 1999; Castro et al. 1999a; Castro et al. 1999b; Castro et al. 2000.

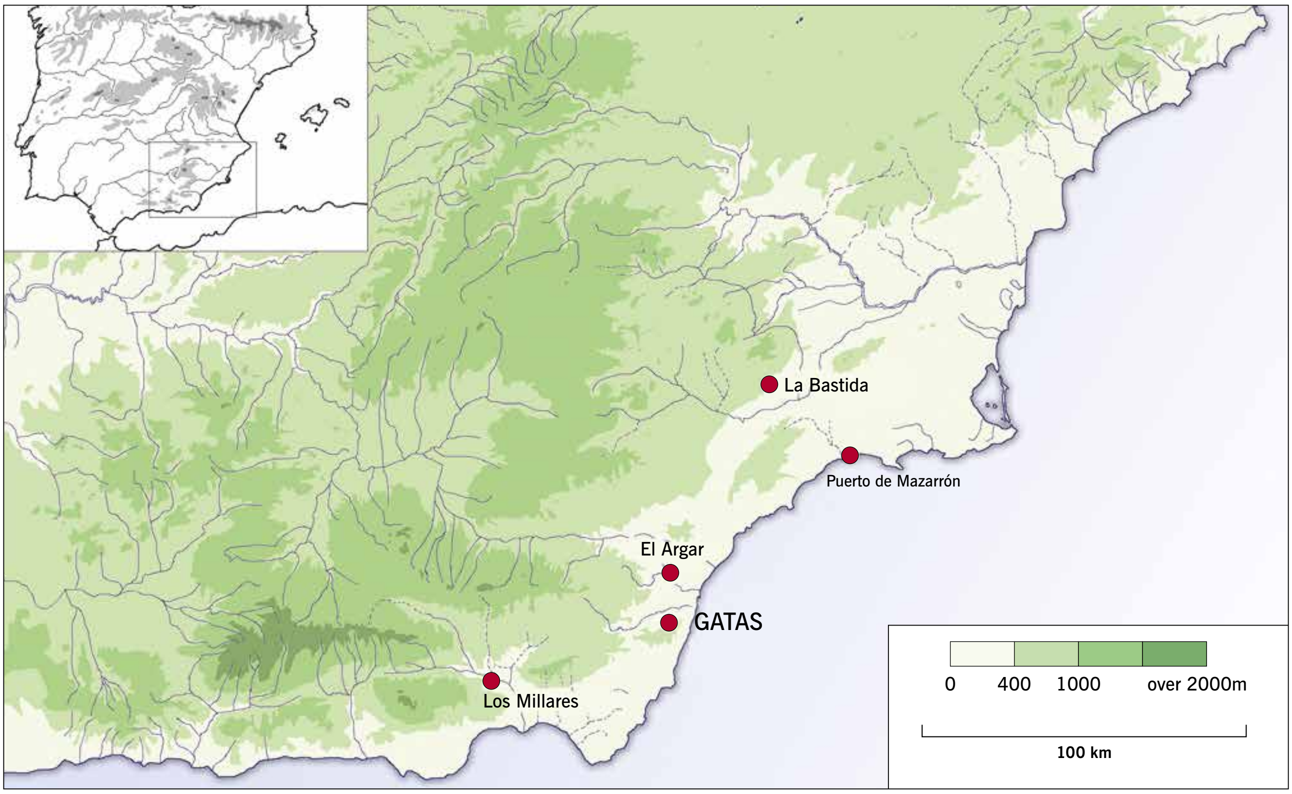

Fig. 1 Location of the Gatas settlement, Prov. Almería (Spain), 5.0 km from the recent coast of south-east Spain.

Abb. 1 *Lage der Siedlung Gatas, Provinz Almería (Spanien), 5.0 km von der heutigen Südostküste Spaniens entfernt.*

shells were selected from different archaeological contexts and dwellings (Appendix 1). Consequently, it is highly unlikely that shells representing the same phase were collected by prehistoric populations on the same spot and at the same time. Instead they are most likely to have come from different coastal areas and to belong to slightly different moments within each archaeological phase.

The clam samples were split in half perpendicularly to the growth axis. One half was fixed to a glass slide using two-part epoxy adhesive. After the glue hardened, the clam was cut again to leave an approximately 2.0 mm slice on the glass support. The slice was polished and briefly cleaned using pure water. Scanned images of the cut surface were taken for reference. The sample was fixed vertically and mm scale sampling was performed using a dentist's drill. Weighing paper was used to guide the carbonate powder directly into 1.0 mL conical sample tubes. Approximately 0.2 mg of sample was used to perform stable carbon and oxygen iso-

Fig. 2 View from the Gatas site, Prov. Almería, (Spain), towards the Mediterranean in the north-east.

Abb. 2 *Blick von der Fundstelle Gatas, Provinz Almería (Spanien), in Richtung Mittelmeer im Nordosten.*

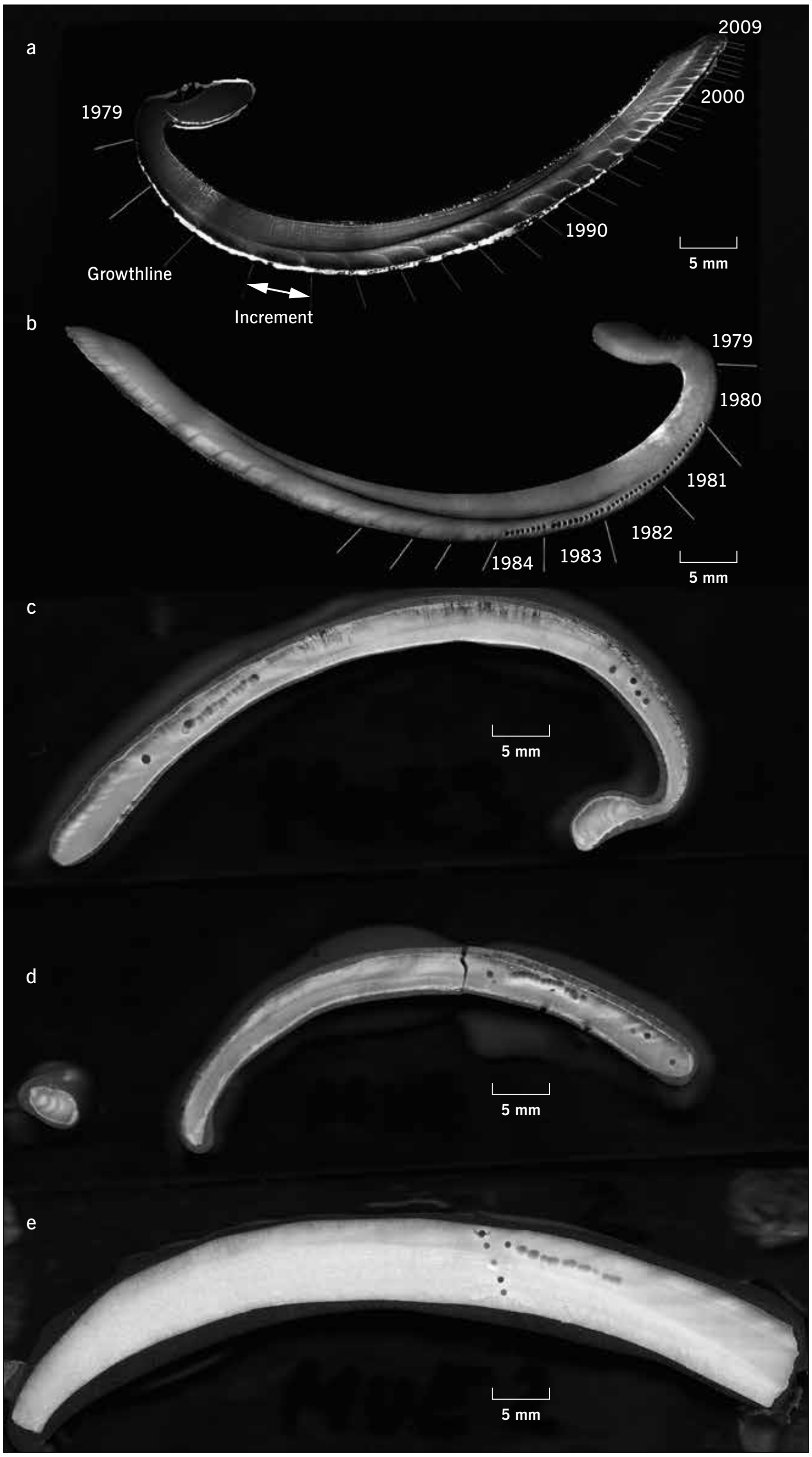

Fig. 3a–e Sections of a *Glycymeris* sp. clam with annual growth structures. *Glycymeris* sp. shells show annual growth structures similar to tree rings: a X-ray of clam sample showing internal growth structures by density bands (in the x-ray: bright = higher density, slow growth, spring/autumn layer; dark = lower density, faster growth, summer layer). The clams show expanded banding in the outer shell which is accessible to mechanical sampling by drills. The inner shell and the hinge show a much more condensed annual banding, which can only be sampled by laser. b B/W positive picture of clam section with sampling holes in the outer, annually banded part of the shell. Due to the internal growth structures of the clams, the recorded temperatures might differ by several degrees centigrade in different structural parts of the clam. For this study, sample series including at least one annual cycle from the outer shell have been used, in order to obtain comparable temperatures. c–e Fossil clam sections from the Gatas sequence; holes from sampling with a 0.8 mm dentist drill: c sample MUE–3 ; d sample MUE–1 with separate hinge; e sample MUE–2 with hinge and lip missing.

***Abb. 3a–e** Querschnitt einer* Glycymerismuschel *mit jährlichen Wachstumsstrukturen.* Glycymerisschalen *weisen jährliche Wachstumsstrukturen auf, die sich mit Jahresringen an Bäumen vergleichen lassen: a Röntgenaufnahme einer Muschelprobe mit internen Wachstumsstrukturen, die sich an unterschiedlich dichten Bändern ablesen lassen (helle Stellen im Röntgenbild entsprechen einer höheren Dichte bzw. einem langsamen Wachstum im Frühjahr oder Herbst; dunkle Stellen zeigen eine niedrige Dichte bzw. ein schnelleres Wachstum in den Sommermonaten an). In der äußeren Schicht der Schale, die sich für eine mechanische Beprobung mit Bohrern eignet, weisen die Schalen erweiterte Bänder auf, während sich die innere Schicht der Schale sowie das Muschelschloss durch eine sehr viel dichtere Bänderung auszeichnen, die nur mittels Laser beprobt werden kann. b Schwarz-Weiß-Aufnahme des Muschelquerschnitts mit Bohrlöchern der Beprobung im äußeren Teil der Schale mit Jahresringen. Aufgrund der internen Wachstumsstruktur können die gemessenen Temperaturen in verschiedenen Bereichen der Muscheln um mehrere Grad Celsius voneinander abweichen. Um vergleichbare Temperaturwerte zu erhalten, wurden in der vorliegenden Untersuchung Probenserien aus den äußeren Schalenteilen verwendet, die mindestens einen vollständigen Jahreszyklus umfassen. c–e Querschnitt durch fossile Muschelschalen von der Fundstelle Gatas. Die Löcher stammen von Probensequenzen, die mit einem 0.8 mm Zahnarztbohrer gewonnen wurden: c Probe MUE–3; d Probe MUE–1 mit abgebrochenem Schloss; e Probe MUE–2 mit fehlendem Schloss und fehlender Lippe.*

tope measurements at the Marum (Center for Marine Environmental Studies, Bremen) on a Finnigan MAT 252 mass spectrometer. Data were calibrated against Standard 19 of the US National Bureau of Standards (NBS), via a house standard. The results are reported in per mil versus Vienna Pee Dee belemnite (VPDB).

Dog cockles grow mainly in three directions. Both at the hinge and on the inside of the shell, the shell thickness increases with age, growth being expressed in finely laminated sub-mm growth structures (Fig. 3). At the lip, the shell diameter increases by quasi-radial growth, with an annual growth band thickness in the range of several mm per year. All three growth-directions provide tree-ring-like structures that record some of the habitat water characteristics (Schöne 2003). The most precise and comparable samples are taken from corresponding parts of the radial bands in the outer part of the shell, avoiding weathered parts at the surface. Dog cockles typically show 20 to 30 years' worth of annual growth structures. The best resolution (strongest annual growth) for sampling is found between five and fifteen years.

Sample series including at least one annual cycle were taken from the outer annual banding of the shells in order to obtain comparable temperature signals. The stable oxygen isotope ratio of the water was estimated from salinity levels according to L. Chauvaud et al. (2005):

$\delta^{18}O_{water\ SMOW} = 0.164\ S - 5.38$
with S – salinity in psu

Stable oxygen isotope ratio measurements have been converted to temperatures using the following calibration, found in C. Royer et al. (2013).

$$T\ (^{\circ}C) = 18.11 - 2.66\ (\delta^{18}O_{aragonite\ VPDB} - \delta^{18}O_{water\ SMOW})$$

$\delta^{18}O_{aragonite\ VPDB}$	oxygen isotope ratio of aragonite against VPDB
$\delta^{18}O_{water\ SMOW}$	oxygen isotope ratio of water against Standard Mean Ocean Water (SMON)

This calibration was established for *Glycymeris* sp. in Brittany in a temperature range of between 15.0 °C and 19.0 °C (Royer et al. 2013). Until there is a detailed calibration for *Glycymeris* sp. in south-east Spain, this is the best available for our purposes, preferable to more general biogenic aragonite calibrations covering a larger temperature range.

Results

All of the recent and most of the fossil clams show $\delta^{18}O$ ratios of between -1.0 ‰ and +2.0 ‰ corresponding to summer temperatures around 22.0 °C and temperatures above 15.0 °C at the beginning and end of the growth season (Fig. 4d). The samples from layers dated around 2325 ± 75 cal BC[2] and 2175 ± 75 cal BC[3] (MUE2, MUE1 and MUE4) show isotope ratios in the same range. While the seasonality seems to be reduced during this period, this might be an artefact of a smaller number of annual cycles that have been analysed. Systematic signals in the clam isotope data point to higher mean temperatures (around 19.0 °C) prior to 2000 cal BC and mean temperatures reaching recent levels of around 17.5 °C by 1200 BC. The samples MUE6, MUE7 and MUE8 show short snapshots of multiannual temperature records directly after the 2200 BC event (2025 ± 75 cal BC) that are similar to temperatures directly before (MUE1 and MUE4) and during or very close to the event (MUE2).

The absolute chronology is based on absolute radiocarbon dates, combined with sequence stratigraphy and pottery typology. Gatas Ia corresponds to the Early Copper Age, Gatas Ib to the late Bell Beaker period and Gatas II represents the first El Argar horizon. However, the settlement was abandoned for about 250 years between Gatas Ia and Ib.

Discussion

There is no indication for an abrupt salinity decrease in the western Mediterranean around 2200 BC. Reconstructed values from core MD99–2346 from the Alboran Sea are approximately 36.5 psu, close to modern salinity (Melki et al. 2009). Until better resolution salinity reconstructions from the area become available, we conclude that stable oxygen isotope signals in western Mediterranean surface waters are mostly temperature-driven.

While the absolute temperatures calculated for this period are subject to the quality of the calibration used for converting *Glycymeris* sp. isotope data to temperatures, the signal itself and its approximate magnitude seem to be robust. In the absence, to date, of a specific calibration for western Mediterranean *Glycymeris* sp., we have used a calibration that was constructed in the Atlantic from *Glycymeris* sp. caught offshore in Brittany (Royer et al. 2013).

Around 2200 BC several authors report indications for cold events in the North Atlantic (Bond et al. 1997) and in the subtropical Atlantic (deMenocal et al. 2000). There are indications of droughts and volcanic-eruption-induced climate change in the Middle East (Fig. 4b; Weiss et al. 1993; deMenocal 2001; Arz et al. 2006). At the same time, western Mediterranean pollen records indicate an increased influence of warm dry air masses from Africa (Magri/Parra 2002). F. Navarro-Hervás et al. (2014) report on an evaporite bed in the lagoon of Puerto de Mazarrón, Murcia, only 60.0 km north-east of our sampling site in Gatas. The age of the upper, 1.0 m thick, halite bed is constrained by dates between 2833–2497 cal BC and 2565–2348 cal BC (1 σ). As these dates were obtained from re-deposited charcoal trapped in the erosive clay sediments, they only mark the *terminus post quem* of a localised salt precipitation process. Out of 20 cores recovered from the coastal area of Puerto de Mazzarón, only core no. 17 drilled through two halite beds. According to the geomorphological study of the beach-ridge progradation complex in Campo de Dalías, Prov. Almería, the transition between units H2 and H3 dates to around 2200 BC and corresponds to increased erosion, a lower sea level and reduced sediment input to the coast (Goy et al. 2003). It is suggested that such boundaries between beach-ridge formations are linked to periods of marked aridity. Similar to our clam record, recent high-resolution records from the Alboran Sea (Rodrigo-Gámiz et al. 2014) do not show any clear indications of sea surface temperature (SST) anomalies in the western Mediterranean at this time period.

Moving beyond the western Mediterranean, V. Gkinis et al. (2014) have recently published a high-resolution temperature reconstruction from a North Greenland ice core, which reveals a significant positive temperature perturbation between 2500 BC and 1900 BC. Due to its short duration, this perturbation is more pronounced when the base

2 MAMS–21375: 3837 ± 28 BP, charred seeds. Several measurements of the same faunal sample provided by the Kiel laboratory (KIA34457) scatter between 3765 ± 23 BP and 3627 ± 32 BP, but are repeated at the moment by the laboratory.

3 OxA–10994: 3765 ± 38 BP, human remains. Shell samples are earlier than OxA–4961: 3690 ± 65 BP, human remains. Several measurements of the same faunal sample provided by the Kiel laboratory (KIA34458) scatter between 3860 ± 27 BP and 3730 ± 28 BP, but are repeated at the moment by the laboratory.

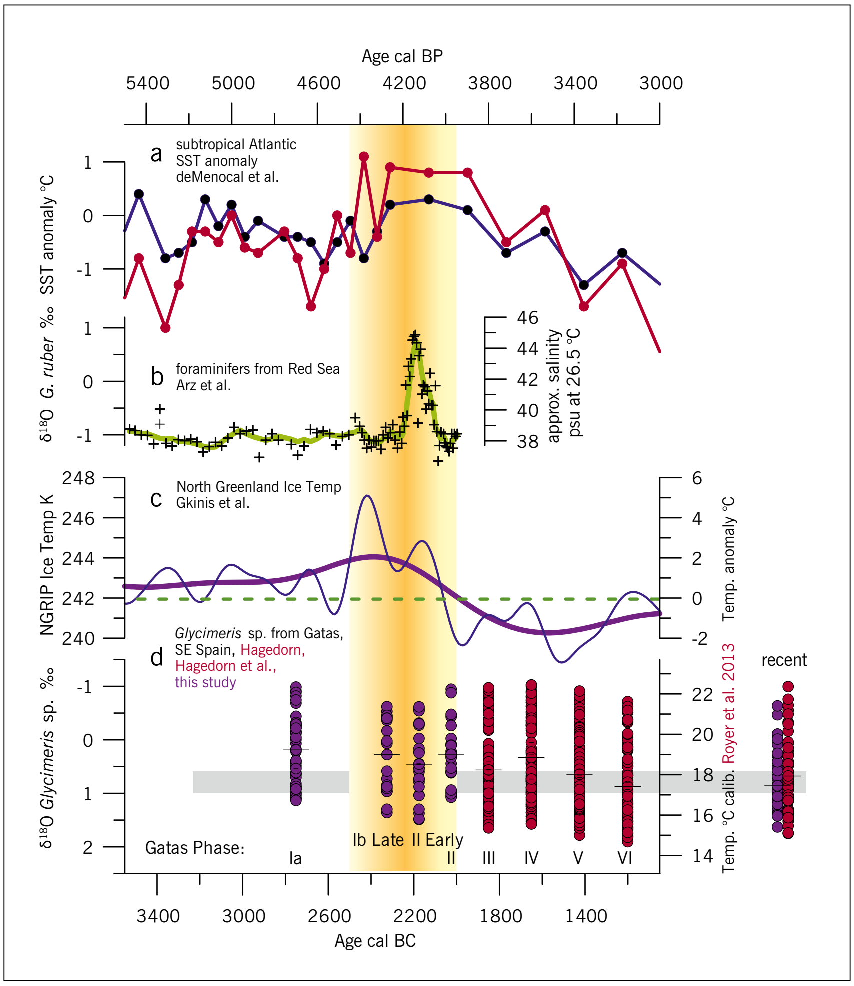

Fig. 4a–d a Subtropical Atlantic sea surface temperature (SST) anomaly reconstructed from core 658C: warm SST anomaly (red) and cold SST anomaly (blue). Note the warm anomaly between 2400 BC and 1800 BC. b Stable oxygen isotope ratios measured in foraminifers (*Globigerinoides* ruber) from a marine core in the Shaban Deep (Northern Red Sea). Independent water temperature proxies indicate stable estimates around 26.5 °C, so the steep isotope excursion around 2200 BC (4.2 ka cal BP) is attributed to a significant salinity increase of several psu. c Time series of ice temperatures in the North Greenland Ice Core (NGRIP) reconstructed from temperature-dependent isotope diffusion. 200-year running average (blue) and 1000-year running average (purple) of original data. The high resolution NGRIP record shows a significant warm anomaly between 2500 BC and 1900 BC. d Stable oxygen isotope ratios measured in marine clams (*Glycymeris* sp.) from acceleration mass spectrometer (AMS)-dated layers in the Gatas settlement. Independent estimates of salinity at this time indicate stable salinities around 36.5 ‰, so the isotope ratio change is attributed to a habitat water mass temperature change during the growth period (approximately from March to September). Recent isotope data are from clam samples collected at the beach close to Gatas. Note that the isotope scale is inverted (low oxygen isotope ratio = higher temperatures and/or lower salinity). The horizontal black bars show the mean of all measurements from one time interval; the grey bar is for orientation.

***Abb. 4a–d** a Rekonstruktionen der Anomalie der Oberflächentemperaturen im subtropischen Atlantik im Bohrkern 658C: warme Temperaturanomalie (rot) und kalte Temperaturanomalie (blau). Zwischen 2400 v. Chr. und 1800 v. Chr. zeigt sich ein Temperaturoptimum. b Stabile Sauerstoffisotopenwerte gemessen an Foraminiferen (Globigerinoides ruber) in einem marinen Bohrkern aus dem Shaban-Tief (nördliches Rotes Meer). Unabhängige Wassertemperaturproxies weisen auf stabile Schätzwerte um 26,5 °C hin, sodass das Maximum in den Sauerstoffisotopenverhältnissen um 2200 v. Chr. (4.2 ka cal BP) auf einen starken Anstieg der Salinität von mehreren PSU zurückgeführt werden kann. c Zeitreihe der Eistemperaturen im North Greenland Ice Core (NGRIP), rekonstruiert aufgrund der temperaturabhängigen Isotopendiffusion. Gleitender Mittelwert: Mittelung der Originaldaten über 200 Jahre (blau), Mittelung über 1000 Jahre (violett). Die hochauflösenden Daten des NGRIP Eiskerns zeigen eine signifikante warme Anomalie zwischen 2500 v. Chr. und 1900 v. Chr. d Stabile Sauerstoffisotopenverhältnisse von marinen Muscheln (*Glycymeris *sp.) aus mit dem Beschleuniger-Massenspektrometer datierten Schichten in der Siedlung Gatas. Unabhängige Schätzungen der Salinität in dieser Periode weisen auf stabile Salinitätswerte um 36,5 ‰ hin, sodass die Änderung in den Isotopenverhältnissen einer Änderung der Wassertemperatur im jeweiligen Lebensraum während einer Wachstumsphase (ungefähr März bis September) zugeschrieben werden kann. Die rezenten Isotopenwerte stammen von Muschelproben, die am Strand in der Nähe von Gatas gesammelt wurden. Man beachte die umgekehrte Isotopenskala (niedrige Sauerstoffisotopenwerte = höhere Temperaturen und/oder geringere Salinität). Die horizontalen schwarzen Balken zeigen die Mittelwerte aller Messungen aus einer Zeitstufe; der graue Balken dient zur Orientierung.*

data are smoothed with a 200 year filter (Fig. 4c) The temperature peak separates the Holocene into a warmer phase, lasting until 2500 BC, and a slightly colder phase after 1900 BC. Interestingly, the maximum 600-year transition phase is expressed as a temperature optimum in the NGRIP record (Gkinis et al. 2014), as opposed to the 6200 BC (8.2 ka cal BP) event (Bond et al. 1997), which is expressed as a cold spell (not shown in Fig. 4), as in other records. Like the latest NGRIP reconstruction from Gkinis et al. (2014), the temperature reconstructions from the subtropical Atlantic (deMenocal et al. 2000) actually show a significant warming accompanied by a greater seasonality between 2500 BC and 1800 BC (Fig. 4a) although in their paper, P. B. deMenocal et al. (2000) only mention a short cooling phase centred around 2600 BC. The reason for a 2200 BC (4.2 ka cal BP) event only having been discovered, until recently, in a few records, is probably its short duration, which in most cases is not resolved with the normal sampling frequency (e. g. in Cacho et al. 2001). At least in the case of the *Glycymeris* sp. shells from the stratified settlement of Gatas, oxygen isotope ratios now provide evidence for sea surface temperatures changing gradually from above 19.0 °C before 2200 BC to 18.5 °C around 2200 BC, and further decreasing to 17.5 °C around 1200 BC without a maximum in mean SSTs around 2200 BC. Different pollen profiles from the nearby inland mountain ranges of Gádor, Prov. Almería, and Segura, Prov. Gipuzkoa (Carrión et al. 2003; Carrión et al. 2004), as well as from the coastal plains of Almería (Pantaleón-Cano et al. 2003), show a more or less rapid substitution of oak (*Quercus* sp.) forests, deciduous in the mountains and evergreen in the coastal cores, by pine (*pinus pinea* L.) trees, and an increase in xerophytic vegetation such as wormwood (*Artemisia* sp.) and goosefoot (*Chenopodia* sp.). The timing of this vegetation transition is best constrained by J. S. Carrión et al. (2004) to around 2600 BC. In Carrión et al. (2003) the age model is based on only a few radiocarbon dates, but there is one data point right at the transition, indicating a period around 2000 BC. Hopefully new proxy data will allow us, in future, to complete the picture of the climatic situation of the western Mediterranean around 2200 BC, which is now starting to emerge. The new isotope data from the well-dated archaeological sequence in Gatas show that a possible prominent climate disturbance around 2200 BC is not expressed in temperature.

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Source of figures

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Appendix

Sample	Context	Phase	Age cal BC	± Age	$\delta^{18}O$ VPDB	T °C	Source
MUE 3	G01–MS19–15A1	Gatas Ia	2750	125	-0.115	20.0	authors
MUE 5	G01–MS04–15A1	Gatas Ia	2750	125	0.535	18.3	authors
MUE 3, 5	mean	Gatas Ia	2750	125	0.186	19.2	authors
MUE 2	G01–MS19–17A2	Gatas Ib Late	2325	75	0.273	19.0	authors
MUE 1	G01–MS19–7A3	Gatas II Early	2175	75	0.456	18.5	authors
MUE 4	G01–MS04–13A1	Gatas II Early	2175	75	0.443	18.5	authors
	mean	Gatas II Early	2175	75	0.453	18.5	authors
MUE 6,7,8	G95–ZC–115A1 G95–ZC–214A1	Gatas II	2025	75	0.268	19.0	authors
G/S3/H101	G/S3/12A2	Gatas III	1850	100	0.551	18.3	Hagedorn 1994; Hagedorn et al. 1999
G/S3/H94	G/S3/12A1	Gatas III	1850	100	0.650	18.0	Hagedorn 1994; Hagedorn et al. 1999
G/S3/H96	G/S3/12A2	Gatas III	1850	100	0.409	18.6	Hagedorn 1994; Hagedorn et al. 1999
	mean	Gatas III	1850	100	0.560	18.2	Hagedorn 1994; Hagedorn et al. 1999
G/S3/H61	G/S3/6A1	Gatas IV	1650	100	0.265	19.0	Hagedorn 1994; Hagedorn et al. 1999
G/S3/H97	G/S3/11A2	Gatas IV	1650	100	0.049	19.6	Hagedorn 1994; Hagedorn et al. 1999
G/S3/H98	G/S3/11A2	Gatas IV	1650	100	0.728	17.8	Hagedorn 1994; Hagedorn et al. 1999
	mean	Gatas IV	1650	100	0.328	18.8	Hagedorn 1994; Hagedorn et al. 1999
G/S2/H1	G/S2/UE001	Gatas V	1425	125	0.701	17.9	Hagedorn 1994; Hagedorn et al. 1999
G/S2/H2	G/S2/UE001	Gatas V	1425	125	0.655	18.0	Hagedorn 1994; Hagedorn et al. 1999
G/S2/H3	G/S2/UE001	Gatas V	1425	125	0.547	18.3	Hagedorn 1994; Hagedorn et al. 1999
	mean	Gatas V	1425	125	0.640	18.0	Hagedorn 1994; Hagedorn et al. 1999
G/S1/H1	G/S1/1A1	Gatas VI	1200	150	0.924	17.3	Hagedorn 1994; Hagedorn et al. 1999
G/S1/H2	G/S1/1A1	Gatas VI	1200	150	0.788	17.6	Hagedorn 1994; Hagedorn et al. 1999
	mean	Gatas VI	1200	150	0.868	17.4	Hagedorn 1994; Hagedorn et al. 1999
rez Hagedorn	beach	recent	-1980	10	0.672	17.9	Hagedorn 1994; Hagedorn et al. 1999
rez	beach	recent	-1990	10	0.854	17.5	authors

Appendix 1 Stable isotope ratios of oxygen and resulting temperature reconstruction of the *Glycymeris* sp. shells from Gatas. Mean data of each clam sample consisting of at least one full annual growth cycle. Mean data for the phases are based on the number of all individual data for the samples from that layer. Full listing of results in Appendix 2.

Anhang 1 *Stabile Sauerstoff-Isotopenverhältnisse und Temperatur-Rekonstruktion an Muschelschalen der Gattung* Glycymeris *aus Gatas. Mittelwerte von jeder Probe umfassen mindestens einen vollen Jahreszyklus. Mittelwerte für eine Zeitstufe basieren auf der Anzahl aller Einzelmessungen aus dieser Schicht. Die Einzelergebnisse der Messungen sind in Anhang 2 aufgeführt.*

Labcode	Sample code	Sample	$\delta^{18}O$ ‰ VPDB	SD ^{18}O ‰ VPDB	T °C	SD T °C
124178	33	rezent 1	1.00	0.02	17.1	0.08
124179	34	rezent 1	1.13	0.02	16.7	0.08
124180	35	rezent 1	1.22	0.01	16.5	0.05
124181	36	rezent 1	1.12	0.02	16.8	0.12
124183	37	rezent 1	0.70	0.02	17.9	0.09
124184	38	rezent 1	0.51	0.02	18.4	0.09
124185	39	rezent 1	1.05	0.01	16.9	0.03
124186	40	rezent 1	0.94	0.02	17.2	0.12
124187	41	rezent 1	1.34	0.02	16.1	0.11
124188	42	rezent 1	0.92	0.01	17.3	0.03
124190	43	rezent 1	1.22	0.03	16.5	0.15
124155	1	rezent 2	0.84	0.01	17.5	0.07
124157	3	rezent 2	1.41	0.02	16.0	0.10
124158	4	rezent 2	1.35	0.02	16.1	0.12
124159	5	rezent 2	1.39	0.02	16.0	0.11
124160	6	rezent 2	1.36	0.03	16.1	0.15
124162	7	rezent 2	1.39	0.02	16.0	0.11
124163	8	rezent 2	1.29	0.01	16.3	0.04
124164	9	rezent 2	1.25	0.02	16.4	0.09
124165	10	rezent 2	1.16	0.02	16.6	0.10
124166	11	rezent 2	1.01	0.02	17.0	0.09
124167	12	rezent 2	0.95	0.01	17.2	0.07
124169	13	rezent 2	0.95	0.01	17.2	0.07
124170	14	rezent 2	1.15	0.02	16.7	0.08
124171	15	rezent 2	1.39	0.03	16.0	0.14
124172	16	rezent 2	1.39	0.02	16.0	0.08
124173	17	rezent 2	1.42	0.01	16.0	0.05
124174	18	rezent 2	1.20	0.03	16.5	0.17
124176	19	rezent 2	1.62	0.01	15.4	0.04
124177	20	rezent 2	1.05	0.02	16.9	0.10
ZMT 2688	GR–37–138	rezent GR 37	0.73	0.01	17.8	0.03
ZMT 2690	GR–37–139	rezent GR 37	0.09	0.01	19.5	0.04
ZMT 2685	GR–56–132	rezent GR 56	0.30	0.02	18.9	0.10
ZMT 2686	GR–56–133	rezent GR 56	-0.11	0.01	20.0	0.07
ZMT 2687	GR–56–134	rezent GR 56	0.68	0.02	17.9	0.10
ZMT 2681	GR–81–117	rezent GR 81	-0.11	0.02	20.0	0.09
ZMT 2683	GR–81–118	rezent GR 81	0.86	0.02	17.4	0.09
ZMT 2684	GR–81–119	rezent GR 81	0.28	0.02	19.0	0.10
ZMT 2678	GR–88–108	rezent GR 88	-0.47	0.02	21.0	0.09
ZMT 2679	GR–88–109	rezent GR 88	-0.02	0.02	19.8	0.11
ZMT 2680	GR–88–113	rezent GR 88	0.57	0.01	18.2	0.07
ZMT 2691	GR–94–141	rezent GR 94	0.41	0.01	18.6	0.06
ZMT 2692	GR–94–142	rezent GR 94	0.25	0.01	19.1	0.05
ZMT 2693	GR–94–143	rezent GR 94	-0.63	0.01	21.4	0.07
124224	66	MUE 6	0.08	0.01	19.5	0.07
124226	67	MUE 6	0.44	0.02	18.5	0.08
124227	68	MUE 6	-0.43	0.04	20.9	0.23
124228	69	MUE 6	0.21	0.02	19.2	0.11

Labcode	Sample code	Sample	$\delta^{18}O$ ‰ VPDB	SD ^{18}O ‰ VPDB	T °C	SD T °C
124229	70	MUE 7	0.61	0.01	18.1	0.08
124230	71	MUE 7	-0.03	0.02	19.8	0.12
124231	72	MUE 7	1.04	0.01	16.9	0.07
124233	73	MUE 7	0.31	0.02	18.9	0.13
124234	74	MUE 8	0.97	0.03	17.1	0.16
124235	75	MUE 8	0.26	0.03	19.0	0.16
124236	76	MUE 8	1.07	0.03	16.9	0.17
124237	77	MUE 8	0.58	0.02	18.2	0.13
152270	MK 8–60	MUE 8	-0.94	0.03	22.2	0.13
152271	MK 8–61	MUE 8	-0.27	0.03	20.4	0.14
152272	MK 8–62	MUE 8	0.10	0.03	19.5	0.16
152273	MK 8–63	MUE 8	0.60	0.05	18.1	0.24
152274	MK 8–64	MUE 8	0.53	0.04	18.3	0.20
152276	MK 8–65	MUE 8	0.33	0.03	18.8	0.14
152277	MK 8–66	MUE 8	1.00	0.03	17.1	0.16
152278	MK 8–67	MUE 8	0.93	0.00	17.2	0.02
152279	MK 8–68	MUE 8	0.11	0.02	19.4	0.09
152280	MK 8–69	MUE 8	-0.48	0.04	21.0	0.20
152281	MK 8–70	MUE 8	-0.88	0.05	22.1	0.27
124191	44	MUE 1	0.22	0.04	19.1	0.19
124192	45	MUE 1	0.73	0.02	17.8	0.09
124193	46	MUE 1	-0.57	0.02	21.2	0.10
124194	47	MUE 1	-0.54	0.02	21.2	0.09
150027	MK M1–1	MUE 1	-0.27	0.02	20.4	0.09
150028	MK M1–2	MUE 1	-0.03	0.01	19.8	0.04
150029	MK M1–3	MUE 1	0.16	0.02	19.3	0.13
150030	MK M1–4	MUE 1	0.78	0.02	17.6	0.12
150031	MK M1–5	MUE 1	1.03	0.04	17.0	0.23
150033	MK M1–6	MUE 1	1.37	0.03	16.1	0.16
150034	MK M1–7	MUE 1	1.48	0.03	15.8	0.16
150035	MK M1–8	MUE 1	1.47	0.01	15.8	0.05
150036	MK M1–9	MUE 1	1.29	0.03	16.3	0.18
150037	MK M1–10	MUE 1	1.04	0.04	17.0	0.22
150038	MK M1–11	MUE 1	0.53	0.02	18.3	0.10
150040	MK M1–12	MUE 1	-0.31	0.03	20.6	0.17
150041	MK M1–13	MUE 1	-0.62	0.03	21.4	0.18
124215	58	MUE 4	0.59	0.02	18.1	0.12
124216	59	MUE 4	0.53	0.02	18.3	0.09
124217	60	MUE 4	0.72	0.03	17.8	0.14
124219	61	MUE 4	0.87	0.01	17.4	0.06
194963	MK81	MUE 4	-0.30	0.01	20.5	0.07
194964	MK82	MUE 4	0.24	0.01	19.1	0.07
124195	48	MUE 2	0.96	0.02	17.2	0.10
124205	49	MUE 2	0.96	0.01	17.2	0.04
124206	50	MUE 2	0.72	0.01	17.8	0.06
124207	51	MUE 2	-0.53	0.04	21.1	0.22
124208	52	MUE 2	-0.62	0.02	21.4	0.09
150067	MK M2–29	MUE 2	1.35	0.02	16.1	0.12

Labcode	Sample code	Sample	$\delta^{18}O$ ‰ VPDB	SD ^{18}O ‰ VPDB	T °C	SD T °C
150069	MK M2–30	MUE 2	0.90	0.03	17.3	0.16
150070	MK M2–31	MUE 2	0.84	0.01	17.5	0.07
150071	MK M2–32	MUE 2	0.06	0.01	19.6	0.05
150072	MK M2–33	MUE 2	-0.36	0.04	20.7	0.22
150073	MK M2–34	MUE 2	-0.43	0.02	20.9	0.09
150074	MK M2–35	MUE 2	-0.45	0.05	20.9	0.25
150076	MK M2–36	MUE 2	-0.17	0.01	20.2	0.07
150077	MK M2–37	MUE 2	0.58	0.02	18.2	0.08
150078	MK M2–38	MUE 2	0.87	0.04	17.4	0.20
150079	MK M2–39	MUE 2	1.29	0.01	16.3	0.05
150080	MK M2–40	MUE 2	0.02	0.01	19.7	0.07
150081	MK M2–41	MUE 2	-0.41	0.01	20.8	0.05
150083	MK M2–42	MUE 2	-0.40	0.02	20.8	0.10
124209	53	MUE 3	-0.27	0.02	20.4	0.08
124210	54	MUE 3	-0.26	0.01	20.4	0.07
124212	55	MUE 3	0.17	0.01	19.3	0.06
124213	56	MUE 3	-0.15	0.02	20.1	0.13
124214	57	MUE 3	-0.15	0.02	20.1	0.10
194967	MK85	MUE 3	0.49	0.02	18.4	0.09
194969	MK86	MUE 3	0.07	0.02	19.5	0.10
150042	MK M3–14	MUE 3	0.64	0.03	18.0	0.15
150043	MK M3–15	MUE 3	-0.44	0.01	20.9	0.05
150044	MK M3–16	MUE 3	-0.91	0.02	22.2	0.11
150045	MK M3–17	MUE 3	-0.98	0.02	22.3	0.12
150055	MK M3–18	MUE 3	-0.32	0.04	20.6	0.23
150056	MK M3–19	MUE 3	0.64	0.03	18.0	0.14
150057	MK M3–20	MUE 3	0.70	0.02	17.9	0.09
150058	MK M3–21	MUE 3	-0.23	0.02	20.3	0.12
150059	MK M3–22	MUE 3	-0.88	0.02	22.1	0.09
150060	MK M3–23	MUE 3	-0.68	0.01	21.5	0.06
150062	MK M3–24	MUE 3	0.87	0.02	17.4	0.09
150063	MK M3–25	MUE 3	0.40	0.03	18.7	0.18
150064	MK M3–26	MUE 3	-0.29	0.04	20.5	0.20
150065	MK M3–27	MUE 3	-0.82	0.03	21.9	0.17
150066	MK M3–28	MUE 3	1.15	0.03	16.7	0.16
124220	62	MUE 5	0.43	0.01	18.6	0.05
124221	63	MUE 5	0.22	0.01	19.1	0.08
124222	64	MUE 5	0.00	0.02	19.7	0.11
124223	65	MUE 5	-0.05	0.01	19.9	0.07
194965	MK83	MUE 5	0.61	0.01	18.1	0.07
194966	MK84	MUE 5	1.00	0.02	17.1	0.11
150084	MK M5–43	MUE 5	0.98	0.02	17.1	0.08
150085	MK M5–44	MUE 5	0.82	0.03	17.5	0.13
150086	MK M5–45	MUE 5	-0.29	0.03	20.5	0.16
150087	MK M5–46	MUE 5	-0.74	0.03	21.7	0.14
150088	MK M5–47	MUE 5	-0.22	0.03	20.3	0.14
150090	MK M5–48	MUE 5	0.39	0.02	18.7	0.09
150091	MK M5–49	MUE 5	0.87	0.01	17.4	0.07

Labcode	Sample code	Sample	$\delta^{18}O$ ‰ VPDB	SD ^{18}O ‰ VPDB	T °C	SD T °C
150092	MK M5–50	MUE 5	1.09	0.02	16.8	0.10
150093	MK M5–51	MUE 5	1.03	0.02	17.0	0.09
150094	MK M5–52	MUE 5	1.09	0.01	16.8	0.04
150095	MK M5–53	MUE 5	1.13	0.01	16.7	0.07
150096	MK M5–54	MUE 5	0.92	0.03	17.3	0.16

Appendix 2 Stable isotope ratios of oxygen and resulting temperature reconstruction of the *Glycymeris* sp. shells from Gatas. Full listing of the results from the isotope analyses (SD Standard deviation).

Anhang 2 *Stabile Sauerstoff-Isotopenverhältnisse an Muschelschalen der Gattung* Glycymeris *aus Gatas. Vollständige Auflistung der Einzelergebnisse der Isotopenanalysen (SD Standardabweichung).*

Bislang erschienene Bände in der Reihe »Tagungsbände des Landesmuseums für Vorgeschichte Halle«

Die Reihe der Tagungsbände des Landesmuseums wurde 2008 ins Leben gerufen. Anlass dazu war die Konferenz »Luthers Lebenswelten«, die im Jahr 2007 in Halle ausgerichtet wurde. Bereits der zweite Tagungsband widmete sich mit dem Thema »Schlachtfeldarchäologie« dem Mitteldeutschen Archäologentag, der seit 2008 jährlich von Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt veranstaltet und zeitnah publiziert wird. Dem großen Anteil internationaler Autorinnen und Autoren entsprechend, erscheinen viele Beiträge dieser Reihe in englischer Sprache mit deutscher Zusammenfassung.

Mit dem bislang zuletzt erschienenen Tagungsband konnten die Vorträge und Posterpräsentationen des 6. Mitteldeutschen Archäologentags »Metalle der Macht – Frühes Gold und Silber« in zahlreichen Artikeln renommierter Forscher verschiedenster Fachdisziplinen vorgelegt werden.

Lieferbar sind folgende Bände:

Band 1/2008 Harald Meller/Stefan Rhein/Hans-Georg Stephan (Hrsg.),
Luthers Lebenswelten.
Tagung vom 25. bis 27. September 2007 in Halle (Saale).
ISBN 978-3-939414-22-3, € 39,00

Band 2/2009 Harald Meller (Hrsg.),
Schlachtfeldarchäologie. *Battlefield Archaeology.*
1. Mitteldeutscher Archäologentag vom 09. bis 11. Oktober 2008 in Halle (Saale).
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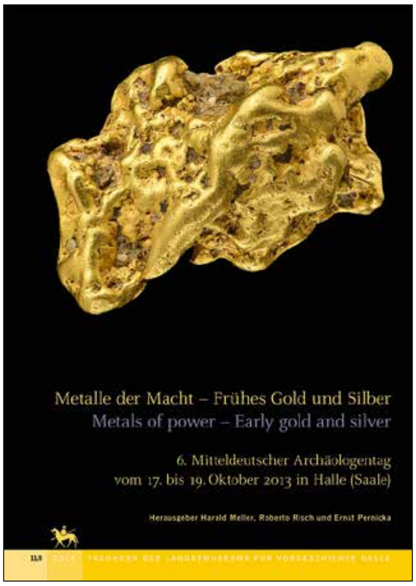

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