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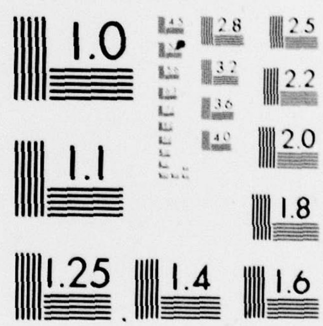

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OFFICE OF NAVAL RESEARCH

BRANCH OFFICE LONDON ENGLAND

DEPARTMENT OF OCEANOGRAPHY, UNIVERSITY OF LIVERPOOL

WAYNE V. BURT

28 JUNE 1979

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The Department of Oceanography at the University of Liverpool is the oldest of the three oceanography departments in the UK. Its research is largely in physical oceanography and marine analytical chemistry. A full range of courses is offered in physical and chemical oceanography. Students are working for undergraduate honors degrees in oceanography and the MS and PhD degrees.

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DEPARTMENT OF OCEANOGRAPHY, UNIVERSITY OF LIVERPOOL

The University of Liverpool houses the oldest and largest university department of oceanography in the United Kingdom. The other departments of oceanography are located at the University of Southampton and at the Menai Bridge (Bangor, Wales) laboratory of the University College of North Wales. The Department at Liverpool was founded by Sir William Herdman, then the Professor of Natural History at the University. Actually, he and his wife, one of the heirs to the Holt shipping firm, gave the necessary funds to found the new chair, which Herdman occupied for the first year and then retired.

The efforts of the Department were largely devoted to marine biology until 1933 when Prof. Joseph Proudman took the chair. He had started the Tidal Institute at the university in 1919. Under his direction, research programs in tides and other branches of physical oceanography were instituted in the Department of Oceanography. In 1950 the marine biology program was taken out of the Department and about the same time a program in marine chemistry was added, under the direction of Dr., later Professor J.P. Riley. After this time the efforts of the Department were devoted entirely to physical and chemical oceanography. Dr. K.F. Bowden, a physicist who had joined the staff in 1945, became chairman of the Department in 1954. At the present time the efforts of the Department are divided almost equally between physical and chemical oceanography.

In past years the Department has gained international repute for training marine analytical chemists. More recently, it has expanded its training program in physical oceanography. A full range of courses is taught in both physical and chemical oceanography, ranging from introductory courses in marine dynamics and marine pollution chemistry to analytical chemistry as applied to oceanography.

Of the students taking courses in physical and chemical oceanography, at present 83, some become sufficiently interested to major in oceanography. These students, usually about a dozen, work toward a B.S. Honours degree in oceanography. They are allowed to take one or two introductory courses in oceanography beginning in their sophomore year, along with a large dose of mathematics, physics, and chemistry. Then most of the courses in their senior year are in oceanography. It is interesting that they receive no grades for their course work until their senior year. The value of their degree then depends entirely on their performance during the last year. In this year they are required to write an original essay of about 50 pages, which counts for 20% of their overall grade. In addition, they are given a laboratory research problem, which counts for another 15% of their grade. This is a very effective way of separating those students who should be encouraged to go on for a graduate degree and do research and writing from those who cannot and thus are not accepted for graduate work.

It appears that this would be an excellent practice to initiate in the United States where students often get well into their MS or PhD programs before it is discovered that they either cannot write proper English or simply cannot carry out original research.

There are currently 17 graduate students, called postgraduate or research students, in the Department. Usually, the majority are working in chemical oceanography, the rest in physical oceanography. An early criticism of this program (ONR Technical Report 21-65) was that these students were not required to take any courses in oceanography, but merely do their thesis research. Now, if they do not have an Honours B.S. degree in oceanography, they must take most of the oceanography courses required of B.S. candidates.

All graduate students must register for the M.S. program unless they already have that degree. If there is a question about the quality of their background, they may be required to take an M.S. preliminary examination. If they already have an M.S. in oceanography from the University of Southampton or the Department of Oceanography at the University College of North Wales, they may be allowed to work directly for the PhD. Those who are exceptional students may be allowed to skip their M.S. and go directly on to their PhD.

In addition to the regular degree programs, there is a six-month short course leading to a Diploma in Marine Pollution Chemistry. About a dozen students are normally enrolled, all from developing countries. In the present class, students are from Ghana, Mexico, Mainland China (2), Peru, Singapore, Costa Rica, India (2), Brazil, and the Philippines. The program is handled by Mr. M.R. Preston, a marine chemist who has almost completed his PhD.

Most of these students have training in chemistry or are biologists with some chemical background. Courses are taught in basic marine chemistry, marine geochemistry, analytical chemistry as applied to sea water, and marine pollution chemistry (where they look at individual classes of pollutants), and there is also a practical course covering the quantitative analysis of the principal marine chemical parameters and also the major pollutants. Individual experts in marine pollution come in to give lectures on their specialties, and visits are made to various working laboratories around England where analysis is made for marine pollutants. One important aspect of this training is that students learn the questions to be asked and where and to whom they can go for answers. This course is sponsored largely by the British Ministry of Overseas Development as part of the British contribution to the I.O.C. Some additional financial support is provided by UNESCO.

The Department receives about 60% of its support from the University and 40% from government agencies. The bulk of the latter comes from the Natural Environment Research Council, (NERC), sort of a cross between our NSF and ERDA. There is no industrial support at present, but some funds come from the Department of Environment for working on specific pollution problems.

It is refreshing to see that some of the major pieces of equipment at the University of Liverpool are shared not only between individuals but also between departments. For example, in the United States it is the mark of arrival for university geochemists to have their own mass spectrometers. At Liverpool, geochemists in the Department of Oceanography send their samples to the mass spectrometer center where a trained technician does the actual analysis. The same thing is true with computer staff, and students in the Department use the computer center through terminals in the oceanography building. The main computer is an International Computer Limited (ICL) 1906S. In the United States it is common for university oceanography departments to have several expensive, very sophisticated mini-computer centers of their own.

NERC operates a fleet of research vessels for the use at the agencies it supports. Most of the ship time used by the Oceanography Department here comes from the NERC fleet, which is most satisfactory to the staff at Liverpool.

Bowden's personal research program has covered a number of different topics in physical oceanography. Recently he and his graduate students have published papers on circulation, mixing and diffusion in estuaries, and on work ranging from sophisticated mathematical modeling of estuaries to field studies of the Mersey Estuary, a part of which forms the Liverpool harbor.

He has also worked on heat budget considerations in a study of upwelling off the northwest coast of Africa, discovering that evaporation over the upwelling area is small enough that salinity can be considered as a conservative property and used as a tracer. The salinity distribution and the net heat gain in the surface waters can be used to trace the source and movements of upwelled water and to estimate the rate of the upwelling.

Currently Bowden and his student, Mr. S.R. Ferguson, are completing a study of the variations with height of turbulence in a shallow-water (30-m depth) tidally induced boundary layer. Turbulent fluctuations of the velocity were measured in the bottom boundary layer at several locations in the Eastern Irish sea near Liverpool. The sensors were two and three component electromagnetic flow meters with a frequency response extending up to 2 Hz. Signals from three sensors at fixed heights of 50, 100, and 200-210 cm above the seabed have been analyzed to observe possible variations with height in the turbulent structure. The frame holding the flow meters had a large canvas vane on the side opposite the sensors that oriented the u-component flow meter in the direction from which the tidal current was flowing. (See figure 1) The sensors were lowered to the bottom shortly after slack water during the ebb phase of the tide and retrieved shortly before the next slack water. The variations with height of the horizontal u component were generally insignificant, but the variations in the vertical w component tended to increase slightly with height above the sea floor. The mean product $\overline{UW}$ correlated well with U^2 at each height, but the variations in the Reynolds stress $\rho\,\overline{UW}$ were larger than any systematic variations with height. The energy density spectra of u, v, and w had similar forms throughout the ebb portion of the tidal cycle, differing only in their general level with the systematic changes in the mean velocity. No systematic variations could be correlated with the phase of the tide of any of the turbulence parameters.

Drs. M.R. Howe and R.I. Tait have been working together for a number of years on the characteristics and movements of the water mass or type (MW) that forms in the Mediterranean Sea and flows out into the Atlantic Ocean over the sill at the Strait of Gibralter. They have discovered that as the MW spreads out at depth in the Atlantic, step layering beneath its core is a permanent feature. As many as 20 or more steps extend from a depth of about 1200 m down to about 1800 m with continuous laminae extending for distances of over 50 km. They have also studied the processes by which the MW core is eroded and mixed with water masses with different characteristics above and below. Tait has also done a considerable amount of research on the water mass characteristic and microstructure in the Mediterranean.

Recently Howe, in cooperation with R.I. Amber from the University of Lisbon, has made a thorough study of the MW core from the point it enters the Atlantic at the Strait of Gibralter up to and around the southwest tip of Portugal. They used 18 closely spaced CTD cross sections through the core that had been made by the UK research ships *Shackleton* and *Discovery*. They found that the MW actually splits into two distinct cores fairly close to the sill outlet at about 7°W, then it hugs the continental shelf off southern Portugal. The center of the upper core (Mu) is at a depth of about 700 m and the center of the lower core (Ml) down to about 1000 m. Mu is always about 1°C warmer than Ml and is always inshore of Ml. Mu is thinner and carries less water than Ml. The separation into two cores is not influenced by any distinct features of the bottom topography. A little farther downstream the cores pass over several submarine canyons which cause more vigorous offshore spreading. These meanders in an offshore direction might partly be related to the conservation of vorticity as well as obstructions in the bottom topography.

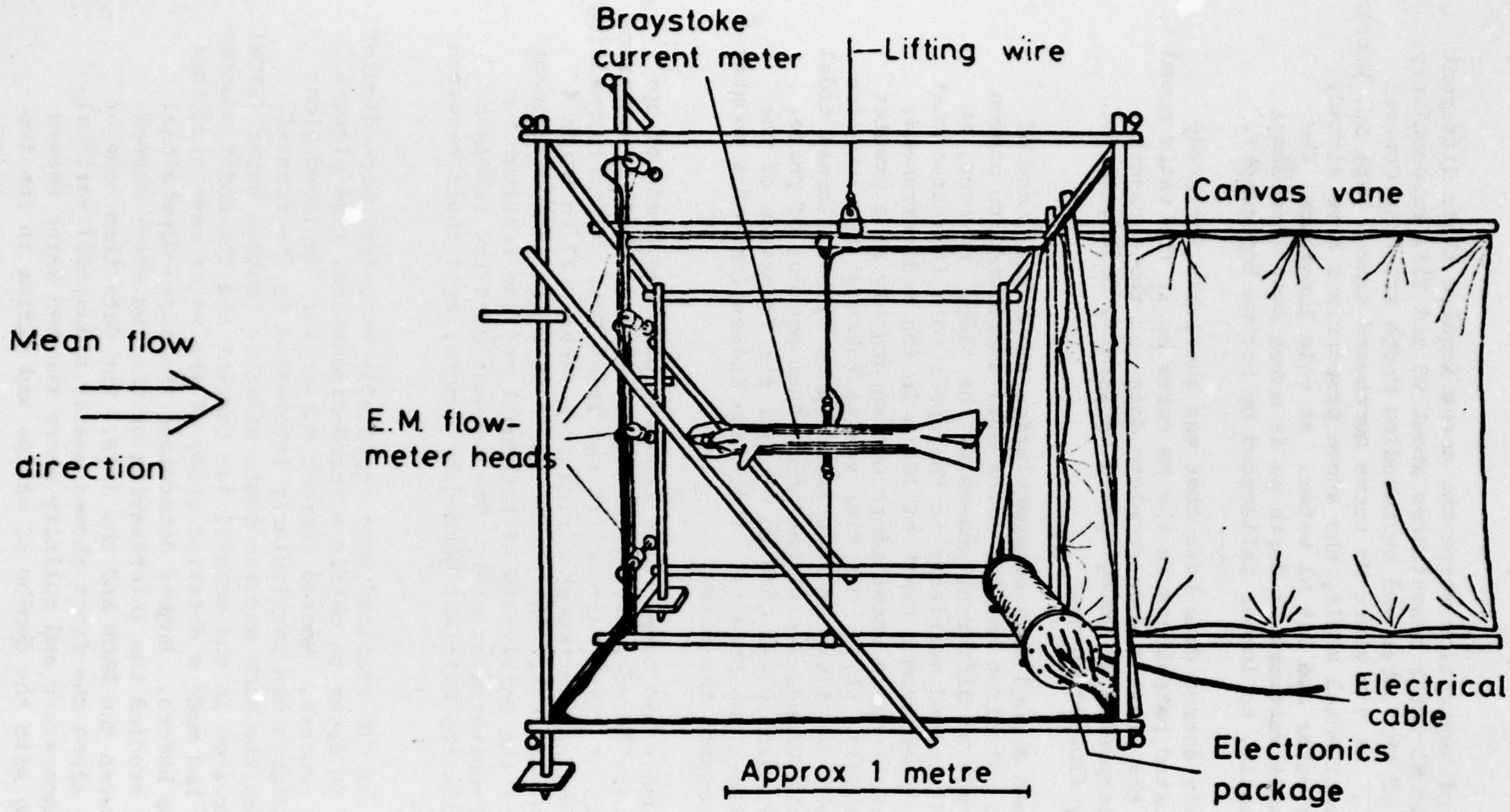

Figure 1. Reproduced from "Variations with height of the turbulence in a tidally-induced bottom boundary layer," by K. F. Bowden and S. R. Ferguson. To appear in the Proceedings of the Eleventh International Liège Colloquium on Ocean Hydrodynamics. J. C. J. Nihoul (Ed.)

In the area of separation where the cores acquire their different identities, Mu and Ml water constitutes about 95 and 72%, respectively, of the admixture of the cores and surrounding North Atlantic Central Water mass (NACW). At 9°W where Mu turns northward around Cape St. Vincent as it hugs the continental shelf, the above proportions have already dropped to 50% Mu water and 38% Ml water. At this longitude, the lower core continues westward at depth as it moves away from shore out into the Atlantic, no longer influenced by bottom topography.

The relatively scarce data base that was available for study in the past indicated patchiness in the MW cores as if the water moved in pulses. With the present more complete data set the apparent patchiness is interpreted as being caused by lateral meandering of relatively steady flowing cores.

There has been a good deal of speculation about the cause of the double cores. At first the two cores were attributed to uneven mixing in the Strait at different phases of the tide. However, an analysis of the dissolved nutrients in the upper core indicates that the source water comes from a depth of 100 m in the Mediterranean, while the lower core source water pours out separately at a greater depth over the Strait's sill. CTD time series taken at the location where the two cores can first be identified shows M_2 semidiurnal tidal oscillations on the boundaries of each core that are out of phase. This vertical periodicity was used to explain the formation of the separate cores within the Straits. There are indications of a counter-current flowing beneath the cores.

Dr. Peter Hughes has been deeply involved with the study of upwelling for the past decade. Prior to that time, he worked on submarine cable measurements of tidal currents in the Irish Sea. A joint upwelling expedition was made off northwest Africa from January 27 to March 4 1975 between 21°N and 26°N. The participants were from the Department of Oceanography of the University of Liverpool and the Institut für Meerskunde an der Universität Kiel. The Germans used the research vessel *Meteor* while the British, headed by Hughes, used their research vessel *Discovery*.

Three lines of CTD stations were repeatedly occupied perpendicular to the coastline in order to obtain a three-dimensional time picture of the upwelling process. Moored current meters were deployed along each CTD line. Hughes was particularly interested in the frontal structures between the NACW and the South Atlantic Central Water (SACW). He was also interested in the coastal jet current and the under counter-current. No one had made a detailed study of the water mass structure in the study area before. Hughes determined the three-dimensional mass balance and studied the interleaving of the two water masses at the front between the NACW and the SACW. The data from some of the CTD stations along the front showed nearly sinusoidal vertical variations of temperature and salinity where the two water masses were interleafing with the depths of maxima and minima in the two curves in phase.

At present Hughes is carrying out further studies of the subsurface features of the frontal structure on the center CTD line of the 1975 upwelling cruise. In collaboration with colleagues from the University College of North Wales, he also plans to work up a time series of the PROTAS data that were taken during the 1975 cruise. The PROTAS instrument was designed and built at the University Collge of North Wales, Marine Science Laboratory, Menai Bridge. It is a free-fall instrument that records the temperature, salinity, and shear in the horizontal currents.

Prof. J.P. Riley is world renowned on the one hand for the large number of marine analytical chemists he has trained, and on the other for the new improved techniques in marine analytical chemistry that have been developed in his laboratories with the help of a whole generation of graduate students. He has made a number of chemical oceanographic cruises during the past 15 years to the Atlantic and Indian Oceans, the Mediterranean Sea, the Skagerak, and Norwegian fjords. Much of his research has been on trace element chemistry in sea water. He feels that this work is almost finished and intends to devote most of his future time to the organic chemistry of fresh water and sea water.

Riley has a number of well-equipped laboratories and an excellent machine shop where all sorts of new equipment have been designed and built. One problem that he returned to several times was overall lack of space. The Department has grown so rapidly in recent years that it has not only utilized all available space in the oceanography building but has absorbed some space in the mathematics building to which it is physically attached. It is interesting to note that a 1962 ONR London report on the Department says that the burgeoning math department was trying to take space from the oceanography department, while now the math department has been shrinking to the point where it cannot hang on to its assigned space.

The Department does not have its own ship, so there are some problems in obtaining samples for chemical analysis. In the Irish Sea Riley uses the Mersey Pilot boat, and and a local naval training frigate. He has also found that a UK Northwest Water Authority helicopter is very handy for obtaining water samples over an area on almost a synoptic basis. During a tour of the laboratories, Riley pointed out the following: (1) a homemade high-performance liquid chromotography instrument being used to study phytoplankton pigments, (2) a quantitative method under development for determining mercury in fresh and salt water, (3) an automatic seagoing titration apparatus for dissolved CO_2, (4) an ion exchange column being used to separate dissolved humic acids into their several components, (5) the development of a method for determining antimony in natural waters, (6) an ultra filtration system for separating humic acids and other dissolved organic compounds into their molecular size fractions, and (7) a new system under development for determining chlorophyll in sea water.

Dr. M.J. Scoullos is nearing the completion of a three-year post-doctoral fellowship in the Department. He teaches chemical oceanography in the Chemistry Department at the University of Athens, has written a chemical oceanography book in Greek, and hopes to set up a chemical oceanography program at the University of Athens.

Scoullos is just completing a monumental study of Elefsis Bay, a few miles west of Athens, Greece. He has carried out approximately 20,000 individual chemical analyses of water, suspended solids, and bottom sediments. The study covers the water circulation, oxygen, nutrients, chlorophyll, trace metals and magnetic monitoring. The latter has been applied in a marine environment for the first time in this case. The Bay is badly polluted from effluents from ~40 industries, including two crude oil refineries, large steel mills, shipyards, etc. In spite of all this, the western part of the Bay remains a popular resort area. The aims of the study are to determine the amount, nature, and eventual fate of the pollutants coming from each plant, which could be used in the future for plans to clean up the bay.

Scoullos' research has been mostly supported by the NATO, UN, two private trust funds that are environmentally oriented, and the Academy of Athens. The trusts are the Hellenic Society and a fund called "Foundation International pour la Sauvegarde du Patrimoine de la Grece".

Dr. R. Chester is a geochemist interested in the minerology, chemical composition, size distributions, and biological components of aeolian wind-blown dust in the atmosphere, particulate matter suspended in the water, ocean bottom sediments, and contributions of rivers to the oceans. He has been working for the past 15 years on deep-sea geochemistry.

Chester made a cruise this January to the Azores-Canary Islands region to collect sediment cores, sea water samples, and atmospheric dusts. He used meter square mesh nets aboard ship to collect the larger aeolian dust particles, but he has developed and perfected most of his own chemistry techniques and sampling equipment.

Dr. E. Joanna Sharples, a marine botanist, assists Chester in his research work. She has recently completed a study of the area in Liverpool Bay, 25 miles west of Liverpool, where large amounts of sewage sludge from both human and industrial sources have been dumped for many years. The municipal sewage authorities of the affected areas had requested that they be allowed to greatly increase the amount of sludge being dumped. The national Department of the Environment required that a study be made of the dumping site to determine whether increasing the amount of sludge being dumped would be detrimental to the environment, and Sharples was one of the study team investigators. Once a month for two years they took water and biological samples on a 30-km^2 grid around the dumping site. The sludge was pumped into the water from a moving ship, and although the water remained cloudy for longer times, the toxicity in the plume of sludge dropped to acceptable levels within two hours. They also found that when the dumping ship steamed across the tidal currents, the concentration of sludge in the water decreased more rapidly than it did on other headings.

Damage to the biological community: The only possibly negative results were that the sludge might be contributing to the abundant growth of Phaeocystis pouchetii, a member of the phytoplankton that sometimes forms smelly gelatinous masses when washed up on beaches, with obviously unpleasant results.

The final conclusion of the study was that the amount of sludge being dumped could be materially increased without permanent damage.

Mr. M.R. Preston, who directs the Marine Pollution Chemistry course, is writing up the results of his PhD thesis research on some of the aspects of organic chemistry of estuaries. He has studied the humic and fulvic acids present in water samples and in the sediments. Gel filtration was used to determine the molecular size fractions of the humic acids and other organic compounds in the samples. Ion exchange resin columns were used to separate the various humic acids present in the samples, and the chemical characteristics of these components were studied. Humic acids occur in nature in rather large molecules making it difficult to determine their chemical properties. Preston's studies have showed that most of the humic acids precipitated rather rapidly in the estuaries. In general, most of the other organic carbon compounds that flow into estuaries do not precipitate as rapidly and tend to flow into the oceans.

Oceanographers who have been studying the optical properties of ocean water masses have been reporting the effects of dissolved "yellow substances." Sometimes these are said to be derived from terrestrial humic acids. Preston does not concur with this thesis because of the rapid precipitation of humic acids that he has discovered in estuaries.

There are some other marine programs at the University of Liverpool. Major biology programs are underway in the various biology departments on campus which also operate a marine biological station on the Isle of Man. Some oceanographic research is being carried out outside the Department of Oceanography in the Department of Applied Mathemathics and Theoretical Physics. Dr. Philip Chatwin is a specialist in the theory of turbulent diffusion and has done research on turbulence and diffusion in estuaries and wind-driven circulation in lakes. Dr. Catherine Allen, who has recently completed her PhD degree in the Department of Physical Oceanography at the University College of North Wales, has recently joined the Department and is working on the three-dimensional time-dependent structure of fronts in the Irish Sea.

Although the oceanography building is overcrowded and almost 20 years old, it is light and airy, neat and pleasant without equipment crowding the hallways, the hallmark of many oceanography buildings. There is a busy air of confidence and competence that make the department pleasant to visit. The educational program and research that is underway appear to be excellent. I hope that it will continue to grow and eventually branch out into other oceanographic disciplines.

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