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THE 326 BC EARTHQUAKE AND TSUNAMI IN THE NORTHERN ARABIAN SEA - IMPACT ON THE FLEET OF ALEXANDER THE GREAT

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ABSTRACT

Ancient Greek and Indian texts support that destructive sea waves along the Makran coast in the northern Arabian Sea were responsible for the partial destruction of Alexander the Great's fleet in 326 BC. At that time, and after the conclusion of all its operations along the Indus River and its tributaries, the Greek fleet had reached the Indian Ocean and was waiting in an estuary of River Hab, north of the Indus River delta, for calmer seas and for the seasonal monsoon winds to subside, before beginning the long journey from India to Babylon, in what is presently known as the Persian Gulf. Since the Greek fleet had spent considerable time in the fall of that year in protective bays of the Indus delta/Kutch and the Makran regions (India in ancient times), it is very possible that the reported sustained damage to the fleet was caused from a tsunami rather than storm waves. After repairs were completed, the fleet under the command of admiral Nearchus of Crete began its long and arduous journey west in the North Indian Ocean, towards Babylon in what is now known as city of Hillah of Iraq in the Persian Gulf. In all probability, the tsunami originated along the Makran Subduction Zone – the same source area that historically has produced several earthquakes and tsunamis, the best known in recent times being one in 1945. Based on reviews of ancient Greek accounts such as those of Plutarch, Nearchus but mainly of Arrian's of Nicomedia "Indice" and to a lesser extent on Sri Lanka and Indian records, the present study reconstructed the chronology of the impact on the fleet based on the ancient Athenian lunar calendar. By using current geophysical knowledge of recent events in this region, and the present study concluded that the 326 BC earthquake occurred in late October or early November of 326 BC (known as Pyanepsion, “Πυανεψιών” in Ancient Greek). As mentioned, at that time the Greek fleet was either at anchor at the estuary near the delta of River Hab, or had just set out to sea on its way to Babylon. The Hab River estuary is located in the easternmost end of the Makran Subduction Zone (MSZ) in the Northern segment of the Arabian Sea - a source region of large earthquakes and tsunamis, recently and in the past. The delay in the departure of the Greek fleet from this estuary caused by opposing monsoon winds, limited the possibility of its total destruction if it had begun earlier its long journey to Babylon.

Earlier in August of that same year, Alexander the Great with about a third of the Greek land forces had already taken a long and difficult march back to Babylon, via a southern land route, which included the harsh Gedrosian desert, a journey which resulted in the death from starvation for most of the soldiers. The present study is an evaluation of these events as deduced, from the historical records, but also from current geophysical understanding of the seism-tectonics of the Makran Subduction Zone - a source region of large earthquakes and tsunamis, recently and in the past. The best-known recent earthquake and tsunami in the same eastern region of the Makran Subduction Zone was the Moment Magnitude 8.1 earthquake of 19 November 1945.

Keywords: *disaster archaeology; seismo-tectonics; Makran Subduction Zone; Alexander the Great’s India Campaign; Arrian’s “Indice”; Plutarch’s “Alexander”; Plutarch’s “Parallel Lives”.*

1. INTRODUCTION

Major earthquakes and destructive tsunami waves have occurred frequently in the past along the Makran Subduction Zone (MSZ) in the northern Arabian Sea. Ancient Greek and India accounts indicate that in late 326 BC a major earthquake on the MSZ generated a tsunami, which impacted and caused some damage to the fleet of Alexander the Great. At that time the Greek fleet was near an estuary of River Hab, just north of the Indus River delta, while waiting for calmer seas and for the seasonal monsoon winds to subside, before beginning the long journey from India to Babylon, in what is presently known as Persian Gulf.

The MSZ is an extensive and complex tectonic plate margin in South-Central Asia along the Makran coasts of Iran, of the since 1947 Pakistan, and of India. This is a region that historically has produced several earthquakes and tsunamis. The best known of such events in recent times, was the great Makran earthquake and tsunami of 1945, but there were many other destructive events before it, particularly along the eastern segment of the MSZ (Pararas-Carayannis. 2001b; 2005b, 2006a).

Most of the earthquakes in this region of Southeast Asia occur mainly on land along the boundaries of the Indian tectonic plate and of the Iranian and Afghan micro-plates. At least 28 earthquakes with magnitudes close to 7 or more have occurred since 1668 to the present time (Ambrasseys and Bilham, 2003). According to historical records, an earthquake in 893-894 AD with an estimated moment magnitude of 7.5, occurred in the Debal (lower Sindh) region of what is now Pakistan, killing 150,000 people and destroying several towns. However, there is no data on whether this earthquake or subsequent similar events in the distant past generated tsunamis, since no one was aware back then of the association of earthquake-induced sea floor displacements and the resulting tsunami wave generative mechanisms. However, based on reviews of ancient Greek accounts of Plutarch, Nearchus but mainly of Arrian's of Nicomedia "Indice" historical account — and to a lesser extent on Indian historical records — the present study reconstructed the chronology of events based on the ancient Athenian lunar calendar and, by using current geophysical knowledge of recent events in this same region, concluded that a major tsunamigenic earthquake occurred in late October or early November of 326 BC (a period known as Pyanepsion - "Πυανεψιών" in the ancient Athenian lunar calendar), when the Greek fleet was in the easternmost region of the MSZ.

The historical ancient accounts by Nearchus of Crete, Plutarch and Arrian are not clear as to whether an earthquake occurred which generated a tsunami, as such events were not well understood and were simply attributed to acts of Olympian gods — mainly Poseidon ("Ποσειδών" - Neptune). Probably many other hardships and losses which occurred during the arduous journey of the fleet down the Indus River and the battles fought on both river sides, overshadowed the damages caused by waves which were experienced later, after the fleet reached the delta of the Indus River in the North Arabian Sea. Furthermore, the accounts by Nearchus and Plutarch are not clear as to the occurrence of earthquakes and resulting sea waves. However based on the historical narrative in Arrian's "Indice", it can be reasonably concluded that the degree of reported damage which occurred to Alexander the Great's fleet — which was located in the vicinity of the River Cab estuary at the time — was not caused by storm waves of monsoon winds, but from tsunami waves similar to those generated by the 1945 earthquake or by other previous earthquakes in the eastern MSZ region of the North Arabian Sea. The present study is based on the chronology of reported events, which indicates that there were no monsoon winds in late October or early November of 326 BC. Based on the well-known high frequency of major earthquakes in this region and elsewhere in the Indian Ocean, as well as on Arrian's account, it can be reasonably concluded that a tsunami was responsible for the partial damage to the Greek ships. Fortunately the fleet was in the estuary of River Hab, in the relatively safe eastern region of MSZ, which limited the size of the tsunami waves and their destructive impact.

2. HISTORIC RECORDS

Prior to discussing in some detail the impact of the 326 BC earthquake and tsunami on the fleet of Alexander the Great and the geotectonic nature of the MSZ and the past disaster events in this region of the North Arabian Sea, it seems appropriate to present first a brief summary of historical events and accounts relating to ancient disasters and of perceptions about them, as well as of Alexander's early life, of his Asian and India campaign, and of the return journeys of his armies by land and by sea to Babylon.

The following is a brief review of his early life, based primarily on the accounts by Nearchus, Plutarch and Arrian. Unfortunately, Nearchus' book "Indike" — which described the journey back to Babylonia - was lost. However, some of its contents are known from another book — also named "Indice" — written by Arrian of Nicomedia. The account of Alexander's voyage of the fleet is based primarily on Arrian's writings. These early historical accounts are not clear as to the occurrence of earthquakes or of resulting sea waves because such phenomena were not understood and were simply attributed to acts of gods. However, Arrian's narrative in "Indice," can be regarded as a book of naval expedition and discovery of the unknown until then North Arabian Sea and Persian Gulf. Following, in the form of an introduction is a brief summary of Alexander's early life, and of Plutarch's account entitled "Alexander". A brief description is also included of Indian records for historical disasters in the North Arabian Sea, as well as of Sri Lanka (Ceylon) accounts and legends pertaining to sea wave disasters along the Southeast coasts of India.

2.1 Tsunami Occurrence Elsewhere in Alexander's Empire

There is also additional mention of a tsunami elsewhere in Alexander's Empire. However, an allegorical account below by the ancient historian, Diodorus Siculus (Diodorus of Sicily) includes a description of a sea-monster creating a huge wave flooding the harbor of Alexandria in Egypt. Of course, the event was attributed to god Poseidon who was believed to be the originator of earthquakes and tsunamis.

Although there is no specific accounting in ancient texts of tsunami along the Makran region, it is interesting to note that besides Alexander the Great's fleet, Julius Caesar's Roman fleet also sustained damage from unusual wave conditions (not a tsunami) and tidal phenomena in 55 AD. Caesar was forced to retreat from the shores of England after suffering damage to his fleet while anchoring in areas that had extensive tidal ranges and unusually large waves. The following account of a tsunami is given by the ancient historian, Diodorus Siculus (Diodorus of Sicily). Diodorus in his rather allegorical narrative below includes a sea-monster in his account of the tsunami wave that flooded Egypt's harbor of Alexandria.

Fig. 1. Depiction of Diodorus Siculus sea-monster creating a tsunami.

“As the Macedonian construction came within range of their missiles, portents were sent by the gods to them in their danger. Out of the sea a tidal wave tossed a sea-monster of incredible size into the midst of the Macedonian operations. It crashed into the mole but did it no harm, remained resting. A portion of its body against it for a long time and then swam off into the sea again. This strange event threw both sides into superstition, each imagining that the portent signified that Poseidon would come to their aid, for they were swayed by their own interest in the matter”.

2.2 Alexander the Great’s Early Life 349-340 BC

Briefly, Alexander was the son of Macedonia’s king Phillip II and of the 19-year old Olympias, the daughter of Neoptolemus I king of Epirus - a fiery woman who took part in secret rites of worship of Dionysus and Orpheus, and had been initiated in the Kaverian Mysteries held yearly on cape of Chloi, exactly opposite the famous Kabeirion of Samothrace. Phillip II was the king of the ancient kingdom of Macedonia from 359 BC until his assassination in 336 BC. He was an accomplished military commander who set the stage for Alexander's victory over Darius III and the conquest of Persia.

Between the ages of 7-16, Alexander displayed arrogant intelligence and clashes with his father. However, despite his violent and nervous character, he was characterized by great self-control and self-discipline. His ambition was always accompanied by magnanimity, unlike Philip who was somewhat vain.

Philip’s career made Alexander’s conquests possible, by saving Macedonia from the verge of extinction, beating off powerful neighbors before expanding, until he dominated the rest of Greece and the Balkans. In the process, he created a uniquely effective army, combining many different types of troops into one formidable, fast moving team. This was the army Alexander led against the Persian Empire, composed of Philip’s men, fighting in the same way they had done for more than 20 years. It was Phillip’s career that made Alexander’s subsequent conquests possible. However, whenever it was known that Philip had either taken possession of a glorious city or had been victorious in some important battle, Alexander the Great did not hear it with much pleasure, but said to his peers, "children, my father will see to it all, and will not leave no work, great and brilliant, to achieve it with you (*which in Ancient Greek is stated «ὦ παῖδες, πάντα προλήψεται ὁ πατήρ, ἐμοί δ΄ οὐδέν ἀπολείψει μεθ΄ ὑμῶν ἔργον ἀποδείξασθαι μέγα καί λαμπρόν)».*

Because Alexander desired neither pleasure nor wealth but virtue and glory, he thought that the more he got from his father, the less he would achieve himself”. However, his views were changed and improved when Aristotle - one of history’s greatest philosophers — became his teacher when Alexander was 13 years old, and taught him about medicine, philosophy, morals, religion, logic and art. Also, under Aristotle's three-year tutelage, Alexander developed a passion for the works of Homer, for which Aristotle gave him an annotated copy, which later he carried in his campaigns.

Philip’s own assessment of the abilities of his son changed drastically after Alexander managed to tame “Bucephala”, a wild horse that no one else had managed to do. The taming of Bucephala made his father recognize that his son would be greater than him. It was then that Phillip the king of Macedonia wept for joy and exclaimed: *"My child, ask for a kingdom equal to yours, because Macedonia is not enough for you (ὦ παῖ, ζήτει σεαυτῷ βασιλείαν ἴσην· Μακεδονία γάρ σ΄ οὐ χωρεῖ)”.*

Alexander’s leadership qualities were further recognized by a delegation of Persians, which Alexander received in the absence of his father. The Persians left impressed, as what they had heard of Philip was nothing compared to what they heard of his son. Of course Aristotle’s teachings had turned Alexander much wiser and diplomatic.

In brief, Alexander’s leadership qualities became more evident during his subsequent campaigns in Asia, where he focused on the unification of conquered regions by taking the Hellenistic culture to a completely different level by introducing ideas of freedom, equality, philosophy, drama, and scientific categorization and study - based on Aristotle’s teachings - and spreading them across Asia Minor and the Middle East all the way to the Indian subcontinent.

2.3 Plutarch’s Account in “Parallel Lives”

A good historical account of Alexander the Great can be found in the works of Plutarch (79 AD) entitled “Alexander”. This account provides good information on the conquest in Asia and India, but very little information about the Greek fleet’s journey in the Northern Arabian Sea and in the Persian Gulf. Furthermore, he does not mention anything about earthquakes or catastrophic sea waves.

In his historical account "Parallel Lives," Plutarch provides in detail biographies of both Alexander the Great and of Julius Caesar, but also discusses the life, character and actions of forty-four other well-known, Greeks and Romans, describing them with parallelisms and an infinite number of historical and psychological elements. In this account Plutarch paints Alexander the Great with every historical detail and accuracy, down to his smallest psychological fibers indicating his determination.

2.4 Sri Lanka and Indian Records

Also, according ancient texts, large earthquakes and destructive waves occurred east of Sri Lanka (Ceylon), although the dates are somewhat conflicting as to the timing of these events, which may possibly relate to differences in calendars. According to Sri Lanka historical records (Fernando, 2005), in Sri Lanka (known as “Mahawamsa” then) in the time of King Kelanitissaa, a town named “Kalyani Kanika” and several other townships in the Eastern seaboard of Ceylon were inundated or destroyed by what must have been tsunami waves. Also provided in these records is an account that “Viharamahadevi”, the daughter of King Kelanitissa, was set afloat at Kalyani Kanika to appease the Gods, but that she was brought back to shore by sea currents, which landed her in Kirinda. However, the dates do not match, since the tsunami in Sri Lanka is purported to have occurred at the time of King Kelanitissa - in the 2nd Century BC, and apparently had a different source of origin.

Ancient Indian legends refer that a port city named Poompuhar, located at the confluence of rivers Kaveri and the Bay of Bengal in the Thanjavur District in the southern Indian State of Tamil Nadu - once known as “Kaveripattinam” — was washed away by a wave around AD 500. According to this legend, goddess “Manimekhalai” was angry with the Chola King and caused the city to be swallowed up by the sea. However, a tsunami in this region of the Bay of Bengal must have had a source near the Andaman Islands and Sumatra - probably in the same source region as that of 26 December 2004, and not in the Makran Subduction Zone of the North Arabian Sea, which would need to refract 180 degrees northward-thus reducing significantly the height and destructive impact of its waves on the very north-eastern region of the Arabian Sea.

As mentioned, Sri Lanka (Ceylon) was struck and devastated by the 2004 tsunami generated by a great earthquake along the coast of the Burma plate, and included the north-west portion of the island of Sumatra as well as the Andaman and Nicobar Islands, which separate the Andaman Sea from the Indian Ocean. Sri Lanka’s south and east coasts were hardest hit by this particular tsunami and more than 50,000 people lost their lives, and about more than 1,200 in the eastern district of known as Batticaloa (Pararas-Carayannis, 2005, 2006 a & b). This disaster was a very similar recurrence of the events reported in the above-cited ancient records. Included in a subsequent section of this report are analyses by the present author based on the documented impacts of the 26 December 2004 and of the 28 November 1945 earthquakes in the Makran region of the North Arabian Sea.

2.5 Brief Summary of Alexander’s Indian Campaign and Return to Babylon

According to Plutarch (79 AD), after defeating the Persians, Alexander continued his conquest of Asia by turning south into Arachosia (southeast Persia) and then continuing north into Afghanistan where he founded cities to serve as army garrisons and centers of his administration. Still inhabiting to the present time in a northern region of Afghanistan is a group of native people who racially differ from the rest of the country’s population, have Greek characteristics, and use words of Greek origin in their language. These people appear to be surviving descendants of s garrison left behind by Alexander’s Macedonian general Craterus or Krateros (in Greek: Κρατερός; c. 370 BC – 321 BC), on his northern land route of return to Babylon with more than a third of the Greek forces. Craterus, who claimed succession of Alexander, was killed subsequently in 321 BC at the Battle of the Hellespont (Fig. 2).

Fig. 2. Battle of the Hellespont

2.6 Construction of Fleet – Journey on River Indus

The following is an account of Alexander's earlier campaign, after entering Bactria and Sogdiana, and marching of his armies as far as the Jaxartes River. After two years in this region, during 327-326 BC, Alexander's army crossed the Hindu Kush mountain region (present Pakistan) and begun the conquest of India. There were several battles fought during the India campaign. Although victorious, after the May 326 BC battle of Hydaspes - near the northernmost of the five great tributaries of the Indus River, and as already stated, Alexander was pressured by his generals to end his Asian conquest and for the troops to return to Babylonia. Reluctantly he agreed and in June of that year, he sent a third of his army under the command of general Craterus, back to Carmania over a northern land route. The size of this army is estimated at 75,000 men. Subsequently, Alexander ordered that 30 oared galleys (Athenian type of triremes as shown in Fig. 3 below)) and other tow boats and rafts to be built, and sail down the Indus River in support of the ongoing Indian campaign and, subsequently, to transport part of the army with these back to Babylonia (Mesopotamia).

Fig. 3. The Athenian type of trireme that served as Alexander's flagship, "Olympias," named after his mother.

In command of the newly constructed fleet and other support vessels, Alexander appointed Nearchus of Crete, who previously had been the satrap of Lycia and Pamphylia (in Asia Minor), after the Sogdian campaign, and one of his two commanders of the Shield bearers, a heavy infantry unit, before the battle of Hydaspes.

Apparently the 30 triremes could not have been sufficient to carry Alexander's army, even with a third of the army already gone back to Carmania by a land route. Based on Plutarch's account, Alexander's army in India at that time amounted to about 140,000 foot soldiers and 15,000 cavalrymen. In all probability, many more barges and tow ships were used to transport some of the soldiers, while the bulk of the army marched along both banks of the Indus. Overall, the India Campaign and the fleet's journey down the Indus River took approximately seven months, during which Alexander conquered of what is now the Punjab State in northwestern India.

The map below (Fig. 4) shows the Indus River and its tributaries leading to the delta of the North Arabian Sea, which was named as the Port of Alexander, which no longer exists since subsequent extensive sedimentation changed the shoreline.

Fig. 4. Alexander's India Campaign along the Indus River Valley (map of livius.org), and of Port of Alexander at the delta of Indus River

2.7 Sea and Land Routes of Alexander's Army and Fleet

Finally, the fleet and the bulk of the army reached Patala, the present city of Bahmanabad, about 75 km northeast of Hyderabad (Fig. 5). A portion of the army continued on land southeast of the Indus River and fought several squirmishes before regrouping in August of 326 BC at Patala for the journey back to Carmania. According to Plutarch's account below, Alexander must have traveled further down the Indus River on a single ship to the ocean, because he describes such a voyage and the appointment of Nearchus as commander of Alexander's fleet, as follows:

“His (Alexander’s) voyage down the rivers took up seven months' time, and when he came to the sea, he sailed to an island which he himself called Scillustis, others Psiltucis, where going ashore, he sacrificed, and made what observations he could as to the nature of the sea and the sea-coast. Then having besought the gods that no other man might ever go beyond the bounds of this expedition, he ordered his fleet, of which he made Nearchus admiral and Onesicritus pilot, to sail round about, keeping the Indian shore on the right hand, **…_”**

The island of Scillustis or Psiltucis mentioned by Plutarch must have been a sand island near the mouth of the Indus River, which no longer exists.

Fig. 5. Alexander’s Sea and Land Routes

2.8 The Greek Fleet’s Journey to the Indus River Delta/Kutch Region

Overall, the India Campaign and the fleet’s journey down the Indus River took approximately seven months, during which Alexander conquered of what is now the Punjab State in northwestern India.

On 15 September 326 BC, following the departure of the bulk of army via the southern land route, the Greek fleet, under Nearchus’ command, set out to sea for Carmania and Babylonia with the remaining army which had dwindled to about 17,000 - 20,000 men. There is no information on the size of the fleet at his time in the ancient texts. It is possible that many more local ships were added since 30 triremes would not have been sufficient to carry so many men and their supplies for the long sea voyage.

September was too early in the season for the journey west as the monsoon winds blow in this region from a southwest direction from May through October. It is possible that Nearchus received false information from the natives who were anxious to see Alexander's ships leave. Almost immediately after leaving Patala, the ships encountered adverse winds. It took almost a week to reach the Erythraean Sea (the Indian Ocean). Subsequently, the fleet headed north, through the lagoon between the mouths of the rivers Indus and Hab (south of present Karachi which was then part of India).

2.9 Alexander's Army Return Via the Southern Land Route

In August 326 BC, Alexander with about 135,000 foot soldiers and cavalry men left Patala towards Carmania, for the long and difficult march back homeward, through the harsh Gedrosian desert (Arrian, 135-37 AD) — which was part of the ancient Achaemenid empire (present region of Baluchistan region in Iran). Fig. 6 below is another map showing Alexander's armies return to Babylon by sea and land routes and the extent of the empire between 334 to 323 BC. Apparently, only one-fourth of the army survived the march back on the southern land route through the harsh Gedrosian desert (Fig. 7). Plutarch describes Alexander's difficult journey via the southern land route and the hardships the army endured as follows:

" ……and (Alexander) returned himself by land through the country of the Orites, where he was reduced to great straits for want of provisions, and lost a vast number of his men, so that of an army of one hundred and twenty thousand foot and fifteen thousand horse, he scarcely brought back above a fourth part out of India, they were so diminished by disease, ill diet, and the scorching heats, but most by famine. For their march was through an uncultivated country whose inhabitants fared hardly, possessing only a few sheep, and those of a wretched kind, whose flesh was rank and unsavory,…."

Fig. 6. The empire established by Alexander the Great between 334 to 323 BC - Routes of the land Armies and of the Greek fleet down the Indus River, its tributaries and the open sea return to Babylon

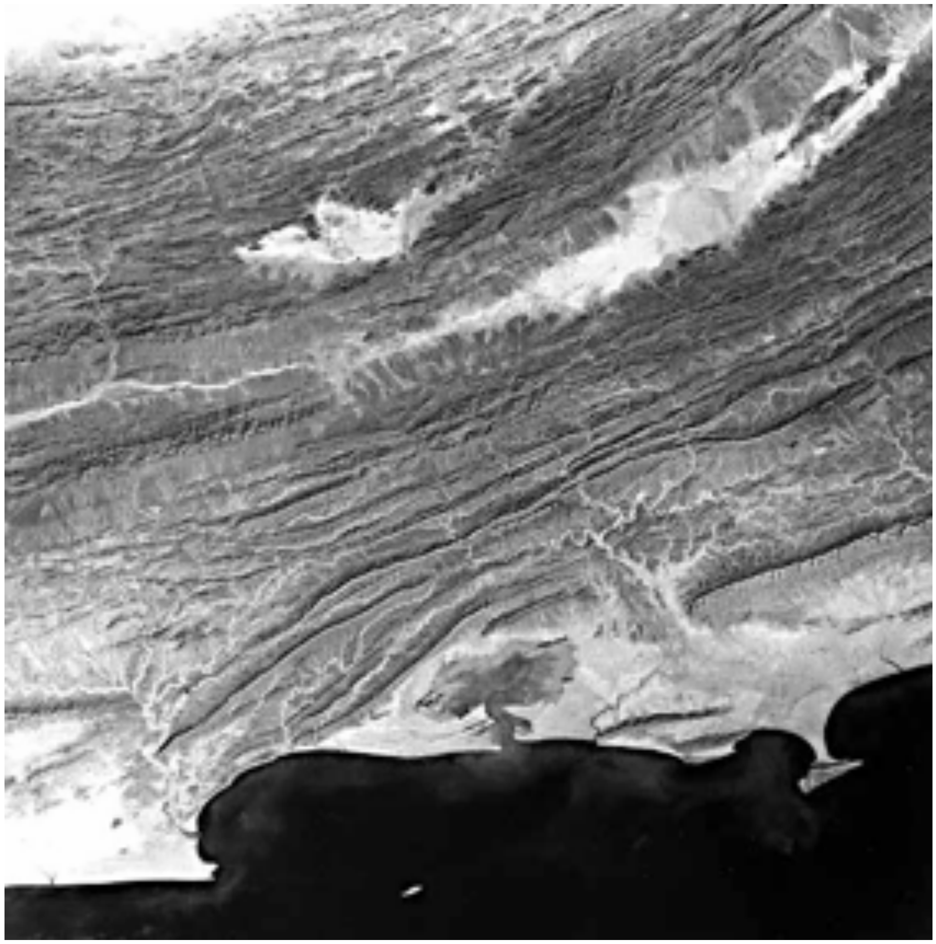

Fig. 7. NASA Satellite photo of a section of the Makran rugged and tectonic coastline showing uplifted terraces, headlands, sandy beaches, mud flats, rocky cliffs, bays and deltas. Numerous mud volcanoes along the shores. Alexander with about 135,000 foot soldiers and cavalry men marched through this harsh Gedrosian desert and only one-fourth of the army survived.

3. EVALUATION OF THE TSUNAMI OF 326 BC THAT IMPACTED THE GREEK FLEET IN 326 BC

There is no specific information in the afore-mentioned historical records about the occurrence of an earthquake or tsunami in 326 BC in the North Arabian Sea. The intensity of such event could not have been felt or estimated in the vicinity of the estuary of River Hab where the Greek fleet was at that time. However for an earthquake along the Makran subduction zone (MSZ) to generate a significant tsunami, its epicenter must have been near the coast further west, its focal depth must have been relatively shallow, its Richter magnitude greater than 7.0, and must have included some sizable degree of vertical crustal displacements of the sea floor.

In all probability, and again based on the historic accounts about the damage to the Greek fleet which was south of present Karachi near the estuary of River Hab at that time at the easternmost and relatively safer eastern region of MSZ, which limited the size of the tsunami waves and their impact. However, based on these considerations and the relative historic recurrence frequency of such earthquakes along the East-West trending seismogenic MSZ coast (of present southern Pakistan and Iran) in terms of geologic time, the present study can reasonably conclude that a significant tsunamigenic earthquake indeed occurred in 326 BC. Such an earthquake on the MSZ could have generated a significant tsunami with greater wave heights to the North and the South, and to a lesser heights along the Western and Eastern ends of the great fault. Such earthquake could have been very similar to the Makran earthquake of 1945, which generated a very destructive tsunami along coastal areas of India, Pakistan, Iran and Oman. Although infrequently, both the East and West segments of the Makran Subduction Zone in the Northern Arabian Sea, are capable of generating tsunamigenic earthquakes that can have an upper limit of moment magnitude of as much as 8, and such events have occurred with relatively high degree of frequency in terms of geologic time. (Pararas-Carayannis, 2005 b, 2006 a; b; Shah-hosseini EtAl. 2011)

Although not as frequent, there is also evidence that major earthquakes along the West segment of the MSZ coast have also generated tsunami waves on the south coast of Iran Shah-hosseini EtAl., 2011). Coastal boulder deposits found along the rocky coasts from Chabahar to Lipar, indicate the formation of Quaternary marine terraces, tectonic uplift, and coastal boulder deposits. Some of the boulders weighing up to 18 tons were found up to 6 m above the present mean sea level and up to 40 meters inland from the present shoreline. (Reyss EtAl, 1998). Based on such determinations of paleo-tsunami events, it may be possible that an earthquake along this Eastern MSZ zone in 326 BC could have generated a tsunami that partially damaged the Greek fleet when it was still in the estuary of River Hab.

Additionally there are other historical accounts of tsunami generation along the eastern and western coasts of India, purportedly causing destruction as far away as Sri Lanka and elsewhere. The best known of the most recent historical events was that of 1945. Other major or great recent and past earthquakes have generated significant tsunamis that impacted different coastlines of the northern Arabian Sea and of the Indian Ocean.

Another possibility is that the 326 BC earthquake occurred in the Gujarat region, where large events are also known to occur — particularly along the Kutch Graben region or even near the Bombay Graben. However, none of the recent earthquakes that have occurred along the Kutch Graben region have generated destructive tsunamis (Pararas-Carayannis, 2001). It is possible that an earthquake in the Guajarat region could have triggered an underwater landslide and a local tsunami, but such an event would not have the azimuthal concentration of energy to cause destruction on the East coast of Sri Lanka. More than likely, the large earthquake reported in the ancient texts originated along the Makran subduction zone — a region capable of generating destructive tsunamis (Pararas-Carayannis, 2005a,b 2006). However other possible tsunamigenic seismic sources in the Indian Ocean are examined to evaluate if a previous earthquake in the 326 BC could have generated waves which damaged the Greek fleet.

3.1 Partial Destruction of the Greek Fleet by a 326 BC Tsunami

Renewed southwest monsoons and dwindling food and water supplies slowed the fleet's progress, forced Admiral Nearchus to seek safe anchorage for the Greek fleet and to establish a fortified shore camp for about 24 days, while waiting for better weather conditions and for the seasonal monsoon winds to subside. From Plutarch's description and timing it can be concluded that the fleet had sailed north of the Indus River delta, and a new camp was established just south of the Hab River (south of present Karachi). Upon establishing this camp, the soldiers were forced to hunt and fish for food and to drink briny water. Fig. 8 below is a map indicating the location of the Greek fleet. It was probably at this time and at this location — in early November 326 BC - that the large earthquake and tsunami occurred probably near the region where the fleet had taken refuge. Fig. -- shows a probable tsunami generation area along the Eastern Makran subduction zone and the location of the Greek fleet at the time of November 326 BC where tsunami waves caused damage. As stated, this date was estimated based on a period known as Pyanepsion - "Πυανεψιών" of the ancient Athenian lunar calendar).

Fig. 8. Most likely location of the Greek fleet at the time of the November 326 BC tsunami.

According to Lietzin (1974), this earthquake had large magnitude and massive tsunami waves which destroyed a good part of Alexander's fleet. Also, according to Sri Lankan texts, a destructive tsunami struck the East side of the island of Ceylon, but the location and the given date of this tsunami's occurrence does not agree with the 326 BC event near the Hab river estuary in the Northwest Arabian Sea.

3.2 More Probable Location and Magnitude of the 326 BC Tsunamigenic Earthquake

In all probability and as stated, the earthquake of 326 BC occurred along the Makran coast (present southern Pakistan and Iran) and generated destructive tsunami waves. This earthquake could have been very similar to the Makran earthquake of 1945, which also generated a destructive tsunami along the coastal areas of India, Pakistan, Iran and Oman. Although infrequently, and as already stated, the Eastern Makran subduction zone in the Northern Arabian Sea is capable of generating tsunamigenic earthquakes that can have an upper limit of moment magnitude (Mw) of as much as 8 (Pararas-Carayannis, 2005; 2006).

There is no information in the historical records about the intensity of such an earthquake in 326 BC earthquake from which a magnitude can be estimated, or to determine that unusual sea waves from such event could have an impact as far away as eastern Sri Lanka (Ceylon) along the East side of India. Thus, it cannot be affirmed with any certainty whether the destructive sea waves in Sri Lanka which were reported in ancient texts, were generated by the same earthquake source in the Northern Arabian Sea as those of the 1945 event, or by any underwater landslide parallel to the NW trending Kutch graben, or even near the Bombay graben (See Fig. 9 below) in the Guajarat region of India - similar to one perhaps caused by a 25 January 2001 event. However, it should be also mentioned that none of the recent earthquakes that have occurred along the Kutch Graben region are known to have generated destructive tsunamis (Pararas-Carayannis, 2001a – see: "The Earthquake of 25 January 2001 in India" http://drgeorgepc.com/Earthquake2001India.html).

Fig. 9. The Indus delta/Kutch region in the Guajarat region of India – east of the Makran Subduction Zone - is a region that has produced numerous destructive earthquakes in recent times, including a devastating earthquake in 2001 (after Pararas-Carayannis, 2001a).

However, it is possible that an earthquake further South in the Guajarat region could have triggered an underwater landslide and a local tsunami, which perhaps could have affected the Greek fleet in 326 BC, although such an event would not have the azimuthal concentration of energy to cause destruction on the East coast of Sri Lanka (Pararas-Carayannis, 2005c, 2006).

3.3 Probable Scenario of the 326 BC Tsunami

It is not known with any certainty if the tsunami of 326 BC struck the Greek fleet while at anchor, or while out at sea. None of the examined ancient texts provide information about losses or extent of the damage. However, based on Plutarch's and other historical accounts, and from current knowledge of the seismo-tectonics of the region, the chronology of the journey of Alexander's fleet and the possible impact of the 326 BC tsunami can be evaluated.

The timing of the large earthquake was critical to the fate of the fleet. What saved the Greek fleet from more extensive destruction was its location at that time when the tsunamigenic earthquake occurred. Such an earthquake probably occurred along the Makran Subduction Zone in late October or early November of 326 BC, when the ships were still in the Indus delta/Kutch region — near the delta of River Hab (just south of present Karachi). According to Plutarch, and the aforementioned Athenian lunar calendar, the Greek ships did not set sail from the estuary between the mouths of rivers Indus and Hab until early November, when the Southwest monsoons subsided (see Fig. 10 below).

Fig. 10. Location of Alexander's Fleet in late October 326 BC before heading for the River Hab estuary

The delay in the fleet's departure due to the adverse winds was a blessing in disguise and probably saved most of the ships from destruction. If the earthquake had occurred later in November after the fleet had left the River Hab estuary and was closer to Morontobara (present day Karachi), or when the fleet was sailing further west along the Makran coast (of southern Pakistan) near Bagisara (of present Ormara), there could have been total destruction of the Greek ships if sailing in shallower waters near the shore.

Not only the timing of the earthquake but the orientation of the tsunami generating area was critical to the fate of the Greek fleet. The tsunami generating area along the Makran Subduction Zone (NSZ) has an east-west orientation. Therefore, the azimuthal propagation of the tsunami energy would have been greater to the North and to the South and much less to the East or West. Thus the tsunami waves would have been very large along the entire Makran region, as well as along the southwestern coasts of India, as the tsunami wave energy refracted in deeper water. Immediately to the East of the MSZ, where the Greek fleet was located, the waves were not as high or as destructive. It is estimated that the tsunami waves at the River Hab estuary did not exceed 2 meters. Apparently, the destruction must have been partial and most of the ships were able to make repairs and continue the journey west.

3.4 The Fleet's Journey after the 326 BC Tsunami

With no opposing winds during the monsoon transitional period in November of 326 BC, the ships made significant progress westward (Fig. 11).

Fig. 11. Greek triremes under sail with favorable westerly winds

According to Arrian (based on Nearchus' account), after leaving the Indus delta/Kutch region, the Greek fleet continued the difficult journey, first to Morontobara or Woman's Harbor (present Karachi) near the mouth of the Hab River, then through the Sonmiani Bay, along the Makran coast. One night, they anchored and camped on the battlefield where Leonatus, one of Alexander's generals, had defeated the native population, the Oreitans ('Mountain people'). Leonatus had left a large food deposit for Nearchus' men — enough for ten days. Thus, with renewed supplies and favorable winds the ships reached the Hingol River and then continued westward to Bagisara (present Ormara), where the 326 BC tsunami probably must have had its maximum impact earlier in November 326 BC.

The fleet made significant progress westward when the Northeast (winter) monsoons picked up in early December, thus reaching rapidly Colta (Ras Sakani), Calima (Kalat) and an island called Carnine (Astola). After provisioning there, the fleet continued and passed Cysa (near Pasni) and Mosarna (near Ras Shahid). Here, a Gedrosian pilot joined them, who led them in two days to modern Gwadar, where they were delighted to see date palms and gardens. Three days later, Nearchus' men surprised Cyisa, a town near modern Châh Bahâr and took away supplies. Next, they anchored near a promontory dedicated to the Sun, called *Bageia* ("dwelling of the gods") by the natives and probably identical to Ra's Kûh Lab. The places that Nearchus mentions in his account of the voyage — as conveyed by Arrian of Nicomedia (Talmena, Canasis, Canate, Taa, Dagaseira) cannot be identified, although it is plausible that the last mentioned town is modern Jâsk.

3.5 Alexander's Army Return Via the Southern Land Route

Apparently 30 triremes could not have been sufficient to carry Alexander's army, even with a third of the army already gone back to Carmania by a land route. In August 326 BC, Alexander with about 135,000 foot soldiers and cavalry men left Patala towards Carmania, for the long and difficult march back homeward, through the harsh Gedrosian desert (Arrian, 135-37 AD) — which was part of the ancient Achaemenid empire (present region of Baluchistan region in Iran). Apparently, only one-fourth of the army survived the march back. Plutarch describes Alexander's difficult journey via the southern land route and the hardships the army endured as follows:

" ……and (Alexander) returned himself by land through the country of the Orites, where he was reduced to great straits for want of provisions, and lost a vast number of his men, so that of an army of one hundred and twenty thousand foot and fifteen thousand horse, he scarcely brought back above a fourth part out of India, they were so diminished by disease, ill diet, and the scorching heats, but most by famine. For their march was through an uncultivated country whose inhabitants fared hardly, possessing only a few sheep, and those of a wretched kind, whose flesh was rank and unsavory,…."

Fig. -- below is a NASA satellite photo of a section of the Makran rugged and tectonic coastline showing uplifted terraces, headlands, sandy beaches, mud flats, rocky cliffs, bays and deltas, as well as numerous mud volcanoes along the shores.

4. EXAMINATION OF RECENT AND PREVIOUS MAJOR EARTHQUAKE AND TSUNAMI GENERATING SOURCES IN THE EASTERN AND WESTERN MAKRAN SUBDUCTION ZONE (MSZ) AND ELSEWHERE IN THE INDIAN OCEAN FOR POSSIBLE IMPACT ON THE GREEK FLEET IN THE YEAR 326 BC

In view of the lack of early historical documentation and understanding of earthquakes, tsunamis or other geophysical phenomena, and in order to narrow down the source of the waves that impacted the Greek fleet in 326 BC while in the Eastern Makran region of the North Arabian Sea, this section of the report reviews briefly the recent development of seismology and of the science of tsunami hazards in the 19th Century, as well as recent and old documented and recurring major earthquakes and tsunamis along the Eastern (Reyss EtAl. 1998), and Western segments of the Makran subduction zone in the North Arabian Sea, as well as elsewhere in the Indian Ocean (Pararas-Carayannis, 1978, 2001, 2005a,b,c,d, 2006a,b.,2007; Mokhtari and Farahbod, 2005; Murty and Bapat, 1999). The Makran accretionary wedge is one of the largest on Earth (Dorostian & Gheitanchi, 2003. A 7-km-thick column of sands and quartzolithic turbidites are incorporated into this wedge in a series of deformed thrust sheets, and has over pressured landward of the deformation front (Fruehn EtAl, 2003).

With the advent of seismology in the 19th century, major destructive tsunamigenic earthquakes begun to be monitored and documented in the Indian, Pacific, Atlantic Oceans and elsewhere around the world. The scientific studies and understanding about tsunamis begun much later, after the moment magnitude 8.6 earthquake of 1 April 1946 struck off the coast of Unimak Island in Alaska's Aleutian Islands. This particular tsunami caused the greatest damage and number of deaths in the Hawaiian Islands. It was an unprecedented disaster which led to the 1960 creation of the United States' first tsunami warning system, and subsequently to the development of extensive international research programs about past tsunami hazards.

These studies were further expanded in the following years to include other previous and subsequent tsunami disasters. Besides the 28 November 1945 earthquake and tsunami in the Northern Arabian Sea, there were more tsunamigenic earthquakes near Karachi in the present Southern Pakistan, near the estuary of River Hab. This is the location where the Greek fleet sustained partial damage from an apparent tsunami in 326 BC. In terms of geologic time such events recur in the same areas, therefore the following is only a cursory review of the impact of the better known recent major tsunamigenic earthquake events, particularly of the 28 November 1945, in the North Arabian Sea. Also reviewed are other historical earthquakes in Northwest India, as well as more recent tsunamigenic earthquakes elsewhere in the Indian Ocean. The following brief review was undertaken in order to evaluate which were the earthquakes elsewhere which may have generated the waves that impacted the Greek fleet in the year 326 BC.

There are several regions where large earthquakes have occurred in the past and destructive tsunamis were generated. Besides the Makran Subduction Zone, the Karachi and deltaic Indus region, the Owens Fault Zone, and the Kutch Grabben region, tectonic subduction and thrust faulting occur also in the Andaman Sea, along a short segment of Sri-Lanka, but also along the great Sunda Arc. Large earthquakes in recent times and in the distant past generated extremely destructive tsunamis along other coastlines of the Indian Ocean. One of the most recent was the one generated by the great earthquake of 26 December 2004 (Pararas-Carayannis 2005 a,b,c) .

As documented by the above referenced study, the on-going and recurring seismo-tectonic processes in the Indian Ocean are mainly the direct result of the Indian and Australian blocks moving northward at a rate of about 40 mm/yr (1.6 inches/yr) and colliding with the Eurasian continent (Fig. 12) (Tapponnier EtAl. 1986).

The main regions that were identified as more critical for past and future tsunami generation are the Andaman Sea Basin, the Northern and Eastern segments of the Great Sunda Tectonic Arc, and the Chagos Archipelago. Therefore the seismicity and potential of tsunami generation of the above-cited tsunamigenic regions are briefly reviewed, for the purpose of evaluating the source of the waves that could have impacted the Greek fleet in the year 326 BC.

Fig. 12. Migration of the India tectonic plate northward in the last 71 nillion tears and its collision with the Eurasian plate and formation of the Himalayan mountain range.

4.1 Evaluation of Possible Impact on the Greek Fleet in 326 BC from an Earthquake and Tsunami Generated along the Makran Subduction Zone (MSZ) in the Northern Arabian Sea, Similar to the 28 November 1945

While in the vicinity of the Hab river estuary on the Northwest coast of India, the Greek fleet could have been partially damaged by a tsunami in 326 BC similar to the one generated by the 28 November 1945 earthquake in the Eastern Makran Subduction Zone (MSZ) in the Northern Arabian Sea. Shown below in figure 13 is the epicenter of the 1945 earthquake, the Makran Accretionary Front, and the tectonic subduction zone in the Northern Arabian Sea, where the Greek fleet sailed later in early November 325 BC on its way to Babylon in the Persian Gulf. In order to evaluate the possibility of impact from a similar tsunami generated in 326 BC, the 1945 earthquake and tsunami were re-examined. Also examined were other major geotectonic features in the Northern Arabian Sea, close to the present day Karachi of Pakistan, the epicenters of historical earthquakes near the Ornach Nal Fault the Makran Accretionary Front, the two major zones of subduction, the Murray Ridge, and the Owen Fracture Zone (Fig. 14), as reported in the literature (Huhn EtAl ,1998; Regard EtAl, 2003; Pararas-Carayannis 2005a,b; 2006). The following is a brief overview of this event.

Fig. 13. The generating area of the 28 November 1945 tsunami off the Makran coast of Pakistan (After Pararas-Carayannis 2006b).

A thorough analysis of historical records reveals that many earthquakes and tsunamis have occurred in the past along the Makran Subduction Zone (MSZ) in the North Arabian Sea throughout geologic history and in recent times (Jacob and Quittmeyer, 1979). An earthquake on the MSZ could have been a most probable source of a tsunami which impacted the Greek fleet in 326 BC when it was in the River Hab estuary. Since earthquakes on the MSZ have occurred frequently in terms of geologic time, such an event could have be very similar to the great earthquake of 28 November 28, 1945 on the MSZ which generated a very destructive tsunami (Pararas-Carayannis, 2006d). According to the literature, the 1945 earthquake was a thrust event that ruptured approximately one-fifth of the entire length of the MSZ, and was estimated to have been 200 – 250 km. (Byrne et al. 1992). However, a revised moment magnitude of Mw 8.1 for this event would suggest a longer rupture - in the order of 300-350 Km. Although infrequent, such large earthquakes occur from time to time mainly on the eastern segment of the MSZ. Nine other smaller earthquakes are known to have occurred also in the eastern Makran with similar thrust tsunamigenic mechanism characteristics (Pararas-Carayannis, 2006b).

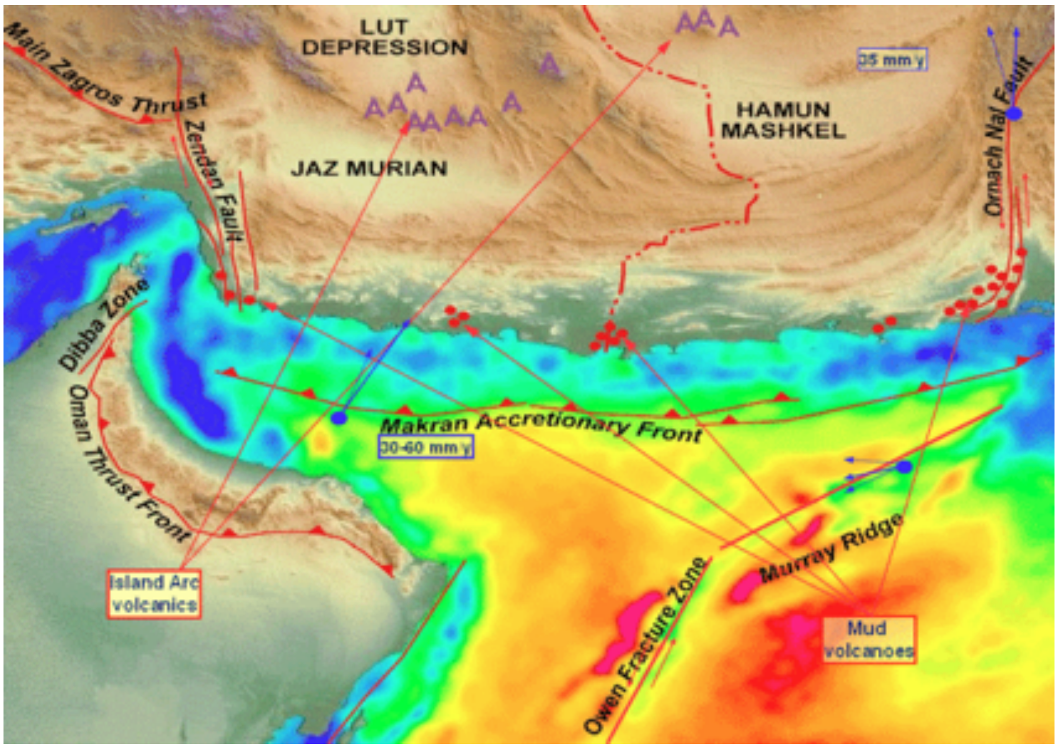

Fig. 14. Map of the Northern Arabian Sea showing the Makran Accretionary Front, two major zones of subduction, the Murray Ridge, the Owen Fracture Zone and the epicenters of historical earthquakes near the Ornach Nal Fault close to the present day Karachi of Pakistan

The great earthquake of 28 November 1945 is an example of the size of earthquakes that subduction along MSZ can produce (Mokhtari and Farahbod, 2005; Pararas-Carayannis 2005a,b.c, 2006). The tsunami was very destructive not only in the Northern Arabian Sea, but caused serious destruction along India's west coast, and great loss of life along the coasts of Pakistan, Iran, India and Oman, where run-up heights varied from 1 to 13 m. Specifically along the Makran coast of Pakistan, the tsunami's maximum run up height of 13 m (40 feet), destroyed fishing villages, caused great damage to port facilities, and resulted in deaths of more than 4,000 people. Waves of about 6.5 feet in height killed all the people of Khudi, a fishing village about 30 miles west of the present city of Karachi. Also Karachi was struck by the 1945 tsunami (Pakistan Meteorological Department, 2005).

Waves as high as 11.0 to 11.5 meters struck the Kutch region of Gujarat causing extensive destruction and loss of life. Eyewitnesses reported that the tsunami came in like a fast rising tide. The tsunami reached as far south as Mumbai, Bombay Harbor, Versova (Andheri), Haji Ali (Mahalaxmi), Juhu (Ville Parle) and Danda (Khar). In Mumbai, the height of the maximum wave was 2 meters, washing away fifteen persons. Five people died at Versova (Andheri, Mumbai), and six more at Haji Ali (Mahalaxmi, Mumbai). Several fishing boats were torn off their moorings at Danda and Juhu (Pararas- Carayannis, 2006b). However to the East of this MSZ zone, the waves were significantly lower. Karachi in present day Pakistan was struck by waves of only about 2 meters (6.5 feet) in height. Therefore, Alexander's fleet - which in 326 BC was located east of the delta of River Hab South of present-day Karachi - when such a similar event may have occurred, must have been inpacted by similar waves of about 2 meters, thus limiting the extent of damage (Pararas-Carayannis, 2006; http://drgeorgepc.com/TsunamiPotentialMakranSZ.html).

In brief, the Makran Subduction Zone always had the potential for very large earthquakes. Fortunately, they are infrequent and are usually preceded by smaller events that signal the occurrence of a larger earthquake. For example, for ten years prior to the 1945 event, there was a concentration of seismic activity in the vicinity of its epicenter. Recent seismic activity indicates a similar pattern and a large earthquake is possible in the region west of the 1945 event (Quittmeyer and Jacob, 1979). Although there are no historical records, it is believed that large earthquakes generated very destructive tsunamis in the distant geologic past.

Finally, a factor that could contribute to the destructiveness of a tsunami generated from this region would be the relatively large astronomical tide, which for the Makran coast is about 10-11 feet. A tsunami arriving during high tide would be significantly more destructive. In addition, the compacted sediments in this zone of subduction could contribute to a greater tsunami by causing a bookshelf type of failure – as that associated with the 1992 Nicaragua earthquake (Pararas-Carayannis, 1992).

The above stated documentation supports a reasonable conclusion that a significant earthquake and tsunami generated along the Makran Subduction Zone (MSZ) in the Northern Arabian Sea in 326 BC may been the event that caused damage to ships of the Greek fleet in the vicinity of the Hab River estuary at that time, in the easternmost end of the Makran Subduction Zone.

4.2 Possible Tsunami Impact on the Greek Fleet from an Earthquake on the Eastern Makran Subduction Zone similar to the 26 January 2001 Guajarat Earthquake

Discussed in section 4.1 of the present report is a brief evaluation of possible tsunami impact on the Greek fleet in 326 BC from similarly repeating earlier historical earthquakes in the Kutch, Bombay, and Cambay and Namacia grabens of Northwestern India. Provided in this section is a brief evaluation of the possible tsunami and earthquake impact on the fleet, from another similar to the more recent earthquake of 26 January 2001, magnitude R7.7, Guajarat earthquake. This recent earthquake also occurred along this same seismically active region of the Northeast trending Kutch and Bombay grabens of Northwest India as shown in Figure, and a previous occurrence in 326 BC could have been responsible in causing some damage to the Greek fleet, when it was still in the vicinity of the Haab river estuary - as reported in Arrian's of Nicomedia "Indice" account. The possibility that an earthquake occurred in the Gujarat region in 326 BC along the Kutch Graben region or even near the Bombay graben was discussed earlier in this report. Although none of the recent earthquakes that have occurred along the Kutch Graben region have generated destructive tsunamis (Pararas-Carayannis, 2001), it is possible that an earthquake could have triggered an underwater landslide and a local tsunami that could have reached the Haab river estuary. Another possibility of tsunami generation could be in the area of present day seismic region of Karachi in Pakistan - the ancient city of Morontobara of India.

4.3 Probable Impact on the Greek Fleet in 326 BC from an Earthquake and Tsunami in the Karachi and Deltaic Indus River Region

This is also a region near present Karachi and the deltaic Indus River where many earthquakes and tsunamis have occurred frequently in the past and could have had an impact on the Greek fleet in 326 BC. Four major faults exist in and around present day Karachi of Pakistan, along the southern coast of Makran, and in other parts of deltaic Indus River (Pararas-Carayannis, 2001, 2005). The first of these is the Allah Bund Fault, which traverses Shahbundar, Jah, Pakistan Steel Mills, and continues to the eastern parts of Karachi - ending near Cape Monze. This fault has produced many large earthquakes in the past in the deltaic river areas along the coast, causing considerable destruction. A major earthquake in the 13th century destroyed Bhanbhor. Another major earthquake in 1896 was responsible for extensive damage in Shahbundar (Pararas-Carayannis, 2001, 2005).

The second major fault near present-day Karachi is an extension of the one that begins near Rann of the Kutch region of India. The third is the Pubb fault which ends into the Arabian Sea near the Makran coast. Finally, the fourth major fault near Karachi is located in the lower Dadu district, near Surajani. A major thrust fault which runs along the southern coast of the Makran coast and parts of deltaic Indus is believed to be of the same character as the West Coast fault along the coast of Maharashtra, where a tsunami may have been generated in 1524, near Dabhol (Pararas-Carayannis, 2001b, 2006). Any earthquake along the Makran subduction zone, but particularly one south of Karachi, in the year 326 BC could have generated a tsunami affecting the Greek fleet. An earthquake in the same area as that of 26 January 2001, magnitude R 7.7 Guajarat earthquake on the Northeast trending Kutch and Bombay grabens of Northwest India – as shown in Figure 15 below - could have generated similar tsunami waves in 326 BC

Also, a recent study of coastal boulder deposition on the Iranian coast of the Makran subduction zone found 58 large boulders weighing up to 18 tons and up to 6 meters above mean sea level and up to 40 meters from the present shoreline (Shah-hosseini, EtAl, 2011). Using hydrological models, this study concluded that only tsunami waves of 4 meters in height were capable of detaching and transporting inland these boulders, and that such tsunami waves have also occurred on the Eastern Makran subduction zone near to the coast of Iran.

Fig. 15 Epicenter of the 26 January 2001, magnitude R 7.7 Guajarat earthquake on the Northeast trending Kutch and Bombay grabens of Northwest India

4.4 Evaluation of Possible Impact on the Greek Fleet in 326 BC from an Earthquake and Tsunami in the Andaman Sea Basin.

The Andaman Sea basin is another seismically active region in the Indian ocean at the southeastern end of the Alpine-Himalayan belt where many earthquakes have occurred recently and in the distant past (Sinvhal et al.1978, Verma et al. 1978). Thus, the seismo-tectonic history of this region was examined for the purpose of evaluating whether a possible tsunamigenic earthquake from this region could have had an impact to the Greek fleet in 326 BC when it was near the estuary of River Hab, in the Arabian Sea near the Makran coast.

Tectonic subduction and thrust faulting occur in the Andaman Sea, the Northern Arabian Sea, along a short segment of Sri-Lanka, and along the great Sunda Arc. Large earthquakes in recent times and in the distant past generated extremely destructive tsunamis along coastlines of the Indian Ocean. One of the most recent was the one generated by the great earthquake of 26 December 2004 (Pararas-Carayannis, 2005). As documented by this referenced study and illustrated earlier in Figure 12 the on-going and recurring seismo-tectonic processes in the Indian Ocean are mainly the direct result of the Indian and Australian blocks moving northward and colliding with the Eurasian continent.

The Andaman Sea basin is characterized by an extensional feature, which developed along a leaky transform segment of the megashear zone - the Andaman fault - between the Indo-Australian domain and the Sunda-Indochina block (Sinvhal EtAl, 1978; Uyeda and Kanamori, 1979; Taylor and Karner, 1983;), Neotectonics and time space seismicity of the Andaman Nicobar). This old shear zone has acted as a western strike slip guide for the extrusion of the Indochina block about 50-20 million years ago, and in response to the indentation of the Indian tectonic plate into Eurasian block as previously shown in Fig. 12.

Subsequently, the Andaman fault system, recently prolonged through the Sumatra zone (the Sumatra fault), reactivated due to the lateral escape of the Sumatra fore-arc sliver plate and as a result of the oblique convergence and subduction with the Indo-Australian plate (Tapponnier et al., 1986).

Although active subduction and sinistral crustal movements in the Andaman Sea Basin have caused many minor and intermediate earthquakes, a few major events and only one known earthquake with magnitude greater than 8. Review of the historical record indicates that in April 1762, an earthquake at the Araken Coast off Myanmar generated the earliest known tsunami in the Bay of Bengal. Also, in October 1847, an earthquake near the Great Nicobar Island generated another tsunami, but no details are available. On 31 December 1881 a magnitude 7.9 earthquake near Car Nicobar, generated another tsunami in the Bay of Bengal. The height of the maximum tsunami wave recorded at Chennai was one meter. During an eighty year period from 1900 to 1980, a total of 348 earthquakes were recorded in the area bounded by 7.0 N to 22.0 N and 88.0 E to 100 E. These earthquakes ranged in magnitude from 3.3 to 8.5 (Bapat, 1982), but only five of these had magnitudes equal to or greater than 7.1 and generated tsunamis (Murty and Bapat, 1999). For the shorter period from 1916 to 1975, only three of the earthquakes had magnitudes greater than 7.2 and generated significant tsunamis (Verma EtAl., 1978).

Until the great earthquake of 26 December 2004, only the earthquake of 26 June 1941 had been the strongest ever recorded in the Andaman and Nicobar Islands, in generating a destructive tsunami. Two other earthquakes on 23 August 1936 and 17 May 1955, with magnitudes 7.3 and 7.25, respectively, did not generate tsunamis of any significance. Based on these statistical information, it can be concluded that most of the earthquakes in the Andaman Sea Basin, even those with magnitudes greater than 7.1, do not usually generate significant tsunamis. The possible reason for the low number of tsunamis is that most of the earthquakes in the Andaman Sea are mainly associated with strike-slip type of faulting that involves lateral crustal movements. The exception was the 26 December 2004 earthquake, which, not only ruptured the Great Sunda Arc along the northern Sumatra region, but also ruptured the same segment in the Andaman Sea as that in 1941 (Pararas-Carayannis, 2006).

A possible explanation for the extreme tsunami generated in the Andaman segment in December 2004 is that this event had a different mechanism and involved both thrust and bookshelf faulting within the compacted sediments of the Andaman Sea segment of the Great Sunda Arc (Pararas-Carayannis, 2005). In brief, and based on the historical record and the tsunami propagation from major and even great tsunamigenic earthquakes as that of 26 December 2004, it can be concluded that no similar event in 326 BC could have caused damage to the Greek fleet which was at that time Northwest of India in the North Arabian Sea.

4.5 Evaluation of Possible Impact on the Greek Fleet in 326 BC from an Earthquake and Tsunami similar to the 19 August 1977 in the Lesser Sunda Islands of Indonesia.

This earthquake occurred in 19 August 1977 just South of the Lesser Sunda Islands (Nusa Tenggara region), West of Sumba Island in Indonesia. The Lesser Sundas include Bali, Lombok, Sumbawa, Sumba, Flores, Timor, Alor and adjacent smaller islands (see Fig. 16).

This was the largest earthquake along the Java Trench in several decades and generated a major destructive tsunami, which was particularly damaging along the coasts of Sumba, Sumbawa, Lombok and Bali. Waves of up to 30 meters in height were reported on the adjacent Indonesian coasts, and as much as 8 meters in Australia. This earthquake's epicenter was at 11.09S; 118.46E about 170 kilometers SSW of Pradapare, Sumba Island (West Nusa Tenggara) and its Moment Magnitude was recalculated (Mw- 8.2, Ms - 8.1, ML - 8.9). The quake's maximum intensity was estimated to be VIII in the immediate area, and Mo - 24*10*20 Nm. (Pararas-Carayannis, 1978;1989).

Fig 16. Flores Island in the Lesser Sunda Islands where a major tsunami was generated on 12 December 1992

With support from INESCO-IOC and the U.S. National Oceanic and Atmospheric Administration (NOAA), the author participated in a survey of this earthquake and tsunami, in order to determine the tsunami run-up and extent of inundation. The survey was conducted by land where accessible, and by air reconnaissance for inaccessible coastal areas of the islands of Sumba, Sumbawa, Lombok and Bali (Pararas-Carayannis, 1978). Based on these observations and the directionality of the source and the tsunami's main energy propagation towards the Southern Indian Ocean, the present study concludes that no historically previous large tsunami waves from this region, could have reached the Eastern Makran area south of present Karachi where the Greek fleet sustained some damage in 326 BC.

4.6 Evaluation of Possible Impact on the Greek Fleet in 326 BC from an Event Similar to the 12 December 1992 Earthquake and Tsunami near Flores Island in Indonesia.

There was repetition of seismic and tsunami activity in the same region about 25 years later. The deadliest tsunamigenic earthquake in the Lesser Sunda Islands region of Indonesia occurred again near Flores Island on 12 December 1992 (Fig. 16 above). It had an Ms 7.8 magnitude, a maximum Mercalli intensity of VIII (*Severe*) and its generating source was a thrust fault dipping 32 degrees to the south and extending about 110 kilometers from Cape Batumanuk to Cape Bunga. The maximum tsunami waves generated by the earthquake were almost 26 meters in height, reached shore in five minutes, and ran inland as far as 300 meters. The disaster caused at least 2,080 fatalities, including 1,490 in Maurnere, on Flores, and 700 on Babi Island (U.S. Geological Survey). More than 500 people were injured and 90,000 were left homeless by this event. Nineteen people were killed and 130 houses were destroyed on Kalaotoa. Damage was assessed at exceeding US $100 million. Approximately 90% of the buildings were destroyed at Maumere, the hardest hit town, by the earthquake and tsunami while 50% to 80% of the structures on Flores were damaged or destroyed. Damage also occurred on Sumba and Alor (USGS, 1992). However, given the southern orientation of this tsunami's source region in the Indian Ocean, and its confinement by surrounding islands, it can be definitely concluded that an earlier occurrence of such an event could not possibly have reached the Eastern Makran area where the Greek fleet sustained some damage in 326 BC.

Fig. 17. Map of East Java and of the Lesser Sunda Islands

4.7 Evaluation of Possible Tsunami Impact on the Greek Fleet from other Earthquake Sources of Indonesia - the 28 March 2005 Earthquake and Tsunami

Provided in the following section is an overview of other major tsunamis in the Indian Ocean in recent times – such as that of 28 March 2005 East of the Island of Java in Indonesia - which although very destructive locally and elsewhere, did not impact significantly the

Northern Arabian Sea in the vicinity of Karachi. Thus a previous recurrence and impact in the North Arabian Sea of such events causing damage to the Greek fleet in 326 BC would not have been possible because of the tsunami's energy southern directionality. None-the-less, and for the purpose of eliminating this earthquake source as having a significant tsunami impact on the Greek fleet, the following section provides a cursory review of this event, emphasizing the different focusing of the tsunami waves that were generated. Fig. 17 above is a map of Eastern Java and of the Lesser Sunda Islands. The block that was moved by the 28 March 2005 earthquake was relatively small in comparison. Whether this movement will now stress loads another segment of the great Sunda fault to the South and causes another earthquake soon, is not known. However, another great earthquake similar to that of 1833 (magnitude 8.7) along the south coast of the western Sumatra will eventually occur. That particular earthquake generated a great tsunami. The waves may have been as much as 10 to 15 meters on the western coast of Sumatra. Luckily, most of the energy from that tsunami was directed towards the unpopulated regions of the southwest Indian Ocean. When such an event will occur again, is not known. The only thing known with certainty is that it will occur in this region. In conclusion, a tsunami from this region could not have had an impact on the Greek fleet in 326 BC while it was in the vicinity of the estuary of River Hab, in the relatively safe eastern region of MSZ,

4.8 Evaluation of Possible Tsunami Impact on the Greek Fleet from the Great 26 December 2004 Earthquakes and Tsunami in Indonesia and the Indian Ocean.

The great tsunamigenic earthquake of 26 December 2004 was also evaluated as a possible source region of destructive waves which could have affected the Greek fleet in 326 BC when it was located in the vicinity of the Hab River estuary, at the easternmost end of the Makran Subduction Zone in the North Arabian Sea.

This 26 December 2004 tsunamigenic earthquake resulted from a sudden episode of the Indian plate's subduction and of the Burma tectonic movement plate in a northeast direction (Paris EtAl. 2010). As previously stated, this movement caused dynamic transfer and loading of stress to both the Australian and Burma plates, immediately to the south, on the other side of the triple junction point. As a result of this load transfer, the Australian plate moved in relation to the Burma plate and probably rotated somewhat in a counterclockwise direction, causing the subsequent great earthquake of 28 March 2005 as explained in section 4.7 above. Thus, a Coulomb stress transfer analysis, based on rupture parameters and the geometric distribution of aftershocks for both the 26 December 2004 and the 28 March 2005 events, would help establish the space-time evolution of stresses and help determine both static and dynamic modifications that could possibly trigger future events along known faults in the region. In conclusion there was no tsunami damage to the Greek fleet from this region in 326 BC.

5. CONCLUSIONS

Although infrequently, large magnitude earthquakes occur along the Makran Subduction Zone (MSZ) region of Southern Iran and Pakistan, the Indus river delta/Kutch region, the Andaman Sea and elsewhere in the Indian Ocean. Such earthquakes, involving mainly thrust motions are known to generate frequent destructive tsunamis. Also, destructive tsunami waves can be generated by underwater landslides particularly in the North Arabian Sea and the Northern Andaman Sea because of extensive sediment accumulation along the deltas of major rivers. Large earthquakes near the Kutch Graben region can trigger also waves from underwater landslides. Major and great earthquakes elsewhere in the Indian Ocean have also generated destructive tsunami waves.

Ancient Greek and Indian texts support that destructive sea waves along the Makran coast in the northern Arabian Sea were responsible for the partial destruction of Alexander the Great's fleet in 326 BC. At that time the fleet was at an estuary of River Hab, north of the Indus River delta/Kutch of India while waiting for calmer seas and for the seasonal monsoon winds to subside, before beginning the long journey from India to Babylon, in the Persian Gulf. It is very possible that the reported damage to the fleet was caused from a tsunami rather than storm waves. Repairs to the ships were made and the journey continued west towards Babylon in the Persian Gulf. In all probability, the reported waves in the ancient texts originated along the Makran Subduction Zone – the same source area that produced a great earthquake and tsunami in 1945 as well as other extreme disasters in the past. Based on reviews of ancient Greek accounts such as those of Plutarch, Nearchus but mainly of Arrian's of Nicomedia "Indice", the present study reconstructed the chronology of the impact on the fleet based on the ancient Athenian lunar calendar, as occurring in early November of 326 BC. By using also current geophysical knowledge of recent events in this region, and the documentation of the 1945 and of other events, the present study concluded that the reported waves of the 326 BC most probably originated on the MSZ.

The azimuthal propagation of the tsunami energy propagation of the 1945 event was greater to the North and to the South with waves reaching a maximum run up height of 13 m (40 feet), causing extensive destruction and numerous deaths. However, the waves that struck Karachi were only 2 meters (6.5 feet) high. Based on the ancient records and current geophysical knowledge, it is believed that a 326 BC earthquake occurred in late October or early November. At that time Greek fleet was either at anchor at the estuary near the delta of River Hab south of Karachi or had just set out to sea. It is estimated that Greek fleet was struck by waves that were as much as 2 meters in height. The timing of the 326 BC tsunamigenic earthquake and the location of Alexander's fleet were critical. If the earthquake had occurred later in November of 326 BC, after the fleet had left Morontobara (Karachi), or when it was near Bagisara (present Ormara), the outcome could have been disastrous. The delay due to adverse monsoon winds probably saved the Greek fleet from total tsunami destruction. Additionally reviewed and evaluated by the present study are other possible tsunamigenic source areas in the Indian Ocean which may have had an impact on the Greek fleet in 373 BC.

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