Archaeology of the Wind

Natural conditions and early sea navigation in the Eastern Mediterranean

The results of the Monoxylon 1 and 2 expeditions (*Tichý 2016*) did not confirm any importance for sea currents in sea navigation with simple types of crafts of the Neolithic level. Rather the opposite, the expeditions stressed the importance of wind and waves. The influence of sea currents is supposed as very important by both earlier (*Nikolov 1990*, *Korfmann 1988*) and newer publications (*Papageorgiou 2014*). The exception is the work of *C. Broodbank* (*2000*, 93–94) who sees sea currants as one of many factors such as the strength of the wind. This article presents the results of 19 months of recording of conditions modelled from weather forecasts in the Eastern Mediterranean from February 2018 to September 2019, i.e. at the time of the preparations for the Monoxylon 3 expedition and after it. The main aim was to compare the forecast with the actual weather conditions experienced at sea during both the survey voyage of June 2018 and the expedition in May and June 2019. On the basis of the findings the article discusses the possibility of using the data for creating a notion on sea conditions in the Neolithic.

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Introduction

Early sea navigation in the Eastern Mediterranean in this article covers the Palaeolithic to the Neolithic (*Pydyn 2015*). During this period there may have been many types of seagoing vessels (*Howitt-Marshal – Runnels 2016*, Fig. 3); the author of this article used as a representative sample of a 'simple craft' a boat made from one log, documented during the Neolithic in the Mediterranean (*Fugazzola Delpino – Mineo 1995*; *Fugazzola Delpino 1995*; *Erić 1993–1994*; *Marangou 1997*; *2001*). The region was chosen because the distribution of obsidian within it (*Reingruber 2011*) is viewed as proof of sea navigation. Dug-out boats are dated to the Neolithic, based on the fact that the polished axes and adzes necessary for their production first appear in this period (*Mc Grail 2010*). It is also a craft that can fulfil the needs for a load volume (*Broodbank – Strasser 1991*; *Vigne et al. 2013*; *Tichý 2016*) and also resemble and therefore could be possible the predecessor of longboats of the Early Bronze Age in Cyclades (*Broodbank 1989*). These vessels are capable of using a sail for propulsion. Modern sea navigation experiments indicate a departure from propulsion by paddling only (Papyrela Expedition in *Tzalas 1989*; *1995*) to combined propulsion (Kythera Expedition in *Sampson 2014*), i.e. paddling and sail. This is despite the fact that so far we do not have any archaeological evidence of sails older than the end of the Neolithic.

The supposed importance of sea currents may have influenced attitudes to the possible use of sail. a vessel without sail fits better the idea of a vessels carried primarily by sea currents. On the other hand, experimental vessels in real conditions are affected more by the impact of the wind so experimenters are inclined to believe it was used also in the past.

Date	Mykonos	Santorini	Melos	Levanta	Karpathos	Pelopennesus	Cyprus	Andros
	Data: speed (km/hour) and wind direction							
25. 5.	0 ⊗	20 →	35 →	35 ↓	10 →	35 ↑	35 ↗	0 ⊗
26. 5.	0 ⊗	0 ⊗	0–10 ↑	0 ⊗	10 ↘	15 ←	10 ↗	0 ⊗
27. 5.	20 ↓	10 ●↓	20 ↙	15 ↓	0 ⊗	20 ←	10 ↓	0 ⊗
28. 5.	16 ↑	15 ↘	30 ↗	15 ↓	35 ↑	30 →	15 ↗	25 ↑
29. 5.	10 ↑	20 →	30 →	20 ↑	15 ↘	35 →	15 →	20 ↑
30. 5.	15 ↓ ●→	15 ↘	10 ●↓	25 ↓	30 ↘	5 ●↓	10 →	0 ⊗
31. 5.	25 ↓	20 →	13 →	15 ↓	30 ↓	15 ●↓	5 →	15 ↓
2. 6.	20 ●→	30 ●→	35 →	15 ↓	15 →	35 →	10 ↗	15 ↑
3. 6.	30 ●↗	20 →	30 →	15 ↓	10 ●→	25 →	10 ●↗	15 ↑
4. 6.	12 ●→	18 →	25 →	35 ↓	5 ⊗	25 →	30 ●↗	10 ↑
5. 6.	20 ↑	15 ↗	20 ↗	30 ↓	5 ⊗	25 →	10 ●↗	10 ↑
6. 6.	5 ●→	20 →	20 →	30 ↓	15 →	20 →	5 ●↗	0 ⊗
7. 6.	25 ↓	20 ↓	10 →	20 ↓	30 ↘	5 ●↓	10 ●↗	16 ↓
8. 6.	20 ↓	25 ↘	15 ↘	20 ↓	35 ↘	10 ↘	10 ●↗	15 ↓
9. 6.	45 ↓	30 ●↓ ↘	30 ●↓	10 ●↗	40 ↘	20 ↓	20 ●↗	30 ↓
10. 6.	40 ↓	25 ●↓ ↘	30 ●↓	10 ↓	35 ↘	20 ↓	20 ●↗	30 ↓
11. 6.	20 ↓	10 →	10 →	15 ↓	20 →	10 ↗	10 ●↗	0 ⊗
12. 6.	20 ↓	15 →	10 →	10 →	15 →	5 ⊗	0 ⊗	5 ⊗
13. 6.	20 ↓	25 ↘	10 ↘	38	18 ↘	5 ⊗	10 ●↗	10 ●↓
14. 6.	15 ↘	15 ↘	5 ↘	5 ⊗	20 ↘	5 ⊗	5 ●↗	5 ●↓

■ **Fig. 1** *Sample of daily records (level 1): speed and main direction of the wind during the Monoxylon 3 Expedition (because of space restrictions not all data from the February 2018 to September 2019 is shown but they were recorded in the same manner); Legend:* ●→ *following or abaft the beam wind;* → *another wind direction, which could have potentially cause problems;* ⊗ *boundary of wind directions.*

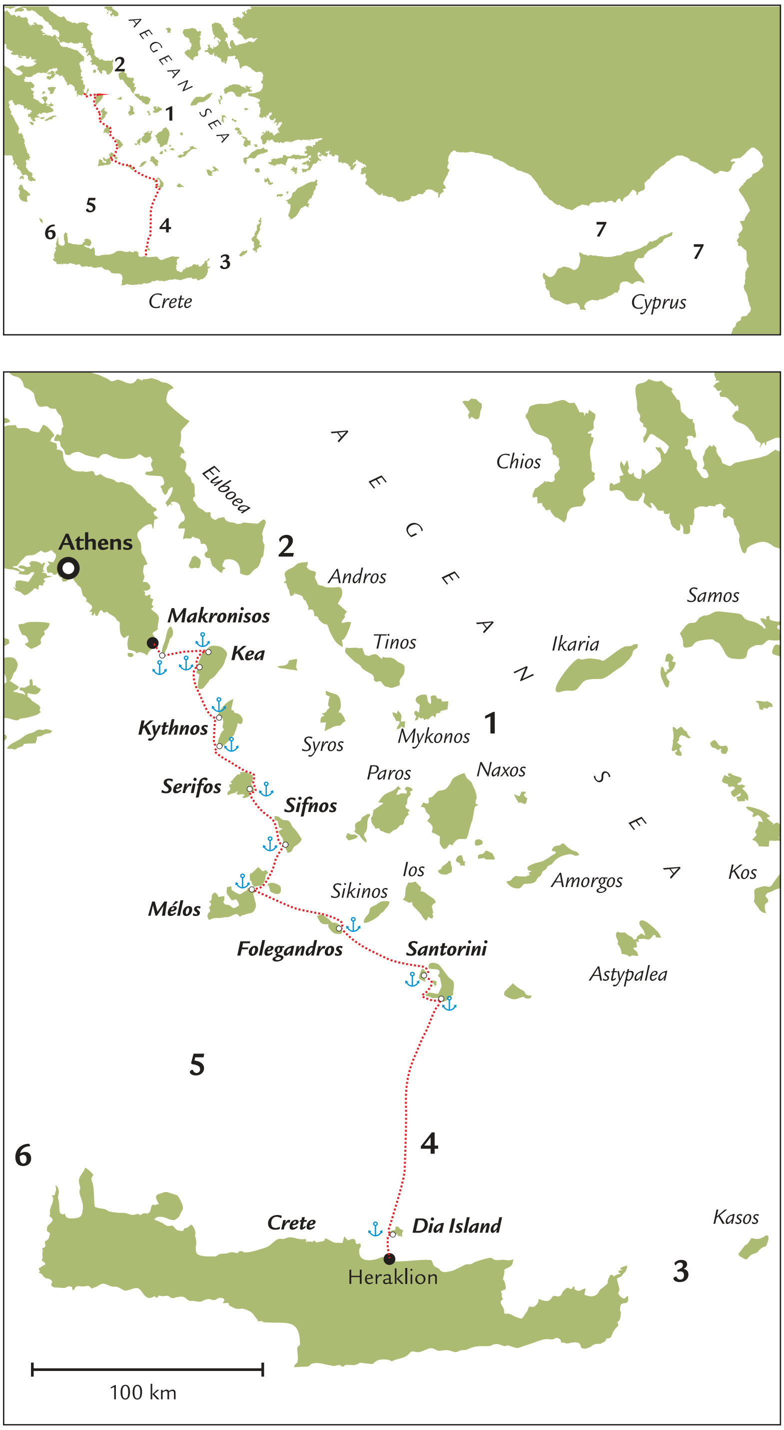
The method of gaining data and their analysis

The weather/wind forecasts were obtained from *windy.com* (ECMWF). In daily entries (here level 1) wind was recorded as either following or abaft the beam in the direction of the potential voyage between two islands (**Fig. 1**) or in another direction which could have caused, depending on the strength of the wind, problems in the potential voyage (carrying the boat off course etc.; **Fig. 1**). Favourable winds are important as even a craft without a sails navigates better downwind than upwind. Wind is usually (but not always) closely related to the direction of waves, therefore navigating downwind in the Eastern Mediterranean (mostly in summer) means travelling with the waves and not against them. Similarly, navigation with side waves is more realistic than navigation against waves, although in the case of side waves this depends on their length and shape. Shorter waves can flood the craft while the longer ones allow for navigation. Side winds of greater strength are dangerous to a vessel using simple sails and rigging.

Observing the direction and strength of wind started on the 26th of July 2017 on the island of Karpathos, which was originally, based on Broodbank and Strasser's hypothesis (*1991*), on the planned route of the expedition to Crete. From the data gained and after consulting yachtsmen it was shown that this is a very hazardous stretch due to the strength of wind. It would be possible to choose a route from Peloponnesus to the western side of Crete via the island of Kythera. This route was already tested in 2014 by the Kythera Expedition. a possible approach to Crete from north from Santorini or directly from Melos, a source of obsidian, seemed interesting. The shortest distance (Santorini – Dia Island near Crete) measures around 120 km, which also corresponds to distances discussed for the settling of Cyprus (*Vigne 2013*; *Vigne 2014*; *Vigne et al. 2013*) or voyages from Sicily to the northern coast of Africa (*Zilhão 2014*).

Data on wind strength and direction for seven areas was obtained from the portal *windy.com* (**Fig. 2**). These areas were chosen according to the configuration of islands in the Eastern Mediterranean and the Aegean Seas using the experiences of Czech, Slovak and Greek yachtsmen. They said that the three windiest places in the Aegean Sea are between the islands of Ikaria and Mykonos, Andros and Euboea, and Karpathos and Crete (**Fig. 2**: **1–3**). Regarding the route of the Monoxylon 3 Expedition (from Attica to Melos and Crete) we also observed the area between Santorini and Crete and from the June 2018 the area between Melos and Crete and the Peloponnesus and Crete (**Fig. 2**: **4–6**). From February 2018 we also observed the area between Cyprus and the Turkish and Syrian coasts (**Fig. 2**: **7**). The areas were chosen to give us an idea on the prevailing wind directions in the Eastern Mediterranean.

Within these areas the places with strongest wind on the route were chosen for the daily recording of



■ **Fig. 2** *Positions of the measuring points (***1**–**7***) and the route of the expedition.*

forecast data, as these were the most hazardous for navigation. It was obvious that the forecast of wind strength would not fully correspond with reality, but the author gave preference to locations on the open sea over measuring stations, as these are placed on land and for the given purpose inaccurate. The land stations have already been used for the potential evaluation of (pre)Neolithic navigation (*Bar-Yosef Mayer et al. 2015*).

On any given day, the strength and direction of the wind were recorded according to the forecast (**Fig. 1**). The aim was to evaluate days suitable for a simple craft navigation, whether with or without a sail. Thanks to experiences of the Monoxylon 3 Expedition, we also started to observe wave direction according to the forecast. This mostly corresponded to wind direction but not at all points. The data were recorded at 11 am, this hour was chosen because it would be between the morning sailing and afternoon/ evening landing.

The main problem, as the author sees it, is the fact that in some months we did not succeed in recording all days. Therefore in the evaluation (level 2; **Fig. 3**) it is always stated how many daily recordings in the given month were taken. The monthly interval was from the 22nd of a given month to the 21st of the following month. Such interval corresponded with the time of the expedition (25th of May 2019 to 15th of June 2019) widened by the days before after it would take place.

During the expedition, we took recordings in the same manner, meaning that the daily recording of 'objective' data (model forecast from windy.com) continued but were complemented with live observation of the wind direction during the journey of the experimental craft. We collected data at 8am, 11am, 12pm, 4pm and 8pm of each day (**Fig. 4**). The basic record by days (level 1; **Fig. 1**) was organised into the record of wind direction and strength in the given interval (level 2; **Fig. 3**). Finally, the days with following or abaft the beam wind for the craft on the given stretch (level 3; **Fig. 5**) were expressed in percentages.

Possible interpretation of data

The obvious question is, how much can we use contemporary weather forecasts to assess weather in the Neolithic with relation to sea navigation of that period. The 'archaeology of the wind' seems, quite rightly, as a contradiction in terms as wind is archaeologically not detectable. The aim of the article is to create at least a notion about the influence of various natural conditions affecting sea navigation in the (pre)Neolithic. This notion could help us to evaluate the influence of single factors and eliminate some basic errors. It is a model of current data in the geographically corresponding conditions of the Mediterranean, an experimental journey of a simple type craft in the contemporary

22. 5. – 21. 6. 2019 (recorded 29 days from 31) data: wind direction and number of days, in brackets wind speed (km/hour)				
Mykonos	↓ 17 (10, 20, 30, 45)	↑ 3 (10, 20)	→ 4 (5, 10, 20)	⊗ 2 (0)
Santorini	↘ → 20 (10, 15, 25, 30)	↓ 3 (10, 25, 30)	↑ 2 (10, 15)	⊗ 1 (0)
Melos	↘ → 17 (10, 20, 30, 35)	↓ 4 (10, 30) 1 (20)	↑ 3 (10, 20, 30)	⊗ 1 (0)
Karpathos	↓ 21 (10, 20, 30, 40)	→ 1 (10)	↑ 1 (35)	⊗ 3 (0,5)
Peloponnesus	↙ ← 5 (15, 20) ↓ 1 (10)	↘ 6 (5, 10, 15)	↗ → 10 (10, 20, 30, 35)	⊗ 4 (0,5)
Cyprus	← ↗ → 9 (5, 10, 35)	← → 4 (10, 20)	↙ ↗ 11 (5, 10, 20, 30)	⊗ 2 (0)
Andros	↓ 10 (5, 10, 15, 20, 30)	↑ 7 (15, 20, 25)	→ 1 (10)	⊗ 3 (0)
22. 6. – 21. 7. 2019 (recorded 30 days from 30)				
Mykonos	↓ 28 (10, 20, 30, 40, 50)	↑ 2 (10, 18)	↑ 2 (30)	
Santorini	↘ → 21 (10, 20, 30, 40)	↓ 6 (10, 20, 25, 30, 50)	↑ 2 (30)	← 1 (30)
Melos	↘ → 15 (10, 15, 25, 30)	↓ 11 (10, 20, 30, 50)	↑ ↑ 2 (15, 25)	↙ 2 (10, 30)
Karpathos	↘ 26 (20, 25, 30, 40, 50)	→ 2 (5, 20)	↗ → 5 (10, 20, 30)	
Peloponnesus	↙ 19 (10, 20, 30, 35, 55)	↘ 2 (10) ↘ 1 (30)	↙ ↗ 14 (5, 10, 15, 20)	⊗ 3 (0,5)
Cyprus	← ↗ → 6 (20, 30)	→ 9 (10, 20, 30)		⊗ 1 (5)
Andros	↓ 26 (20, 30, 35, 40, 50, 55)	↑ 2 (15)		⊗ 2 (0)
22. 7. – 21. 8. 2019 (recorded 31 days from 31)				
Mykonos	↓ 21 (10, 20, 25, 30, 35, 40, 45)	↑ 2 (10, 20)		
Santorini	↘ → 21 (15, 20, 25, 30)	↘ 9 (30, 40)		
Melos	↘ → 11 (10, 15, 25, 30)	↓ 20 (15, 25, 30, 35, 40)		
Karpathos	↘ 29 (20, 30, 35, 40, 45)	→ 2 (10, 25)		
Peloponnesus	↙ 24 (15, 20, 30, 40, 45)	↗ → 3 (15, 20, 25)	↘ 1 (15)	↘ 2 (10, 20)
Cyprus	← ↗ → 20 (10, 15, 20, 25, 30)	→ 2 (15, 20)	↑ 7 (5, 10, 15)	⊗ 2 (5)
Andros	↓ 30 (10, 25, 30, 35, 40, 45, 50)	↑ 1 (5)		

■ **Fig. 3** *Sample of daily records (level 2): main direction of wind and the number of days it blew in that direction, speed in brackets (km/hour). The records are from a time interval which includes the period of the Monoxylon 3 Expedition – apart from the number of days wind strength is shown in the brackets (because of space restrictions not all data from the February 2018 to September 2019 is shown but they were recorded in the same manner); Legend:* → *following or abaft the beam wind;* → *another wind direction, which could have potentially cause problems;* ⊗ *boundary of wind directions.*

day/ time	8:00	12:00	16:00	20:00	agreement between forecast and reality
26. 5. Makronisos – Kea					
forecast	0	0	0	0	**yes**
reality	calm				
27. 5. Kea – Kythnos					
forecast	10 ↓	10 ↓	5 ↓	15 ←	**partially** (local storm)
reality	↓ storm →				
28. 5. Kythnos – Kythnos					
forecast	26 ↑	25 ↑	25 ↑	34 ↗	**partially** (after 4pm weaker wind)
reality	no wind			↗	
29. 5. Kythnos – Serifos					
forecast	21 ↗	22 ↗	20 ↗	15 ↗	**no** (different wind direction)
reality	↘	↗			
30. 5. Serifos – Sifnos					
forecast	10 ↓	10 ↓	10 ↓	5 ↓	**no** (different wind direction)
reality	↘	↘			
31. 5. Sifnos – Mélos					
forecast	13 ↗	12 ↗	10 ↗	20 ↗	**no** (different wind direction)
reality	↘	↘			
2. 6. Mélos – Folegandros					
forecast	30 ↗	30 ↗	30 ↗	35 ↗	**yes** (delayed strong wind)
reality	↗	↗			
3. 6. Folegandros (without setting off)					
forecast	30 ↗	30 ↗	30 ↗	30 ↗	**yes** (without setting off because of strong wind)
reality	without setting off				
4. 6. Folegandros – Santorini					
forecast	15 →	15 →	15 →	15 →	**no** (different wind direction)
reality	↗	↗			
5. 6. Santorini (Caldera and exit from Caldera)					
forecast	17 ↗	17 ↗	18 ↗	16 ↗	**yes** (stronger wind)
reality	↗	↗			
6. 6. Santorini (without setting off)					
forecast	16 ↗	15 →	17 →	17 →	–
reality	without setting off				
7. 6. Santorini – Dia Island					
forecast	15 ↓	20 ↓	20 ↓	22 ↓	**partially** (wind direction)
reality	↘	↘	↘	→	
8. 6. Santorini – Dia Island					
forecast	20 ↓	20 ↓	25 ↓	20 ↓	**partially** (wind direction)
reality	↘				
9. 6. Dia Island – Heraklion (Amnisos)					
forecast	25 ↓	25 ↓	25 ↓	25 ↓	**partially** (wind direction)
reality	↘				

■ **Fig. 4** *Forecast of wind direction and strength (km/hour) during the expedition at 8am, 12pm, 4pm and 8pm of any given day and its comparison with the direction of the wind perceived in the experimental craft of the Monoxylon 3 Expedition.*

conditions of the Mediterranean and paleoclimate results in corresponding conditions of the Mediterranean.

Each of the three mentioned levels of the direction and strength of wind recordings brings different possibilities for analysis.

1. The everyday recording (level 1) shows if there are days suitable for navigation and how long these intervals are. The records show the danger of frequent changes of the wind direction. The suitable wind direction can last for only a short time, which is not suitable for navigation. After casting off the condition can quickly worsen and these may be the reason for the wrecking of ancient crafts in some places of the Eastern Mediterranean; for example, the Bronze Age boats near the southern coast of present day Turkey or the concentration of ancient shipwrecks found between the islands of Samos and Ikaria.

2. The evaluation of the direction of the wind and its strength within the given month (level 2) shows a gradual decrease in wind direction fluctuation in the second half of summer (distinctively visible from the second half of July). This lowers the level of risk of journeys registered at level 1. The accessibility of many islands increases with the presence of wind direction boundaries (mark X in **Fig. 3**) where the strength of the wind usually reaches values of between 0, 5 or 10 km/hour, creating a feeling of "windlessness". Such low wind speeds allow for paddling or rowing but are not sufficient to use a sail; despite this these conditions could have played an important role in simple craft navigation.

3. The analysis of the recording of ideal wind direction (following wind) at level 3 (**Fig. 5**) allows for the evaluation of the accessibility of chosen islands.

a) The islands of Mykonos, Karpathos and Andros seems to be badly accessible thanks to their position on a potential route East–West (or the other way round) with prevailing north (or to a lesser extent south) winds.

b) The islands of Santorini and Melos seem to be a good departure point to access Crete thanks to Crete's orientation at right angles to the prevailing north winds and the North–South route (alternatively South–North).

c) From January to April the islands of Mykonos, Karpathos and Andros seems to be accessible thanks to a diversity of wind directions but the optimal (following) wind last for only a short time.

d) Cyprus is the most accessible thanks to overall lower strength of wind and the possible use of routes North–South (the southern coast of Turkey) and East–West (the Syrian coast).

e) The accessibility of Crete from Peloponnesus seems as given from the above. It is because of the direction of the route from Northwest to Southeast (and the other way), which does not use the influence of north wind. Usable is also the "windless" situation created thanks to the wind contact between the Aegean and Ionian Seas.

date	Mykonos	Santorini	Mélos	Karpathos	Peloponnesus	Cyprus	Andros
Data (%): percentage of days with suitable wind direction (in brackets number of days without wind)							
3/2018	8	37 (46)		12 (16)		12 (21)	
4/2018	4 (19)	19 (27)		4 (11)		61 (100)	8 (27)
5/2018	5 (7)	3 (17)		0		38 (93)	(27)
6/2018	(10)	35 (48)	64 (68)	(6)	16 (29)	39 (77)	(22)
7/2018	0	**14** (21)	**32** (43)	0	18 (36)	**75** (86)	(7)
8/2018	(10)	0	**52**	0	7 (10)	69 (96)	(10)
9/2018	9	**32**	**54**	0	9 (18)	**64** (95)	4 (9)
10/2018	0	**77**	**69**	**4** (8)	**4** (11)	**77** (92)	4
11/2018	0	**53**	**53** (61)	7 (11)	(11)	**100**	3
12/2018	(4)	**69** (73)	**50** (54)	**8**	**15** (19)	**69** (84)	11 (19)
1/2019	**21**	**45**	**31** (34)	**34**	11 (15)	**63** (86)	**17**
2/2019	**7**	**68**	**53**	**21** (28)	**21** (25)	**78** (85)	**11** (14)
3/2019	**8**	**33**	**16**	16 (21)	0	**79** (87)	**12**
4/2019	**13** (16)	**58** (61)	**55**	**16**	**10** (16)	**68** (81)	**10** (16)
5/2019	**7** (19)	**11** (21)	**25**	7 (11)	7 (11)	**61** (78)	3 (14)
6/2019	15 (23)	**11** (15)	**15** (19)	4 (15)	23 (38)	**58** (65)	4 (35)
7/2019	0	**20**	**37**	7	7 (16)	77 (80)	(7)
8/2019	0	**29**	**64**	6	6 (10)	29 (35)	0
9/2019	0	**16**	**77** (81)	0	3	13 (19)	**3**

■ **Fig. 5** *Percentage of days in month with following and abaft the beam wind in the direction of the potential route of the craft from February 2018 to September 2019 (level 3),* **in bold**, *days with wind strength over 30 km/hour when we do not presume journey possible.*

Based on conditions of navigation observed during the Monoxylon Expedition, waves became another important parameter (**Fig. 6**). (The author recorded them only from the beginning of July 2019.) In the forecast from *windy.com* the direction and strength of the wind relates partially to the direction and height of waves. The biggest difference between the two can be observed in the area of Levant (nearly 90 degrees). On the other hand, correlation is apparent between the islands of Crete and Karpathos or Nysiros and Rhodos. In other places the divergence is small or irregular (Crete – Peloponnesus). Even from such a short observation it seems that in accordance with wind there is a regularity in the wave directions during summer, which increases during the summer. The situation is depicted on **Fig. 8**. The deficiency of the wave forecast is in the fact that we do not know the frequency of waves (long, short, broken) which is an important parameter for navigation in side waves.

Navigation against waves was tested during the expedition at the island of Kythos when the waves were 1.5 m high and wind was 5 to 6 degrees Beaufort. In context of the other performances of the experimental craft during the Monoxylon 3 Expedition we can assume that navigation in the direction of the waves and in side waves was possible. In contrast the expedition used the wind for sailing (**Fig. 7**) only a little despite the mastery of the crew in working with the sail (sailing even in side wind). **Figure 8** depicts that the prevailing direction of waves does not prevent voyages to Crete or from Crete to the coast of contemporary Turkey via Karpathos. Though during the journey back north frontal waves appear (the best route is along the Peloponnesus along the coast in calmer waters or from Cyprus to the West into the Aegean Sea). The route from Samos to Euboea is mostly under side wind. In all cases local conditions can modify the direction and strength of the wind.

The model forecast of wind and waves can be used to evaluate regions of the Eastern Mediterranean from the point of view of their accessibility (**Fig. 3** and **5**). The route Peloponnesus – Crete via the island of Kythera is sometimes on the boundary of waves from North and West or can be on the boundary of north wind and western waves. The first creates "windlessness" allowing for a calm journey, the other a potential clash of waves and rough seas. Melos allows better accessibility to Crete thanks to the waves coming from the North, and also the wind blows more often towards Crete. Between the two islands there is though distance of over 160 km which seems to be difficult to overcome. From Santorini to Crete the distance reduces to 120 km (to Dia Island near the north coast of Crete), the waves are most often in the direction to Crete but the wind often turns in southeastern direction, more towards the island of Karpathos. From May to September, Crete is more accessible from Melos than from Santorini. Both routes are equal from October to November and from December to April the return journey from Crete to Santorini is more realistic. The lowest accessibility is presented by the route Ikaria – Mykonos and Karpathos – Crete. Apart from side wind and waves it is also caused by the not negligible distance. The route Andros – Euboea represents a slightly better situation, mostly because of the shorter distance. The accessibility from Cyprus seems the best with overall lower wind speeds and more frequent periods of "windlessness". While the waves mostly move from West to East, navigation in side waves is possible. The coast of Levant represents a stable situation, the wind there is the calmest and most stable, the wind is often in a south-westerly direction and therefore useable for sailing.

The recorded and analysed data concern the contemporary weather, concretely wind and waves. It is important to consider to what extent they correspond to the situation in the (pre)Neolithic. If we presume temperature improvement for a certain part of the Neolithic, it is possible, that such a climate would correspond to the current one. There is a question though how much wind could differ before the beginning of the Holocene in relation to the temperature drop in the Dryas and later in the RCC (Rapid Climate Change) period in 6600 to 6000 BC. At that time the winter season was longer and would have had larger extremes than today and more frequent strong winds or storms in comparison to the present could be expected. Such extreme conditions would strengthen further away from the coast. In the winter months a north wind would predominate (*Clare et al. 2008*, 70–71). The direction of winds probably did not differ from the current one (*Weninger et al. 2009*, Fig. 2; *Clare – Weninger 2010*, Fig. 1).

Another factor aside from the temperature would have been the sea currents after the change of the Marmora Lake into the flow through Marmora Sea in the context of the presumed rise of Black Sea levels (*Ryan – Walter 1998*). Around 6600 BC the Marmora Sea was still a lake (*Özdoğan 2018*) and therefore the current from the Black Sea would not have been present. The final factor would be differences in the distances between the islands caused by the gradual rise of sea levels after the last maximum glaciation (*Howitt-Marshall – Runnels 2016*, Fig. 2) to the Neolithic (*Broodbank 1999*). Along with the rising sea level, we can suppose slower speed of currents between the islands. The connection of the Black and Aegean Seas through the Marmora Sea would again act as an influence on the existence of a current from the North.

■ **Fig. 6** *Dugout boat of the Monoxylon 3 Expedition while travelling against waves (above) and in long side waves.*

If we imagine the RCC conditions in the era from 6600 to 6000 BC as an amplification in changeability or even unpredictability in the strength and direction of wind and waves. Then it is tempting to connect the RCC with the presumed absence of agricultural settlement at the site of Knossos on Crete in the era after 6600 BC (*Douka et al. 2017*). Contrary to that, the presence of obsidian and repeated import of animals to Cyprus during the (Pre) Neolithic till the phase Khirokitia supports the idea of frequent sea links to the mainland (*Bodet 2018*, 81). We could connect that with the previously mentioned better accessibility of Cyprus, which after mastering sea navigation should be considered a part of Levant (*Mc Cartney et al. 2010*, 143).

The positions of possible ports can tell us much about the natural conditions of (pre)Neolithic sea navigation. For example, the site of Agios Petros on the island of Kyra Pangia is localised in a protected bay open to the Southeast. It could have been the best port in the region of the Sporades Islands (*Efstratiou 2018*). The only supposed entrance into the Santorini caldera before the explosion of the volcano in the Bronze Age was oriented

Overall summary of Monoxylon 3 Expedition single stretches

Stretch number	Start – Finish	Date (2019)	Time of cast off	Time of landing	Journey time	Distance (km)	Average speed (km/hour)
1	Lavrio – Makronisos	25. 5.	14:07	16:07	2:00	7,7	3,9
2 (1)	Makronisos – Kea (Ayia Irini)	26. 5.	6:18	10:42	4:23	21,2	4,8
2 (2)	Kea (Ayia Irini) – Kea (Pisses)	26. 5.	14:09	17:25	3:16	12,7	3,9
3	Kea (Pisses) – Kythnos (Kolona Beach)	27. 5.	7:12	12:47	5:34	26,4	4,7
4	Kythnos (Kolona Beach) – Kythnos (Agios Dimitrios)	28. 5.	6:59	9:52	2:53	13,5	4,7
5	Kythnos (Agios Dimitrios) – Serifos (Livadi)	29. 5.	6:17	13:35	7:18	33,3	4,6
6	Serifos (Livadi) – Sifnos (Vathy)	30. 5.	7:48	15:03	7:15	31,1	4,3
7	Sifnos (Vathy) – Milos (Pollonia)	31. 5.	7:10	13:50	6:39	28,0	4,2
8 (1)	Milos (Pollonia) – Folegandros (Agios Georgios)	2. 6.	3:10	10:29	7:19	33,2	4,5
8 (2)	Folegandros (Agios Georgios) – Folegandros (Karavostasis)	2. 6.	11:59	14:40	2:41	12,0	4,5
9	Folegandros (Karavostasis) – Thira (Thirasia)	4. 6.	4:11	13:32	9:20	45,1	4,8
10 (1)	Thira (Thirasia) – Nea Kameni	5. 6.	6:35	7:53	1:17	5,7	4,4
10 (2)	Nea Kameni – Santorini (Exomytis)	5. 6.	9:08	13:35	4:26	16,0	3,6
11	Santorini (Exomytis) – Dia Island (*following day)	7. 6.	3:22	*7:25	28:03	115,4	4,1
12	Dia Island – Crete (Karteros)	9. 6.	7:03	9:59	2:55	14,2	4,8
	Total				**95:27**	**415,5**	**4,4**

Overview of the stretches under sail

Stretch no.	Start – Finish	Date (2019)	Sail used from	to	Journey time	Dist. (km)	Av. speed (km/hour)	Crew / Note	
2 (2)	Kea (Ayia Irini) – Kea (Pisses)	26. 5.	16:57	17:25	0:28	1,3	2,7	J	finishing of the stretch, sailing without paddling
3	Kea (Pisses) – Kythnos (Kolona Beach)	27. 5.	9:20	10:00	0:40	4,3	6,4	J	with paddling, ideal following wind
5	Kythnos (Agios Dimitrios) – Serifos (Livadi)	29. 5.	7:52	9:31	1:38	8,1	4,9	J	with paddling, stable wind 6 knots, direction gradually from following to side wind, long waves
5	Kythnos (Agios Dimitrios) – Serifos (Livadi)	29. 5.	9:45	10:28	0:42	3,9	5,6	H	with paddling
5	Kythnos (Agios Dimitrios) – Serifos (Livadi)	29. 5.	13:11	13:27	0:16	1,1	4,0	J	finishing of the stretch, sailing without paddling
7	Sifnos (Vathy) – Milos (Pollonia)	31. 5.	9:14	9:31	0:17	1,6	5,6	J	with paddling; restriction – cameraman on board; correction of course – following wind
8 (1)	Milos (Pollonia) – Folegandros (Agios Georgios)	2. 6.	9:53	10:08	0:15	1,2	4,7	J	with paddling, very weak following wind
8 (2)	Folegandros (Agios Georgios) – Folegandros (Karavostasis)	2. 6.	12:12	13:07	0:55	4,8	5,2	H	with paddling, abaft the beam wind along the coast
9	Folegandros (Karavostasis) – Thira (Thirasia)	4. 6.	9:40	10:54	1:14	6,9	5,5	J	with paddling, weak abaft the beam wind from starboard
9	Folegandros (Karavostasis) – Thira (Thirasia)	4. 6.	11:03	12:26	1:23	7,7	5,6	H	with paddling
10 (2)	Nea Kameni – Santorini (Exomytis)	5. 6.	13:01	13:20	0:19	2,0	6,0	J	with paddling, following wind, large waves cca 1.5 m
11	Santorini (Exomytis) – Diův ostrov	7. 6.	16:18	17:24	1:06	6,0	5,4	J	with paddling
11	Santorini (Exomytis) – Dia Island	7. 6.	19:28	20:35	1:07	5,4	4,7	J	with paddling, sailed lowered because of darkness, concern about sailing in the dark
12	Dia Island – Crete (Karteros)	9. 6.	7:24	8:39	1:15	6,9	5,6	J	with paddling, fresh wind from starboard at about 10 knots
12	Dia Island – Crete (Karteros)	9. 6.	8:52	9:27	0:34	3,2	5,6	H	with paddling, fresh wind from starboard at about 10 knots, the end distorted by waiting for a preparation for celebratory landing
12	Dia Island – Crete (Karteros)	9. 6.	9:27	9:50	0:22	1,4	3,8	H	waiting for a preparation for celebratory landing
	Total				**12:38**	**65,9**	**5,2**		
	Total after subtraction of landings and waiting				**11:31**	**62,1**	**5,4**		

■ **Fig. 7** *The route and performance of the dugout boat during the Monoxylon 3 Expedition.*

similarly (*Strasser 2010*, 9–10, Fig. 7) and the caldera of the island of Melos could also have had a similar position. All these landing places would have been protected from the most frequent north or northeast winds and waves. They would have been ideal ports to wait for favourable conditions for a sea journey. On Crete it is possible to consider the Karteros Bay (ancient Amnissos?) near Knossos as a landing place protected from frequent western winds (*Schafer 1991*).

Based on the comparison of the two Monoxylon Expeditions (1995 and 2019) we have had to correct the performance of a dugout boat stated by *C. Broodbank* (*2000*, 100). The craft from 2019 moved along the route Attica – Melos (e.g. on the route identical with the voyage of Papyrella) at speed higher than 20 km/day. It was around 30 km without fully exploiting the daylight for navigation (**Fig. 7**). When extending the journey till evening it was not a problem to reach 40 km, as shown later by the performance on the stretch from Melos to Santorini (**Fig. 7**). The fact that Monoxylon 3 completed the stretch to Melos in one go can be regarded as fundamental. C. Broodbank justifiably considers interruption of a longer route as a risk in navigating the Aegean Sea (*Broodbank 2000*, 105). The author of this article does not deny the difficulties of navigation in a dugout boat. The journey to Melos was interrupted due to weather on the evening of the 28th of May 2019 on the island of Kythnos, and then, from Melos, once more on the 3rd of June 2019 on the island of Folegandros. In both cases, it was because of strong wind and the corresponding wave state.

In the context of facts, it is possible to show connection within the Aegean Sea as documented by material culture (*Perlès 2001*, *2005*), genetics (*Fernández et al. 2014*), absolute dating (*van Andel – Runnels 1995*), and the distribution of obsidian across the sea (*Perlès – Takaoğlu – Gratuze 2011*; *Horejs et al. 2015*) as a possible though dangerous activity.

Conclusions

The centre of interest of this article is the comparison of the current forecast of the direction and strength of wind (recorded from February 2018 to September 2019) and the direction and height of waves (recorded from July to September 2019) at the portal windy.com, with observations recorded during the actual journey in a simple craft. The aim is to ponder the possibility of transfer of such data into the (pre)Neolithic in the region of the Eastern Mediterranean.

The fact that the forecast was usable to plan the experimental voyage in a simple craft – dugout boat can be considered the most basic outcome. The spring season (May, June) was chosen as the most suitable period. At this time there is not a stable wind direction and therefore there is a chance to use a sail in following or abaft the beam wind. Later (July to September) the wind gets gradually stronger and its direction becomes stable but makes access to some places unsuitable (routes Mykonos – Ikaria, Karpathos – Crete, Santorini – Crete). The wind can become so strong that even if in the correct direction it is not useable (wind speed over 30 km/hour). The waves usually relate to the wind direction but not always (the areas between Peloponnesus and Crete, along the Levant coast).

During the Monoxylon 3 Expedition frontal wind over 30 km/hour connected to frontal waves proved to be limiting to the simple craft. The height of the waves was not a problem but it did halt forward movement of the craft. The real conditions of the expedition and the model forecast corresponded in principal (**Fig. 4**). While planning the route, we could therefore forecast strong evening waves and wind on the 28th of May to the south of the island of Kythnos or strong wind by the island of Folegandros on the 3rd of June. On the other hand, we were surprised by a local storm on the morning of the 29th of May while departing from the island of Kythnos. The crew and the craft managed the situation but it was one of the surprises in the weather forecast. The Monoxylon 3 Expedition also did not confirm any strong or stable importance in sea currents. The only exception was the night journey from the 7th to 8th of June when both crews independently observed that the craft's advance slowed down.

Following the forecast confirmed the existence of three places in the Aegean most difficult to navigate (Ikaria – Mykonos, Karpathos – Crete, Andros – Euboea). The Monoxylon Expedition 1995 encountered two of these while testing the route from Samos to Attica speculated as the direct route (*van Andel – Runnels 1995*) connecting the opposite coasts of the Aegean Sea. Following the forecast also allowed us to compare the accessibility of chosen islands. Cyprus represents the most accessible, which corresponds with the idea (*Mc Cartney – Manning – Sewell – Stewart 2010*, 143) that it should be considered nearly a part of the opposite mainland. Crete is difficult to access form the East, from where the advance of agricultural colonist is presumed (*Broodbank – Strasser 1991*). The direction from the Peloponnesus represents better access but that direction corresponds more with the Preneolithic settlement (*Sampson 2014*; *Strasser et al. 2010*). This way would have been the easier route for importing obsidian to Crete, if we would do not consider the more difficult route directly from Melos to Crete or similarly difficult route from Santorini, tested successfully by the Monoxylon Expedition in 2019 (**Fig. 2**). The current level of knowledge may mean worsening of Crete accessibility during the cooling after 6600 BC (*Douka et al. 2017*) which would have presented stronger northern winds (*Clare et al. 2008*, 70–71; *Weninger et al. 2009*, Fig. 2; *Clare – Weninger 2010*, Fig. 1) compared to contemporary conditions.

Despite the weather unpredictability as proven by the Monoxylon 3 journey, the journey's data represent different and better results (daily distance more probably 40 km than 20 km) of possible ancient crafts than has been so far considered (*Broodbank 2000*). Especially crossing the distance of around 120 km from Santorini to Dia Island (or directly to Crete) which casts new light on the accessibility of Cyprus (*Bodet 2018*; *Vigne 2013*; *Vigne 2014*; *Vigne et al. 2013*). One of the main questions remains not navigation from North to South but in the opposite direction against the prevailing waves in the summer season (direction shown on **Fig. 8**). The accessibility of the islands in the Aegean Sea is decided mostly by north winds together with the islands configuration Paradoxically, the irregular direction of winds could be the key to northward navigation. Not against the waves. Not against the prevailing northern wind. The alternative could be navigation along the Greek or Turkish coast where the wind is weaker.

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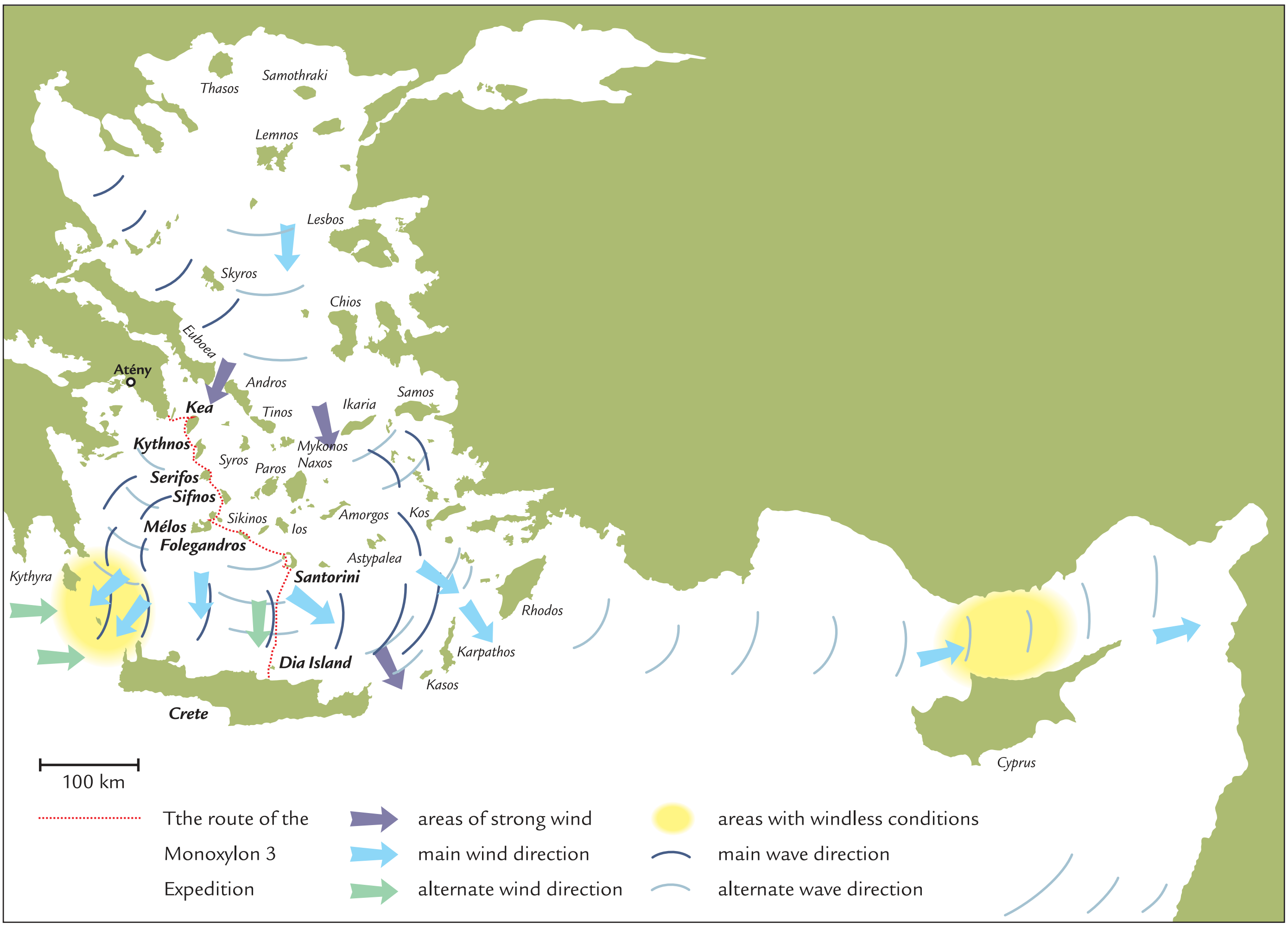

■ **Fig. 8** *Map of the Eastern Mediterranean with evaluation of navigation possibilities.*

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Souhrn

Archeologie větru. Přírodní podmínky a raná námořní plavba ve východním Středomoří

Centrem zájmu této stati je porovnání předpovědí směru a síly větru (sledováno únor 2018 až září 2019) a směru a výšky vln (sledováno červenec až září 2019) na portálu *windy.com* se záznamy pořízenými během reálné plavby na jednoduchém plavidle. Cílem je zamyšlení nad možností přenosu takových údajů do (pre)neolitu v oblasti východního Středomoří.

Za základní výsledek můžeme považovat skutečnost, že předpověď byla využitelná k naplánování pokusu plavby na jednoduchém plavidle typu dlabaný člun z jednoho kusu kmene. Jako nejvhodnější termín bylo vybráno jarní období (květen, červen). V tomto období jsou nejdelší dny v roce a nepříliš spalující slunce, není ustálený směr větru, a proto je šance využít k použití plachty na zadní či zadoboční vítr jiný než jeho severovýchodní směr. Později (červenec až září) vítr postupně sílí a jeho směr se stává pravidelným. Pro dostupnost některých míst však nevhodným (trasy Mykonos – Ikaria, Karpathos – Kréta, Santorini – Kréta). Dokonce, i pokud má správný směr, může být tak silný, že pro plavbu není využitelný (rychlost větru nad 30 km/h). Vlny zpravidla souvisí se směrem větru, ne však ve všech případech (oblast mezi Peloponésem a Krétou, při pobřeží Levanty).

Při expedici Monoxylon 3 se pro jednoduché plavidlo ukázal být limitní čelní vítr od 30 km/h spojený s čelními vlnami. Limitní nebyla samotná výška vln, ale zastavení pohybu plavidla vpřed. Reálné podmínky expedice ve srovnání s modelovou předpovědí vycházely v hlavních rysech správně (**obr. 4**), ne však zdaleka ve všech případech. V plánu postupu díky tomu bylo možné předpovědět podvečerní silné vlny a vítr 28. 5. 2019 na jihu ostrova Kythnos, nebo silný vítr u ostrova Folegandros 3. 6. 2019. Naopak překvapením byla místní bouřka dopoledne 29. 5. 2019 při vyplutí z ostrova Kythnos. Posádka i plavidlo situaci zvládly, ale šlo o jedno z překvapení v předpovědi počasí. Další odlišnosti ukazuje **obr. 4**. Nemusely být vnímány negativně díky tomu, že síla větru byla mírnější než původní předpověď. I expedice Monoxylon 3 nepotvrdila silný či stálý význam mořských proudů. Výjimkou byla noční plavba ze 7. na 8. 6. 2019, kde nezávisle obě posádky evidovaly zpomalení postupu plavidla. K tomu ale mohlo dojít i vlivem silného pravopředního větru a především vyčerpáním posádek po dni a noci pádlování.

Sledování předpovědi potvrdilo výskyt tří plavebně nejnáročnějších míst v Egejském moři (Ikaria – Mykonos, Karpathos – Kréta, Andros – Euboia), z nich dvě měla na své trase už expedice Monoxylon 1995, aby testovala trasu Samos – Attika uvažovanou (*van Andel – Runnels 1995*) jako přímá cesta spojující protilehlé břehy Egejského moře. Sledování předpovědi umožnilo také porovnat dostupnost vybraných ostrovů. Nejdostupnější je Kypr, což odpovídá představě (*Mc Cartney – Manning – Sewell – Stewart 2010*, 143), že je téměř součástí přilehlé pevniny. Kréta je obtížně dostupná z východu, odkud byl předpokládán postup zemědělských kolonistů (*Broodbank – Strasser 1991*). Lepší dostupnost je ve směru od západu od Peloponésu, ten ale odpovídá spíše osídlení předneolitickému (*Sampson 2014*; *Strasser – Panagopoulou – Runnels – Murray – Thompson – Karkanas – McCoy – Wegmann 2010*). Mohla tudy ale směřovat snazší cesta pro dovoz obsidiánu na Krétu, kdybychom nechtěli uvažovat náročnější trasu přímo z ostrova Mélos na Krétu, nebo obdobně náročnou trasu, kterou úspěšně testovala expedice Monoxylon v roce 2019 (**obr. 2**). Současný stav poznání může naznačovat zhoršení dostupnosti Kréty v období ochlazení po 6600 BC (*Douka et al. 2017*), kterou mohly způsobit silnější severní větry (*Clare et al. 2008*, 70–71; *Weninger et al. 2009*, Fig. 2; *Clare – Weninger 2010*, Fig. 1) v porovnání se současným stavem.

Plavba expedice Monoxylon 3 ověřila nevyzpytatelnost počasí. Její výsledky ale byly jiné a lepší (denní vzdálenost spíše 40 km místo 20 km) než doposud uvažované výkony dávných plavidel (*Broodbank 2000*). Zvláště přeplutí úseku délky kolem 120 km ze Santorini na Diův ostrov (či přímo na Krétu) vrhá nové světlo na dosažitelnost Kypru (*Bodet 2018*; *Vigne 2013*; *Vigne 2014*; *Vigne et al. 2013*). Jednou z hlavních otázek zůstává ne plavba ze severu k jihu, ale opačným směrem proti převládajícím vlnám v letním období (směr ukazuje **obr. 8**). O dostupnosti ostrovů Egejského moře rozhoduje hlavně vítr přicházející od severu v kombinaci s konfigurací ostrovů. Paradoxně nepravidelnost směru větru by mohla být klíčem k plavbě na sever. Tedy ne proti vlnám. Ne proti převládajícímu severnímu větru. Alternativou by mohla být i plavba na sever podél řeckého či tureckého pobřeží, kde je vítr u pobřeží slabší.

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