to be communicated from the outer to the inner segment in the absence of both changes of membrane voltage and current flow between outer and inner segments (in perfusate low in Na+). Such intracellular transmission of excitation might be accomplished by diffusion of an intracellular messenger substance. However, because light-induced changes of optical transmission have been observed from isolated rod outer segments, we think that the changes in transmission measured from intact rods occur in the outer segments.
17. For examples, arsenazo III: J. E. Brown, L. B. Cohen, P. DeWeer, L. H. Pinto, W. N. Ross, B. M. Salzberg, *Biophys. J.* **13**, 1155 (1975); J. E. Brown, P. K. Brown, L. H. Pinto, *J. Physiol. (London)* **267**, 299 (1977).
18. W. N. Ross, B. M. Salzberg, L. B. Cohen, A. Grinvald, H. Davila, A. Waggoner, C. Wang, *J. Membr. Biol.* **33**, 141 (1977).
19. We wish to thank J. E. Dowling for his support and encouragement. We thank P. K. Brown, F. D. Carlson, T. G. Goldsmith, R. Hubbard, D. H. Kelley, and H. Ripps for their thoughtful comments on the manuscript. Supported by NIH training grant 5701 GM00782-19 (to H.H.H.), NIH grants EY 01914 and EY 01915 (to J.E.B.), and EY 01221 (to L.H.P.).

24 February 1978; revised 6 July 1978

Mediterranean Water: An Intense Mesoscale Eddy off the Bahamas

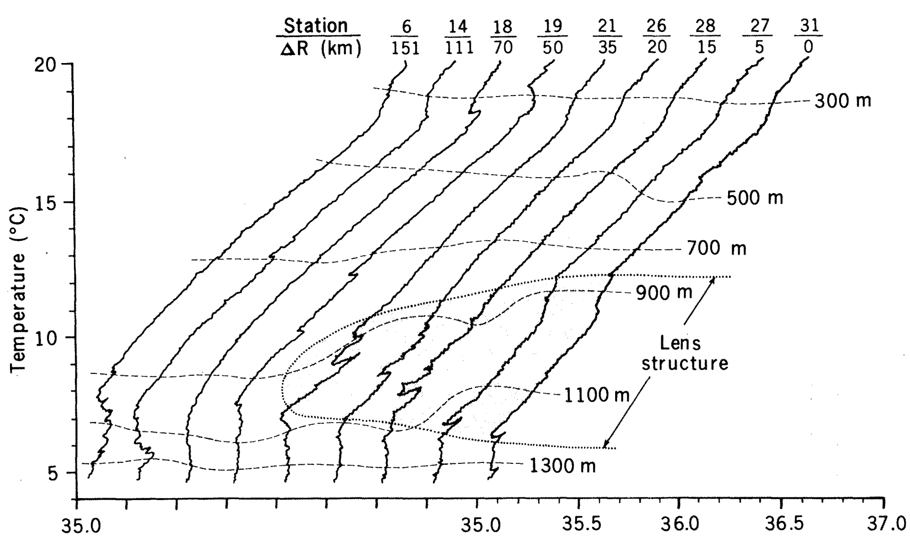
Abstract. *An anticyclonic lens of water in the permanent thermocline off the Bahamas has water mass characteristics representing Mediterranean and eastern Atlantic central waters. This eddy's ability to translate across the Atlantic without losing its identity points to baroclinic eddies as a specific mechanism for large-scale mixing.*

Thermocline waters of the North Atlantic are characterized by an extremely tight relationship between temperature (T) and salinity (S) in the range from 6° to 17°C. Geographical variations in this T/S relationship are caused mainly by intrusions of relatively saline Mediterranean water and fresher Antarctic intermediate water. The hydrographic treatise of Iselin (*1*) and the more recent volumetric census of Wright and Worthington (*2*) suggest that T/S anomalies in the western North Atlantic imposed by these two water masses are limited to temperatures less than 8°C. Recent hydrographic observations from the western Sargasso Sea revealed an anomalously saline water mass ranging from 7° to 12°C which was embedded in the thermocline. The characteristics of this feature indicate that it contained water from the eastern Atlantic and the Mediterranean Sea. This report is a presentation of the property anomalies associated with this intense baroclinic eddy.

The mass of highly saline thermocline water was discovered in the Hatteras abyssal plain during cruise 15 of the R.V. *Oceanus* in October 1976. This Mediterranean eddy (or "Meddy") was initially detected during a survey in which 750-m expendable bathythermograph probes (XBT's) were dropped in a 1° square centered at 25°N, 70°W. The Meddy appeared as an extremely warm feature in the temperature field below 700 m, with resulting horizontal temperature gradients as large as 1°C in 30 km. Although the XBT-derived temperature-depth measurements did not penetrate the lower limit of the lens, the nearly circular geometry and 100-km radius were evident.

After the XBT survey, a series of 32 lowerings of a salinity-temperature-depth (STD) recorder were made within 150 km of the Meddy. Continuous vertical profiles were obtained from the surface to a depth of 1500 m at each station. Figure 1 is a composite of nine T/S curves obtained at various radial distances from the center of the Meddy. These profiles illustrate the rich vertical structure of both temperature and salinity within the Meddy. Temperatures within the Meddy exceeded those of surrounding stations in the depth range from 700 to 1300 m; for example, 10°C water was observed at 1010 m inside the Meddy and generally remained near 800 m for all far-field stations. The vertical temperature gradient within the Meddy was also highly depth-dependent: at 900 and 1100 m the gradients were 0.7°C/100 m and 2.8°C/100 m, respectively, compared to typical values of 2.0°C/100 m. Although vertical temperature profiles were smooth and monotonically decreasing with depth at stations taken outside the Meddy, significant temperature inversions were evident in profiles taken around its periphery. The largest of these inversions extended between 970 and 1020 m at a station approximately 35 km from the center of the Meddy.

The distribution of salinity in the vicinity of the Meddy was similar to the general characteristics of the temperature field. Salinities within the Meddy ex-



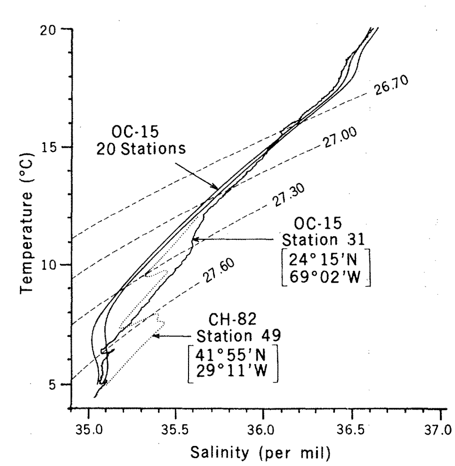


Fig. 1 (left). Temperature/salinity curves through the main thermocline for selected stations occupied during R.V. *Oceanus* cruise 15, October 1976. Station numbers and their respective radial distances from the center of the Mediterranean lens (ΔR) (24°N, 69°W) are indicated. Each successive profile has been displaced by 0.25 per mil. Note the variation in the vertical temperature gradient imposed by the lens. Portions of individual curves which contain excessively high salinities are shaded to illustrate the temperature range and the horizontal and vertical scales of this feature. Fig. 2 (right). Temperature/salinity curves from R.V. *Oceanus* cruise 15, station 31, within the lens of Mediterranean water, and R.V. *Chain* cruise 82, station 49, at the Mid-Atlantic Ridge (*5*). An envelope enclosing 1 standard deviation from the mean T/S curve of 20 *Oceanus* cruise 15 stations outside the lens illustrates the typical characteristics of thermocline waters in the survey region. Dashed lines are σ_t curves.

0036-8075/78/1208-1085$00.50/0

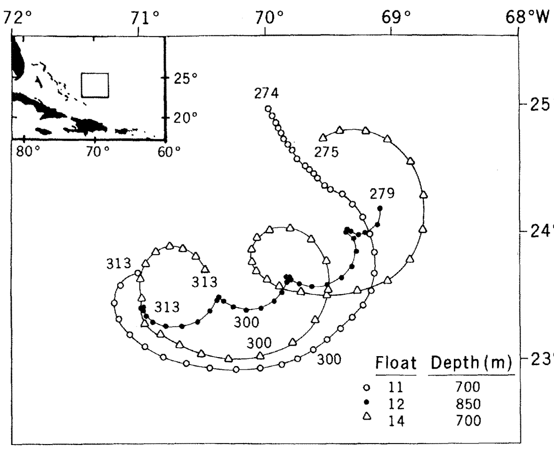


Fig. 3. Trajectories of three sofar floats launched in October 1976 during R.V. *Oceanus* cruise 15. Three-digit numbers adjacent to daily float positions denote the day of the year. The rectangle within the small-scale physiographic inset illustrates the location of the present survey relative to the Bahama Islands.

ceeded those from neighboring stations within the range from 700 to 1300 m. Vertical displacements of isohalines through the Meddy were as large as 200 m, and the density-compensating salinity inversions, corresponding to the temperature inversions, had amplitudes in excess of 0.15 per mil and vertical scales as large as 80 m.

The inversions in the *T/S* relationship between 7° and 11°C at stations 21, 26, and 28 suggest that active mixing was occurring at the outer edges of the Meddy. Conversely, the center of this eddy was characterized by a quasi-homogeneous central core in which the *T/S* relationship was linear over this temperature range. Observations suggested that this core had a thickness and diameter of approximately 200 m and 20 km, respectively.

The intensity of the salinity anomaly associated with the Meddy is illustrated by the *T/S* curves in Fig. 2. An envelope which includes data from 20 background stations in the present survey provides an estimate of the spatial variability of the *T/S* relationship within the undisturbed thermocline of this region. Station 31 is representative of the relatively saline characteristics that were observed at four stations within 10 km of the Meddy center. The positive salinity anomaly of this station increases sharply with decreasing temperature in the range from 12° to 10.5°C. Between 8° and 10°C the salinity excess in the center of the Meddy was on the order of 0.2 per mil, or approximately 20 times the standard deviation in salinity observed at the background stations. At the base of the thermocline, where the influence of saline Mediterranean water is normally observed in the Sargasso Sea, the *T/S* characteristics did not differ significantly from observations at adjacent stations.

The waters between 15° and 19°C above the Meddy were significantly less saline than those observed at the background stations in the survey, but the magnitude of this negative salinity anomaly was considerably less than the underlying positive anomaly. This shallow, relatively fresh water mass may have been coupled to the Meddy below, but this hypothesis cannot be demonstrated through inspection of the *T/S* properties alone.

The dynamic topography of the 500-m surface relative to 1450 m revealed a high in the vicinity of the Meddy. This feature exceeded the background topography by three dynamic centimeters, with this horizontal variation generally being confined to a band of thickness 20 km and corresponding geographically with the perimeter of the Meddy. This topographic high was completely compensated in the upper water column, to the extent that there was no detectable topography of the sea surface relative to 1450 m.

This saline thermocline eddy apparently contains eastern Atlantic and Mediterranean waters which, from the volumetric census of Wright and Worthington (*2*), are extremely rare in the western North Atlantic. The majority of hydrographic surveys from which vast amounts of historical serial data have been collected were based on station spacings and a vertical resolution on the order of 100 km and 100 m, respectively. Therefore, it is possible that intense transient phenomena having scales comparable to the Meddy could exist in the Sargasso Sea and avoid detection.

Numerous hydrographic investigations of the Sargasso Sea have revealed dilute Mediterranean water in the lower portion of the permanent thermocline (*1*, *3*). The temperature and salinity inversion layers and the *T/S* properties that characterize this water mass are generally observed in the range from 4° to 6°C, or between σ_t values of 27.6 and 27.8 (if $\sigma_t = 27.6$, the specific gravity of water is 1.0276). As illustrated in Fig. 2, the large salinity anomaly of the Meddy occurs at σ_t values of 27.3 to 27.55. Observations of Mediterranean water west of the Iberian Peninsula (*4*) and in the vicinity of the crest of the Mid-Atlantic Ridge, near 42°N, 29°W (*5*), have shown that two distinct types of Mediterranean water may persist for great distances to the west of Gibraltar. The classical mode is characterized by a large salinity maximum near 1000 m with σ_t equal to approximately 27.6. A shallower salinity maximum is sometimes observed between σ_t values of 27.3 to 27.4. A single station from R.V. *Chain* cruise 82 has been superimposed on Fig. 2 (dotted line) to illustrate the *T/S* characteristics of this water mass. The saline property of the Meddy suggests that its core initially contained an appreciable volume of upper Mediterranean water.

In conjunction with the STD survey, six neutrally buoyant sound fixing and ranging (sofar) floats were deployed in a 1.5° square centered at 24°30′N, 69°30′W. Five floats, numbered 11, 13, 14, 15, and 16, were ballasted to a depth of 700 m and an additional float (float 12) was set to remain near 850 m. Floats 13, 15, and 16, which were deployed north of 24°30′N, all moved continuously to the southeast for approximately 2 weeks, in agreement with the dynamic topography that was determined from the STD survey. Floats 11 and 14, which were deployed at distances of 80 and 50 km from the center of the Meddy, exhibited intense anticyclonic motion shortly after launch (Fig. 3); float 12, which was launched nearer the center, behaved similarly. These trajectories exhibited orbital velocities which reached a maximum of 30 cm/sec at a radial distance of 50 km from the center of the Meddy. Decomposition of the float trajectories, to remove the rotational component of velocity, indicated that the Meddy was moving to the southwest at a rate of 6 cm/sec during the 38-day period over which this analysis could be made.

The most remarkable aspect of this Meddy was its very existence more than 6000 km from its parent water mass. How could it traverse the ocean without losing its identity to the surrounding thermocline waters? Was it passively advected across the ocean by a westward mean flow, or could its available potential energy provide a dynamic basis for self-propulsion in the absence of a sustained mean flow?

Our knowledge of the mean flow within the subtropical North Atlantic is contradictory. Recent sofar float tracks from 24°N (*6*) suggest significant eastward flow, which is in agreement with the direction of flow inferred from charts of the dynamic topography presented by

Defant [plate 21 in (7)] and Leetmaa *et al.* [figure 1 in (8)]. Sverdrup *et al.* (9) and Worthington (10), on the other hand, require westward flow in the main thermocline of a few centimeters per second, corresponding to a zonal transit time of approximately 10 years.

Our knowledge of the decay of baroclinic eddies is also limited. It is known that newly formed Gulf Stream rings lose their anomalous water properties within 1 to 2 years after formation (11). Although their 100-km horizontal scale approximates that of the Meddy, they are considerably more energetic. If the rate of mixing within these baroclinic eddies is proportional to the radial shear, one can speculate that the containment time of the Meddy would be much greater than that of rings.

McCartney (12) has shown that barotropic vortices can propel themselves westward on a beta-plane (13). If this applies to baroclinic eddies as well, the Meddy would provide an efficient mechanism for large-scale preferentially zonal mixing. In this case, one may expect an upper bound for the intensity of a Meddy since both mixing and dissipation would be accelerated with increased baroclinicity.

SCOTT E. MCDOWELL
H. THOMAS ROSSBY
Graduate School of Oceanography, University of Rhode Island, Kingston

References and Notes

1. C. O. Iselin, *Pap. Phys. Oceanogr. Meteorol.* **4** (No. 4), 101 (1936).
2. W. R. Wright and L. V. Worthington, *Serial Atlas of the Marine Environment* (American Geographical Society, New York, 1970), folio 19.
3. S. P. Hayes, *Deep-Sea Res.* **22**, 1 (1975); ———, T. M. Joyce, R. C. Millard, Jr., *J. Geophys. Res.* **80**, 314 (1975).
4. M. R. Howe, M. I. Abdullah, S. Deetae, *J. Mar. Res.* **32**, 377 (1974); W. Zenk, *"Meteor" Forschungsergeb. Reihe A* **16**, 35 (1975); I. Ambar, M. R. Howe, M. I. Abdullah, *Dtsch. Hydrogr. Z.* **29** (No. 2), 58 (1976).
5. E. J. Katz, *Deep-Sea Res.* **17**, 611 (1970).
6. J. Price and S. Riser, *Polymode News No. 36* (1977) (unpublished manuscript, Woods Hole Oceanographic Institution, Woods Hole, Mass.).
7. A. Defant, *Dtsch. Atl. Exped. "Meteor" 1925–1927* **6**, (No. 2, 5), 191 (1941).
8. A. Leetmaa, P. Niiler, H. Stommel, *J. Mar. Res.* **35**, 1 (1977).
9. H. V. Sverdrup, M. W. Johnson, R. H. Fleming, *The Oceans: Their Physics, Chemistry and General Biology* (Prentice-Hall, New York, 1942), p. 1087.
10. L. V. Worthington, *On the North Atlantic Circulation* (Johns Hopkins Univ. Press, Baltimore, 1976), p. 110.
11. R. B. Lambert, Jr., *Deep-Sea Res.* **21**, 529 (1974).
12. M. S. McCartney, *Polymode News No. 10* (1976) (unpublished manuscript, Woods Hole Oceanographic Institution, Woods Hole, Mass.).
13. The beta-plane is a surface upon which latitudinal variations in the Coriolis parameter, f, are constant ($f = 2\omega \sin \theta$, where ω is the angular velocity of the earth's rotation and θ is the latitude).
14. We thank E. J. Katz, C. Polloni, and M. Jones for their assistance. This work was supported by National Science Foundation grant OCE 76-11726 to H.T.R.

16 March 1978; revised 7 August 1978

Kainic Acid Injections Result in Degeneration of Cochlear Nucleus Cells Innervated by the Auditory Nerve

Abstract. *When kainic acid, a putative neurotoxin for neurons with glutamatergic input, is injected into the brainstem, it produces a selective pattern of degeneration in the cochlear nucleus. The rate and extent of degeneration is correlated with the distribution of the primary auditory fibers. This evidence supports the hypothesis that glutamate is the neurotransmitter for primary auditory fibers.*

Evidence suggests that glutamate or aspartate, or both, may be neurotransmitters for the auditory nerve in the cochlear nucleus. The concentrations of both amino acids decrease in the cochlear nucleus (1) when primary auditory terminals degenerate, whereas several other amino acids (1) and the enzymes choline acetyltransferase, glutamate decarboxylase, and tyrosine hydroxylase (2) do not change. Aspartate has a distribution in the cochlear nucleus similar to that of the auditory nerve terminals (3), and the decreases in glutamate and aspartate after auditory nerve lesions are greatest in areas of the nucleus that contain the highest concentration of primary auditory terminals (4). Kainic acid, an analog and agonist of glutamic acid (5), causes selective degeneration when administered to the central nervous system in nanomole amounts (6–8). The neurotoxic effects of kainic acid may be due to its neuronal excitatory action (9), and present evidence suggests that neurons with receptors for glutamate may be especially susceptible to destruction by kainic acid (6, 7). To characterize further the synapses of the auditory nerve, we have studied the effects of kainic acid on neurons in the cochlear nucleus. Our results suggest that the destruction of neurons in the cochlear nucleus by kainic acid follows the distribution of auditory nerve synapses. This is additional evidence that auditory nerve synapses may use glutamate as a neurotransmitter.

Thirty male tricolor guinea pigs weighing 400 to 600 g were anesthetized with pentobarbital or methoxyflurane (or both) and stabilized in a stereotaxic apparatus. A hole was made in the skull over the right cerebellar hemisphere. With a micromanipulator, a 30-gauge needle attached to a 10-μl Hamilton syringe was positioned with the tip 4.5 mm anterior to the lambdoidal suture and 3.5 mm lateral to the sagittal suture and, at an angle of 18° to the vertical, lowered to a depth of 9 mm. These coordinates placed the tip of the needle in the middle cerebellar peduncle, 0.2 to 0.5 mm medial to the cochlear nucleus, at the level of the caudal anteroventral cochlear nucleus and the rostral posteroventral cochlear nucleus. The anteroventral cochlear nucleus and the posteroventral cochlear nucleus are equidistant to the injection site, and the dorsal cochlear nucleus is further by a factor of less than 1.5.

Phosphate-buffered saline containing 1.0, 0.5, 0.15, or 0.05 mg of kainic acid per milliliter, pH 7.4, was infused into the brainstem over 10 minutes. The volume infused was always 2 μl. Control injections consisted of α-methylaspartate (1 mg/ml in phosphate-buffered saline) and buffered saline alone. Animals were killed at 1, 3, 6, 12, 18, and 24 hours after injection by cardiac perfusion with 3 percent glutaraldehyde, 2 percent paraformaldehyde, and 0.005 percent $CaCl_2$ in 0.1M sodium cacodylate buffer. Slices of the brainstem containing the cochlear nuclei, both ipsilateral and contralateral to the injection site, were postfixed, dehydrated, and embedded by procedures described previously (10). Sections 1 to 2 μm thick from all regions of the cochlear nuclei were cut and examined with the light microscope. Two of the animals were injected with 2 μg of kainic acid as described above, and after 3 hours they were killed by perfusion with 10 percent formalin. The brainstem was removed and frozen serial sections, 20 μm thick, through the cochlear nucleus were cut in the parasagittal plane. These sections were stained with thionine.

The cochlear nucleus is divided into three anatomical divisions, the anteroventral cochlear nucleus, the posteroventral cochlear nucleus, and the dorsal cochlear nucleus (11). The anteroventral cochlear nucleus contains a homogeneous population of spherical cells at the rostral pole, dorsally (Fig. 1A); ventrally, smaller oval-shaped neurons occur among the spherical cells. A distinct layer of granule cells and other small neurons covers the anteroventral cochlear nucleus and extends over the posteroventral cochlear nucleus (Fig. 1A). The posteroventral cochlear nucleus and the dorsal cochlear nucleus contain populations of neurons heterogeneous in size and shape with the dorsal cochlear nucleus containing a distinguishable layer of fusiform cells.

One hour after injection of 2 μg of kainic acid, degenerating neurons were present in the ventral cochlear nucleus