Discussion

The dual phase nature of dumped dredger spoil has been noted by other workers in this field. Gordon (1974) reported a turbulent jet that was found to accompany spoil dumping and the Hydraulics Research Station (1971) observed twin phase behaviour in sludge deposited by a dredger in Liverpool Bay.

A cloud of suspended sediment was also observed by Nittrouer & Sternberg (1975) during dredger dumping in Puget Sound, Washington. The formation of mud 'pebbles' or 'balls' has been noted by Kornicker *et al.* (1958) and by Hellier & Kornicker (1962) who concluded that the presence of mud pebbles in sediments was a definite indication of dredger spoil dumping.

The production of a turbid cloud of suspended particulates of high mobility may even result in the re-silting of the harbour from which the spoil was obtained, should the currents at the time of dumping be in an unfavourable direction. During the course of this study, in Autumn 1976, the Lowestoft Harbour Authorities reported an accelerated silting of the dock which suggested that this might indeed be the case. This evidence was supported by current meter records and calculations of the suspended sediment flux off the Lowestoft coast, Joyce (1976), which showed a transport of suspended silt towards the harbour mouth and confirmed by the Hydrographer for the Navy who demonstrated a southerly tide residual towards the harbour mouth. On the recommendations produced by this project the dump site was subsequently re-located once again to a site some 1500 m south of the Old Newcome Channel site (position B on Fig. 1). It has been recommended that, wherever possible, dumping should take place on a south-going tide so that the turbid cloud of suspended solids that is produced will be carried safely away from the harbour mouth.

Clearly the need can be seen for a greater understanding of the mechanism of inshore spoil dumping and for the identification of the forces operating on both phases of the dredger spoil once it is introduced into the marine environment.

Cloet, R. L. (1963). Hydrographic analysis of the sandbanks in the approaches to Lowestoft Harbour. Admiralty Marine Science publication No. 6. (Hydrographic dept. Admiralty 1963).

Davies, C. M. (1972). Aspects of suspended sediment transport in Swansea Bay. Unpublished Ph.D. thesis, University College of Swansea.

Gordon, R. B. (1974). Dispersion of dredge spoil dumped in nearshore waters. *Estuarine Coastal Mar. Sci.*, **2**, 349–358.

Hellier, T. Jnr. & Kornicker, L. S. (1962). Effects of hydraulic dredging on sedimentation. *Publ. Inst. Mar. Sci. Univ. Texas*, **8**, 147–150.

Hydraulics Research Station. (1971). Sludge disposal in Liverpool Bay. H.R.S. Yearly Report, pp. 54–57.

Joyce, J. R. (1976). Properties of fine sediments in relation to marine spoil dumping. Unpublished Ph.D. thesis, University of East Anglia.

Kirkby, R. & Parker, W. R. (1974). Seabed density measurements related to echo sounder records. *Dock and Harbour Authority*, **54**, 423–424 (March 1974).

Kornicker, L. S., Oppenheimer, C. H. & Conover, J. T. (1958). Artificially formed mud balls. *Publ. Inst. Mar. Sci. Univ. Texas*, **5**, 148–150.

Nittrouer, C. A. & Sternberg, R. W. (1975). The fate of a fine grained dredged spoils deposit in a tidal channel in Puget Sound, Washington. *J. Sed. Petrol.*, **45**, 160–170.

Smith, D. B., Parsons, T. V. & Cloet, R. L. (1965). An investigation into the silt movement in an ebb channel, Firth of Forth, 1965. A.E.A.E. Technical Report No. R5080.

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Surface Circulation and the Distribution of Pelagic Tar and Plastic

D. G. SHAW and G. A. MAPES
Institute of Marine Science, University of Alaska, Fairbanks, Alaska 99701, USA

Pelagic tar and plastic have been measured along 158°W in the North Pacific. Maxima in the abundance of tar are associated with convergent meso scale and with small scale surface circulation features observed at the same time. There is no significant correlation between abundance of tar and that of plastic. It appears that this difference in distributions is the result of different input patterns or residence times.

The occurrence of pelagic tar and plastic in the world ocean has been repeatedly documented in the past decade (*inter alia:* Sleeter *et al.*, 1976; Shekel & Ravid, 1977 and references therein). Three lines of evidence suggest that much of this tar is introduced by human activity (National Academy of Sciences, 1975). First, abundant tar occurs in regions of heavy oil transport. Second, the normal alkane distribution of most tar balls is bimodal, a characteristic of sludge from tank ship holds. Third, the concentration of iron in most tar balls is higher than for crude oils, indicating contact with steel structures. While the most intense study of pelagic tar and plastic has been in the Mediterranean, Atlantic and Caribbean, several surveys in the North Pacific (Marumo & Kamada, 1973; Wong *et al.*, 1974; Wong *et al.*, 1976; Shaw, 1977) have indicated that the major source of tar in this region is the tanker route southwest of Japan and that tar moves around the North Pacific through the Kuroshio–subtropical gyre system.

All studies have shown a large degree of patchiness in tar and plastic distribution. A dramatic example of the patchiness of pelagic tar comes from sequential samplings at a station near Bermuda in the Sargasso Sea (Butler *et al.*, 1973). There it was observed that the abundance of tar could change by a factor of 100 in 2 weeks and by a factor of 10 in 2 h. In this note we report the abundance of pelagic tar and plastic in the North Pacific along a transect extending roughly between the islands of Kodiak and Hawaii. Furthermore, we relate these abundances to simultaneously observed surface circulation features to elucidate some of the causes of the observed patchiness.

Patchiness in the pelagic environment is a well recognized phenomenon (Parsons & Takahashi, 1973). For plankton, patchiness has been observed on scales ranging from meters to thousands of kilometers and a variety of biological and physio-chemical causes have been investigated. One of the reasons that patchiness of organisms remains incompletely understood is that it is the result of many variables (light, temperature, salinity, advection, reproduction, behavior, competition, etc.) acting together. However, for inanimate pelagic material such as tar and plastic it is possible to ascribe patchiness to currents, winds and geographically non-uniform inputs.

Methods

Seston tows for tar and plastic were made in October and November, 1976, as the R/V *Moana Wave* proceeded south along 158° west longitude. Twenty-eight tows were made between 56° and 22° north latitude during a 2-week period. For each tow a seston sampler made to the design of Sameoto and Jaroszynski (1969) was deployed for one nautical mile (1.85 km) thereby sampling 740 m^2 of sea surface. Tar and plastic were picked from the catch. In the laboratory on shore weights of tar and plastic, including encrusting organisms if any, were determined and for six tar samples gas chromatographic (GC) profiles were obtained. For these a portion of tar was taken up in hexane, insoluble residue removed by centrifugation and an aliquot of the solution chromatographed on an OV-101 support coated open tubular column with temperature programming and flame ionization detection.

Results and Discussion

Figure 1 shows the abundance of tar and plastic as a function of latitude together with 0–1000 dbar dynamic topography determined from hydrographic data collected during the same cruise (Royer, 1978). Negative slope in the dynamic topography signifies westward flow and positive slope eastward flow. Thus the large hydrographic features are the westward flowing Alaska Stream from 55.5° to 54° N and the eastward flowing North Pacific Current between 54° and 22° N. Several regions of current reversal (negative slope) are embedded in the North Pacific Current. The mesoscale (400–600 km) features south of 35° N have been identified as eddies by Bernstein (1974). Roden (1977) has documented the continued presence of these eddies and discussed their origin. Four regions of smaller scale (75 km) eddies at approximately 38°, 43°, 47° and 51°N have been identified by Royer (1978).

A relationship exists between tar abundance and the mesoscale eddies south of 35° N. It has been shown that a cyclonic eddy results in surface convergence (Schmitz & Vastano, 1975) while an anticyclonic eddy produces surface divergence (Schmitz & Vastano, 1976). For discussion we assume that the dynamic topography shows anticyclonic, divergent eddies centres at 24°, 27° and 30°N. (The alternate assumption of cyclonic, convergent eddies at 25.5°, 28.5° and 32°N leads to exactly the same conclusions.) The zones of divergence correspond to local minima in tar abundance (Fig. 1). This is eminently reasonable; the divergent surface flow at 24°, 27° and 30°N sweeps seston out of those areas and causes it to accumulate at adjacent latitudes, i.e., 25.5°, 28.5° and 32°.

Small scale eddy regions identified by Royer at 47° and 38°N also coincide with local maxima in tar abundance. However, the scale of these eddies is too small, relative to the scale of tar sampling, to allow detailed correlation of maxima and convergences.

In keeping with the primary North Pacific pelagic tar source southwest of Japan and the dispersal of that tar by the Kuroshio-subtropical gyre system, Wong *et al.* (1974) found that along 35°N in the Pacific, peak tar concentrations were associated with subtropical water while low tar abundance was associated with subarctic

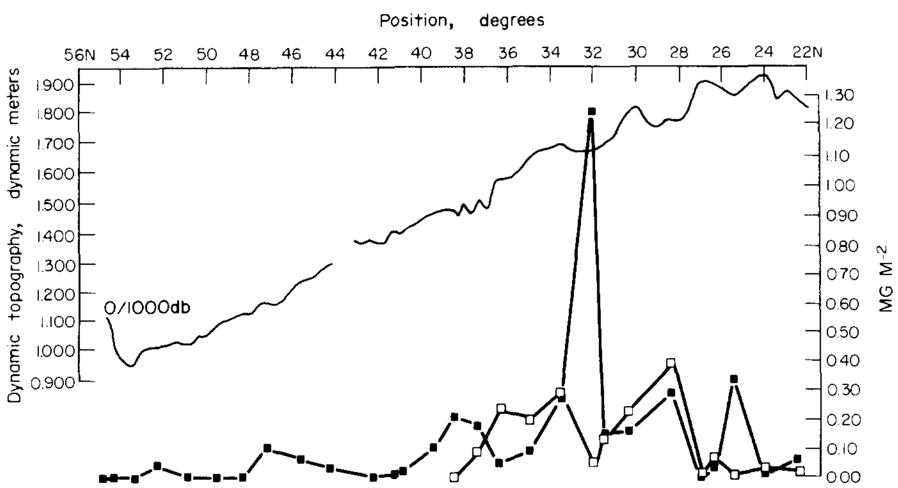

Fig. 1 Pelagic tar (solid squares), pelagic plastic (open squares) and 0/1000 dbar dynamic topography (smooth line, adapted from Royer, 1978) observed along 158°W longitude.

water. The surface boundary between subarctic and subtropical water on our north to south transect is indistinct because of seasonal surface cooling at the time of sampling; however the boundary is in the region 39° to 43°N (Royer, personal communication). Relatively little tar and no plastic whatsoever was found to the north of this region. Thus, the association of tar and plastic with subtropical water is confirmed.

The factors controlling the abundance of plastic are more complex than those for the tar just discussed. For the region where plastic was found (i.e., south of 38°N) there is no statistically significant correlation between the abundances of tar and plastic. However, if the data from only two stations (25.5° and 32°N) is rejected, the correlation between the abundances of tar and plastic south of 38°N becomes highly significant.

Because the two suspect stations had the highest abundances of tar of the entire transect, we considered the possibility that some of that tar was 'extra' from some additional source such as a recently passed ship. However, we discarded this hypothesis for two reasons. First, the GC profiles of tar from these stations were similar to others in degree of weathering and bimodal alkane distribution. Second, tar from these stations was, like all tar and plastic collected between 24° and 35°N, encrusted by bryozoans. The alternate hypothesis, that plastic abundances at 25.5° and 32°N are artificially low, is more difficult to evaluate directly, but also appears unlikely. This would require that some plastic-specific removal process operate only at those two locations.

We feel that there is inadequate evidence to firmly reject the two suspect stations and conclude that the differences in the distribution of tar and plastic reflect either different input patterns or different survival times at sea.

Our results along 158°W show a maximum in plastic at about 29°N and relatively low abundances north of 38°N and south of 26°N. Wong and co-workers (1974) found that the maximum plastic abundance along 35°N occurred at 142°W and that very little was present either east of that location or west of 180°. The suggestion (Wong *et al.*, 1974) that plastic accumulates in this region because of low net wind stress appears valid in view of all available results.

The fact that the majority of the plastic occurs more to the south and east than do the highest tar concentrations may, as suggested by Wong, be the result of a significant input of plastic but not tar from Hawaii. The distributions may also reflect a longer lifetime for plastics which enter the system in the Western Pacific along with the tar. Thus, it may be that plastic entering the Western Pacific in low abundance has a long enough residence time on the sea surface to accumulate in the Northeast Pacific.

Conclusions

Our observations indicate that small scale (75 km) and mesoscale (500 km) tar distribution is influenced by surface circulation features. Although the situation is not nearly as clear cut with regard to plastic, surface circulation must be important here too. Wind patterns appear to control the accumulation of plastic in the Northeast Pacific. The lack of a high tar concentration in this area may indicate that the tar's lifetime is not great enough to permit transport from the area of origin southwest of Japan. These advective forces controlling the distributions of tar and plastic in the North Pacific must be among those influencing the patchiness of pelagic organisms in the region.

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Bernstein, R. L. (1974). Mesoscale eddies in the North Pacific: Westward Propagation. *Science*, **183**, 71-72.

Butler, J. N., Morris, B. F. & Sass, J. (1973). Pelagic tar from Bermuda and the Sargasso Sea. Special Publ. No. 10, Bermuda Biological Station, St. Georges West, Bermuda. pp. 43-45.

Marumo, R. & Kamada, K. (1973). Oil globules and their attached organisms in the East China Sea and Kuroshio area. *J. Ocean. Soc. Japan*, **29**, 155-158 (in Japanese).

National Academy of Sciences (1975). *Petroleum in the Marine Environment.* Washington, D.C. pp. 48-53.

Parsons, T. R. & Takahashi, M. (1973). *Biological Oceanographic Processes.* Pergamon, New York. pp. 30-35.

Roden, G. I. (1977). On long-wave disturbances of dynamic height in the North Pacific. *J. Phys. Oceanogr.*, **7**, 41-49.

Royer, T. C. (1978). Ocean eddies generated by seamounts in the North Pacific. *Science*, **199**, 1063-1064.

Sameoto, D. D. & Jaroszynski, L. O. (1969). Otter surface sampler: A new neuston net. *J. Fish. Res. Bd. Can.*, **25**, 2240-2244.

Schmitz, J. E. & Vastano, A. C. (1975). Entrainment and diffusion in a Gulf Stream cyclonic ring. *J. Phys. Oceanogr.*, **5**, 93-97.

Schmitz, J. E. & Vastano, A. C. (1976). On entrainment and diffusion in a Gulf of Mexico anticyclonic ring. *J. Phys. Oceanogr.*, **6**, 399-402.

Shaw, D. G. (1977). Pelagic tar and plastic in the Gulf of Alaska and Bering Sea: 1975, *Sci. Total Environ.*, **8**, 13-20.

Shekel, Y. & Ravid, R. (1977). Sources of tar pollution on Israeli Mediterranean coast. *Environ. Sci. Technol.*, **11**, 502-505.

Sleeter, T. D., Morris, B. F. & Butler, J. N. (1976). Pelagic tar in the Caribbean and equatorial Atlantic, 1974. *Deep Sea Res.*, **23**, 467-474.

Wong, C. S., Green, D. R. & Cretney, W. J. (1974). Quantitative tar and plastic waste distributions in the Pacific Ocean. *Nature*, **247**, 30-32.

Wong, C. S., Green, D. R. & Cretney, W. J. (1976). Distribution and source of tar in the Pacific Ocean. *Mar. Pollut. Bull.*, **7**, 102-105.