Table 3 Average Manganese, Nickel and Cobalt Contents of Sahara Desert Dusts and Mid-ocean Atlantic Sediments

Trace element	Average of dusts originating in Sahara Desert *	Average of <2 μm fractions of Sahara Desert dusts †	Average of mid-ocean sediments ‡
Mn	1,647	1,300	5,912
Ni	37	30	418
Co	16	15	138

Contents are given in p.p.m.
* Data from Table 1, expressed on a carbonate-free basis for those dusts containing >10% total carbonate.
† The average for the <2 μm fractions of dusts M1, M2 and M24; the data include any carbonates present in the <2 μm fractions.
‡ Data from Chester and Messiha-Hanna[9]. The analyses, which are expressed on a carbonate-free basis, are for the following sediment cores: J4 (37° 22′ N, 38° 47′ W); I4 (34° 06′ N, 38° 55′ W); H4a (31° 02′ N, 45° 13′ W); F5 (24° 56′ N, 39° 30′ W).

between about 10° N and about 35° N, aeolian dusts make up a large proportion of the land-derived material in the deep-sea sediments[1,4]. The principal source area of these dusts is the Sahara Desert of West Africa. Table 3 lists the average Mn, Ni and Co contents of aeolian dusts from this source, and compares them with mid-ocean sediments in the Sahara Desert latitudes. The average Mn, Ni and Co content of the <2 μm fractions of some of the dusts is also included as it is these small particles which will be transported farthest from the land masses. Table 3 shows that when bulk compositions are considered, the aeolian dusts cannot supply sufficient Mn, Co and Ni to account for the enrichment of these metals in mid-ocean sediments. If these dusts constitute a large proportion of the land-derived material in the deep sea sediments of this area[1], then at least some of the "excess" Mn, Ni and Co in the sediments must originate from seawater. One possibility is that the dusts are capable of adsorbing trace elements from seawater. This problem is being investigated in our laboratories.

The data now available do not, however, permit the overall importance of aeolian dusts on oceanic trace element economy to be determined. Before this can be evaluated, it is necessary to estimate the efficiency of the dusts as trace element adsorbents and, equally important, to compare the rates of sedimentation of the dusts (and their associated trace elements) with those of the land-derived fractions of deep sea sediments. These factors must be evaluated in terms of the supply of dissolved trace elements to the Atlantic Ocean.

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Thermohaline Staircase

The use of salinity-temperature depth (STD) systems to study the Mediterranean outflow in the North-East Atlantic[1,2] has recently drawn attention to the complexity of the thermohaline properties of this mass of water. Our contributions[3,4] have been concerned with a "step-like" structure in temperature and salinity found within the lower layers of the Mediterranean water from 1,200 to 1,800 m. From August to September 1970, the Liverpool University Oceanography Department conducted an extensive investigation of this phenomenon and some preliminary results are reported here.

One aim of the work was to delineate the horizontal extent of the step-layer zone. Fig. 1 shows the area of operation and the station positions where this type of stratification had previously been observed. Our new measurements revealed an extensive zone (shaded in Fig. 1), which was somewhat further south than had been expected. The western, southern and eastern limits were established by a network of STD stations based on a 10–15 mile grid, but there was insufficient time for a full investigation of the northern limit, which is therefore represented by a broken line on the chart. The results showed that the step layers were distributed over an area of at

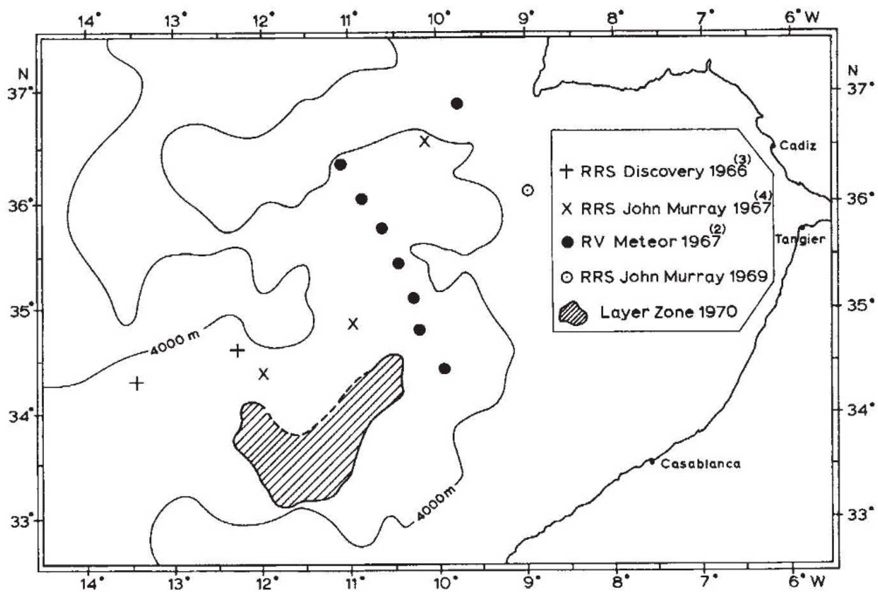

Fig. 1 The location of the layer zone.

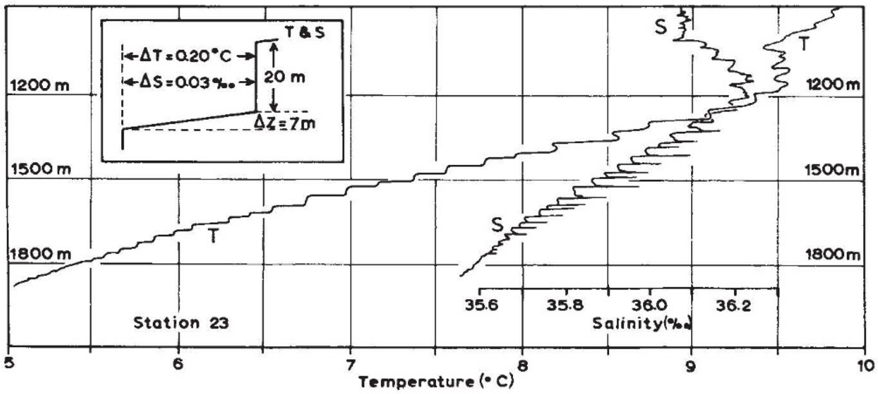

Fig. 2 Part of the STD record for station 23: the sharp spikes to the right of the salinity trace are instrumental and can be ignored.

least 4,000 square miles, the boundary of which could be located to within a few miles. More than 150 STD records, usually to depths of 2,000 m, were obtained and all those from stations within the zone showed ten or more well defined step layers. Previously, a maximum of eleven consecutive steps had been reported[2], but many of the new records showed more than twenty steps forming a thermohaline "staircase" through the lower layers of the Mediterranean water. As well as the standard STD records, expanded scale traces, with a ten-fold increase in resolution, were obtained for all stations.

A typical standard record is given in Fig. 2 which depicts the overall T and S stratification at station 23 (33° 10′ N, 11° 46′ W) from 900 to 1,900 m. Analysis of the basic parameters from the high resolution traces for this and similar stations produced mean values which can be represented (insert to Fig. 2) as a single step with a layer thickness of 20 m, an interface thickness of 7 m and a decrease in T and S across the interface of 0.20° C and 0.03‰, respectively. Stability is maintained with an increase of 0.005 in σ_τ. These values are generally consistent with our previous results. The step and interface thicknesses and the magnitudes of ΔT, ΔS and $\Delta\sigma_\tau$ all decreased significantly with depth. The interface gradients of T, S and σ_τ were more uniform but there was some indication that maximum values occurred through the middle section rather than at the upper or lower extremes.

A primary objective of the cruise was to investigate the horizontal coherence of the stratification, that is, to determine how far a particular layer could be traced by its T/S characteristics before losing its identity. The analysis so far has shown that individual horizontal layers may extend for at least 30 miles. This result is based on data from closely spaced stations at 1 mile intervals as well as more widely spaced stations. For example, the correlation of station 23 with adjacent stations 15 miles away gave T and S values for individual layers which agreed, on average, to within 0.02° C and 0.001‰, an order of magnitude less than the interface values, which leaves little doubt as to the continuity of the layer system.

Over the entire lower boundary of the Mediterranean water outflow, the physical conditions are favourable to the differential diffusion of heat and salt, which has been cited[5] as the basic mechanism governing the formation of the step layers. The results described here should provide a critical test of any theories concerned with this phenomenon and may stimulate further work. The reason for the development of the layers within a specific area is still unknown, but we hope that the answer will be provided by a complete analysis of the new data. Further results will be reported in due course.

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Depth Distribution in Ocean Basins and Plate Tectonics

In this article I shall show that relationships between the movement of lithospheric plates[1–3] and the depths of the sea floor are leading towards a quantitative theory of the distribution of oceanic depths, and that some predictions can be made. Several principal lithospheric plates have now been recognized; their relative motion over the mantle is described by a rotation of one plate relative to an adjacent plate[4–6]. The rotation requires two parameters to locate the pole of relative rotation, and one to specify the magnitude of the angular velocity. The direction of spreading is along small circles concentric about the pole of rotation and the velocity of spreading varies as the sine of the distance (measured in degrees of arc) from that pole, to a maximum at a distance of 90° along the equator of rotation. The angular velocity of rotation is the same everywhere. In the Atlantic Ocean the fracture zones between about 60° N and 10° S are very nearly small circles centred about a pole near the southern tip of Greenland ($62\pm5°$ N, $36\pm2°$ W), and the spreading rates approximately agree with the velocities required for the opening of the North Atlantic about this pole[1,3].

Examination of the topography of the sea floor and spreading rates in the central region of the world system of mid-ocean ridges shows that the width of the ridge[7], the local topography[8], and the thickness of layer 2 of the oceanic crust[8] seem to be related to the spreading rate in the following way. (1) Slow spreading (1–2 cm yr^{-1}) away from the ridge centre is associated with a narrow ridge, a central rift, adjacent rift mountains and a thick layer 2. (2) Fast spreading (3–4.5 cm yr^{-1}) is associated with a wide ridge, subdued topography (no central rift) and a thin layer 2. (3) The volume of lava discharged in layer 2 per unit time and unit length along the crest of the whole active system is relatively constant regardless of the spreading rate. Thus, topography and the thickness of layer 2 can be predicted if the rate of spreading is known.

An examination of topographic profiles perpendicular to various sections of the world mid-ocean ridge system supports the inference that topography is a function of spreading rate[9]. The relationship between the slope of ridge flanks and the spreading rate from the ridge crest to magnetic anomaly No. 5 at a distance corresponding to 10^7 yr was formulated from this series of profiles so that, by knowing the spreading rate, the slope can be calculated[9]. The faster the spreading rate within an episode of spreading, the lower the topographic slope and roughness, measured over a distance corresponding to the crust generated during that episode. The decrease in