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SEA LEVEL CHANGES FROM THE I TO THE XIII CENTURIES AND THEIR CLIMATOLOGICAL SIGNIFICANCE

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Abstract: Correlation between archaeological ruins and geological observations show that the region of the port city of Caesarea in central Israel has been stable during the last 2000 years. This stability, and the low range of the diurnal tidal variations of sea level, attributes global climatic significance to the reconstructions of various sea levels during several clear archaeological time-frames. It seems that while 2000 years ago sea level, and therefore also climate, was similar to the present one. Sea level was higher in the VII–VIII Centuries AD, and the climate was probably warmer, and sea level was lower, and the climate colder, in the XII–XIII Centuries AD. Consequently it is suggested that the presumption that the present global climatic warming in anthropogenic requires strong supporting evidence. On the other hand, the link between recent heavy damages to coral reefs and the anthropogenic activities that caused the rise in atmospheric CO_2 content seems quite likely.

Keywords: sea level change, active tectonics, climate change.

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ИЗМЕНЕНИЯ СТОЯНИЯ УРОВНЯ МОРЯ С I ВЕКА ПО XIII ВЕК И ИХ КЛИМАТИЧЕСКОЕ ЗНАЧЕНИЕ

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Аннотация: Корреляции между археологическими материалами и геологическими наблюдениями показывают, что регион портового города Кейсария в центральной части Израиля в течение последних 2000 лет был относительно стабилен. Такая стабильность и малый диапазон суточных приливно-отливных колебаний уровня моря позволяют провести реконструкцию разных уровней моря в рамках ряда археологических временных периодов с учетом климатической значимости. По нашему мнению, в течение 2000-летнего периода стояние уровня моря, а также климат были аналогичны современным. Уровень моря был выше в VII–VIII веках н.э., а климат, возможно, был теплее; в XII–XIII веках н.э. уровень моря был ниже, а климат холоднее. Высказывается мнение, что предположение о том, что современное глобальное потепление вызвано антропогенным воздействием, нуждается в убедительных доказательствах. Вместе с тем, весьма вероятной представляется связь между современными значительными разрушениями коралловых рифов и антропогенными факторами, вызывающими повышение содержания углекислого газа в атмосфере.

Ключевые слова: изменение уровня моря, активная тектоника, изменение климата.

Introduction

Yachts that sail in recent summers in northern Canada and pass easily from the northern Atlantic Ocean to Beaufort Sea, north of Alaska (Fig. 1), are commonplace recently. Such sea-voyages are recent phenomena, and were not possible even some 20 years ago because sea-ice covered the routes of northern Canada and made then unnavigable for small vessels. Only ice-breakers could have sailed in the Arctic Sea until very recently, and well known is the courageous voyage of the explorer Roald Amundsen through the Northwestern Passages, that lasted 3 years, from 1903 to 1906 (Fig. 2).

The massive melt of marine glaciers in the Arctic seas is a clear evidence of global warming, although the continental glaciers, located mostly in Antarctica and Greenland, are still mostly intact, and sea-level rise is barely noticeable. It should be noted that there is a major difference in the rate of melting of sea- and continental ice as far as sea level is concerned. The melting of the ice floating on the water of the ocean does not change the sea level, the same way that the melting of ice cubed in a glass of Whisky does not change the level of the liquid in that glass. On the other hand, accretion of ice on the continents detracts water from the sea, and the melting of continental glaciers raises the global sea level. Consequently, a change in sea level is a reliable proxy for global climatic variation, because sea level is uniform everywhere, and it represents the balance between the quantity of water in the oceans versus the amount of water stored in continental glaciers.

Precise measurement of sea level is far from obvious or simple, firstly, because sea level changes incessantly due to the diurnal tidal oscillation. Tidal sea-level variations occur approximately every 12 hours and 30 minutes, and they are not uniform around the globe or throughout the lunar month. While the differences between spring and neap tides are not large, disparity between high and low tide at various locations is significant. Tidal differences in the Bay of Fundy in East Canada can reach 14 m, whereas these same variations in the eastern Mediterranean are circa 30 cm. Furthermore, tide is not the only obstacle to precise sea-level measurement, the stability of land, the frame of reference, is another. Indeed the position of land does not vary as quickly as sea level, but many coasts move vertically for various tectonic or structural causes, and may reach a change rate of more than 2 mm per year. The region of SE Anatolia, for example, rise at a rate of ca. 2.5 mm/yr [*Pirazzoli, 1992*]; north Eurasia and north America are still rising due to the removal of the load of the ice-age glaciers [*Sella et al., 2007*], while Alexandria on the Nile Delta subsides at a rate of 1 mm/yr due to the sedimentary load of the Nile River [*Emery et al., 1988; Stanley, 1988*]. There is ground to presume, therefore, that reliable sea-level measurements should be carried out in sites were the daily tides are small, and land stability was measured and verified.

Land stability in recent times can be measured reliably in reference to archaeological structures that were build level, or in a known, pre-planned gradient, such as aquaducts. Coastal Israel is a preferred location to measure sea-level variations in historic times because the daily tides are small and Roman aquaducts and other archaeological sea-related constructions can serve as a frame of reference to measure the geological stability of the area that they transect. Aquaducts, for example, are long structures built with very gentle gradient, therefore they are well suited to measure geological stability. In the area of Caesarea in coastal Israel the Romans built two high aquaducts, the first was built from 10 BC by the orders of King Herod the Great and the other – in 135 AD, by the Roman Emperor Hadrian. The two aquaducts are merged together, column to column and arch to arch along most of their length (Fig. 3). They both acquired their water from springs at the southern foothill of Mt. Carmel and carried it across the coastal plain, from east to west, and then along the coast, from north to south, to the contemporaneous municipal water distribution system. Dating of the archaeological evidencewas carried out using ^{14}C dating of embedded organic finds, and correlations of dated ceramic artifacts [*Raban, 2009*]. Geodetic and geologic measurements [*Mart, Perecman, 1996*] show that the sections of the aquaducts built on Pleistocene sandstone maintained their original gradient of approximately 0.5 m per km, as recommended

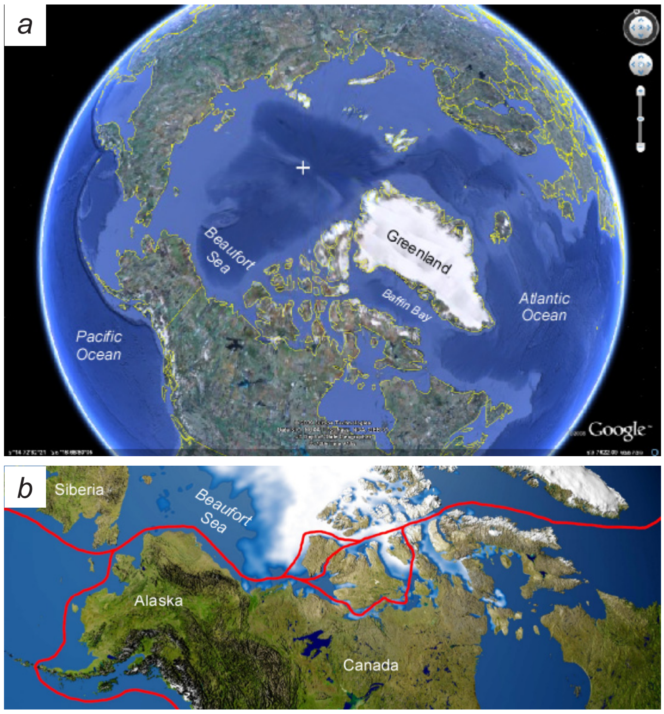

Fig. 1. The Arctic region. *a* – regional map (source: www.earth.google.com); *b* – chart of the Northwestern Passages from the Atlantic Ocean to Beaufort Sea and the northern Pacific (source: www.wikipedia.org).

Рис. 1. Арктический регион. *a* – региональная карта (источник: www.earth.google.com); *b* – схема проливов на северо-западе из Атлантического океана в море Бофорта и в северную часть Тихого океана (источник: www.wikipedia.org).

Fig. 2. The hazards of crossing the NW Pasage is emphasized by a detail of the painting Das Eismeer (The Sea of Ice), 1823–1824, a painting by Caspar David Friedrich, inspired by William Edward Parry's account from the 1819–1820 expedition. Source: www. wikipedia.org.

Рис. 2. Опасность прохождения северо-западных проливов. Картина *«Ледяное море»*. На создание этой картины художник Каспар Д. Фридрих (1823–1824) (*Eismeer. Caspar David Friedrich)* был вдохновлен описаниями экспедиции 1819–1820 гг., составленными Уильямом Э. Пэрри (*William Edward Parry*). Источник: www.wikipedia.org

Fig. 3. The Roman high aquaduct near Caesarea, coastal Israel. The Aquaduct transects the coastal plain from east to west, and then runs some 5 km along the coast, and still, after 2000 years, it still maintains its average gradient of 0.5 m/1 km, as recommended by Vitruvius. This gradient indicates that the areas transected by the aquaduct were tectonically stable during the last 2000 years.

Рис. 3. Римский акведук неподалеку от г. Кейсария, Израиль. Акведук пересекает прибрежную зону в направлении с востока на запад, затем идет примерно 5 км вдоль морского побережья. Даже по прошествии 2000 лет его градиент по-прежнему составляет в среднем 0.5 м / 1 км, в соответствии с рекомендациями Витривиуса (*Vitruvius*). Такой градиент показывает, что участки, по которым проходит акведук, оставались тектонически стабильными в течение последних 2000 лет.

by the Vitruvius[1]. The preserved Caesarea aquaducts show that the coastal plain off southern Mt. Carmel has been tectonically stable for the last 2000 years.

Having found out that the Caesarea region has been tectonically stable since the construction of the high aquaducts, the present elevation of structures and other features that relate to ancient sea-levels were measured, in order to reconstruct the their elevation during specific historic periods. Comparative measurements were carried out at the royal swimming pool, discovered in the ruins of the coastal Herodian palace. The pool was built so that seawater could flow in and out and circulate freely, to keep the water fresh. The channels that let the water in and out are still at sea level (Fig. 4). Therefore it is plausible that sea-level of 2,000 years ago was similar to the present one, therefore there is ground to presume that the climate during the early Roman period in Palestine was similar to the present one.

Furthermore, a method was developed to measure and date changes in sea level in antiquity using coastal water wells [*Nir, Eldar, 1987*]. The dominant rock formation in the Israeli coast is calcareous sandstone of Pleistocene age. The freshwater aquifer in the sandstone is freatic, derived from rains, and it floats on seawater that penetrate the coastal subsurface from the ajacent sea. The gradient of the penetrating seawards is approximately 1% landwards, and the slope of the overlying fresh water aquifer is circa 1% seawards, forming a wedge-shaped aquifer. The water level in ancient wells is marked by a horizon of dry algae that habitated to upper part of the water in the wells. Dates of the wells were obtained by dating the ceramic artifact fragments encountered in the well.

Measurement of the water level in abandoned well in Caesarea and the dating of the ceramics in these wells [*Sivan et al., 2004*], show that during the VII–VIII Centuries sea-level was higher than the present one by approximately 50 cm, indicating a warmer, and, in the Levant, also drier period, that prevailed some 1300 years ago. Issar [*2003*] remarked that such climatic conditions could form a sound incentive for the inhabitants of dry Arabia, in addtion to their religious zeal and drive, to go and conquer the Levant. Then, the late A. Raban [*pers. comm., 1995*] investigated a series of columns submerged flat in shallow seawater, and showed that these formed the foundation of a jetty from the Crusaders' times. Since the jetty was probably raise above sea level, sea-level during the Crusaders' times was approximately 0.5 m below the present one. The Crusaders' jetty indicates therefore that sea level during the XII–XIII Centuries global climate was probably

[1] Marcus Vitruvius Pulio (15 BC – 80? AD) was a Roman engineer and architect who served as a chief military engineer (ballista) in the army of julius Caesar. Vitruvius is known for his textbook *De Architectura*, its 10 volumes, which survived, served as guide books to Roman engineers.

Fig. 4. Relicts of the Herodian royal swimming pool and the coastal palace in Caesarea. Channels were cut in the rock to enable circulation of seawater. It is evident that the present sea level is very close to the level during the construction of the pool, some 2000 years ago.

Рис. 4. Руины бассейна у дворца царя Ирода и дворца на побережье в г. Кейсария. Для циркуляции воды в камне были прорублены каналы. Очевидно, что уровень моря сейчас очень близок к уровню того периода, когда был построен данный бассейн, т.е. примерно 2000 лет назад.

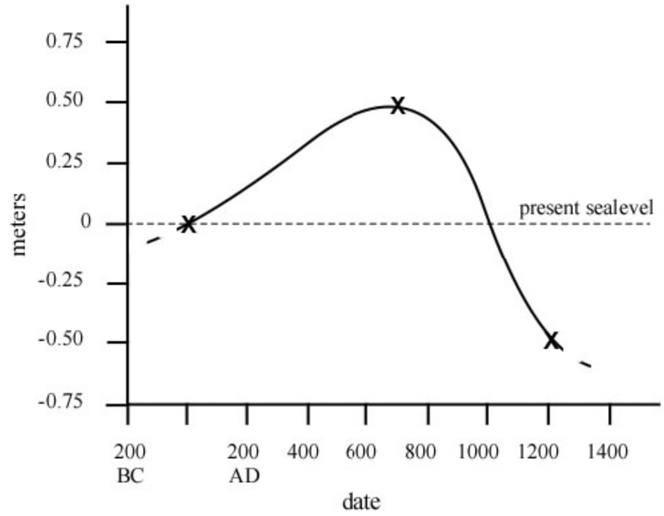

Fig. 5. Interpolated variations of sealevel in the eastern Mediterranean, as indicated by measurements in caesarea duirng the I, VII and XIII Centuries (marked by ×). The curve before and after these times is extrapolated.

Рис. 5. Кривая изменений уровня стояния моря в восточной части Средиземного моря по замерам в г. Кейсария по состоянию в I, VII и XIII веках (помечено знаком ×). До и после указанных сроков кривая была экстраполирована.

colder. The conteproraneous climate in western and central Europe was colder and wetter [*Fagan, 2000*], which could contribute to the religious zeal and the social constraints in Christian European of that time to set forth to the Crusades, and to conquer the warmer Holy Land and other countries on their route. The variations of sea level measured in Caesarea are summarized in Fig. 5.

In Caesarea specifically, and in coastal Israel in general, conspicuous archaeological relicts that are younger than the Crusaders' period (end of XIII Cnetury) are rare, because the Mammeluks, who conquered the land from the Crusaders, razed to the ground all the coastal cities and their fortification to prevent the Crusaders from returning to the Holy Land and gain a safe beach-head. Consequently scientific archaeological exploration during the last 60 years discovered remarkably undisturbed finds.

THE GEOLOGICAL SIGNIFICANCE OF THE ARCHAEOLOGICAL EVIDENCE

These and other findings were also interpreted to indicate different indicators of sea-level. Neev [*1977*] and Neev et al. [*1976, 1987*] presented numerous findings that, presumably, were indications for intensive vertical structural offsets, which they interpreted that the coastline is constrained by repeated large faulting events. Neev et al. [*1987*] encountered Byzantine[2] ceramic shards covered with oysters, barnacles and other shells of marine molusc. The shards were discovered on land and Neev et al. [*1976; 1987*] claimed that these shards were found *in situ*, therefore they indicate the subsidence and the subsequent uplift of the Caesarea sandstone ridge. Furthermore, Neev et al. [*1976*] also reported the occurrence of large acummulations of the seashell *Glycimeris sp.* at elevations of 5-10 m above the present sea level, which were dated to ca. 1000 AD. These shells indicated, according to Neev et al., intensive faulting and large tsunamis that occurred after the early Islamic period[3]. Neev et al. [*1987*] summarily argued that a large fault runs along the Israeli coastline, and that structural processes displaced the western block downwards after the VII Century, and then uplifted it several meters after the XIII Century. Assessment of these observations during extensive archaeological excavations in Caesarea [*Raban, 2009*] found out that the shells-covered Byzantine ceramics was dredged during the rehabilitaion of Caesarea harbor in the VI Century and the dredged material was left behind along the coastal zone. The origin of the *Glycimeris* shells seems to derive from a burial custom of Moslems during the early Islamic period, when they used to cover their graves with a thick layer of shells. It seems that the evidence that supports intensive neotectonic activity is anthropogenic. As for the claims for large vertical fault offsets in Caesarea, geodetic surveying of the high aquatuct described above [*Mart, Perecman, 1996*] show that the ducts, as well as their lithologic foundation, were not affected by vertical offset and the region has ben tectonically stable during the

[2] The Byzantine period in Israel lasted from 324 to 638 AD.

[3] The Early Islamic period in Palestine lasted from 638 to 1099.

last 2000 years at least. Consequently, the evidence of sea level and its variations discerned in various structures and several historic periods indeed reflect changes in global sea level.

The significance of these observations of sea-level variations is that global climate was similar to the present one some 2000 years ago, it was warmer circa 1300 years ago and colder approximately 800 years ago.

Plio-Quaternary climate variations

Climate variations characterize the natural history of planet Earth. Since global geography has always been dynamic on geological time scale, and since global climate has been determined primarily by expanses of continuous open seas in the tropical regions, climate variations are the consequences the dynamic geography of the planet. Large equatorial seas increased the absorption and improve the distribution of solar irradiance and caused warmer climates, while stronger polar oceanic currents brought about colder climates. The processes of plate tectonics that changes the configuration of the oceans and the position of the continents are the primary reason for the climatological variations. However, the last 7 Ma have been characterized by especially fast and abrupt climate changes that are rare in pre-Miocene epochs, changes which became more drastic during the Quaternary.

Two paloegeographic events caused the remarkable cooling of the global oceanic system since the late Miocene, which subsequently led to extreme and fast climate changes. Some 7 Ma. First, the marine passage between the Pacific and the Indian oceans diminished due to the northwards motion of the Indo-Australian plate, and the Indian Ocean cooled considerably [*Cane, Molnar, 1995*], second, in the late Pliocene, some 2 Ma, the marine passage between North and South America, in the present Panama region, closed as well [*Discoll, Haug, 1998; Haug et al., 2001*]. The Atlantic equatorial currents could flow westwards no more, and the Pacific Ocean cooled drastically. Since the equatorial oceanic system, and specifically the equatorial Pacific, are the main heat reservoirs of planet Earth, world climate cooled considerably. This climatic cooling rendered the cyclic orbital variation, and subsequently the effective solar irradiance that reaches Earth, climatic significance (see J. Imbrie and K. Imbrie [*1979*] for details). It should be stressed that the orbital variations probably ocurred since the earth stabilized in its orbit around the sun, but climate change due to these changes took place only when the paleogeography of the continents led to metastable climatic conditions, like the variable climate during the last 7 Myr.

The orbital variations that change the effective solar irradiance that reaches Earth were analyzed already by Milankovic [*1920*]. The cyclic variation of the excentricity of the eliptic orbit of the earth aroud the sun lasts about 100000 years, changes in the tilt of the axis of the earth rotation to the ellipsoid, which ranges from ca. 21° to 24.5°. has cycles of 42000 years, and precession changes the tilt further on a cycle of 23000 years [*Imbrie J., Imbrie K., 1979*]. The climatologic significance of these cycles is derived mostly, but not uniquely, from changes in the solar irradiance in the northern hemisphere during the summer. When the irradiance increases, the winter ice melts, but during insolation decreases, snow turns into ice and accumulates on the continents. The water that builds the ice is detracted from the sea and its level drops. Thus climatic variations, which had been measured using oxygen isotopes, are expressed as sea-level changes (e.g. [*Emiliani, 1957*]). The cyclicity of climate variations in the Quaternary is not uniform, because in some cases the climatic changes canell each other, and in other, the variations enhance each other (Fig. 5). One of the climaxes occurred some 22000 years ago. When 3–5 km thick glaciers covered large tracts of the northern hemisphere, and sea level dropped some 125 m. Warming started soon after that Last Glacial maximun, but sea level stabilized only 6000 years ago.

Conclusions

The combined evidence of the structural stability of the coastal plain of central Israel near Caesarea and the indications for the variability of sea level there from the I to the XIII Centuries present solid environmental evidence for several discrete global events of climate warming and cooling. The data show that sea level during the early Roman period in Israel was similar to the present, it was nearly 0.5 m higher in the late Byzantine – early Islamic period and about 0.5 m lower in Crusaders' times. These observations suggest that climate some 2000 years ago was similar to the present, in the period of nearly 1300 years ago (VII Century AD) climate was warmer that the present, and some 800 years ago (XIII Century) the global climate was colder than today (Fig. 5).

The meaning of these geological and archaeological observations to our (e.g. IPCC 2007) expectations to the occurrence of imminent climate variations is significant. Considering that the climate variations that affected Earth in the last 2000 years were not man-made, there is ground to presume that the global warming that is discernible at present, like the dissolution of the sea-ice in north Canada, is mostly not anthropogenic either. Nevertheless there is a considerable contribution to humans doings to the rise in the atmospheric CO_2 content since the early stages of the Industrial revolution, which endangers the stability of life in the oceans (e.g. [*Fine, Tchernov, 2007*]). Even though most scientists accept the conclusions of the U.N.'s International Panel for Climate Change (IPCC, 2007) that the principal reason for the observed global warming is the anthropogenic emissions of greenhouse gases, the indications from the geological and archaeological evidence from Caesarea in coastal Israel is different.

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