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Pelagic Tar, Dissolved/Dispersed Petroleum Hydrocarbons and Plastic Distribution in the Cretan Sea, Greece

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During the first cruise of R/V 'Philia' in July 1997 within the framework of the TALOS programme supported by the Greek Ministry of Physical Planning and Public Works, the sampling of floating tar, litter and sea water for dissolved/dispersed petroleum hydrocarbons (DDPH) was carried out in the Cretan Sea. Analysis of these data has allowed a first assessment of the status of floating marine pollution in the region. DDPH measurements showed a mean concentration of 0.145 μg/l of chrysene equivalents ($n = 24$). Tar and plastics concentrations were in the range of 1–4280 and 0–1160 μg/m^2, respectively. Mean pelagic tar concentration was 318 μg/m^2, more than two times higher than what was reported for the area in previous studies. Based on *in situ* hydrographic observations there is strong evidence that most of the floating tar enters the Cretan Sea through the Ionian Sea. © 1998 Elsevier Science Ltd. All rights reserved

Keywords: Cretan Sea; tar balls; petroleum hydrocarbons; water masses; hydrography; Eastern Mediterranean.

The most recent report on pelagic tar distribution in the Eastern Mediterranean concludes an overall steady decrease since 1975 (i.e. Golik *et al.*, 1988). Field measurements by R/V Meteor during the summer of 1987 showed negligible pelagic tar concentrations in the Cretan Sea. However, in recent years continuous tar contamination throughout the year has been observed along the northern and western beaches of the island of Crete. In addition, it appears that tar deposition has increased in many coastal locations of the island. Given the fact that the island economy depends mainly on tourism, and in order to assess the extent and to determine the source of the tar pollution and further more to take steps to control it, a 3-year monitoring programme of floating marine pollution around Crete island under the code name of TALOS was designed. The first results of this monitoring project are described in this paper.

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Methods

Within the framework of the project, a first cruise of R/V 'Philia' was carried out in the Cretan Sea during July 1997. Sampling for floating litter-tar and sea water for dissolved/dispersed petroleum hydrocarbons (DDPH) was performed in 25 stations (Fig. 1). In addition, simultaneous hydrographic measurements were used to infer the surface circulation.

Water samples for dissolved/dispersed petroleum hydrocarbons (DDPH) were treated and analysed following the method described by IOC (1984). Samples collected 1 m below the surface with a 2.5-l volume weighted bottle were extracted twice with nanograde hexane. The extracts were combined, dried over anhydrous sodium sulfate, concentrated using a rotary evaporator, and made up to 10 ml in a volumetric flask. Total hydrocarbons concentrations were determined against chrysene standard using a spectrofluorometer. All measurements were made at fixed wavelengths with excitation at 310 nm and emission at 360 nm.

The surface sampler used was a construction consisting of a catamaran floating part carrying a steel frame (100 × 60 cm) and equipped with a nylon plankton net (500 μm mesh). The sampler was towed out of the ship's wake at a speed of 3–4 knots over a distance of about one nautical mile, covering approximately a sea surface of 2000 m^2 to a depth up to 40 cm from the surface. After each tow the material that was collected at the cup was washed with distilled water, separated, allowed to dry at room temperature and weighed.

For the collection of hydrographic data in all stations a SBE-19 Seacat internally recording CTD was used to measure conductivity and temperature as a function of depth. The hydrographic data along with standard geostrophic objective analysis techniques provided the surface geostrophic flow field at the time of the expedi-

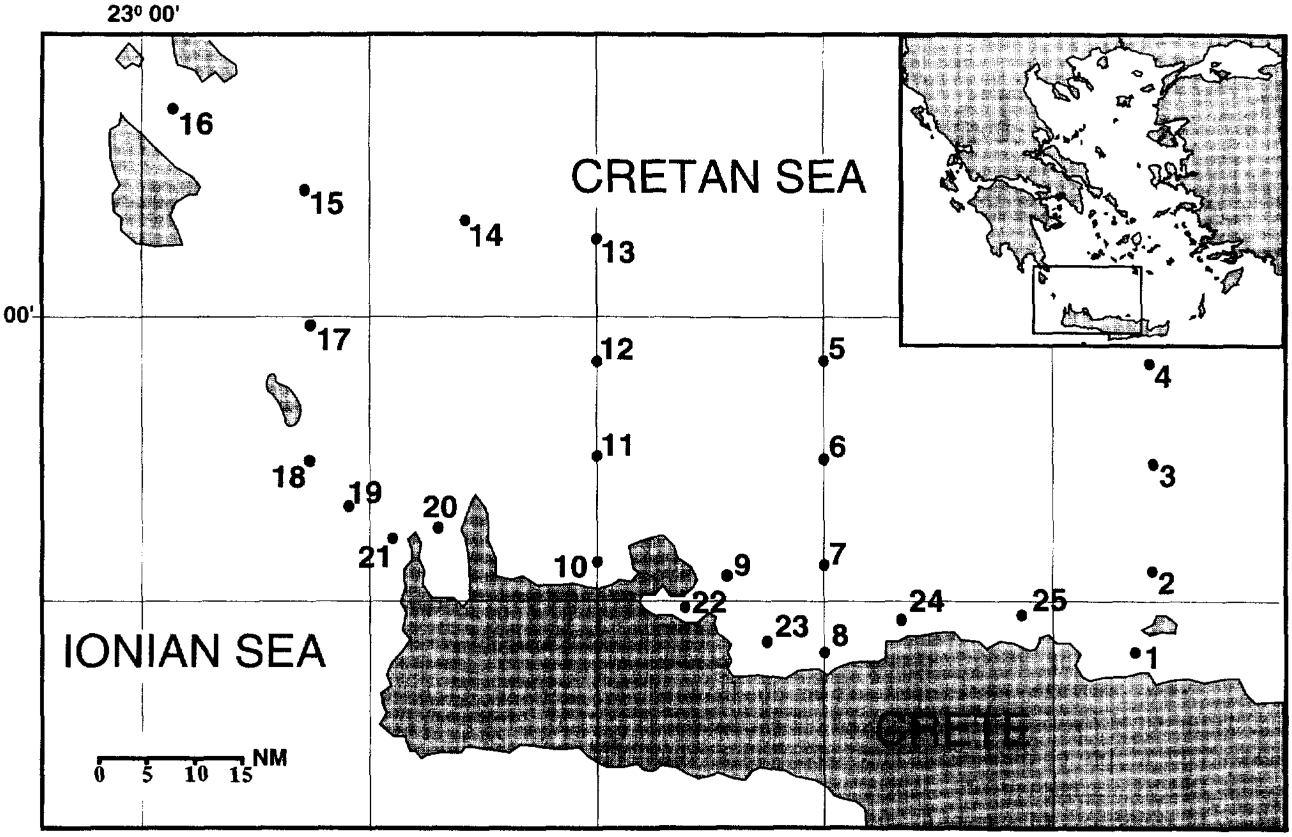

Fig. 1 Map of the study area indicating the sampling stations.

tion. To supplement the *in situ* hydrographic observations and as an aid to data interpretation, several NOAA-AVHRR satellite thermal images concurrent with the cruise period were examined. These were provided by the DLR land station in Germany (Dech, 1995).

Results and Discussion

The measurement of the UV fluorescence is a well known fast and sensitive method of assessing trace concentrations of dissolved and finely dispersed petroleum residues in seawater. Although fluorescence is related not only to the occurrence of petroleum hydrocarbons but also to other biogenic compounds, the method is considered satisfactory for 'hot spot' determination (Knap *et al.*, 1986; UNEP/IOC, 1988; Ehrhart and Petrick, 1989). Results expressed as $\mu g\, l^{-1}$ chrysene equivalents indicate low concentrations of DDPH with a narrow range of values from 0.092 to 0.317 $\mu g\, l^{-1}$ all within the backgound level for the Mediterranean Sea (UNEP/IOC, 1988).

Measurable amounts of tar were found in all sampling stations with weight densities ranging from 1 to 4284 $\mu g\, m^{-2}$ with a mean value of 318 $\mu g\, m^{-2}$. At the natural border between the Ionian and Cretan Seas (Antikithira Straits), high densities of tar from 871 up to 4284 $\mu g\, m^{-2}$ were observed in three stations (Fig. 2). Plastics were found in 90% of the tows at a density ranging from 1 to 1160 $\mu g\, m^{-2}$, consisting primarily of fishing lines, cellophane and small plastic pieces as eroded fragments of larger items. Examining the pattern of the DDPH, plastic and tar distributions, an increase in concentrations close to the coasts is evident. Table 1 shows the DDPH concentrations and the pelagic tar and plastic litter weight densities found in all sampling stations.

The occurrence of tar in quantities throughout the year on the beaches of the north coasts of Crete is directly related to the near-shore pelagic tar distribution. Tar deposition on the shore is controlled by the emanating source, the mean surface circulation, and the prevailing wind patterns. The northern part of Crete is under the influence of the highly variable Cretan Sea circulation as a series of gyres, eddies and other smaller scale structures, interconnected by currents and jets, variable in space and time are present. Some of these features are permanent, others seem transitional or recurrent (Theocharis *et al.*, 1996; Poulos *et al.*, 1997). The complex circulation pattern along with the prevailing northerly and north-westerly winds determine the surface water mass transports.

In Fig. 3, a schematic presentation of the mean surface circulation as implied by the geostrophic

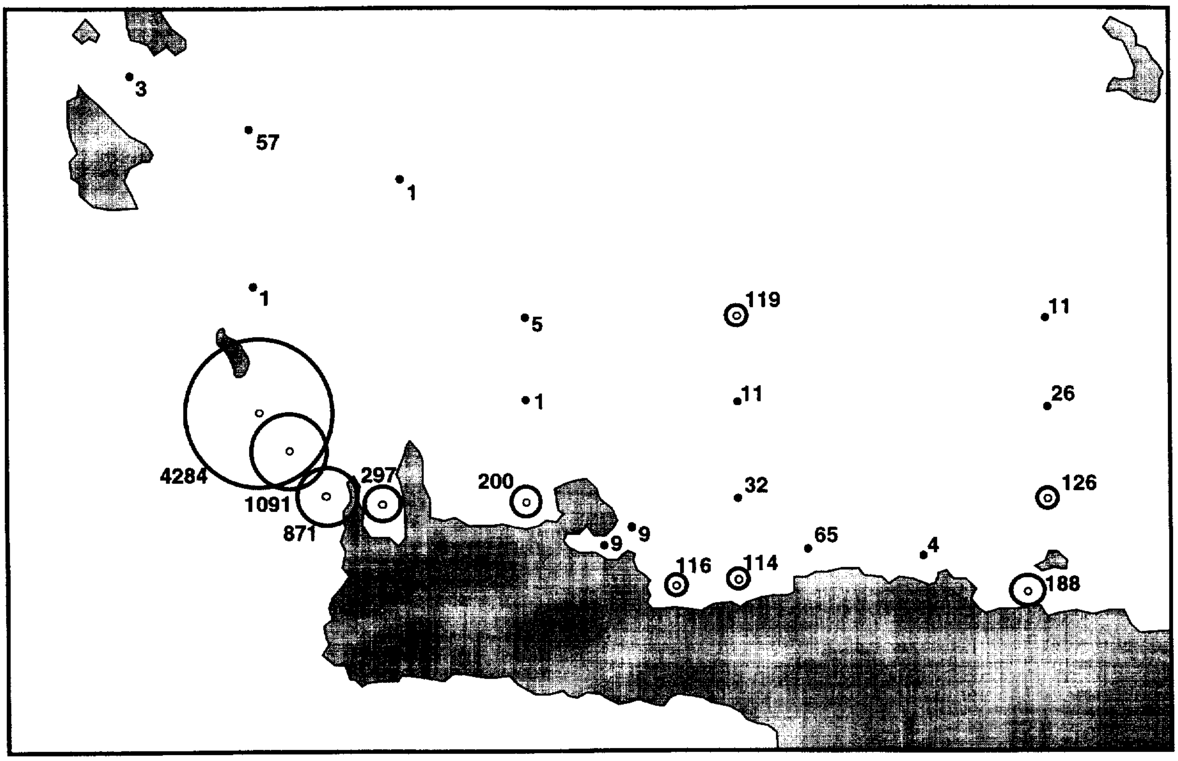

Fig. 2 Pelagic tar distribution in the Cretan Sea. Size of the circles is proportional to the measured tar concentrations.

TABLE 1

DDPH, pelagic tar and plastic concentration in all sampling stations.

Station	Latitude	Longitude	DDPH (μg/l*)	Tar (μg/m²)	Plastics (μg/m²)
1	35° 23.22′	25° 09.17′	0.154	188	102
2	35° 33.93′	25° 10.24′	0.317	126	1160
3	35° 43.23′	25° 09.81′	0.100	26	1
4	35° 53.05′	25° 10.08′	0.129	6	245
5	35° 52.29′	24° 30.09′	0.171	119	2
6	35° 42.52′	24° 28.85′	0.125	11	166
7	35° 33.02′	25° 28.48′	0.125	32	1
8	35° 23.70′	24° 28.30′	0.179	114	78
9	35° 31.84′	24° 13.74′	0.250	9	1
10	35° 33.75′	24° 00.00′	0.113	200	439
11	35° 42.97′	24° 00.14′	0.129	1	1
12	35° 52.90′	24° 00.03′	0.129	5	54
13	36° 03.05′	24° 00.06′	0.133	–	–
14	36° 07.68′	23° 44.47′	0.133	1	8
15	36° 14.48′	23° 26.62′	0.117	57	16
16	36° 25.54′	23° 02.43′	0.158	3	13
17	35° 56.58′	23° 23.99′	0.104	1	0
18	35° 45.30′	23° 23.80′	0.096	4284	83
19	35° 40.44′	23° 28.69′	0.092	1091	5
20	35° 36.38′	23° 39.24′	0.138	297	31
21	35° 35.20′	23° 32.98′	–	871	2
22	35° 29.31′	24° 10.26′	0.150	9	346
23	35° 25.35′	24° 20.69′	0.146	116	70
24	35° 28.04′	24° 40.16′	0.158	65	42
25	35° 27.00′	24° 56.36′	0.138	4	0
Mean			0.145	318	119
Range			0.092–0.317	1–4284	0–1160
Standard deviation:			0.049	887	250

*In Chrysene equivalents.

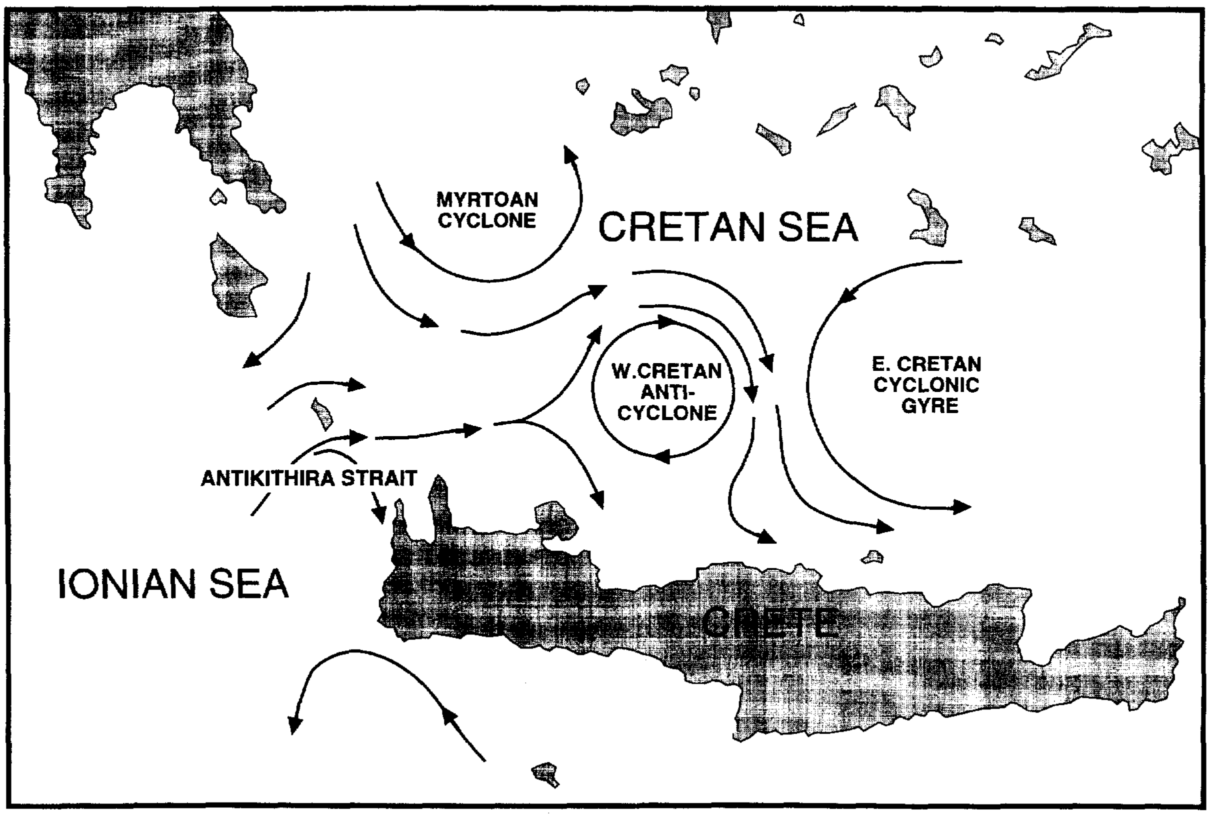

Fig. 3 Schematic presentation of the mean surface circulation in July 1997.

analysis of the collected hydrographic data combined with the current thermal images is shown. The aforementioned existence of a complex structure is verified and a series of cyclonic (Myrtoan), anticyclonic (West Cretan) and again cyclonic (East Cretan) formation is evident. This sequence invokes a surface circulation with currents meandering from west to east. During the sampling period an inflow of surface water through the Antikithira Strait was observed. This inflow is also confirmed by long-term current meter data collected in the surface layer of the Antikithira Strait with a mean speed of 40 cm/s (Tsimplis *et al.*, 1997). The surface water masses enter the Cretan system of the gyres and are partially trapped within the anticyclonic eddy while the remainder move in a southeastern direction and eventually end up in a coastal flow.

The low salinity of the water masses entering through Antikithira Strait (Fig. 4) is an indication of their Atlantic origin. These water masses propagate along the coast of north Africa, meander in the Ionian and Levantine Seas and enter the Cretan Sea through the western straits (Robinson *et al.*, 1991). As a consequence, floating material found in the Cretan Sea following the surface flow, can easily originate from regions possibly quite far away from the island. The sampled highest floating tar concentrations near the westernmost end of the Antikithira Strait suggest that the floating tar entering the Cretan Sea through this Strait could originate from the southern Ionian Sea. Regarding the near-shore stations, the relatively high concentrations of floating tar and litter should result from the interaction of the prevailing north and northwest winds with the mean water flow.

Information on floating tar distribution in the Mediterranean is available from various studies (UNEP/IOC, 1988). For the Ionian Sea, Horn *et al.* (1969) and Morris *et al.* (1975) reported mean tar concentrations of 130 and 16 mg m^{-2}, respectively, indicating that during the period of their studies this area was by far the most polluted in the Mediterranean. In the Eastern Mediterranean, El Heyawi (1979) and Aboul-Dahab and Halim (1981) reported mean tar concentrations ranging from 2.82 up to 5 mg m^{-2} (coasts of Egypt) while Saydam *et al.* (1985) measured 33.4 mg m^{-2} in Iskenderun Gulf (north-east coast of Turkey). Some years later Golik *et al.* (1988) observed a sharp decrease in tar pollution throughout the Mediterranean and characterised the Ionian Sea and the surrounding Cretan waters as the least polluted area in the Mediterranean with a mean pelagic tar concentration of 0.15 mg m^{-2}. In contrast, the same authors described the Gulf of Sirte off Libya as the most polluted area (6.85 mg m^{-2}). The increase in tar concentration reported in this study along with the observed massive entrance of tar from Antikithira Strait into the Cretan Sea suggest a possible increase of

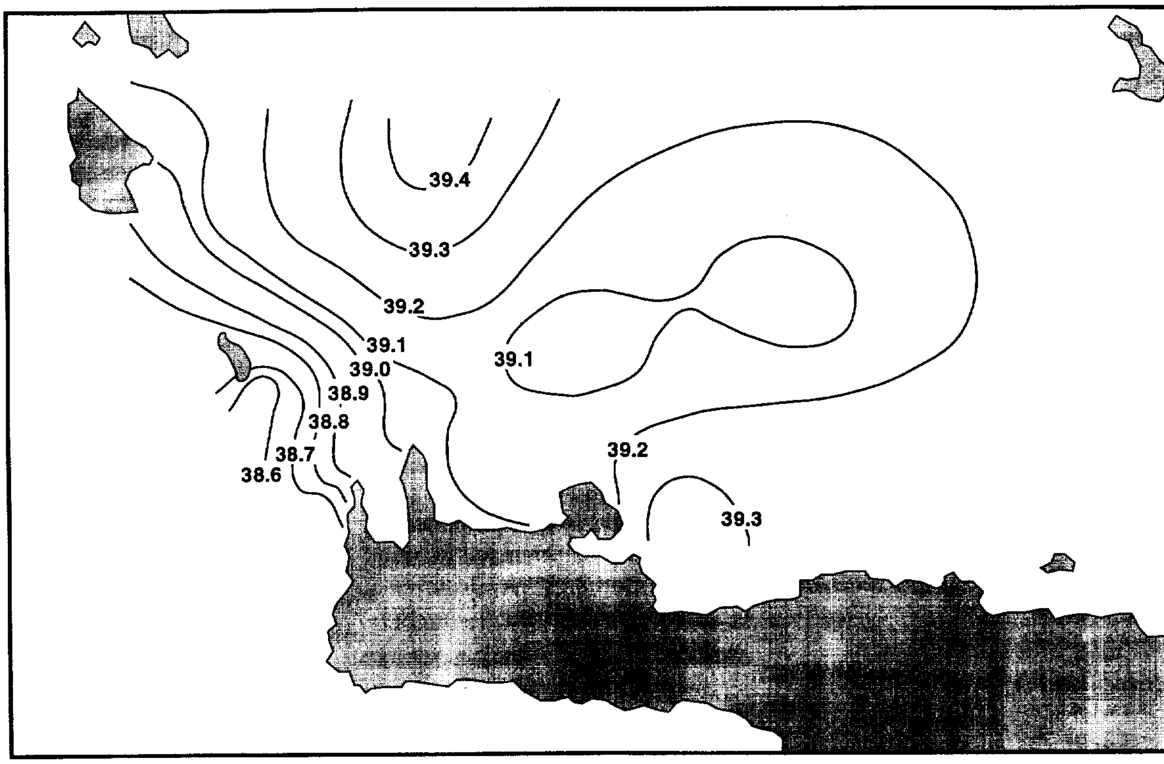

Fig. 4 Sea surface salinity during the sampling period.

oil loading activities at the Libyan oil terminals and/or an increase in international oily ballast water discharges in Ionian Sea tanker lanes. Future work in progress is expected to confirm the persistence of pelagic tar concentrations in the Cretan Sea and will provide more information as to the origin and source of pollution.

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