United Nations
Educational,
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Tales set in stone, p.2

# A World of SCIENCE

Natural Sciences
Quarterly Newsletter

**Vol. 10, No. 3**
July–September 2012

IN THIS ISSUE



**EDITORIAL**

## Time travel

If beauty is in the eye of the beholder, so too is utility. As Iain Stewart from Plymouth University (UK) observed last February at the 40th anniversary of the International Geoscience Programme (IGCP) at UNESCO in Paris, show a piece of coal to an industrialist and they will see a source of fuel; show it to an ecologist and they will see a source of carbon emissions; show it to a geologist and they will see a climate which existed more than 300 million years ago (Ma).

Geoscientists help us to travel through time. The IGCP was founded in 1972 to confirm the existence of Gondwana, one of two megacontinents with Laurasia which formed about 145 Ma, by correlating the geology of modern continents. As time went by and supporting evidence for Gondwana became overwhelming, IGCP research teams turned to questions of special societal relevance. New disciplines emerged like archaeoseismology, which draws on both the geological and archaeological record to identify past earthquakes. One IGCP project in 2000 was even at the origin of a new field: medical geology, the science dealing with the impact of our natural environment on human and animal health. Arsenic, for example, is a natural chemical which poisons millions of people worldwide who absorb it unwittingly through groundwater.

Given the concern over climate change and the looming shortage of fossil fuels and uranium which overshadows our industrial future, geoscientists are focusing more on renewable energy these days. Kenyan geoscientists, for instance, are currently employed on a government project to develop geothermal energy in the Great Rift Valley.

As the third Earth Summit (Rio+20) in June has just demonstrated, civil society and the private sector have become central players in sustainable development. UN Secretary-General Ban ki-Moon announced in Rio that more than 50 governments had launched new energy strategies but also that private investors had pledged more than US$50 billion towards the goal of doubling the share of global renewable energy and improvements in energy efficiency by 2030.

Understanding natural disasters is another critical area for sustainable development in which the IGCP can make a difference. A consensus rapidly emerged in February of the need for IGCP projects to monitor seismic activity in subduction zones like that responsible for the Japanese earthquake and tsunami last year.

One of the world's most active subduction zones is located in the Mediterranean Sea, south of the island of Crete. Overleaf, we follow the fortunes of *Homo sapiens sapiens* around the Black and Mediterranean Seas through 30 000 years of a tumultuous history marked by sporadic earthquakes, tsunamis and volcanic eruptions, as well as more insidious hazards tied to a changing climate, such as flooding from glacier melt, gradual sea-level rise or prolonged drought. Through these palaeostudies, the IGCP is helping us to understand how human societies and ecosystems coped with a changing environment in the past and why some civilizations failed. There are obvious lessons to be learned for contemporary societies.

*Gretchen Kalonji*
*Assistant Director-General for Natural Sciences*

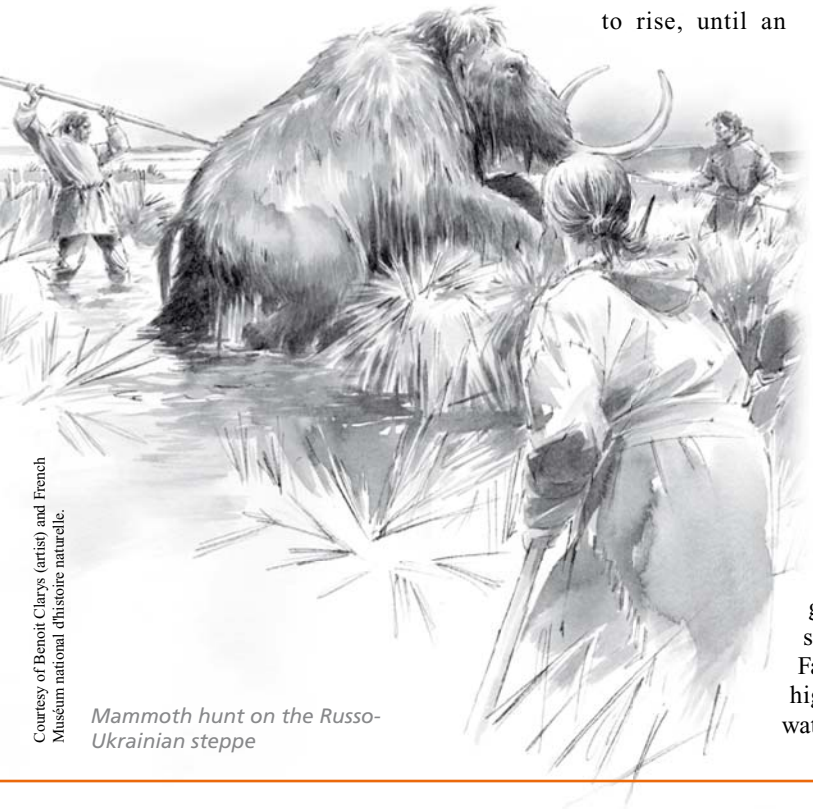
# Tales set in **stone**

**Over the past 30 000 years, humans living around the Caspian, Black and Mediterranean Seas have had to adapt to climate change, with warmer periods chasing ice-age temperatures. Over time, progress in navigation and the development of sophisticated bronze and iron weapons enabled dominant powers to extend their empire across the Mediterranean region. Ultimately, however, even these civilizations would falter. In some cases, their fall would be precipitated by an environmental catastrophe, like the Minoan volcanic eruption 3 600 years ago; other civilizations would survive nature's wrath, like Pharaonic Egypt 4 200 years ago.**

**To what extent did climate change and environmental catastrophes influence the rise and fall of civilizations? Within the International Geoscience Programme (IGCP), geoarchaeologists, palaeontologists, archaeoseismologists and others have pooled their talents to piece together parts of the puzzle. One project studied the history of the corridor formed by the Caspian, Black and Mediterranean Seas as a single entity for the first time. It asked questions like: When the last Ice Age waned, was sea-level rise so abrupt that it dispersed early cultures, or did it leave them time to adapt? Could the Black Sea be the site of the Great Flood depicted in the *Bible*? At times, these IGCP projects crossed paths with historic sites safeguarded by UNESCO under the Convention on World Heritage or the Convention on the Protection of Underwater Cultural Heritage. Let's take a stroll through history.**

For 30 000 years, the corridor formed by the Caspian, Black and Mediterranean Seas has been shaped by sweeping changes in climate and sea level. In glacial times when global sea level was low, the Black and Marmara Seas were isolated from the Mediterranean, becoming inland lakes like the Caspian Sea today. When temperatures warmed, water was able to flow from the Mediterranean through the Bosphorus Strait into the Sea of Marmara then on through the Dardanelles Strait into the Black Sea, a journey of 6 000 km.

Our story begins towards the end of the last Ice Age. After 90 000 years, it is about to reach its coldest point, 21 000 years ago. Temperatures will subsequently start rising, causing ice sheets to melt and sea level to rise, until an abrupt change in climate known as the Younger Dryas (or Big Freeze) sends temperatures plummeting again about 11 000 years ago.[1] The Younger Dryas was probably triggered by the melting North American ice sheets, which many attribute to overflow from glacial Lake Agassiz in Canada, once the largest lake in the world. The rapid influx of a huge volume of freshwater into the North Atlantic Ocean would have slowed or stopped the northward transport of heat currents via the Gulf Stream, sinking temperatures in the North Atlantic by about 5°C in less than a decade. Glaciers in Europe advance once more and a glacial climate returns to the continent for 1 000 years before temperatures begin warming again.



Courtesy of Benoit Clarys (artist) and French Muséum national d'histoire naturelle.

*Mammoth hunt on the Russo-Ukrainian steppe*

About 10 000 years ago, the Earth left behind the Pleistocene period for the Holocene period we still inhabit today. Then, 6 000 years ago, Europe experienced a particularly warm period normally associated with the Holocene Climatic Optimum in the Northern Hemisphere before cooling slightly again. The Holocene Climatic Optimum may be the result of the Earth tilting slightly on its axis thousands of years earlier. By orienting the Northern Hemisphere a little closer to the Sun, this change in the Earth's orbit had already brought the Ice Age to an end.

Our journey into the past will end about 2 000 years ago, at a time when the development of human societies around the Caspian, Black and Mediterranean Seas has become so complex that we could never hope to tell a fraction of the tale in just a few pages.

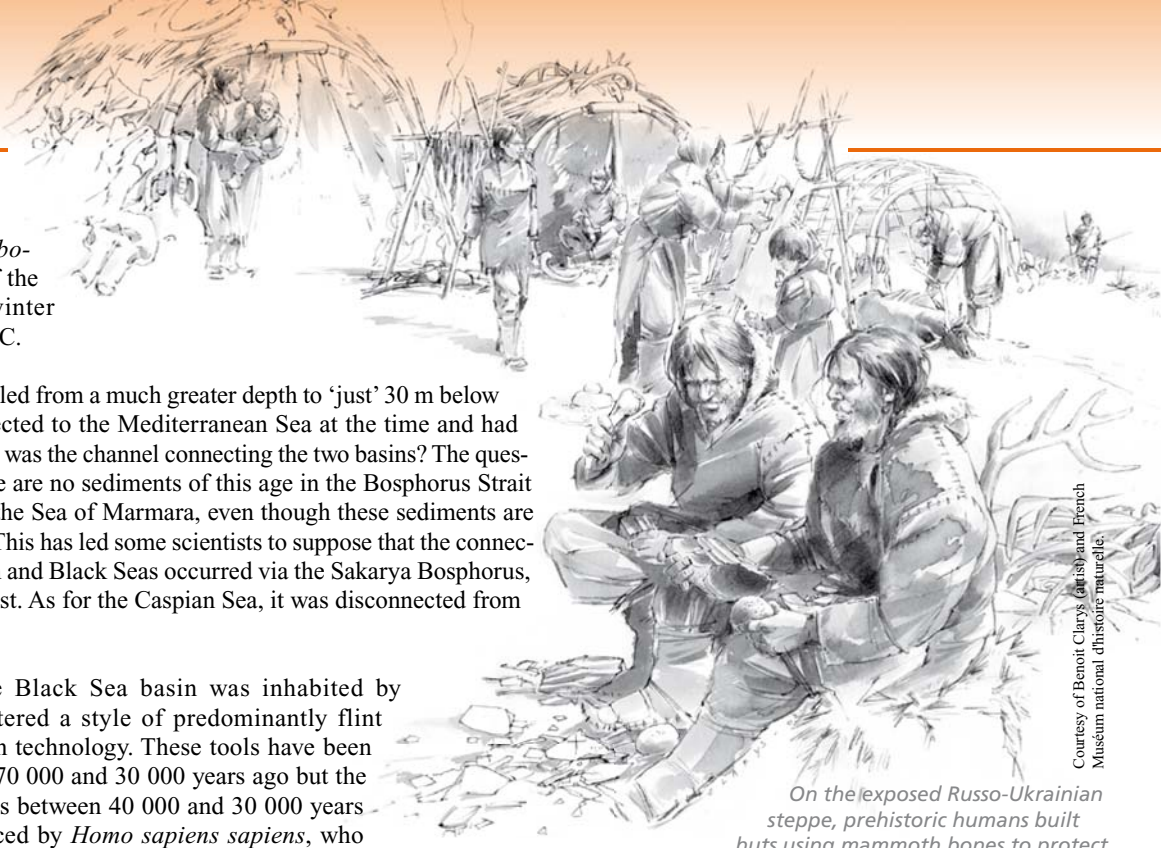
## *Homo sapiens sapiens* takes up residence in the Black Sea

Temperatures during the last Ice Age were not uniform. Prior to 28 000 years ago, the climate in the Eastern Mediterranean was generally mild for the time, with only shallow permafrost (frozen soil) at high latitudes and greater rain- and snowfall than today. Farther south, the level of the Mediterranean Sea was a few metres higher than today and the basin was populated by exotic warm-water animals of the type that you would find in Senegal nowadays,

like the mollusc *Strombus bubonius*, which lives in waters off the West African coast where winter temperatures hover around 20°C.

The Black Sea itself had swelled from a much greater depth to 'just' 30 m below present sea level. It was connected to the Mediterranean Sea at the time and had salinity of around 11‰[2]. Where was the channel connecting the two basins? The question remains unanswered. There are no sediments of this age in the Bosphorus Strait linking the two seas today via the Sea of Marmara, even though these sediments are present in Izmit Bay in Turkey. This has led some scientists to suppose that the connection between the Mediterranean and Black Seas occurred via the Sakarya Bosphorus, a strait slightly farther to the east. As for the Caspian Sea, it was disconnected from the Black Sea at this time.

The northern coast of the Black Sea basin was inhabited by Neanderthals. They had mastered a style of predominantly flint tools known as the Mousterian technology. These tools have been radiocarbon dated to between 70 000 and 30 000 years ago but the main cluster of dated sites falls between 40 000 and 30 000 years ago. Neanderthals were replaced by *Homo sapiens sapiens*, who first appeared on the East European Plain and Caucasus between 41 000 and 32 000 years ago.



Courtesy of Benoit Clarys (artist) and French Muséum national d'histoire naturelle.

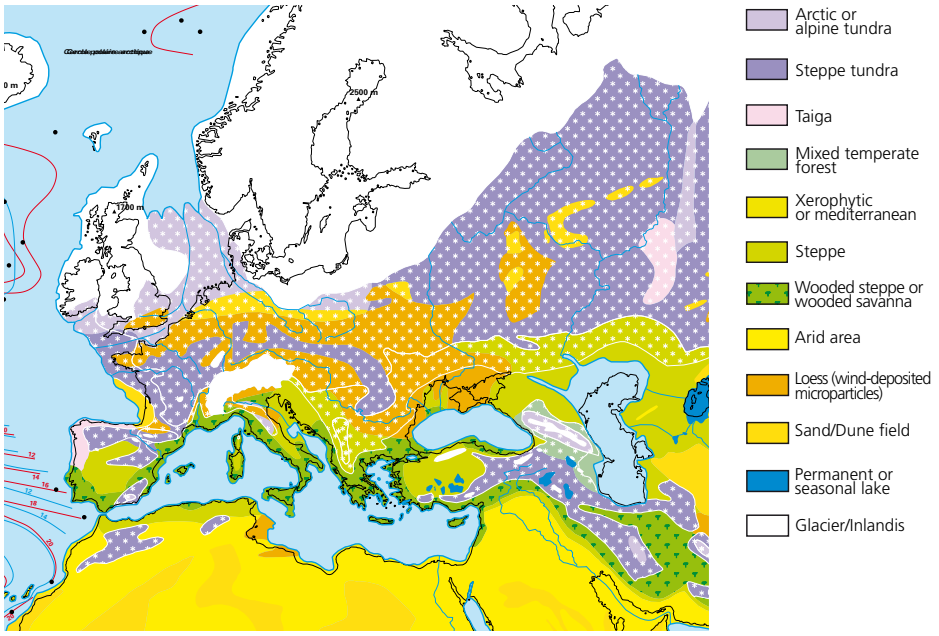
*On the exposed Russo-Ukrainian steppe, prehistoric humans built huts using mammoth bones to protect themselves from the glacial wind.*

The appearance of anatomically modern humans in the northern Black Sea region could be the result of migration from Africa through the Levant[3] and southeastern Europe that would eventually extend to western Europe. Neandertals and *H. sapiens sapiens* probably cohabited in western Europe for several thousand years. The most recent remains of Neandertals have been found in Spain and date back less than 30 000 years.

IGCP project co-leader Pavel Dolukhanov observes that the northern Black Sea region, positioned as it was south of the continental glaciers, would have appealed to *H. sapiens sapiens* with its mild climate, regular water supply and abundant prey. Large Palaeolithic settlements like Anetovka 1 in Ukraine (*see box overleaf*) were concentrated along the Dniester, Dnieper and Don Rivers and also in the Carpathians and Crimea. The growth of these settlements coincides with the disappearance of the bones of mammoths and woolly rhinoceroses from the region. Around 20 000 years ago, the fossil remains of bison begin to appear more frequently in ancient settlements. We can deduce from this that mammoths and woolly rhinoceroses had been exterminated by this time and replaced by bison as the main prey for hunting groups.

## The Ice Age hits its coldest point

The Last Glacial Maximum occurred between about 27 000 and 17 000 years ago. Ice sheets spread over much of North America and Asia. Over Hudson Bay in Canada, the ice was 4 km thick. In Europe, ice sheets extended over much of the UK and as far south as Germany and Poland (*see map*). The spread of ice profoundly impacted the Earth's climate, causing drought, desertification and a dramatic drop in sea levels in basins connected to the ocean. You would have been able to walk from England to France without getting your feet wet. 'About 21 000 years ago,' observes Paolo Pirazzoli from the French National Centre for Scientific Research, 'the world's oceans were 120 m lower than today. So too was the Mediterranean Sea, which was connected to the Atlantic Ocean through the Gibraltar Strait. The north of the Adriatic Sea was completely exposed and, in the Aegean Sea, it would have often been possible to walk from one island of the Cyclades to another.'




Map courtesy of Philippe Bouysse, CGMW/ANDRA (2002)

*Ice cover in Europe 18 000 years ago when the world was 4.5°C colder on average than today*

On the edges of glacial areas, the entire East European platform was covered with tundra-steppe vegetation. The climate was also dry and cold along the Black Sea coast, which was covered by pine and birch forest in Romania and by plants that had adapted the capacity to survive in a water-stressed environment (xerophytic plants) on the grassland steppes of southern Ukraine and Moldova. Given the cold climate, there would have been little river flow into the Black Sea. This would have caused the level to drop dramatically to 100 m below the present level, exposing a large portion of the sea shelf (or floor). Farther south, the Balkan Peninsula was covered in grassland steppe and forest.

The level of the Marmara and Aegean Seas was about 100 m and 115 m lower than today respectively. Both the Marmara and Black[4] Seas were land-locked lakes isolated from each other, populated by organisms that could survive in cold water with a salt content of 1–5‰. All the Mediterranean species had disappeared. The entire coastal plain was covered by a relatively fertile soil composed of a mixture of clay, sand, silt and organic matter. The mouths of the Pre-Danube, Pre-Dnieper, and Pre-Dniester Rivers would have been located 80–100 km farther seaward than today with poorly developed deltas.

The extremely harsh climate drove people to migrate from Central and Western Europe onto the more fertile steppes of the Black Sea. We know this from the great variety of cultural groups living in Eastern Europe at the time, in contrast to the virtual depopulation of southern Germany and the UK. The high population density around the Black Sea suggests that these groups thrived. Similarities in lifestyle and stone tools indicate that these groups circulated freely along the coast, with the Black Sea's northern coast representing a bridge between modern-day Varna in Bulgaria and Sarych Cape in Crimea in Ukraine. All the occupied sites belonged to groups of foragers who specialized in hunting big game. In their search for food, the bison hunters moved south and southwest along the Dnieper, Southern Bug, Dniester and Prut River valleys to the shores of the Black Sea.

The lake water was undrinkable, with salinity of 0.5–5‰ (near-brackish). The coast was marshy and mosquito-infested and the rivers periodically flooded the region. This may have been good for hunting and fishing but would not have been conducive to settled farming. The soils would have been too salty, a problem that still plagues farmers today. People preferred to settle in the valleys of small rivers.

The settlements were so successful that population growth ended up forcing the hunter-gatherers to search for food farther afield. An Eastern European people known as the Anetovka Mikrogravette (28 000–23 000 years ago) established a large settlement which served as their base, together with a series of camps a day's walk from each other. While at their home base, these hunter-gatherers produced stone tools with small pointed blades which they used to hunt bison, horses, reindeer and mammoths. They spent most of the year scattered along the valleys of small rivers in search of prey, visiting their base only a few times a year for a short respite to celebrate a successful hunt and prepare for the next one.

## Two hypotheses for a Great Flood

Between 17 000 and 10 000 years ago, the Black Sea remained a lake, even if it rose from 100 m to just 40 m below the present sea level. The greatest change occurred in the first 3 000 years. As Europe became warmer, the Scandinavian ice sheet and permafrost melted. This in turn swelled rivers, causing megafloods and resulting in a cascade of Eurasian basins extending from the Aral Sea all the way down to the Aegean Sea (*see map*). Contributing to this deluge was an outburst of flooding from ice-dammed lakes in the Altai Mountains. The cascade inundated about

## Taking climate archives from a lake

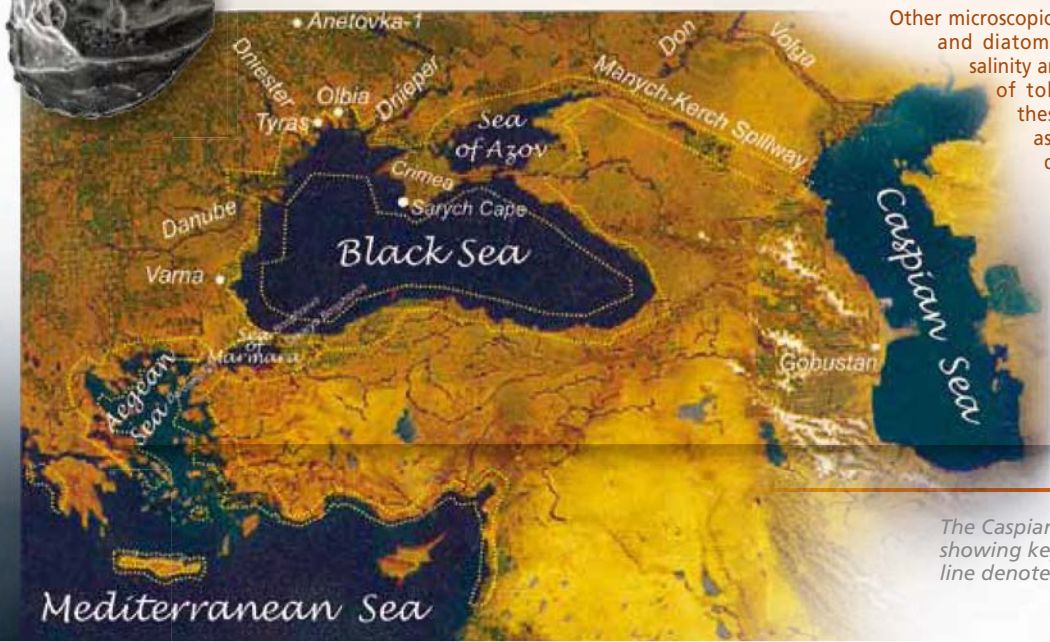
© V. Yanko-Hombach

Palaeontologists study fossils to reconstruct the past sea level and the salinity, depth, oxygen content and temperature of the Caspian, Black and Mediterranean Sea basins (or Corridors). Some organisms lived on the bottom (we call them benthic), while others swam in the water column (we call them planktonic). They fall into different groups, such as single-celled foraminifera, ostracoda (microcrustaceans like the fossil on the left) and molluscs. These organisms grow hard shells made of calcium carbonate which are well preserved in sediments after they die. Foraminifera and ostracoda are usually as small as a grain of sand and can only be seen under a microscope.

The shells of planktonic foraminifera contain oxygen isotopes that enable scientists to determine the temperature of surface water, which is controlled by the state of the climate at the time. Molluscan shells contain radiocarbon (14C) isotopes that allow us to determine the age of the sediments in which they were buried. The presence of Mediterranean or Caspian fossils in Black Sea sediments indicates a connection with either basin.

Other microscopic planktonic fossils called dinoflagellates and diatoms are used to reconstruct the water's salinity and temperature due to the narrow range of tolerance many species demonstrate to these conditions. Remnants of plants, such as microscopic spores and pollen, provide direct evidence for Neolithic agriculture on shelves that were once exposed until sea level rose. Correlating the succession of pollen zones for the Late Pleistocene and Holocene with the pollen zones of surrounding upland areas helps us reconstruct the temperature and precipitation (rain- and snowfall) dynamics across these entire corridors.

*Valentina Yanko-Hombach*




*The Caspian–Black–Mediterranean Sea Corridor today, showing key archaeological sites. The dotted yellow line denotes the study area of the IGCP project.*

1.5 million km$^2$ of land and raised the level of the Caspian Sea[5] by 50 m. The Caspian basin could not retain all the inflowing water, so the excess was discharged through the Manych–Kerch Spillway into the Black Sea, raising the lake by at least 60 m and causing it to spill into the Marmara Sea.

The dramatic rise in sea level caused extensive coastal flooding (up to 10–20 km per year) of lands which would have been of great value to Stone Age populations. This has led A. L. Chepalyga to claim that a Great Flood took place at this time. In fact, there is not one theory but two about a Great Flood inundating the Black Sea. However, the second hypothesis, that of W. Ryan *et al.*, dates the Great Flood to a much later period, 8 400 years ago in the Early Holocene (*see box*).

©A.L. Chepalyga, modified by V.Yanko-Hombach

*Pre- and post-flood size of the Black and Caspian Seas, according to A.L. Chepalyga*

## Was there a Great Flood in the Black Sea?

The book of Genesis from the *Bible* tells the tale of how God sent a Great Flood lasting 40 days to punish human beings for their sins. Warned by God in advance, Noah built a giant boat (the Ark) for his family and a pair of each animal species on Earth, who were all saved.

Some think there really was a huge flood in the Black Sea a few thousand years ago which swept Noah's ark to the top of Mount Ararat and that vestiges of the boat remain there today. The scientific evidence, however, clearly shows that the flood waters were never higher than 20 m below present sea level and that the biggest flood took place just after the Ice Age, thousands of years before the first towns and farms were settled.

Two hypotheses situate a Great Flood in the Black Sea basin, both at a time when it was a lake. The first hypothesis is proposed by A.L. Chepalyga (2007), who situates the Great Flood just after the Ice Age between 17 000 and 14 000 years ago with no link to the biblical story. According to Chepalyga, the brackish Black Sea filled rapidly with the overflow from the Caspian Sea via the Manych Spillway shortly after the Last Glacial Maximum when ice cover was melting rapidly.

The second hypothesis, or 'Noah's Flood', is proposed by W. Ryan *et al.* (2003). They claim that the climate became drier immediately after the Younger Dryas and that the resulting evaporation caused the Black Sea to drop to 95 m below the present level. As the climate warmed and ice cover melted in Europe, sea level rose in the Mediterranean, causing a catastrophic flow of salt water into the Black Sea 8 400 years ago.

If a catastrophic flood did occur in the Black Sea, there should be a record of it. An IGCP project searched for traces in sea-bottom sediments, fossils, landforms, old coastlines and so on. Here is what it uncovered.

### *How low did the Black Sea sink?*

Ryan *et al.* claim that dry climatic conditions caused the water in the Black Sea to evaporate to 95 m below the present level. Yet, we know from pollen records that the exposed shelf and immediately adjoining coasts were covered by moisture-demanding forest trees such as deciduous oak, linden, beech and elm, together with shade ferns, aquatic and swamp plants. These plant species are indicative of warm winters and year-round rainfall of between 600 mm and 1000 mm.

The last time the level of the Black Sea basin dropped to 95 m lower than today was during the Last Glacial Maximum. At the beginning of the Holocene period about 10 000 years ago, the Black Sea, a lake at the time, gradually rose from 40 m to 20 m below the present level, owing to the inflow of Mediterranean water. Could such an insignificant rise in water level cause catastrophic flooding?

### *Was the Black Sea a freshwater lake?*

If the Black Sea contained freshwater suitable for drinking, as Ryan *et al.* claim, why do all the fossils discovered in the lake sediments belong to organisms that thrived in brackish water? And if the lake water was potable, why would people have chosen to settle instead in the valleys of small rivers, as supported by numerous archaeological sites?

### *Were prehistoric settlements submerged by the Great Flood?*

Ryan *et al.* claim that, before the Great Flood, people inhabited not only today's coast but also that part of the present sea bottom (called the shelf) which was dry land at the time. Despite decades of searching for submerged prehistoric habitations on the previously exposed shelves of the Black Sea, there have been no definite finds below a water depth of 10 m.

### *Was there farming in the Black Sea region at the time?*

The pollen records reveal no evidence of grain production around the Black Sea before 5 718 years ago. The sparse nature of traces in shelf cores of charcoal particles from burned grasslands and fungal spores grown on animal dung in crowded enclosures discredit the idea that animal husbandry was practiced on the exposed shelf. This absence contrasts with the archaeological evidence for animal husbandry as early as 8 000 years ago found at Ilipinar south of the Sea of Marmara.

### *The evidence points to gradual sea-level rise in the Black Sea*

The hypothesis of a Great Flood in the Black Sea 8 400 years ago captured the public's imagination but what most media failed to mention was that geologists and archaeologists from Ukraine, Russia, Canada and elsewhere had found no evidence of catastrophic flooding of the Black Sea. Rather, the evidence points to a gradual reconnection with the Mediterranean Sea from about 9 500 to 8 000 years ago.

For Chepalyga, the Great Flood of 17 000–14 000 years ago is not the one described in the Bible. He argues that catastrophic floods would have endured in the collective memory for thousands of years, until they were consigned in ancient Aryan scriptures such as the Rigveda (Hindu) and Avesta (Indo-Iranian). The story of a Great Flood was also told by the ancient inhabitants of Mesopotamia.

This research was part of a joint project involving the IGCP and International Union for Quaternary Research between 2005 and 2011 on sea-level change and human adaptive strategies in the Caspian–Black–Mediterranean Sea Corridor.

*Valentina Yanko–Hombach*

*Bowl from the Tripolye-Cucuteni culture*

Photo: Wikipedia Commons

## The rise of agriculture

Although they situate the Great Flood thousands of years apart, both Chepalyga and Ryan *et al.* posit that there would have been a mass exodus from the flooded areas and that this, in turn, might have allowed new communities to settle and an agricultural economy to develop. Chepalyga even suggests that horses may have been domesticated during this conversion to a productive economy. The available evidence contradicts this theory, as it places horse domestication sometime between 8 500 and 4 300 years ago, long after Chepalyga's Great Flood. Chepalyga also argues that the advent of agriculture could have favoured the rise of ancient civilizations and the construction of the first ships for the purposes of exploration. To support this hypothesis, he cites the oldest-known images of boats, dated to 8 000–9 000 years ago. These rock carvings were discovered in Gobustan on the Caspian coast, south of the Kura River Delta. The carvings show flat-bottomed boats and keel-built vessels suitable for marine navigation, some with as many as 37 oarsmen (*see photo*).

As yet, there is no archaeological evidence linking the Great Floods with the transition from hunting-gathering to stock-breeding. No large, long-term settlements have been found in the submerged parts of the Black Sea, nor any trace of an agricultural economy before 5 718 years ago. The only major ecological catastrophe on record for the late glacial period that prompted major changes in settlement or subsistence is the disappearance of bison from the steppes, which Ukrainian archaeologist Vladimir Stanko attributes to overkill by hunters.

The earliest evidence for animal husbandry was found at Ilipinar on the coastal plain south of the Sea of Marmara. It has been dated to 8 000 years ago. Plants were first domesticated prior to this, during the Younger Dryas. When the global temperature suddenly dropped by several degrees celcius, this corresponded to a drying in the Levant. It seems more and more likely that climate-induced stress caused annual yields of wild cereal strands to drop, creating the need for cultivation. Recent research indicates that some of the main steps happened within years rather than decades. Prior to the Younger Dryas, dense populations of hunter-gatherers lived in some year-round settlements. In addition to hunting, they gathered wild cereals, fruits and nuts. During the Younger Dryas, most of these sites were abandoned. Some groups, however, became sedentary in order to grow cereals. Alongside cultural and social changes, the Younger Dryas played an essential role in this dramatic change in lifestyle, laying the foundations for the early civilizations of Mesopotamia[6] (including the Assyrians and Babylonians) and Egypt (*see box*).

Thanks to the Tripolye-Cucuteni culture, which flourished 5 900–5 600 years ago, we know that there were fully developed farming economies in the forest steppe northwest of the Black Sea by this time. The Tripolye-Cucuteni culture stretched from the Carpathian Mountains to the Dniester and Dnieper regions in modern-day Romania, Moldova and Ukraine.

In addition to developing new techniques for agriculture and animal husbandry, the Tripolye-Cucuteni produced woven

## How a drought brought Egypt's pharaohs to their knees

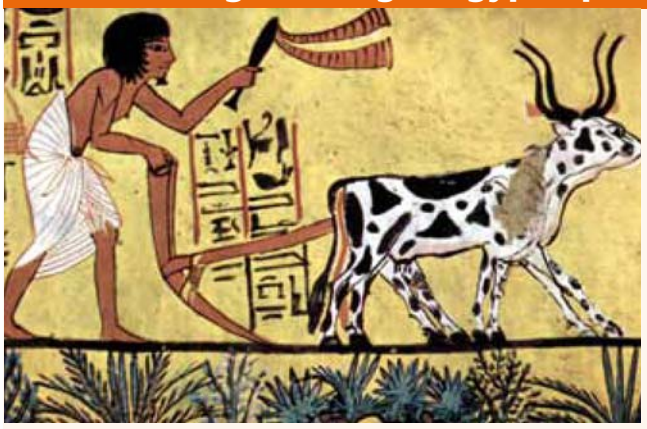


Photo: Wikipedia Commons

*Scene dating from 3 200 years ago*

Some 11 300 years ago, the Sahara was dotted with lakes. Giraffes, hippopotamuses, lions, elephants, zebra, gazelles, cattle and horses roamed across grasslands that may have received ten times more rainfall than the same area today.

By 9 000 years ago, pastoralists had colonized much of the Sahara. They prospered for another 3 000 years, until a shift in the monsoon belt to lower latitudes steered potential rains away from the continent, causing catastrophic droughts. The pastoralists took refuge in the Sahel, Saharan highlands and Nile Valley, where they gave rise to numerous African cultures, including that of Pharaonic Egypt.

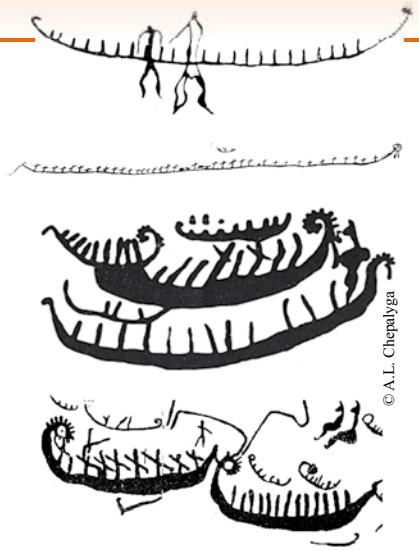
Those who settled in the Nile Valley were forced to abandon nomadic pastoralism for lack of summer rains. Instead, they adopted an agricultural way of life. Small sedentary communities gradually coalesced into large social groups. About 5 200 years ago, the first pharaoh managed to unify Upper and Lower Egypt into a single state with Memphis as its capital.

A long period of prosperity followed, characterized by bountiful Nile floods that produced abundant grain harvests. Successive pharaohs took advantage of this prosperity to launch ambitious pyramid-building programmes to give themselves a tomb worthy of their rank. The pharaohs asserted their authority over the population by claiming the power to intercede with the gods to ensure the Nile River flooded each year. This strategy worked perfectly – until about 4 200 years ago when the harvests failed for six long decades. Brought about by a drop in rainfall at the Ethiopian headwaters during a prolonged El Niño cycle, this drought was so long and so severe that the Nile could be crossed on foot. With the pharaoh powerless to prevent the resulting famine, regional governors seized control.

It took 100 years for Egypt to reunify and thereby bring to an end a century of political and social chaos known as the First Intermediary Period. The return to stability heralded the advent of the Middle Kingdom. This time, the pharaohs would not make the same mistake. To avoid suffering the fate of their improvident predecessors, they would invest massively in irrigation and grain storage.

This work was part of an IGCP project from 2003 to 2007 on The Role of Holocene Environmental Catastrophes in Human History.

***Suzanne Leroy***



© A.L. Chepalyga

*These are the oldest-known images of boats. They were carved into rock on the Caspian coast 8 000–9 000 years ago.*

clothing, finely decorated ceramics, tools and weapons. They also mass-produced salt, as evidenced by what may be the world's oldest saltworks uncovered in Lunca (Romania). One of the most notable aspects of this culture was that, every 60–80 years, the inhabitants would burn down their entire village then reconstruct it. Why remains a subject for debate among scholars.

The Tripolye-Cucuteni culture became vulnerable when the climate grew more arid between *circa* 4 700 and 4 200 years ago. Faced with water shortages and overpopulation, one of the Tripolye groups, Usatovo, turned to stock-breeding, especially horses, sheep and goats. The Tripolye gradually abandoned agriculture in favour of nomadic cattle-breeding. After the total collapse of the Late Tripolye agricultural societies, there followed the gradual rise of the Pit-Grave, Catacomb and Timber Grave cultures based on nomadic cattle-breeding. The Pit-Grave (or Yamna) culture reached its peak during the course of the 3rd millennium BCE[7]. By this time, it encompassed the entire East European steppe, from the Urals in the east to the lower reaches of the Danube River in the west.

## The Bronze Age

The Pit-Grave culture signals the transition from the Stone Age to the Bronze Age in the 4th millennium BCE. It was a contemporary of the Maykop culture, to which is attributed the most ancient bronze sword ever found. The sword was discovered in the northern Caucasus between the Black and Caspian Seas. Implements and weapons from the early Bronze Age have also been found in the Aegean, Anatolia (modern-day Turkey), Egypt and the Levant.

The birth of the European Bronze Age dates back about 5 200 years in the Aegean Sea. The Aegean Bronze Age civilization encompassed the Greek mainland and Greek populations on the Cyclades islands and the islands of Cyprus and Crete.

The technology for smelting copper and its alloy, bronze, spread across Asia and Europe, thanks in part to the development of maritime trade in the Mediterranean, which opened up new markets and favoured the emergence of a monetary economy.

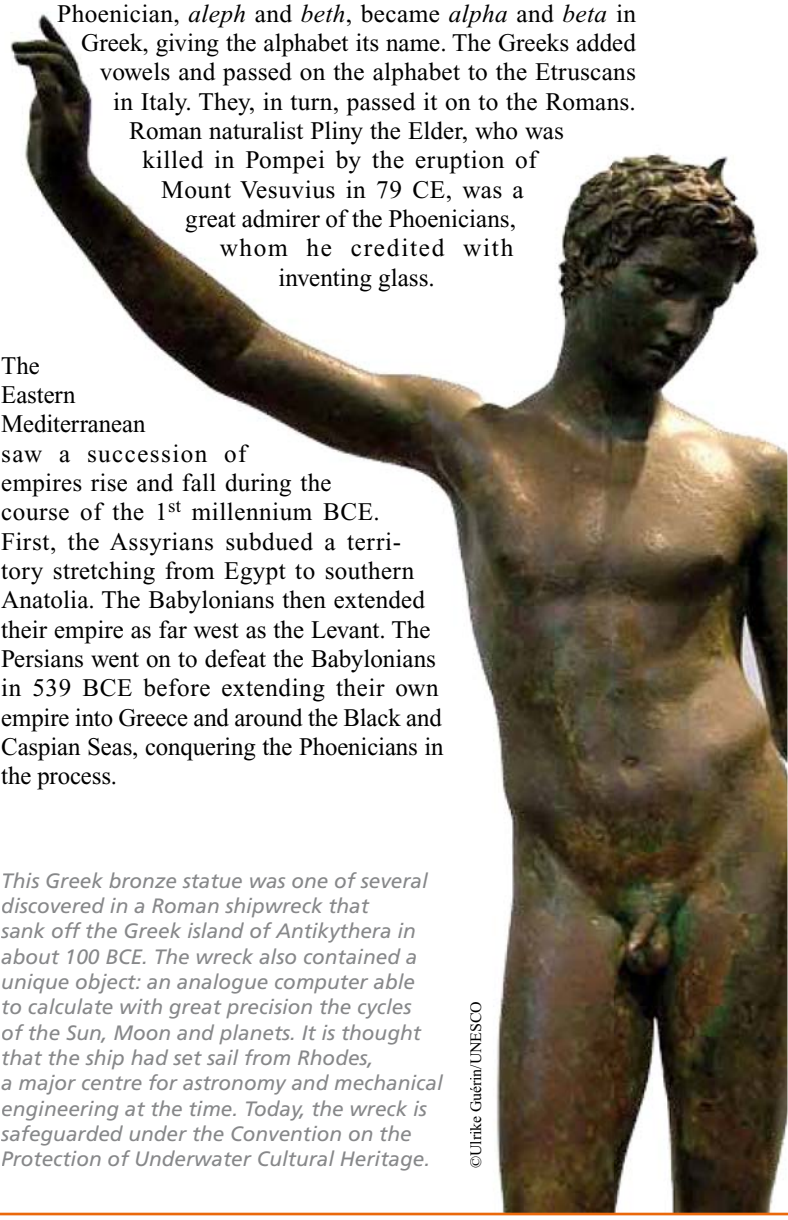
Scholars still debate the reasons for the collapse of the Bronze Age civilizations in the course of the 1st millennium BCE. Some suggest that strong migration during this period may have been linked to power struggles or natural disasters, or both. Conflicts in the Mediterranean may also have made it harder for merchants to obtain bronze goods, inciting them to turn to iron implements.

## Power struggles around the Mediterranean

Excellent navigators, the Phoenicians turned the Mediterranean into a thoroughfare for trade during the Bronze Age. Originally from the Levant, they established several city-states south of Ugarit (Syria) on the coast, including Byblos, Sidon and the major centre of Tyre in 2 750 BCE (*see box and map overleaf*). Phoenician merchants ventured far afield in search of new markets. From about 1 550 BCE onwards, they colonized much of the Mediterranean, including the islands of Sicily and Sardinia, founding cities which functioned as independent political entities, like Kition on the island of Cyprus or Carthage (814 BCE) on the Tunisian coast. From North Africa, they imported minerals like gold and copper, as well as ivory and other goods. After Rome was founded in the 8th century BCE, Carthage, Athens and Rome became rivals for the domination of the Mediterranean's shores.

The Phoenicians developed an alphabet to keep track of their trade with North Africa and Europe. The first two letters in Phoenician, *aleph* and *beth*, became *alpha* and *beta* in Greek, giving the alphabet its name. The Greeks added vowels and passed on the alphabet to the Etruscans in Italy. They, in turn, passed it on to the Romans. Roman naturalist Pliny the Elder, who was killed in Pompei by the eruption of Mount Vesuvius in 79 CE, was a great admirer of the Phoenicians, whom he credited with inventing glass.

The Eastern Mediterranean saw a succession of empires rise and fall during the course of the 1st millennium BCE. First, the Assyrians subdued a territory stretching from Egypt to southern Anatolia. The Babylonians then extended their empire as far west as the Levant. The Persians went on to defeat the Babylonians in 539 BCE before extending their own empire into Greece and around the Black and Caspian Seas, conquering the Phoenicians in the process.



©Ulrike Guérin/UNESCO

*This Greek bronze statue was one of several discovered in a Roman shipwreck that sank off the Greek island of Antikythera in about 100 BCE. The wreck also contained a unique object: an analogue computer able to calculate with great precision the cycles of the Sun, Moon and planets. It is thought that the ship had set sail from Rhodes, a major centre for astronomy and mechanical engineering at the time. Today, the wreck is safeguarded under the Convention on the Protection of Underwater Cultural Heritage.*

Two centuries later, Alexander the Great won back these same territories from the Persians in just a few years. He founded a city on the coast in 331 BCE which would remain Egypt's capital for 1000 years. Alexandria became famous for the Pharos lighthouse, one of the seven wonders of the ancient world. Today submerged, it is safeguarded under the Convention on the Protection of Underwater Cultural Heritage. Alexandria was also famous for its library, the largest in antiquity until it burned down in 48 BCE.

Following a popular uprising in Athens in 508 BCE, the Greeks granted this city-state and others a new form of government which they termed democracy (rule of the people). About this time, the Romans themselves devolved the supreme power to a representative of the people, thereby replacing their kingdom with a republic (the *res publica*, literally public affair). Other civilizations also employed democratic practices at the time, including Mesopotamia and Phoenicia.

As Greek influence waned, many Phoenician cities flourished under Roman occupation. Carthage counted a population of about 100 000 in the 3rd century BCE. This did not prevent it from being completely destroyed by Rome at the height of the third Punic War in 146 BCE. By this time, the Romans controlled so much of the Mediterranean that they even referred to it as *mare nostrum* (our sea). However, their vast Mediterranean empire was also vulnerable to piracy, especially in light of the Romans' growing dependence on grain imports from Egypt. In 30 BCE, Rome secured its supply line – and a new source of taxes – by making Egypt a Roman province.

### Greek colonies on the Black Sea coast

The Greeks did not limit their colonies to the Mediterranean basin. They also established a string of colonies along the northern Black Sea coast between the 7th and 5th centuries BCE at sites close to large estuaries and river mouths. The main colonies were Gorgippia on the Caucasian coast (the site of modern-day Anapa in Russia) and, in Ukraine: Tyras in the Dniester Estuary, Olbia Pontica in the Bug-Dnieper Estuary and Chersonesos, Theodosia and Panticapaeus in Crimea. In a stable environment, the Greeks introduced numerous customs related to agriculture, trade, worship and their own democratic political system,

## Tyre: the city that sank beneath the waves

Six thousand years ago, the island on which Tyre would be founded in 2 750 BCE lay a few metres above sea level. Today a World Heritage site, Tyre was an ideal location for the Phoenician city-state, as the island was easy to defend and an ideal port of call for maritime trade between the Levant, Egypt and the Aegean Sea.

The decline of Crete's Minoan civilization in about 1 400 BCE, coupled with a drop in Egyptian influence, paved the way for Tyre to become a major commercial hub and port in the Eastern Mediterranean. During the Iron Age, the city prospered, thanks to locally made glassware and cedarwood products, as well as the invention of a purple dye from sea snails that made expensive Tyrian textiles a must for any nobleman's wardrobe. The Greek historian Theopompus (born circa 380 BCE) wrote that 'purple for dyes fetched its weight in silver at Colophon' (city in Asia Minor).

Tyrian merchants ventured far and wide in search of new markets. They founded many prosperous trading centres, including Carthage in modern-day Tunisia and Cadiz on the Atlantic side of the Gibraltar Strait. The growing maritime traffic obliged the city to build complex port equipment to enable sailing vessels to berth and unload and store their cargo.

Tyre was repeatedly attacked, including by the King of Assyria, Shalmaneser V, between 727 and 722 BCE, and by Egypt. The city withstood most of these onslaughts thanks to its imposing fortifications. Alexander the Great nevertheless managed to subdue Tyre on his way to conquer Egypt.

During his seven-month siege of the city in 332 BCE, he built a causeway linking the island to the mainland using cut stones from buildings he had demolished. Over time, sediments accumulated on this causeway, creating a spit (tombolo) and turning the island into a peninsula (*see figure*).

In 64 BCE, Tyre became a Roman province. By this time, enough sediment had accumulated on the spit for the Romans to build an impressive urban infrastructure, including a stadium and necropole.

However, a serious problem of subsidence affected Tyre towards the end of Roman occupation in the 4th century CE. Seventeen hundred years later, divers discovered a submerged urban quarter 2 m beneath the water level, together with a quarry and remnants of the original city walls.

This dive was one of about 100 carried out in 2002 within a project funded primarily by UNESCO's World Heritage Centre and the Association internationale pour la sauvegarde de Tyr. A multidisciplinary team travelled to Tyre to study the ancient port with the support of CEDRE, a Franco-Lebanese agreement for scientific cooperation. The first objective was to locate the port, no easy task when much of it lies buried beneath the current city centre.

The second objective was to date the ancient ports. Due to the dense urban fabric, the team relied on drilling samples to probe past environmental changes. These samples can be radiocarbon dated, thereby giving a rapid and accurate chronology of events. If we combine radiocarbon dating with information from ancient texts and archaeological publications, it appears that the ancient port of Tyre was partially abandoned in the 6th century CE for both environmental and cultural reasons: the Levant suffered earthquakes and numerous tsunami between the 4th and 11th centuries CE which caused the ancient city to sink farther; and, by 650 CE, the south of the Levant, Persia and Egypt were all controlled by Islamic forces.

In light of these discoveries and given the speed with which Tyre is urbanizing, the research team recommended to the municipality and the Department of Antiquities that they protect all the vestiges of the port lying 5 m or less underwater.

***Christophe Morhange* and Nick Marriner****

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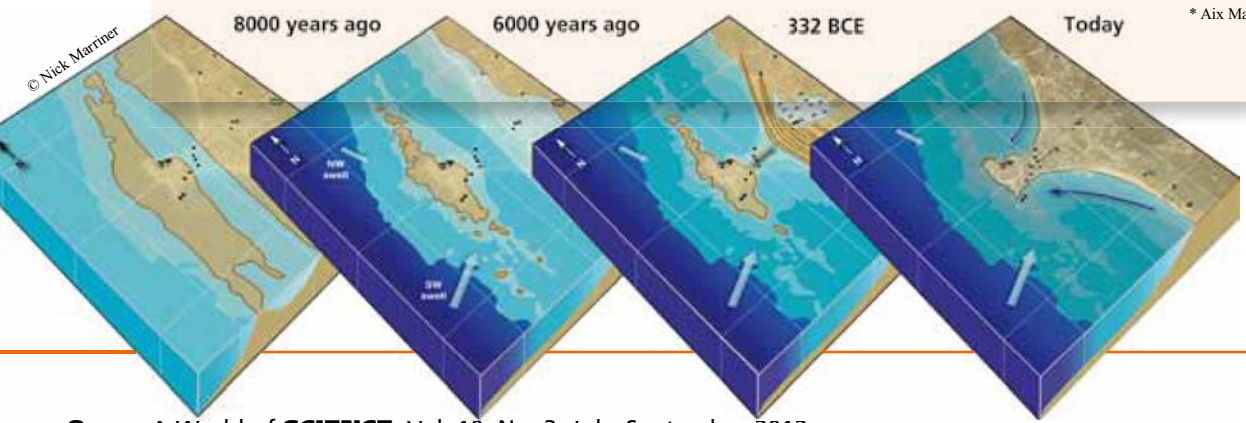


*Tyre's changing seashore over the past 8000 years*

gradually improving the welfare of the local populations. First, they imported the concept of city-state (*polis*) then, in the 4th and 3rd centuries BCE, they integrated each *polis* with the surrounding countryside (*chora* in Greek) to form a single territory.

Olbia Pontica was one of the first Greek settlements. Dating back to the 7th century BCE, it was established on the island of Berezan, about 2 km from Bug Estuary. At the time of Greek colonization, the island was part of the mainland and remained so until the 1st century CE. Between the 6th and 3rd centuries BCE, Olbia Pontica became one of the largest of all Greek settlements with an estimated population of 30 000–40 000, including the hinterland where intensive agriculture was practiced.

A combination of factors triggered the general decline of settlements in the North Pontic area in the 2nd and 1st centuries BCE. Growing aridity caused harvests to fail at a time when the settlements were overpopulated. This led to a spate of popular uprisings opposing rich and poor. In parallel, Scythians, Sarmatians and other nomadic populations who had been cohabiting peacefully with the Greeks invaded the settlements. Archaeological sites in most northwestern Pontic colonies attest to the numerous armed conflicts which erupted among these cohabiting cultures during this fraught time.

The environmental crisis deepened towards the end of the 1st century CE when sea level rose by 1–3 m, causing large-scale soil erosion and landslides, as well as salinization and water-logging of soils. Known as the Nymphaean transgression, this rise in sea level was the result of shifting wind patterns over the Atlantic Ocean. These winds dumped additional rainfall on the region over a very short period, swelling the rivers which emptied into the Black Sea. The shift in wind patterns also channelled greater volumes of water first into the Mediterranean Sea then, through the Marmara Sea and Bosphorus Strait, into the Black Sea.

## Mediterranean civilizations in a changing environment

Mediterranean civilizations also had to cope with a changing environment. 'By about 6 000 years ago, towards the end of the Holocene Optimum, all the freshwater from the melted ice sheets had found its way back into the oceans,' observes Paolo Pirazzoli, 'raising sea level in the Mediterranean by 120 m. This influx of water exerted pressure on the seafloor, causing it to

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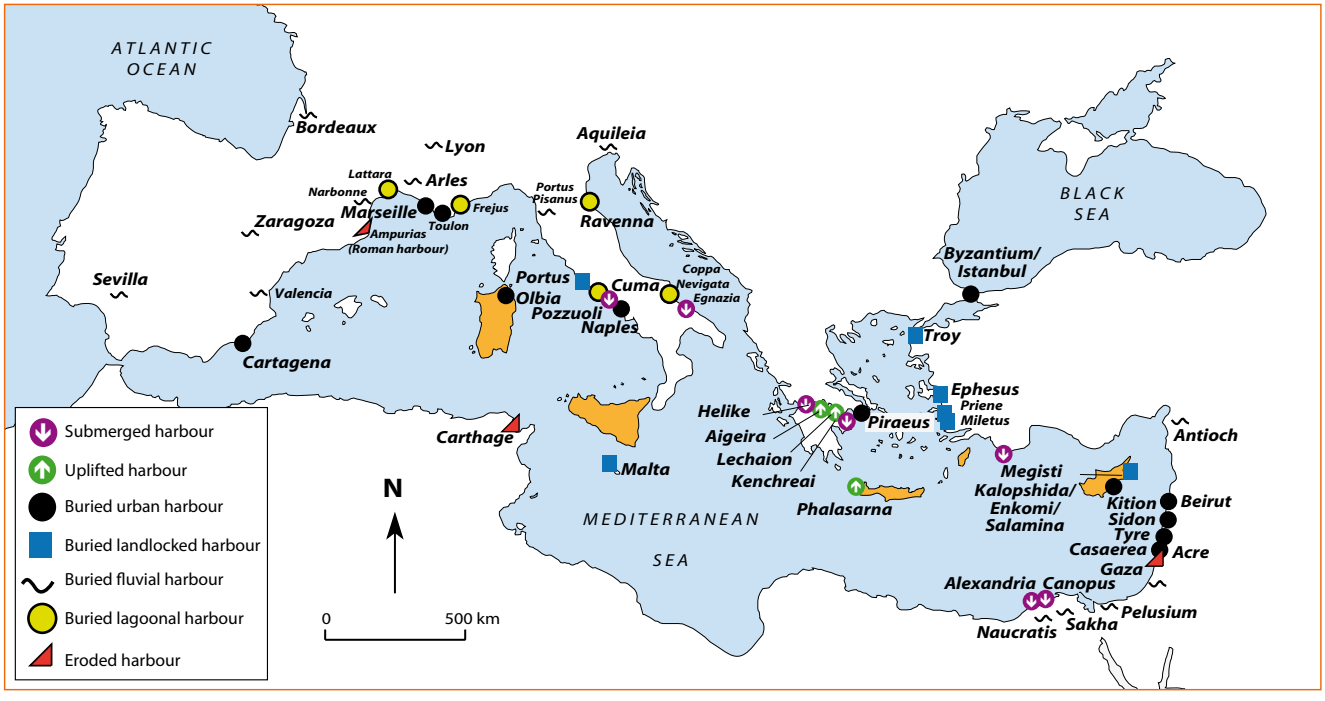
*Ruins of Ephesus, on the west coast of Turkey. First Greek then Roman, Ephesus had a population of more than 250 000 by 100 BCE, making it a megacity by the standards of antiquity. Today, Ephesus lies 8 km inland from the sea but, from excavated sedimentary deposits, we know it was once a port.*




Reproduced with permission. © Map Marriner, N. (2007) Geoarchaeology of Phoenicia's buried harbours.

*Some of the Mediterranean's ancient sunken harbours. The islands highlighted in yellow are, from left to right, Sardinia, Sicily, Crete, Rhodes and Cyprus.*

subside in shallow waters in particular. As a result, sea level rose less along the coast than in deep waters. This explains why humans were able to access Cosquer Cave, for example, which today lies 37 m below sea level (*see box*).' For the past 6 000 years, the level of the Mediterranean Sea has remained more or less stable.

'Over time,' Pirazzoli explains, 'sediments deposited near river estuaries caused the coastline to expand into the sea, leaving ports high and dry, as in the case of Ephesus in the Aegean Sea (*see photo*). The coastline was also modified by tectonics, above all in the Eastern Mediterranean. An earthquake in the Golf of Corinth in 373 BCE caused the land to subside, submerging the Greek town of Helike. In 365 CE, another earthquake had the opposite effect, raising the western part of Crete by 8 m.'

The earthquake of 365 CE generated a tsunami which swept across the Eastern Mediterranean. The wave reportedly penetrated far inland in Alexandria, drowning more than 5 000 people, and also caused great suffering on the island of Sicily. Records suggest that most large earthquakes and tsunamis in the Mediterranean are generated south of Crete. This is logical, as this is the only segment where you still have an old oceanic plate moving under (subducting) the Eurasian continent.

The Minoan civilization originated on the island of Crete, where it built extravagant palaces during the Bronze Age, including Knossos. Most probably once a century, these palaces suffered serious damage in an earthquake but were rebuilt each time. A maritime power, the Minoan civilization came to dominate the islands of the Aegean Sea, including that of Santorini.

When the Thera volcano on Santorini erupted about 3 600 years ago, the population of Akrotiri managed to evacuate. We know this because not a single skeleton has been found under the layers of ash which buried the town and have preserved many of its frescoes. The Santorini eruption, the largest volcanic eruption witnessed by humanity since the end of the

## Cosquer Cave: the sunken world

Today, Cosquer Cave near the French city of Marseille lies below sea level. A sanctuary used for religious ceremonies, it was abandoned between 27 000 and 19 000 years ago for an unknown reason. Numerous statictites have fallen from the ceiling, suggesting that an earthquake may have made the cave unsafe for a time.

The walls of the sanctuary were decorated by hunter-gatherers with stenciled hand prints and engravings or coloured paintings of animals: horses (35.6%), ibex, chamois, bison and auroch (18.6%) and deer (9.6%). Some rarer subjects for prehistoric rock art are represented, such as saïga (Eurasian antelope), megaceros (extinct Eurasian giant deer) and elk, as well as marine animals that include penguins and seals. One engraving could even be interpreted as being half-human, half-seal.

We know from an ancient accumulation of pebbles and mussel shells cored near the Planier lighthouse 10 km to the southwest that, by 14 000 years ago, the Mediterranean had risen to 100 m below the present level. At the base of the Ile of Riou, algal rims encrusted in the limestone cliff face testify to a sea level 55 m lower than today about 10 000 years ago. Another 1 000 years and the entry to Cosquer Cave would disappear beneath the waves.

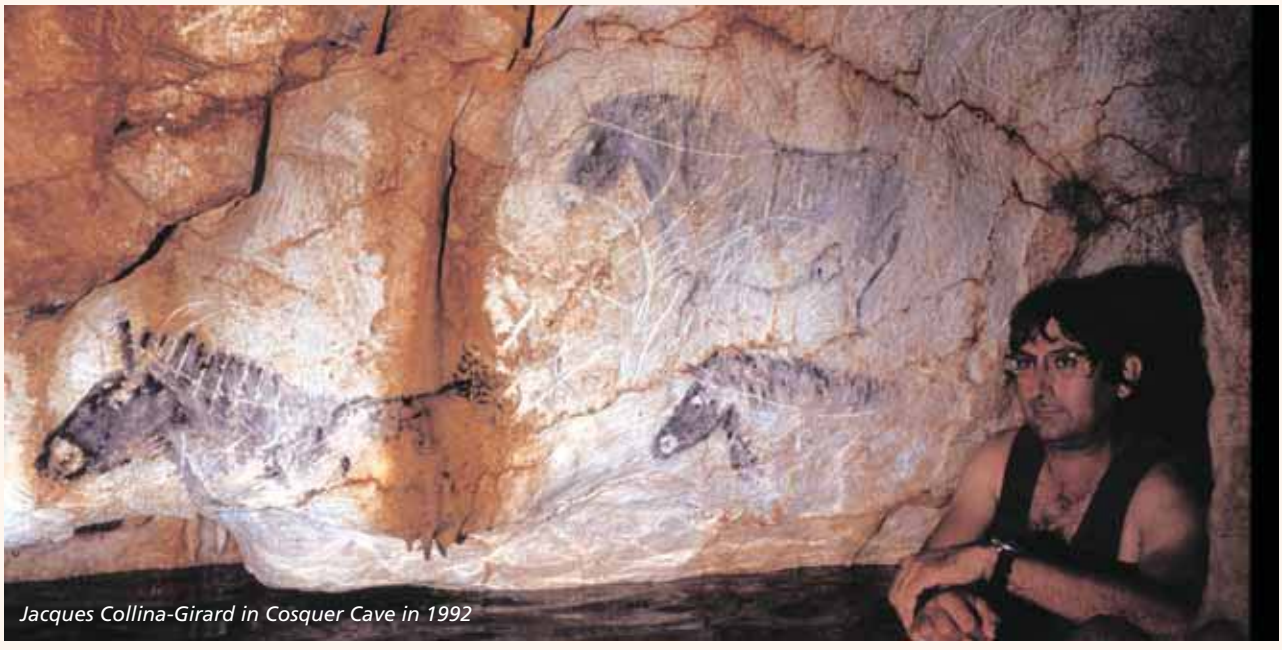
The cave is closed to the public but if you are lucky enough to be authorized to visit, you will find a dry environment after the initial perilous dive. From the entrance 37 m below sea level, a narrow tunnel sloping gently upwards for 116 m takes you to one of two spacious semi-submerged caves. Most of the wall paintings have been engulfed by the sea in the caves explored by the speleologists; at the back of one cave, a panel showing horses and ibex, drawn with charcoal or engraved, is slowly disappearing beneath the current sea level (*pictured*).

A geomorphological study in 2001 revealed that sea level only stabilized in the ancient port of Marseille 1 500 years ago. Marseille was founded by the Greeks about 2 600 years ago before coming a Roman city.

Cosquer Cave falls under the Convention on the Protection of Underwater Cultural Heritage managed by UNESCO.

***Jacques Collina-Girard****

* University of the Mediterranean, Marseille, France



*Jacques Collina-Girard in Cosquer Cave in 1992*

Ice Age, set in motion a series of environmental changes that would eventually lead to the demise of the Minoan civilization. The ash from the Minoan eruption blanketed fields on Crete, poisoning crops and wrecking the harvest for years. By the time the Greek Myceneans took over Crete about 3 450 years ago, Minoan society had collapsed, leaving a power vacuum.

British archaeologist Arthur Evans (1928) was the first to suggest that successive earthquakes were responsible for the destruction of the palace at Knossos. In 1936, Carl Blegen also ascribed structural damage to the sixth layer of ruins[8] in the city of Troy (Asia Minor, *see map*) to a massive earthquake about 3 300 years ago. Likewise, Claude Schaeffer associated structural damage to Ugarit (Syria) with successive earthquakes. In fact, Schaeffer drew a parallel between structural damage to ruins at all Late Bronze Age sites throughout the Middle East and the Eastern Mediterranean in his *Stratigraphie Comparée* (1948). This idea gave rise to the myth of an earthquake storm, or 'Late Bronze Age paroxysm', occurring in a 50-year time period between 1 225 and 1 175 BCE, which caused the demise of the Late Bronze Age civilizations throughout the region.

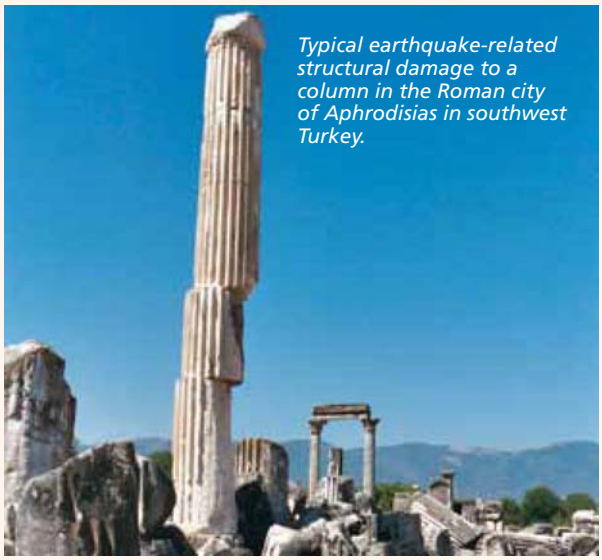
## Signs of trouble in all that rubble

Archaeoseismology is a young discipline that sets out to fill gaps in the historical and geological record of earthquakes. After all, the instruments that can record earthquakes have only been around for about 100 years.

Archaeoseismology studies cultural indicators of catastrophic earthquakes, such as structural damage to buildings (*see photo*) and myths and legends. The biblical story of the walls crumbling in the city of Jericho definitely refers to an earthquake. Jericho is built on top of one of the major earthquake faults in the region, the Dead Sea Transform Fault.

Archaeoseismology calls upon the expertise of historians, anthropologists, archaeologists, geologists, seismologists, geophysicists, architects and structural engineers. The challenge for one IGCP project running from 2008 to 2012 was to bring all these disciplines to the table to develop a rigorous methodology for this burgeoning field.

***Manuel Sintubin***



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*Typical earthquake-related structural damage to a column in the Roman city of Aphrodisias in southwest Turkey.*

It is true that the archaeological evidence of earthquakes from Bronze Age sites in the Eastern Mediterranean confirms that earthquakes did affect these ancient settlements. The Eastern Mediterranean and Middle East is indeed seismically a very active region. A debate within an IGCP project on archaeoseismology (*see box*) concluded that these earthquakes may have influenced the local power balance but that they in no way led to a catastrophic collapse of the Late Bronze Age civilizations.

### We can learn from the past

Studying the past can teach us a lot about how natural phenomena and changing environments affect civilizations and how they manage to adapt. These natural phenomena may be a 'flash in the pan' like an earthquake, volcanic eruption or tsunami, or more insidious threats like sea-level rise as a corollary of climate change. How effective are the adaptive strategies that contemporary human societies have put in place to cope with extreme natural hazards and the environmental change expected this century? To what extent are we still able to adapt? These questions are of critical socio-economic and political importance for every country.

We have come to realize that the interrelation between human societies and their natural environment is one of such complexity that no single science can alone complete the puzzle. That is why, increasingly, palaeostudies are not purely the purview of geoscientists but also involve the collaboration of biologists, archaeologists, historians, meteorologists and other specialists.

*Valentina Yanko-Hombach[9], Suzanne Leroy[10], Manuel Sintubin[11] and Susan Schneegans[12]*

*Read about these and other IGCP projects in* Tales set in Stone, *see page 24*

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1 *Dates in the present article are based on non-calibrated radiocarbon dating using the Carbon 14 method. For details of this method, see* A World of Science, *October 2007 (page 4).*

2 *Brackish water has a salt content of about 5–12‰. Today, the salinity of the Black Sea varies from 1–3‰ in the Danube Delta to 26‰ near the Bosphorus, compared to 39‰ in the Eastern Mediterranean.*

3 *The Levant comprised modern-day Israel, Lebanon and Palestine, western Jordan and Syria.*

4 *Scientists refer to it as the Early Neoeuxinian Lake.*

5 *Scientists refer to it as the Early Khvalynian Lake.*

6 *Mesopotamia comes from a Greek word meaning 'land between rivers', used to designate the Tigris–Euphrates river system, a territory largely corresponding today to Iraq and parts of Iran, Syria and Turkey.*

7 *BCE (Before the Common Era) and CE (Common Era) mark the period prior to and following the start of the Gregorian calendar that has become the common standard today.*

8 *Troy was rebuilt six times, according to evidence left behind in six destruction layers. The Archaeological Site of Troy is a World Heritage site.*

9 *IGCP project co-leader, I.I.Mechnikov National University, Odessa, Ukraine, and Avalon Institute of Applied Science, Canada*

10 *IGCP project co-leader, Institute of Environment, Brunel University, UK*

11 *IGCP project co-leader, Katholieke Universiteit, Leuven, Belgium*

12 *Editor,* A World of Science