GEOLOGICAL EVENTS DURING THE HOLOCENE: AN OVERVIEW FOR NORTHERN EUROPE AND THE MEDITERRANEAN

Silvia Peppoloni & Giuseppe Di Capua

Istituto Nazionale di Geofisica e Vulcanologia – Rome, Italy

1. Introduction

The Holocene is the most recent geological epoch spanning from about 11700 years ago to the present day. The most important human civilizations appeared during the Holocene. From the Holocene onwards, environmental changes, and the hazards associated with them, became extremely important for their impact on historical events, in some cases blending with humanity's vicissitudes and influencing the rise and decline of civilizations.

This paper summarises the geological and climatic conditions of Northern Europe during the Holocene and tries to determine whether or not they support the hypothesis formulated by Felice Vinci (Vinci, 2003) about the migration of Baltic populations towards the Mediterranean in the Bronze Age at the end of the "climatic optimum" (Houghton et al., 1990; Rohling & De Rijk, 1999). This study presents data on glacio-eustatic changes and on isostatic uplift together with information on probable tsunamis that occurred in the North Atlantic, North Sea, Scandinavia and the Baltic Sea. Moreover, some data on catastrophic events that affected the Mediterranean region are reported, because these catastrophes could have favoured the settlement of "people coming from the sea" that took advantage of the demographic and socio-economic weakening of indigenous populations (Driessen, 2002).

The paper aims to provide geological and palaeogeographic constraints to the hypotheses formulated by Felice Vinci on the migration of Scandinavians towards the Mediterranean.

The data analysed have been collected from the available scientific literature (see references). The amount of information available for each geological phenomenon is vast and sometimes theories developed from the same data are in conflict. The comparison between the Mediterranean and the Baltic areas (one of which could have been the theatre of the Homeric events) will be useful to find evidence of geological phenomena within the Homeric texts, giving useful indications to better understand where the poems are set or at least to provide interesting discussion points related to Felice Vinci's hypothesis (Vinci 2003).

2. Preliminary considerations

Before entering into the details of the analysis, it is useful to give some preliminary considerations on geological time and on the location of the geographic-climatic regions investigated.

One of the key principles of geology is Actualism, which expresses the concept that "the present is the key to the past" (Hooykaas, 1996). The events that we observe today or the events with precise historical references allow us to understand what happened in the past. The term “actualism” means that the same physical laws governed in the past as they do at present, and that all postulated processes are in agreement with the present properties of matter and energy. This implies that natural phenomena always occur for the same causes and are governed by the same physical laws.

In addition, the geological phenomena, although treated separately, are not disconnected from one another but are often linked by a relationship of cause and effect and therefore their consequences are the result of the sum of their effects.

Moreover, it has to be considered that the two areas (i.e. Northern Europe and Mediterranean regions) are located at different latitudes and therefore, even in the past, they have never had alike climates simultaneously. Their climates may have been similar, but at different times as a result of the shift of climatic zones (Ortolani & Pagliuca, 2007).

On one hand humankind intervenes on nature, but on the other hand it is a component of the same nature. So, it is inevitable that the natural phenomena have a big influence on human life and activities, in the past as in the present (Driessen, 2002; Ortolani & Pagliuca, 2006).

3. Geological phenomena

The study started with this question: are there some geological phenomena directly mentioned in the Homeric texts, or that can be indirectly deduced from the Homeric descriptions? As many of these phenomena were and are widespread in the Mediterranean area, whilst others characterize Northern Europe, this preliminary analysis could help us to highlight the differences between the two investigated areas. If some results and elements will be in agreement with Felice Vinci’s hypothesis, it will be possible to better understand the role that geological events might have played in the collapse of the Minoan civilization (Driessen, 2002) and in favouring the settlement of the Scandinavian-Baltic populations of the Bronze Age, which migrated towards lower latitudes due to changing climatic conditions, as many researchers suggest. The Scandinavian-Baltic populations would have found the native civilizations already weakened by natural disasters.

These two ancient events - the migration of the Northern Europe populations to the south in response to climatic changes and the destruction of civilizations in the Mediterranean area due to catastrophic geological events- could be connected.

3.1 Earthquakes

An earthquake is the result of a sudden release of energy in the Earth's crust that creates seismic waves. The seismicity or seismic activity of an area refers to the frequency, type and size of earthquakes experienced in that area over a period of time. In its most general sense, the word “earthquake” is used to describe any seismic event — whether natural or caused by humans — that generates seismic waves. Earthquakes are caused mostly by rupture of geological faults, but also by other events such as volcanic activity, landslides, mine blasts and nuclear tests. Faults are fractures in the crust with displacement of the two parts involved.

The largest earthquakes in historic times have been of magnitude slightly over 9. The most recent large earthquake was a magnitude 9.0 event in Japan in March 2011 and it was the largest Japanese earthquake since instrumental records began.

The destructive effects on the modern reinforced concrete buildings are well-known. It is then easy to imagine the vulnerability of ancient structures to seismic events, and to picture the difficulties experienced in ancient times in rebuilding a village after an earthquake: often a seismic event was capable of undermining the development or the life of a civilization (Driessen, 2002).

3.2 Volcanic eruptions

During a volcanic eruption, lava, ash, lapilli, volcanic bombs and blocks and various gases are expelled from a volcanic vent or fissure. Several types of volcanic eruptions have been distinguished by volcanologists. Some volcanoes may exhibit only one characteristic type of eruption during a period of activity, while others may display an entire sequence of types all in one eruptive series. There are two types of eruptions in terms of activity, explosive eruptions and effusive eruptions. Explosive eruptions are characterized by gas-driven explosions that cause the energetic ejection of magma and tephra. Effusive eruptions are characterized by the outpouring of lava without significant explosive activity.

The effects of volcanic eruptions are well known and evident: ash fall, flashing lights and red fire of the volcano, ash clouds that rise to many kilometres (Polenger Foster & Ritner, 1996).

It is easy to imagine the impact of a huge volcanic eruption on an ancient civilization in psychological terms (fear, terror also due to ignorance about the causes of the phenomenon)

(Driessen, 2002); and also the impact on economic activities (for example, agriculture) or on simple buildings. The breathing difficulties in humans and animals caused by ash should not be underestimated, especially in an ancient society.

Some researchers study the close link between earthquakes and volcanic activities, considering earthquakes as triggers of volcanic eruptions. It has often been observed that very big eruptions usually occur immediately after a powerful earthquake. The volcano Puyehue-Cordo Caulle in Chile is part of a volcanic chain that consists of 4 single volcanoes. One of them erupted immediately after the 1960 earthquake in Chile. This was the most powerful earthquake ever recorded with a magnitude of 9.5.

Even in the case of Thira, Greek researchers report that the eruption that destroyed Thira occurred immediately after a strong earthquake (Galanopoulos, 1960).

3.3 Tsunamis

A tsunami is a series of water waves generated by the displacement of a large volume of a body of water. Earthquakes, volcanic eruptions, landslides, ice calving, meteorite impacts and other disturbances above or below the sea surface all have the potential to generate a tsunami.

Tsunami waves do not resemble normal sea waves, because their wavelength is far longer. The tsunamis waves generally have periods ranging from minutes to hours, arriving in a so-called "wave train". Their destructive power can be enormous and they can affect entire ocean basins.

As early as 426 B.C. the Greek historian Thucydides inquired in his book “History of the Peloponnesian War” about the causes of tsunami, and was the first to suggest submarine earthquakes as a possible cause.

The Roman historian Ammianus Marcellinus (*Res Gestae* 26.10.15-19) described the typical sequence of a tsunami, including an incipient earthquake, the sudden retreat of the sea followed by a gigantic wave, after the 365 A.D. tsunami that devastated Alexandria (Galanopoulos, 1960; Pararas-Carayannis, 1992).

While Japan may have the longest recorded history of tsunamis, the sheer destruction caused by the 2004 Indian Ocean earthquake and tsunami event marks it as the most devastating of its kind in modern times, killing around 230,000 people. The tsunami caused by the earthquake in Japan on March 2011 was characterized by a wave with a maximum height of 39 m.

So, a tsunami could have had a very strong impact on an ancient civilization characterized by predominantly maritime activities: harbours would have been destroyed, docks submerged, commercial and military fleets sunk (Driessen, 2002). Perhaps a tsunami may have been capable of causing the destruction of an ancient civilization.

3.4 Isostasy and isostatic effects of ice-sheets

Isostasy is a term used in geology to describe the state of gravitational equilibrium between the earth’s lithosphere and asthenosphere (the fluid part of the mantle) such that the tectonic plates "float" at an elevation which depends on their thickness and density. This concept is invoked to explain how different topographic heights can exist at the Earth's surface. A certain area of the lithosphere tends to reach isostatic equilibrium. A mountain exposed to erosion undergoes a weight decrease. Consequently, new isostatic equilibrium is reached which causes the mountain’s uplift.

The formation of ice-sheets can also cause the sinking of the Earth's surface. Conversely, isostatic post-glacial rebound is observed in areas once covered by ice sheets now melted, such as around the Baltic Sea (Miettinen, 2004). The rebound movements are so slow that the uplift caused by the ending of the last ice age is still occurring.

During the last ice age, the Baltic Sea was covered by ice sheets with a thickness of about 3000 m (Bojanowski, 2006). The landmass surrounding the Baltic Sea is currently experiencing uplift due to the crustal rebound of the crust previously covered by the ice mass (Miettinen et al., 2007). Throughout the rest of the European continent, the expansion of the ice sheets has been less pronounced (for example in the Alps). The ice age caused a general lowering of sea level, which was approximately 120m lower than today (Fleming et al., 1998), a shift in climatic zones, the establishment of geomorphological environments different from those currently present at the same latitude.

3.5 Eustasy

Eustasy is another cause of relative sea level change, quite different from isostatic causes. The term "eustasy" or "eustatic" refers to changes in the amount of water in the oceans, usually due to global climatic changes. When the Earth's climate cools, a greater proportion of the water is stored on land masses in the form of ice sheets or snow. This results in a relative fall in global sea levels. The refilling of ocean basins by ice sheet melt-water at the end of ice ages is an example of eustatic sea level rise.

Therefore, while in the Baltic area uplift is occurring because of isostasy, at the same time the melting of the ice sheets induced by global climatic changes causes a global sea level rise (which equates to a relative lowering of the coast). So, the uplift that we measure in the Baltic area is not an absolute value but is the result of the combination of these two effects (Miettinen, 2004).

3.6 Tides

Tides are the rise and fall of sea level caused by the combined effects of the gravitational forces exerted by the Moon and the Sun and the rotation of the Earth.

Most places on Earth usually experience two high tides and two low tides each day, but some locations experience only one high and one low tide each day. Their amplitude is influenced by the shape of the coastline and near-shore bathymetry.

Tides are responsible for changing the depths of estuaries, a type of river's mouth which results in a single channel or branch. Tides connect estuaries with the open sea.

The water currents created by the tides go in two opposite directions: during the high tide, sea water enters the river, during the low tide sea water level falls.

4. A comparison between the two regions with regard to seismicity and volcanism.

The Seismicity Map of Europe (by USGS - United States Geological Survey: http://earthquake.usgs.gov), in the time period 1990-2000, shows the areas where earthquakes are more frequent. The most seismic regions are located in Southern Europe, particularly in Italy and in Greece. Some seismic activity is also present in France and Germany, although we know that the magnitude of the events in these regions is far less than the magnitude of Italian and Greek events. A significant seismic activity is also present in Turkey. There is a weak seismicity in the South-Western and even less in Eastern England. Instead, an absence of seismicity characterizes the Baltic Sea and the rest of the Scandinavian Peninsula.

The Seismic Hazard Map of Europe (fig. 1) shows the distribution of the expected horizontal seismic acceleration values, and so it indicates the expected seismic shaking at any given location. It is a probabilistic map, which quantifies through numbers the level of seismic hazard existing in Europe. The Mediterranean area is characterized by hazard levels higher than Northern Europe. One exception is Iceland, which has seismic hazard levels comparable with those of some Italian areas. The North Sea shows a weak seismic hazard, concentrated on the shores of Norway, while in the Baltic area the seismic hazard can be considered negligible.

It is important to highlight that during the last 10000 years (i.e. during the Holocene) the climate has changed several times, while the level of seismicity remained practically constant over the entire planet.

These differences in seismicity can be explained by analysing the different geodynamical frameworks existing in each of these two macro-areas. Northern Europe is a passive plate margin. Earthquakes can occur along the continent borders and usually they are caused by normal faults, extensional faults. But they have usually lower magnitude compared with active margins.

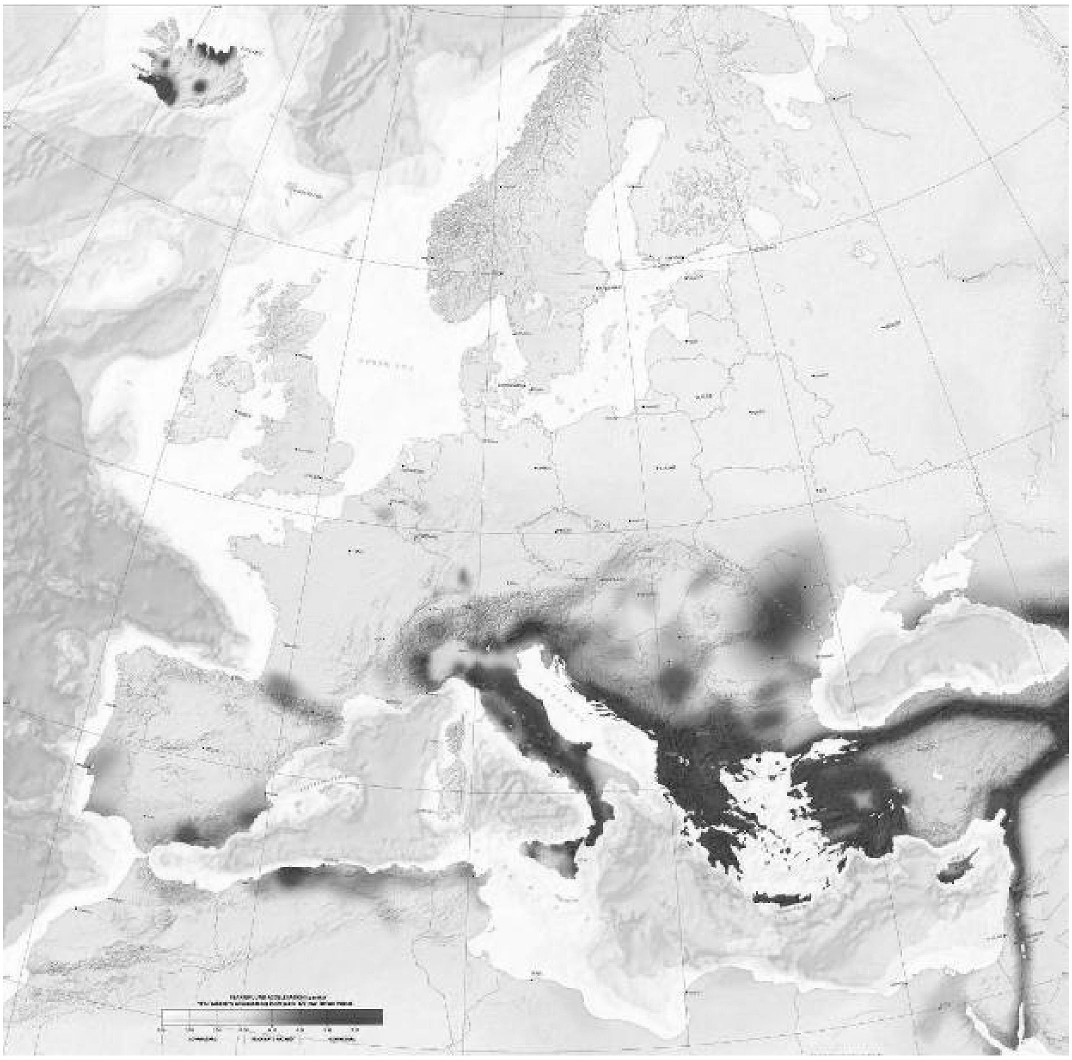

Fig. 1 – European-Mediterranean Seismic Hazard Map: distribution of the expected horizontal acceleration values (values grow with increasing intensity of the gray) (ESC, 2003).

There is no volcanic activity, except for the volcanism associated with the mid Atlantic ridge that emerges from the ocean in correspondence of Iceland. It is mainly characterized by effusive events, but it is at a considerable distance from the Baltic area.

In the case of the central Mediterranean Sea we are in the presence of an active margin, along which the subduction of the African plate under the Eurasian plate is occurring.

The subduction zone, where the African plate slides beneath the European plate, runs exactly under the island of Crete. In particular, Crete and Thira are located at the convergence between the African plate and the Anatolian plate.

In the Mediterranean area, seismic events are usually accompanied by volcanic activity and often even by tsunamis. These three types of phenomena can occur simultaneously. In particular, the Mediterranean geodynamical system is associated with an explosive volcanism: on many Aegean islands there are volcanoes. Among them, the volcano of Thira is still active and considered responsible for the collapse of the Minoan civilization (Driessen, 2002; Pararas-Carayannis, 1992 and 2006). The volcanic archipelago of the Cyclades shows an alignment similar in shape to the subduction zone, just south of it. In fact, the volcanism is the result of the subduction: the subduction leads to melting at depth and the melting determines an upward movement of the magma due to its lower density compared with the solid rocks.

In the Aegean Sea the strong earthquakes that occur beneath the sea are considered the main responsible for triggering tsunamis.

Available information highlights the great vulnerability of the island of Crete to tsunamis, since it is surrounded by seismogenic faults (i.e. earthquake prone faults) that have historically generated destructive tsunamis.

So in the central Mediterranean different types of geological hazards are seen to overlap:

1. presence of seismogenetic sources (the subduction zone);
2. presence of explosive volcanism (the arc of Cyclades);
3. evidence of past- tsunamis.

5. Historical information and geological phenomena

5.1 Mediterranean area

The Palace of Knossos was destroyed several times by earthquakes (in 2700 BC and again in 1500 BC) (Galanopoulos, 1960; Pararas-Carayannis, 1992 and 2006), and a 9m uplift affected the western part of Crete during the Magnitude 8.5 earthquake occurred on 21 July 365 AD.

The earthquake caused the uplift of the coast and now this groove is at 9 m above the current sea level. The earthquake had far reaching consequences, causing damage in central and Southern Greece, Northern Libya, Egypt, Cyprus and Sicily. The earthquake produced a large tsunami, which mainly devastated the Eastern Mediterranean region. This event left many traces in ancient texts. The tsunami of 365 A.D. was so devastating that until the end of the sixth century the day of the disaster was commemorated every year in Alexandria, Egypt, as the "day of horror”.

Although the tsunami produced by the eruption that destroyed Thira and Akrotiri (the important Minoan village) is not present in the Greek catalogue of tsunamis, this event is considered responsible for the end of the Minoan civilization by many researchers (Driessen, 2002; Pararas-Carayannis, 1992 and 2006).

If the hypothesis that the Thira eruption caused the collapse of Minoan civilization is true, when did it take place and what happened?

The year of the eruption is the subject of a complex debate, not yet concluded. Some authors believe that the eruption probably happened about 3600 years ago (Polinger Foster & Ritner, 1996), other authors place this event a bit later (Galanopoulos, 1960; Pararas-Carayannis, 2006). The eruption destroyed the island of Thira, and some authors believe that it caused significant climate change in the Mediterranean area, the Aegean Sea and in a large part of the Northern hemisphere (Polinger Foster & Ritner, 1996). Some researchers link this eruption and the following cooling period with the collapse of the Xia Dynasty in China and the advent of the Shang dynasty. In fact, in Chinese texts some climatic effects connected to a large volcanic eruption are reported ("yellow fog, a pale sun, 3 solar discs, frost in July, famine, drying up of all five cereals") (Polinger Foster & Ritner, 1996). Perhaps, the connection between these events and the eruption of Thira is daring and their cause may have been an eruption that occurred in other areas, such as the Kamchatka Peninsula, Japan or Indonesia.

The Thira eruption was certainly accompanied by a large tsunami, caused by the collapse of the caldera and also by landslides along the slopes of the volcano (Galanopoulos, 1960; Pararas-Carayannis, 1992; Driessen, 2002). The waves may have reached heights between 35 and 150m (Driessen, 2002; Pararas-Carayannis, 1992; 2006). For a comparison, we can consider that during the earthquake in Japan, the tsunami waves appear to have reached a maximum height of 39m.

The formation of the caldera, due to the rapid emptying of the magma chamber below the volcano, would not have been immediate but would have occurred at a later time (Pararas-Carayannis, 1992). The final collapse would have caused, together with submarine landslides and earthquakes, a great tsunami or a series of tsunamis (Pararas-Carayannis, 1992 and 2006). As already mentioned, perhaps these events accelerated the decline and collapse of Minoan civilization, producing damages so severe to make recovery impossible. In fact, some authors believe that the eruption served as a catalyst of the Minoan crisis, producing negative effects in the short and long term (Driessen, 2002).

It is important to remember that Minoan ruins have been found above the levels of ash related to the Thira eruption. Therefore, the eruption itself did not cause the immediate collapse of this civilization. So, probably the conquerors met a civilization in great crisis, which did not offer particular resistance (Driessen, 2002).

With regard to the texts that describe other well-known historic events (for example the Tambora eruption occurred in 1815 and the Krakatoa eruption in 1883) an interesting aspect has to be underlined: the descriptions of the spectacular post-eruptive effects, as climatic and atmospheric phenomena, are much more frequent than the description of the eruption itself. This is an important element to consider for the analysis of the Homeric texts.

5.2 Northern Europe

As already said, Northern Europe is characterized by low seismicity and by the presence of Icelandic volcanism - mainly effusive- which is located at a considerable distance from the Scandinavian coast. The powerful volcanic events in Iceland are due to the presence of the mid-ocean ridge in the Atlantic Sea, along which the production of oceanic crust is active.

The eruptions that occur in Iceland have certainly an impact on a large scale. With regard to the distance, Iceland is situated about 1200 km from the Norwegian coast, 1000 km from the British Isles, 1700 km from Denmark, 2000 km from the Baltic Sea. It is a wide distance, but surely, in the Bronze Age, important eruptions in Iceland may have produced effects on the atmosphere and climate. In addition, these events may have impressed populations, so that they could have left traces in very ancient texts and myths.

Submarine landslides are among the causes of tsunamis. These phenomena occur along the continental slope, the inclined surface submerged by the sea, which connects the continental shelf to the abyssal plain. This area is characterized by the presence of unstable sediments, which are frequently subjected to landslides. The amount of material involved is so great that these landslides are able to cover kilometres and kilometres, to move huge masses of water and generate mega-tsunamis.

It is documented that in the North Atlantic and in the North Sea, about 8100-8200 years ago, a giant submarine landslide occurred that produced an impressive tsunami: the Storegga landslide (Bondevik et al., 2005; Romundset & Bondevik, 2011). This tsunami entered also the Barents Sea and damaged the Norwegian coasts, with different wave heights in different parts of the coast (Romundset & Bondevik, 2011).

Sediments deposited by the tsunamis, and so named "tsunamiti", have been found on the Norwegian coasts and in Scotland (Dawson & Smith, 2000; Smith et al., 2004; Bondevik et al., 2005). They are characterized by a typical stratification composed by sand, clay and silt interlayered with peat. These deposits have been found up to 80km from the current shoreline, in the Shetland Islands, Faroe Islands and the eastern coast of Greenland (Grauert et al., 2001; Bondevik et al. 2005; Wagner et al.; 2006). Their great thicknesses and their lateral extension suggest a catastrophic event that has certainly brought death and destruction among human civilizations that lived near the coast (Romundset & Bondevik, 2011).

But this tsunami is not the only one that has left traces in this part of the Earth. Other sediments have been interpreted as tsunamiti and have allowed for the identification of at least two events: one 5500 years ago, the other 1500 years ago (Bondevik et al., 2005).

The results of a study carried out in the Shetland Islands allowed for the identification of two smaller events, called "Garth tsunami" and "Dury Voe event" (Bondevik et al., 2005), but with the same origin: submarine landslides, smaller compared with the Storegga landslide (fig. 2).

Other smaller landslides, which could have caused minor tsunamis, have been identified at the foot of the Norwegian continental slope (Bojanowski, 2006).

In 1999 traces of another massive landslide (the Yermak landslide) along the northern coast of Norway were discovered. This landslide occurred about 30000 years ago and would have created another mega-tsunami (Bojanowski, 2006).

These are prehistoric events, occurred before the Holocene, but their study can help us to understand their magnitude and frequency in this area.

Traces of tsunamis have been found also in the northern Baltic Sea, but it is not clear if they may be the effects of the tsunamis occurring in the North Sea and Norwegian Sea (Andrén & Andrén, 2000; Veski et al., 2002). The Baltic Sea is a shallow sea, characterized by the presence of a sill in correspondence of the Strait of Denmark. This sill could have blocked the tsunami waves, not allowing them to penetrate deeply inside the Baltic Sea. In line with this consideration, Raukas (2000) suggests that a meteoritic impact could have triggered these mega waves.

With regard to the eustatism in the Baltic area, it is well-known that the Scandinavian Peninsula and the Baltic Sea were covered by an extensive ice sheet during the last glaciation (Wurmian, 11700 years ago). The central part of the ice sheet body had a maximum thickness of about 3000m. At that time sea level was lower than about 120m compared to the present level (Fleming et al., 1998).

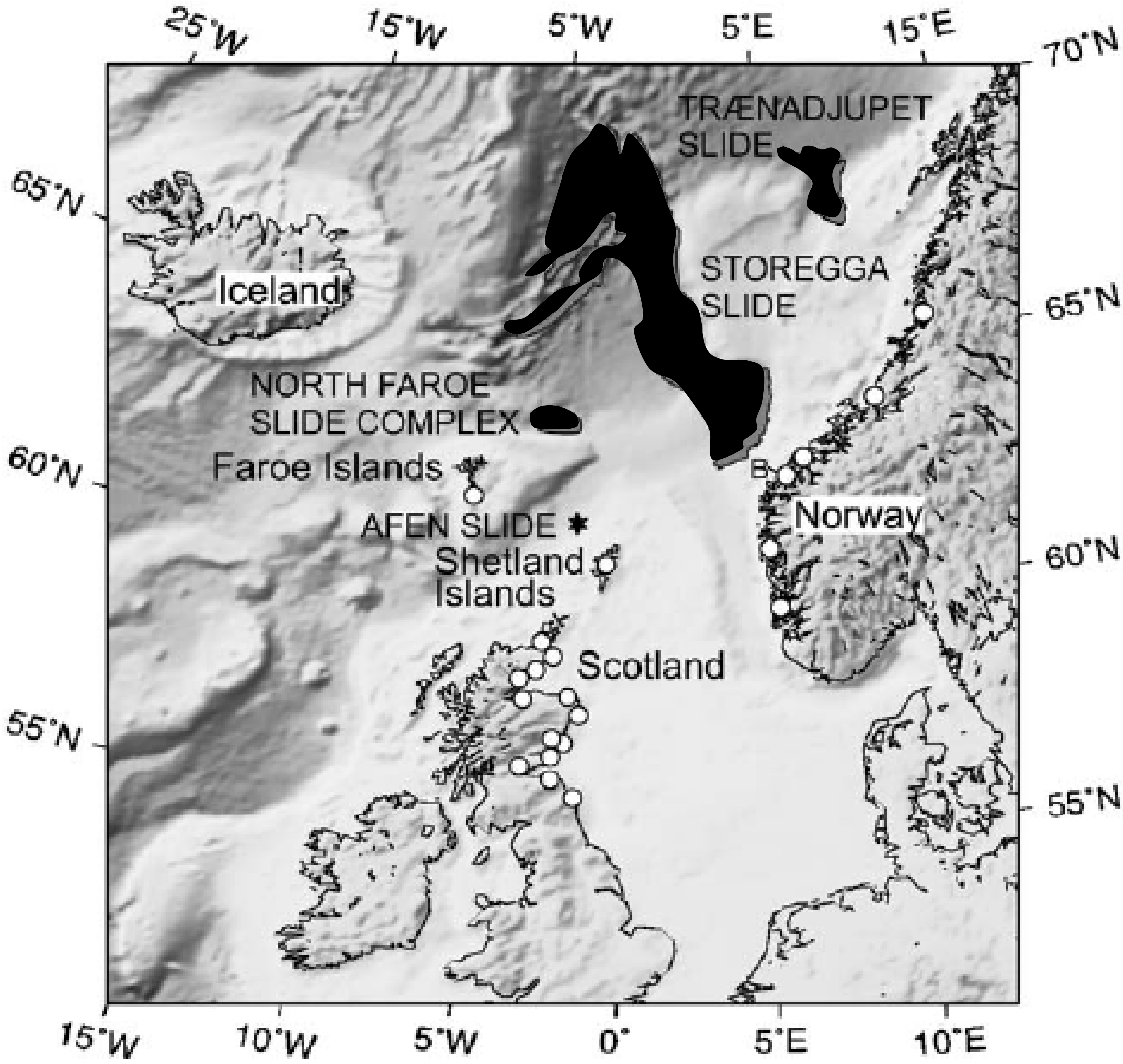

Fig. 2 – Location of some submarine landslides in Northern Europe, black coloured (Bondevik, 2005). White dots show where tsunami deposits from the Storegga event have been mapped.

At the end of the glacial period, the ice sheet began to melt. This fact had two consequences: the rise of sea level and the regional uplift of the landmass where the ice was melting (Miettinen, 2004; Miettinen et al., 2007).

The combination of these two effects gives an overall uplift of the ground with respect to sea level, shown by the lines on the map in fig. 3. In the Gulf of Bothnia the uplift reached its maximum, equal to 9 mm/year (Ekman &Mäkinen, 1996; Miettinen et al., 2007). The uplift is less important in the peripheral areas, and in some cases there is an observed lowering (for example in Denmark). Geophysical models suggest the uplift will continue for thousands of years and the maximum residual yet to be reached is roughly equal to 90m (Ekman &Mäkinen, 1996; Miettinen et al. 2007).

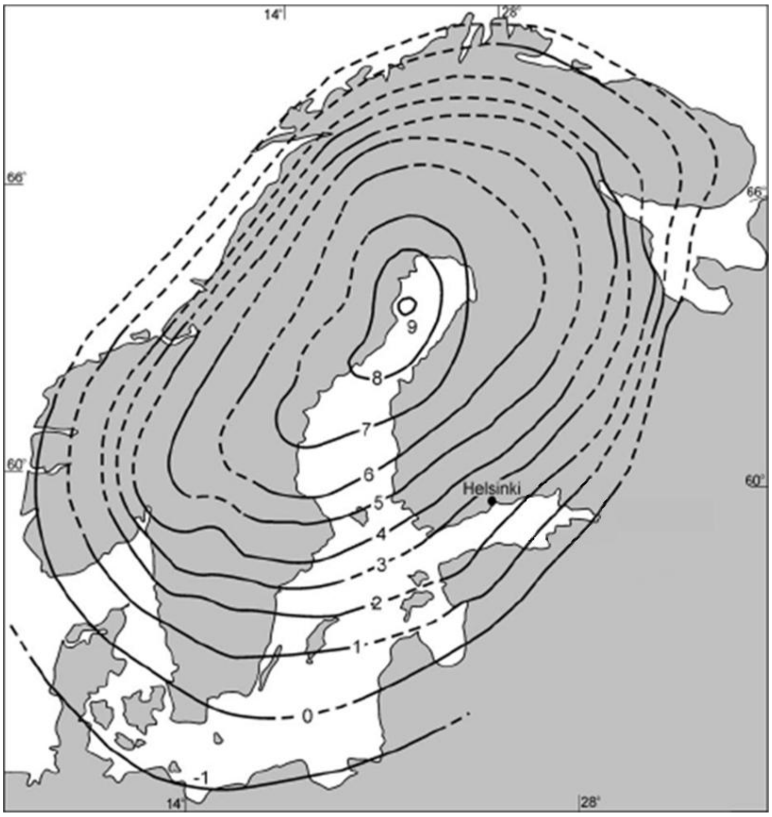

Fig. 3 – Map of the Scandinavian area with the rate of the apparent land uplift (mm/yr), i.e. the uplift of the crust relative to mean sea level Black lines join points with equal apparent uplift rate. (Miettinen, 2004, modified from Ekman & Mäkinen, 1996).

This uplift produces: changes in shorelines, increase in the rate of erosion and sediment accumulation, changes in river networks and in links between post-glacial lakes, different landscapes to consider in paleogeographical reconstruction (Björck, 1995).

Finally, four different phases have characterized the Baltic Sea evolution: the Baltic Ice Sea, the Yoldian Sea, the Ancylus Lake, the Littorina Sea (Björck, 1995; Miettinen, 2004; Berglund et al. 2005) . These time intervals are still subject to discussion among researchers.

The Yoldia Sea is the first Holocenic phase of the Baltic Sea. The Ancylus Lake is the phase when the Baltic became a freshwater lake. During the Littorina Sea phase the seawater salinity increased and the level of the water gradually lowered until it reached the current level. Maybe during this phase the Storegga tsunami could have occurred.

6. Conclusions

This preliminary overview is based exclusively on existing data and it has the aim of stimulating the debate on Felice Vinci’s hypothesis, introducing geological elements and topics in the discussion.

The information collected allows us to make some considerations.

The first one concerns variations in surface elevation and sea level rise. If we place the Homeric sites in the Baltic area, we have to take them into account. The difference between the current share of ground and the share during the Bronze Age should be considered in the planning of geognostic investigations (borings or geophysical tests), in the search for buried remains of that civilization and in the reconstruction of the topographic surface at Homeric age (Miettinen et al., 2007).

The second consideration is relative to tides. As Felice Vinci wrote about the Southern coast of Norway (Phaeacians land), the Homeric poems tell us about currents along the waterways that periodically inverted the flow of the rivers from the sea toward the inland. This could be caused by the tides: the waters go up the estuaries of the rivers during the high tide. Even if in the Baltic Sea the tidal range is low (8-18 cm) (Björck, 1995), currents along the rivers may have existed because of two other important factors. The Baltic Sea is the largest brackish water system in the world, is a closed sea, relatively shallow, connected to the open sea only through a threshold between Sweden and Denmark. Through this threshold, water is exchanged with the North Sea, but it is limited, resulting in a marked salinity gradient. Most of the water supply comes from rivers, with a high seasonal and long-term variability. The difference in salinity produces incoming and outgoing flows. Even the winds from the west can cause changes in the direction of the currents that run along the rivers. These two phenomena could clarify some references in the Homeric texts, highlighted by Felice Vinci.

The third consideration regards the uplift of the Baltic Sea. It is a young sea, formed after the last glacial retreat of the ice about 10000 years ago (Björck, 1995; Berglund et al., 2005). The geological uplift continued after the ice age, especially in the northern part, where the coastal uplift is also visible in the timeframe of a generation. Because of this geological uplift, its size is slowly decreasing. This phenomenon could also justify the fact that Troy may have been closer to the coastline in the past.

In conclusion, table 1 presents a summary of the characteristics of geological hazard and glacio-eustatism of the analysed regions.

Regarding the seismicity, it would be important to verify the presence of references to seismic events inside the Homeric poems. In case there is no mention about them, we could think that the area in which the Trojan War took place did not had appreciable seismicity or, alternatively, we should find an explanation to justify the absence of references to earthquakes in the Homeric texts, if the Trojan War took place in the Aegean Sea.

The same can be said for the volcanic phenomena: the eruptions that occur in Iceland are very distant from Scandinavia and the Baltic Sea. On the contrary, the volcanic phenomena of Thira would be very close to Homeric sites, if these were located in the Mediterranean Sea.

With regard to the tsunamis, violent events are possible (and have been detected) both in northern Europe and in the central Mediterranean area (ESPON, 2005). Any references to such events cannot be considered as discriminating between the two regions. Moreover it has to be said that in the Mediterranean area many tsunamis have occurred in historic times (well-documented), whereas tsunamis in North Europe are mainly prehistoric events.

Table 1 - Summary of the characteristics of hazards and glacio-eustatism of the analysed regions

Region	**Hazard**			**Glacio-Eustatism**
	Seismic	**Volcanic**	**Tsunami**	
Central Mediterranean Sea	high	medium	high	Very low
Northern Atlantic Ocean	medium	high	high	Very low
North Sea	low	Very low	high	Very low
Baltic Sea	Very low	Very low	Very low	present

References

Andrén T. & Andrén E. (2000) – *Did the Storegga tsunami reach the Baltis Sea?* In Sandgren P. (ed.), Environmental changes in Fennoscandia during the Late Quaternary. Lundqua Report, 37, 108.

Berglund B., Sandgren P., Barnekow L., Hannon G., Jiang H., Skog G., Yu S. (2005) – *Early Holocene history of the Baltic Sea, as reflected in coastal sediments in Blekinge, southeastern Sweden.* Quaternary International, vol 130, pp 111-139 (2005).

Björck S. (1995) – *A review of the History of the Baltic Sea, 13.0 – 8.0 ka B.P.*. Quaternary International, vol 27, pp 19-40 (1995).

Bojanowski, A. (2006) – *Tidal Waves in Europe? Study Sees North Sea Tsunami Risk*. Spiegel Online. http://www.spiegel.de/international/0,1518,441819,00.html. Retrieved 2007-07-24.

Bondevik S., Mangerud J., Dawson S., Dawson A., Lohne O. (2005) – *Evidence for three North Sea tsunamis at the Shetland Islands between 8000 and 1500 years ago.* Quaternary Science Reviews, 24 (2005), 1757-1775.

Dawson S. & Smith D.E. (2000) – *The sedimentology of mid-Holocene tsunami facies in northern Scotland*. Marine Geology, 170, 69-79.

Driessen J. (2002) – *Towards an Archeology of crisis: Defining the long-term impact of the Bronze Age Santorini eruption*. In: Torrence, R., Grattan, J.P. (Eds.), Natural Disasters, Catastrophism and Cultural Change. Routledge, London, pp. 252–263.

Ekman M. & Mäkinen J. (1996) – *Recent postglacial rebound, gravity change and mantle flow in Fennoscandia*. Geophysical Journal International, 126, 229-234.

ESC - European Seismological Commission (2003) – *European-Mediterranean Seismic Hazard Map* (scale 1:5.000.000).

ESPON - European Spatial Planning Observation Network (2005) – *Historically recorder tsunami runups*. Project 1.3.1 (http://www.preventionweb.net/files/3831_TsunamihazardN3.jpg).

Fleming K., Johnston P., Zwartz D., Yokoyama Y., Lambeck K. and Chappell J. (1998) – *Refining the eustatic sea-level curve since the Last Glacial Maximum using far- and intermediate-field sites*. Earth and Planetary Science Letters 163 (1-4): 327-342. doi:10.1016/S0012-821X(98)00198-8

Galanopoulos A.G. (1960) – *Tsunamis observed on the coasts of Greece from antiquity to present time.* Annali di Geofisica, Vol. 13, pp. 369-386.

Grauert M., Björck S., Bondevik S. (2001) – *Storegga tsunami deposits in a coastall ake on Suderøy, the Faroe Islands*. Boreas 30, 263–271.

Hooykaas R. (1996) – *Natural Law and Divine Miracle: The Principle of Uniformity in Geology, Biology, and Theology*. Leiden: EJ Brill.

Houghton, J.T., Jenkins, G.J. and Ephraums, J.J. (Eds.) (1990) – *Climate Change: The IPCC Scientific Assessment*. Cambridge University Press, Cambridge, UK.

Miettinen A. (2004) – *Holocene sea level changes and glacioisostasy in the Gulf of Finland, Baltic Sea*. Quaternary International, 120 (2004), 91-104.

Miettinen A., Jansson H., Alenius T., Haggren G. (2007) – *Late Holocene sea-level changes along the southern coast of Finland, Baltic Sea*. Marine Geology 242, 27-38.

Ortolani F. & Pagliuca S. (2006) – *The climatic risk for the circummediterranean area on the base of geoarchaeological data.* Atti del Convegno GEOSED 2006 – Modena 25-29 settembre 2006, a cura di Stefano Lugli.

Ortolani F. & Pagliuca S. (2007) – *Geoarcheological evidences of cyclical climatic-environmental changes in the Mediterranean area (2500 BP-Present Day).* Geoitalia 2007 Conference, Rimini (Italy), 12-14 September 2007.

Pararas-Carayannis G. (1992) – *The tsunami generated from the eruption of the Volcano of Santorini in the Bronze age.* Natural Hazards, vol. 5, n. 2, 115-123, DOI: 10.1007/BF00127000.

Pararas-Carayannis G. (2006) – *The potential of tsunami generation in Eastern Mediterranean basin and in Aegean and Ionian Seas in Greece.* (www.drgeorgepc.com/TsunamiPotentialGreece.html)

Polinger Foster K. & Ritner R. (1996) – *Texts, storm and Thera eruption.* Journal of Near Eastern Studies, vol. 55, n. 1, 1-14.

Raukas A. (2000) – *Investigation of impact spherules – a new promising method for the correlation of Quaternary deposits*. Quaternary International, 68-71, 241-252.

Rohling, E.J. & De Rijk, S. (1999) – *Holocene climate optimum and Last Glacial Maximum in the Mediterranean: the marine oxygen isotope record*. Marine Geology 153, 57–75.

Romundset A. & Bondevik S. (2011) – *Propagation of the Storegga tsunami into ice-free lakes along the southern shores of the Barents Sea*. Journal of Quaternary Science, Volume 26, pages 457–462, July 2011

Smith D.E., Shi S., Cullingford R.A., Dawson A.G., Dawson S., Firth C.R., Foster I.D.L., Fretwell P.T., Haggart B.A., Holloway L.K., Long D. (2004) – *The Holocene Storegga tsunami in the United Kingdom*. Quaternary Science Reviews, 23.

Veski, S., Heinsalu, A., Klassen, V., Kriiska, A., Lõugas, L., Saluäär, U. (2002) – *Prehistoric man and the Baltic Sea at Pärnu, southwestern Estonia. Shifting coasts and a possible tsunami in the Baltic Sea 8400-8200 years BP*. In Leroy, S. and Stewart, I.S. (Eds.) Environmental Catastrophes and Recoveries in the Holocene. Abstracts Volume. Brunel University, west London (UK), 28 August - 2 September, 2002, 86-87.

Vinci F. (2003) – *Omero nel Baltico*. Palombi Editore, Roma.

Wagner B., Bennike O., Klug M. and Cremer H. (2006) – *First indication of Storegga tsunami deposits from East Greenland*. Journal of Quaternary Science, 22, 321-325.