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Measuring salinity: ICES link to the scientific community and developing world

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The founding meetings of ICES in 1899 and 1901 witnessed the development of the accurate method of salinity determination by Knudsen and his Copenhagen group. Their universally accepted definition of salinity and how to measure it continued unchallenged through the first half of the 20th century. This achievement opened the way for ICES cooperation, in different forms, with the international scientific community. The issue of Mediterranean standard seawater occupied the meetings of the Mediterranean Commission (ICSEM) and generated scientific exchange among the scientists of the two organizations, but was not a formal issue between them. Bilateral relations developed between ICES and IAPO (now IAPSO), thanks to Martin Knudsen (1871–1949), the key figure in both organizations. IAPO supervised the development of Primary Standard Seawater, 1937, and eventually assumed responsibility for the Standard Seawater Service in 1948. The Joint Panel on Oceanographic Tables and Standards (JPOTS) was established in 1962 through an ICES initiative and the drive of Roland Cox (1923–1967). It remained, for three decades, the most active forum for cooperation between ICES, UNESCO, SCOR, and IAPSO, the sponsoring organizations which finally endorsed, with IOC, the two major achievements of JPOTS: the Practical Salinity Scale, 1978, and the International Equation of State of Seawater, 1980. The shipment of standard seawater in the early decades from Copenhagen and Oslo made ICES a familiar name in oceanographic laboratories all over the world, including developing countries, where, for generations, students of oceanography regarded ICES as their link to the scientific world and an assurance of the universality of their chosen discipline.

Keywords: CIESM, IAPSO, ICES, ICSEM, JPOTS, salinity, seawater, Standard Seawater.

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Introduction

Salinity is probably the most common term in oceanography and is widely used in many of its disciplines. Before ICES was founded, there were no widely accepted definitions of salinity, chlorinity, and density in spite of the excellent works of Marcet (1770–1822), Forchhammer (1794–1865), Dittmar (1833–1894), and other 19th century scientists (Wallace, 1974, 1990). The problems of how to define and measure salinity were first resolved by the work of Martin Knudsen, Carl Forch, S. P. L. Sørensen, and J. P. Jacobsen under the auspices of ICES. During the short period between the two conferences in Stockholm in June 1899 and Kristiania (Oslo) in May 1901, Knudsen and his colleagues were able to establish an accurate method for salinity determination and prepare the Hydrographical Tables. This high-quality work received wide recognition, and ICES, the only international marine science body at the time, started to produce standard seawater. Twenty years later, Knudsen wrote his reminiscence on this undertaking in a note published in Monaco (Oxner, 1920). Because of its historical interest, it is reproduced here (Figure 1).

ICES contributions to marine and fisheries sciences influenced the scientific community worldwide. However, among all ICES contributions, salinity stands out as the most binding connection that made ICES, in its early decades, the custodian of the universal standard seawater and the responsible body for the comparability and continuity of salinity measurements. This brought obligations and opened the way for cooperation with the scientific community and concerned international organizations. The Convention, signed by the Member Countries of ICES on 7 September 1964, placed an obligation on the Council "to establish and maintain working arrangements with other international organiza-

PART I

CHLORINITY BY THE KNUDSEN METHOD

By Mieczyslaw Oxner

PREFACE (By Martin Knudsen)

Credit is due to Professor Otto Pettersson for having introduced the titration of chloride, which is now the basis for all measurements of salinity in hydrographic work. The method is both accurate and rapid. However, the determination of the concentration (titer) of a solution by titration is an exacting procedure, and can be executed properly only by a skilled chemist. It has been shown, in fact, since the introduction of the method into other countries, that the results established for a single water sample may vary in an undesirable way.

My attention was particularly attracted to this matter by a series of analyses made in a survey of the salt content of the surface water of the North Atlantic Ocean, on the navigation route between Scotland and Iceland. In order to know the real significance of the salinity determinations made in these waters by various persons at different times it was necessary to have a greater guarantee of accuracy than was possible at that time. Because of this, at the First International Conference for the Exploration of the Sea at Stockholm in 1899, I submitted the proposal of Professor Otto Pettersson for the establishment of an international commission charged with the production of a "standard water" to be used for all sea water titrations. According to the prospectus which I published (Conférence Internationale pour l'Exploration de la Mer, Stockholm, 1899, Supplément 4, p. XLII), the commission was to undertake other researches and standardizations important for hydrographic studies.

This proposal led to the nomination of a committee composed of John Murray, Knudsen, Pettersson, Nansen, Krümmel, H. N. Dickson, and Makaroff, charged with establishing the constants of sea water experimentally at the Polytechnic School of Copenhagen. According to the resolution adopted, the research had as its objectives (1) the determination of the relation between the amount of halogen and the density; (2) the revision of the tables for calculation of specific gravity of sea water prepared by Makaroff, Krümmel, and others; and (3) the final establishment of the relation between density and salinity.

Thanks to the cooperation of various scientists, the work was completed in two years, and therefore, at the Second Conference for the Exploration of the Sea, held at Christiania in 1901, I was able to submit the Hydrographic Tables. The rules for the execution of the titrations were written out at the same time and in such a manner that the tables could be utilized in the reduction of observations. Some of the water samples whose constants had been determined were sealed in about 200 glass tubes, the first "standard water" samples. On the foundation of the Central Laboratory in Christiania in 1903, with Professor Nansen as Director, some of these tubes were sent to that institution. Using them as a basis, standard water was made there until, on the closing of the Central Laboratory in 1908, I was invited to resume its production and distribution.

The use of standard water permits an exact comparison between titrations done by different people at different times; moreover the execution of the titration itself is so simplified that high chemical skill is unnecessary. However, the detailed directions are an absolute necessity for persons not trained in analytical chemistry, and I am particularly happy that Dr. Oxner has undertaken their preparation.

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Figure 1. Twenty years after the introduction of the widely accepted method of salinity determination, Martin Knudsen wrote his reminiscence in French in a preface to Oxner (1920). The English translation by Georgina B. Deevey was made (ca. 1962) for the Woods Hole Oceanographic Institution.

tions" thus reflecting "what had been the effective position since the formation of the Council in 1902" (Went, 1972a, 1972b). The present paper is a study of the external relationships of ICES in the unique domain of salinity.

Mediterranean Standard Seawater and the Mediterranean Commission (ICSEM), 1919–1927

The International Commission for the Scientific Exploration of the Mediterranean Sea (ICSEM/CIESM) was established when the first meeting of the "Mediterranean Commission" was held in Monaco on 30 March 1910 and chaired by Prince Albert I of Monaco. In addition to the representative members, the meeting was attended by some leading scientists who were in Monaco on the occasion of the inauguration of the Musée Océanographique.

The standard seawater of Copenhagen became an issue soon after the founding congress of ICSEM in Madrid in November 1919, when the Spanish Delegation submitted a proposal to the Central Bureau of ICSEM in December 1919 to verify the validity of applying Knudsen Tables in the Mediterranean, suggesting the use of standard seawater from the Mediterranean. The main reason is that the Copenhagen standard seawater has a chlorinity of about 19.38‰, corresponding to a salinity of about 35‰, while the salinity in the Mediterranean exceeds 38‰, corresponding to a chlorinity of about 21‰. This is also reflected in the chemical composition and physical properties (e.g., density, viscosity, surface tension) of both waters. Another reason was the probable change in composition of Copenhagen water with prolonged storage due to the "attack" of seawater on the glass tubes.

From 1919 to 1926, the problem of the Mediterranean standard seawater received the attention of the General Assembly or the Central Bureau of ICSEM and was actively discussed, mainly by the Spanish, French, and Italian Delegates, as shown in the *ICSEM Bulletin* (1919–1924) and the *Rapports et Procès-Verbaux des Réunions* (1926, 1928). Excerpts of these discussions were given by Freundler and Pilaud (1930). The Delegates generally agreed that Copenhagen standard seawater should be replaced either by Mediterranean standard seawater or a standard solution of sodium chloride, and that each country should produce its own standard seawater rather than having one Mediterranean standard seawater produced by a central laboratory. In October 1924, the ICSEM Assembly in Madrid charged José Giral of the Spanish Institute of Oceanography in Madrid with preparing a Mediterranean standard seawater on an experimental basis for a period of two years, a charge which was extended, during the July 1926 Venice meeting, for another two years.

Meanwhile, the International Union of Pure and Applied Chemistry (IUPAC) recommended, in 1923 in Cambridge, an earlier proposal made by M. G. Bertrand at its 1922 meeting in Lyon, to use sodium chloride as a standard for halogen determination in seawater. Between 1922 and 1925, several papers were published in the *Comptes Rendus de l'Académie des Sciences à Paris* by French and Spanish scientists on the accuracy of chlorinity determination and the use of sodium chloride as a standard. Giral appeared to be a central figure as the rapporteur of chemistry in ICSEM, while being a frequent participant in ICES meetings as a Spanish Delegate and expert between 1924 and 1933[1]. His paper in the ICES *Publications de Circonstance* (Giral, 1926) gave a summary of his views and those of the Mediterranean community. He advocated the use of a sodium chloride solution in place of Copenhagen standard seawater. Giral's paper attracted critical comments by Mathews (1926), an ICES scientist, in the *Journal du Conseil*. Knudsen (1925), while dismissing the use of a sodium chloride standard, accepted the thesis of using different kinds of standard seawaters for different sea regions. For the Mediterranean, it required the calculation of a new titration table and a comparison between the Mediterranean standard seawater and the Copenhagen water to maintain continuity. In his report to the July 1926 ICSEM meeting in Venice, Giral accepted Knudsen's arguments and informed the meeting of Knudsen's proposal that all questions should be studied for some time before convening a meeting of chemical oceanographers to reach an agreement (ICSEM, 1927). Such a meeting apparently never took place, and the issue was not raised again during the following ICSEM meetings.

However, the problem continued to attract the attention of Mediterranean scientists. Morcos (1968) developed a method by which seawater of any salinity (in this case from Alexandria) could be used as a secondary standard while applying the titration tables in Knudsen's Hydrographical Tables. Menaché (1951) worked with Frede Hermann in the Standard Seawater Service in Charlottenlund and, while using Copenhagen standard seawater, obtained satisfactory results in the chlorinity determination of Mediterranean seawater samples from Monaco. In an introduction to the Menaché (1951) paper, Helge Thomsen and Frede Hermann of the Standard Seawater Service referred to Knudsen's opin-

[1] José Giral rose to be Prime Minister of Spain (ca. 1934–1935). He is the only professional oceanographer to head a government of a major state. He was cited as the Honorary President of the Spanish National Commission of ICSEM in the *Procès-Verbaux* of the meetings between July 1932 and October 1937, which was the last meeting before World War II. In 1932, he was Minister of the Marine, parliamentary Deputy, State Counselor, and Rector of the University of Madrid. He was cited in the 1933 and 1934 meetings as a former minister, and in the 1935 and 1937 meetings as a former prime minister (ICSEM, 1932–1938).

ion that the accuracy of the chlorinity determination was reduced when the concentration of the seawater sample differed substantially from the standard seawater, which was the case in the Mediterranean. They added, "We do not know if Martin Knudsen had ever examined experimentally these questions and we believe well that his opinion is based only on theoretical consideration." The accuracy of the classical method using the standard seawater of Copenhagen is "greater than what was supposed by Martin Knudsen, and in reality of the same order as that obtained with the titration of oceanic water." One wonders if Knudsen was influenced by the strong views of the Mediterranean scientists or, for the sake of diplomacy, gave them the benefit of the doubt. The Mediterranean scientists showed great respect for Knudsen in their writings as well as in their discussions during ICSEM meetings.

Ironically, the Standard Seawater Service now produces standard seawater of high salinity of about 38 (by evaporation), close to the Mediterranean salinity. This series (38H) and the low salinity standards (30L and 10L) are produced to check the linearity of instruments at salinities different from the normal calibration point of 35.

The problem of measuring high salinity exceeding the upper limit of Knudsen's Hydrographical Tables is evident in some semi-closed, warm seas in arid regions. Salinity values higher than 43‰ are found in the Suez Canal and its Bitter Lakes and in the northern and bottom waters of the Gulf of Suez. Higher values are also found around the Qatar Peninsula in the Persian Gulf. To overcome this difficulty, hydrographical tables for high salinities from 41.5‰ to 47‰ (Morcos, 1960) and sigma-t (σt) tables for high densities (Morcos, 1967) were computed.

The more recent International Oceanographic Tables designed by JPOTS and published by UNESCO in 1981 and 1987 do not cover this high range of salinity. To address the problem of higher salinities, Poisson *et al.* (1991) used concentrated samples of standard seawater to compute tables designed to allow the users to calculate the salinity and density of seawater in the higher range of salinity between 42 and 50.

ICES and the International Association of Physical Oceanography (IAPO), 1936–1949

The International Association of Physical Oceanography (IAPO) traces its origin to the Oceanographic Section of the International Union of Geodesy and Geophysics (IUGG) established in Brussels in July 1919. At an IUGG Assembly in Seville, Spain, in 1929, the Oceanographic Section became the Association of Physical Oceanography (APO). In 1931, the IUGG was restructured to comprise several associations including APO. At its 1948 Oslo meeting, the Association became the International Association of Physical Oceanography (IAPO). At its 1967 meeting in Switzerland, the IAPO name was changed to the International Association of the Physical Sciences of the Ocean (IAPSO) to reflect the broader interest in chemical and geological sciences as well as the physical sciences.

Primary Standard Seawater 1937 or Urnormal 1937

Sørensen determined the chlorinity of batch VI of the standard seawater in 1901 as 19.380‰. Primary Standard Seawater (designated P) was prepared in 1903 and analysed in 1905 in the Central Laboratory in Kristiania by direct comparison with batch VI. Between 1902 and 1938, a total of 20 batches of standard seawater, also called "Normal Water" or "Eau Normale", were prepared by comparison with standard water VI or P. By 1925, only 60 tubes of Primary Standard Seawater were left, sufficient, according to Knudsen (1925), to maintain continuity for another 40 years. However, in May 1936, Knudsen submitted a report to the ICES Hydrographical Committee on the situation of the "Primary Standard" stating that "as the present stock is nearly exhausted, a new one must be prepared, and this must be done in the course of some few years to secure the continuity". He went on to say, "As the question regarding standard-water is of importance not only to the countries which have joined the Council, but also to other countries (the standard-water has hitherto been distributed to 37 different countries) it is my idea to propose in the coming meeting (Sept, 1936) of the 'Association International d'Océanographie Physique' that the Association charges me with the task of directing the preparation of a new 'Primary Standard' and the necessary physical and chemical investigations for this purpose, and that the Association defrays the expenses of assistance etc. in connection with this work and publishes a printed report thereon." (ICES, 1936).

On the recommendation of a subcommittee consisting of Defant, Knudsen, and Hans Pettersson, the Hydrographical Committee agreed with the views stated in the report of its Chair, Knudsen.

At the meeting of the IAPO Executive Committee in Edinburgh in September 1936, "a scheme was considered for the preparation of a new primary standard of sea-water, the details of which had been circulated to members of the Executive Committee in June 1936. It was agreed to make a grant of £350 to Professor Knudsen towards the cost of assistance and apparatus. The Executive Committee authorized Professor Knudsen to prepare and distribute ordinary samples of standard seawater based on this primary standard and reserved the right to authorize all modifications of this arrangement" (IAPO, 1937).

Knudsen is credited with his timely initiative in preparing the new primary standard early enough to precede the outbreak of World War II. Jacobsen and

Knudsen (1940) described the preparation of "Urnormal 1937" and the determination of its chlorinity as 19.3810‰ by direct comparison with the old standard seawater. Because of the change in the atomic weights used by Sørensen, and to avoid any break in continuity, Urnormal 1937 was analysed using extremely pure atomic weight silver, *atomgewichtssilber*, and a new definition of chlorinity was based on the amount of the atomic weight silver required to precipitate the halides in a specific amount of Urnormal 1937. The definition guaranteed continuity since it was independent of changes in the atomic weights and the availability of Urnormal 1937. The main reference became the atomic weight silver stored in Copenhagen.

It is not surprising that Knudsen handed the supervision of the "Primary Standard" to IAPO. In fact, he was stepping down after six years as president of IAPO and before Helland-Hansen took over in Edinburgh in 1936. Knudsen had also been Chair of the ICES Hydrographical Committee since its inception in 1925. He was, therefore, comfortable with both bodies.

Owing to his long experience with ICES, Knudsen was probably the most internationally minded among the oceanographers of his time. In his opening address to the IAPO General Assembly in 1936, he referred to the statutes of IAPO adopted three years earlier in Lisbon and noted, "they contain a prominent point,...which permits international organizations to be active members of the Association. In my opinion this point may be of vital importance to our Association" (IAPO, 1937). Among the international members of the Association at that time were ICES, ICSEM, and IHB.

The transfer of the Standard Seawater Service to IAPO

The 1914–1916 report of the Hydrographical Department of the ICES Bureau stated, "At the commencement of the war, the Laboratoire Hydrographique and the normal water, with instruments appertaining thereto, and other assets and liabilities, were taken over by Professor Martin Knudsen for his personal account, in order to relieve the Council of pecuniary responsibility" (ICES, 1917). Knudsen continued to run the service in his personal capacity. At the age of 65, he expressed the desire in his 1936 report that "the preparation of the ordinary standard-water should go on as hitherto under my direction. When I no longer desire to keep this responsibility, the 'Primary Standard' should be at the disposal of the Council. The Council could then charge the Danish Hydrographical Laboratory or some other competent institution or person in Copenhagen with the preparation and distribution of the ordinary standard-water" (ICES, 1936).

Twelve years later, Knudsen relinquished his responsibility, not to ICES as he stated before, but to IAPO. One may surmise that there was a tacit agreement within ICES and the host institution in Denmark that this was the right step to take. "The Service had for so many years been Knudsen's private business that the ICES authorities...may not have wished to interfere," reasoned Jens Smed (2000) in a letter to S. Morcos. In a circular letter, Knudsen announced, "Since 1914 I have on my own responsibility prepared and supplied Standard Sea Water to be used with the chlorine titration of seawater. I have felt, however, that this responsibility ought to be taken over by some competent scientific body interested in the matter, in order to secure the continuation of this work. Consequently I wrote to the 'Association d'Océanographie Physique' and proposed, that organization should take over the responsibility for the preparation of Standard Sea Water and support the preparation financially, so that it could be sold at a price, which would allow the users to use it more freely than hitherto. This proposal was adopted at the Oslo-meeting of the Association in August 1948, and I was charged with the preparation" (Knudsen, 1949).

The annual reports of the Hydrographical Committee do not show any involvement of ICES in this transfer except a reference in the 1948 report that the Chair, Helge Thomsen, presented a report on his participation in the Oslo meeting and mentioned the future arrangement for procuring standard water (ICES, 1948). The report on the first five years of the Standard Seawater Service under IAPO (1948–1953) stated that "Martin Knudsen placed to the free disposal of the Service all his gears and instruments hitherto used for preparation of Standard Sea-Water, and Danmarks Fiskeri- og Havundersøgelser (Denmarks Fishery- and Sea Investigations) placed the necessary premises at their seat in Charlottenlund near Copenhagen at free disposal" (Standard Seawater Service, ca. 1953). Batch P16, prepared in 1943, was the last batch carrying the name of Professor Knudsen. Batch P17, prepared in late 1948, was labeled "Association d'Océanographie Physique, Dépôt d'Eau Normale". The new arrangement was announced by Knudsen, who was now 78 years old, in his circular of 1949. A few months later, Martin Knudsen passed away and an era in the history of the Standard Seawater Service ended. Because of his foresight, however, the Service was able to continue (Culkin and Smed, 1979).

At the request of IAPO, Helge Thomsen took over the administrative responsibility, while Frede Hermann continued to prepare the standard and carry out the analyses. From January 1960 until 1974, Hermann assumed full responsibility. In August 1973, Hermann wrote to Eugene LaFond, the IAPSO Secretary, expressing his wish to retire and proposing Fred Culkin as the new Director in view of his long collaboration with the Service (Hermann, 1973).

The decision to appoint Culkin as the new Director of the Service entailed the transfer of the equipment and stocks from Copenhagen to the Institute of Oceanographic Sciences (IOS), Wormley, UK, a delicate operation that was accomplished at the end of 1974 with

financial assistance from IAPSO. The transfer of the Standard Seawater Service from Copenhagen ended an era of 66 years since the first transfer from the Central Laboratory in Kristiania in 1908. The preparation and export of standard seawater from Copenhagen, as well as its association with Knudsen's name, reinforced the perception of the ICES image as producer and supplier of standard seawater, although the official link ended in 1914 when Knudsen took over in his personal capacity.

After running the service for 15 years, Fred Culkin tendered his resignation to IAPSO, saying, "This is not a situation which IAPSO has had to face very often as there have been only five holders of the position in 89 years" (Culkin, 1989). Upon his recommendation, a former colleague at IOS, Paul Ridout, was appointed Director of the Standard Seawater Service. Because of changes taking place at IOS at that time, agreement was reached between IAPSO, IOS, and its parent body, the Natural Environment Research Council, for a new company, Ocean Scientific International Ltd., to be set up to continue the operation of the Standard Seawater Service, with Ridout as Managing Director and Culkin as consultant.

ICES/IAPSO and the scientific community

The Knudsen–Mohr method for chlorinity determination introduced three innovations: 1) the standard seawater, 2) the Knudsen automatic pipette and burette, and 3) the Hydrographical Tables. All of these were exported during the first half of the 20th century from Copenhagen, the headquarters of ICES. However, the exhaustible standard seawater continued to be an on-going operation connecting Copenhagen to the oceanographic laboratories the world over.

ICES literature gives a glimpse of the expansion of the early operations. From May 1900 to August 1902, standard seawater was sent to five countries. In the following months until mid-1903, 168 tubes of batch VIa were sent by Knudsen, at ICES expense, to ten countries surrounding the Baltic and North Sea (Knudsen, 1903). The geographical distribution changed with time. From 1920 to 1925, a total of 1581 tubes were sold to 24 countries, mostly in the ICES Area, but also to Mediterranean countries, the United States, Canada, Japan, and some developing countries such as Ceylon, Egypt, India, and South Africa (Knudsen, 1925). In 1936, the number of countries increased to 37 (ICES, 1936). During the five years after IAPO took charge of the Standard Seawater Service (1948–1953), over 10 500 ampoules were distributed to 32 countries, including nine developing countries (Standard Seawater Service, ca. 1953). From 1960 onwards, there was considerable expansion in oceanography throughout the world, with a corresponding increase in the demand for standard seawater, rising to more than 30 000 in some years. "The sales has increased to 36 122 ampoules in 1972, which is the greatest number ever sold", wrote F. Hermann (1973) to E. LaFond. During the last 10 years, standard seawater was produced at an annual rate of about 15 000 ampoules. Over the three-year period 1996–1999, 47 countries imported standard seawater (Ridout, 1995, 1999).

During World War II, the supply of standard seawater, particularly to the Western Hemisphere, was disrupted, and a secondary "American Standard Seawater" was produced in 1941, by comparison with Copenhagen standard water, at the Woods Hole Oceanographic Institution in the United States (Iselin, 1943). This was a temporary measure. However, one of the present practices is the production of standard seawater in countries where large quantities are required, mainly to avoid purchasing the IAPSO standard seawater. In 1984, JPOTS voiced its concern about the calibration of these standards and recommended that they be considered secondary standards on the condition that they are calibrated against IAPSO standard seawater (UNESCO, 1986) and not against the potassium chloride solution defined in the Practical Salinity Scale, 1978.

Following this recommendation, S. Morcos, during his time in UNESCO, gave special attention to the main producers of the secondary standard seawater, offering them the voluntary help of the IAPSO Standard Seawater Service. In 1986, 10 000 ampoules were produced annually by the Standard Seawater Service in Moscow, established in 1956. In the People's Republic of China, production was started in 1960 and reached 5000–7000 ampoules per year in 1986.

The Standard Seawater Service in Moscow was visited by the members of the Joint Editorial Panel on the Oceanographic Manual during their July 1986 meeting in Moscow. UNESCO also arranged a visit by M. P. Nesterova, the head of this Service, and two of her colleagues, to the IAPSO Standard Seawater Service in the UK. Fred Culkin checked several ampoules of their standard and found them to be very satisfactory.

During his UNESCO mission to China in September 1984, S. Morcos visited Shandong College in Qingdao, where the Chinese standard seawater was produced. An agreement was reached with the Chinese authorities to provide the services of F. Culkin as UNESCO consultant. He spent two weeks in May 1986 working with the scientists in the two facilities in Qingdao and Tianjin. He made several recommendations and expressed his satisfaction that both groups were capable of preparing reliable standard seawater.

UNESCO/ICES/SCOR/IAPSO Joint Panel on Oceanographic Tables and Standards (JPOTS), 1962–1992

The Joint Panel on Oceanographic Tables and Standards was created in 1962 as a direct result of an ICES initia-

tive. The Panel, which became one of the longest serving international bodies, offered, during its three decades of activity, the strongest and most active link ICES ever had with international organizations in this domain. It is admirable that ICES, credited with the establishment of the universally accepted method of measuring salinity, was the body that initiated, 60 years later, the process that led to its replacement. The present paper describes the background and events that led to the creation of JPOTS. A broader and more detailed account can be found in Wright and Morcos (1982) and Morcos *et al.* (1990).

Two fundamental developments led to this situation. Accurate chemical analysis showed that there are variations in the composition of seawater, particularly between the oceanic and Baltic waters, which influenced Sørensen's determination of gravimetric salinity. The constancy of the composition of seawater was the basis of Knudsen's empirical relationship between chlorinity and salinity. The development of instruments capable of measuring electrical conductivity with great precision introduced a more rapid, inexpensive, and reliable technique for salinity determination. However, the relationships between conductivity, chlorinity, salinity, and density were not known with the same precision as that of measured conductivity values.

Starting in 1958, the "Rapports Administratifs" and the records of the annual meetings of the ICES Hydrographical Committee (renamed Hydrography Committee in 1966) showed a steady and continuous interest in matters related to electrical conductive salinometers and the relationship between salinity and conductivity. This was mainly owing to the efforts of Roland Arthur Cox (1923–1967) of the National Institute of Oceanography (NIO), Wormley, UK (later renamed Institute of Oceanographic Sciences Deacon Laboratory) in developing the NIO Thermostat Salinity Meter.

At its 1959 meeting, the Hydrographical Committee gave special attention to this problem. A "Sub-Committee for considering Standard Methods of Salinity determination" was formed. The Committee also initiated the involvement of UNESCO by recommending that "the projected investigation…being of international importance in oceanography, … an application should be addressed by ICES to UNESCO for a grant of $4000 over the next two years….". The 47th Statutory Meeting of ICES in 1959 (ICES, 1960) passed this recommendation as Council Resolution 1959/8. UNESCO immediately replied, offering "after consultation with our Advisory Committee on Marine Sciences" a grant of $1500, a sum which was raised in December 1960 to $3000 "to investigate the relationship between conductivity, chlorinity and density of seawater of the world" (UNESCO, 1960).

This UNESCO grant came before the Intergovernmental Oceanographic Commission (IOC) was established within UNESCO and is remarkable evidence of the favourable climate of international cooperation in oceanography in the early 1960s. In July 1960, the Intergovernmental Conference on Oceanographic Research was convened in Copenhagen under the auspices of UNESCO. As a result, the Office of Oceano-graphy was established within UNESCO and began its activities in 1961. The Director of this Office acted simultaneously as the Secretary of the IOC, which was founded in 1961 within UNESCO and which held its first assembly in UNESCO, Paris, in October 1961.

The need to standardize methods and units was one of the proposed functions of IOC. There were also several proposals from various groups and scientists. Warren Wooster, the first Director of the Office of Oceanography, gave details of seven fields (in addition to salinity) requiring standardization and calibration (Wooster, 1962). Roland Cox and the Hydrographical Committee of ICES were able to put salinity as a priority item on the program of UNESCO. Salinity is of particular interest to physical oceanographers whose influence, at that time, was felt in the international sphere. Both the first Director and Deputy Director (K. N. Fedorov) of the Office of Oceanography were physical oceanographers. This explains, at least in part, the positive response to Cox's proposal to establish an international committee to deal with this issue.

Cox wrote, in August 1961, to Wooster referring to the ongoing research saying, "we shall have to face the re-definition of 'salinity' for our most accurate work…. Now this subject is clearly one of considerable international importance. When a similar situation, in some respects, occurred about 1900 ICES, which at the time was the only international body in oceanography, appointed an international commission to study the situation; and from the recommendations of this commission came the standard seawater service and the Knudsen methods for chlorinity.

I suggest it would be appropriate if a similar committee were to be formed… ICES covers only part of the world, and in particular the U.S.A. and Japan are not members, so I feel that your office could more appropriately sponsor such a group" (Cox, 1961).

In October 1961, the ICES Statutory Meeting (ICES, 1962), acting on a proposal by its Hydrographical Committee, approved a recommendation to UNESCO (Council Resolution 1961/12) to support, in collaboration with ICES, IAPO, and SCOR, a joint effort "a) to review present knowledge of the equations of state of seawater, in particular of the properties of chlorinity, salinity, density, conductivity and refractive index, and the relationships among these properties, b) to consider whether re-definition of any of these properties is necessary, and c) to advise on such further investigations as may be required."

A positive response to this recommendation came in record time. In his reply of 7 November 1961 to Arní Fridriksson, General Secretary of ICES, Wooster, in his capacity as Director of the Office of Oceanography of UNESCO, mentioned that after consultation with the

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In memory of...

... Günther Dietrich (1911-1972)

(Chairman of JPOTS from 1962 to 1964)

Günther Dietrich was born in Berlin in 1911. He studied at the University of Berlin from 1931 to 1935, taking his doctorate after studies in mathematics, physics, oceanography and meteorology. For several years he worked as an assistant at the Berlin Institute of Oceanography, where he was inspired by such renowned scientists as Albert Defant and George Wüst. During this time he took part in four cruises of the famous 'Meteor' expedition in the Atlantic Ocean (1935-1938).

During World War II, Professor Dietrich was called up to serve as an oceanographer at the Naval Observatory at Wilhelmshaven. In 1943, he qualified as a lecturer in geophysics and oceanography at the University of Berlin and was nominated custodian of the University's Institute of Oceanography. He joined the staff at the German Hydrographic Institute of Hamburg in 1950 and, in 1953, became a member of the faculty of the University of Hamburg. In 1959, Professor Dietrich was nominated Director of the Institute for Marine Research at the University of Kiel. Under his directorship, the institute became one of the world's leading oceanographic institutions. During the academic year 1969-1970, he held the Captain Cook Chair for Oceanography at the invitation of the University of Hawaii.

Professor Dietrich's expertise in regional oceanography is widely recognized. In addition to the 130 publications in his various fields of endeavour, he has left the oceanographic world a standing monument: his book entitled *General Oceanography*, which has been translated into both English and Russian. Moreover, he always demonstrated a willingness to share his vast knowledge of oceanography with his colleagues and students. A seagoing oceanographer, he organized and led many well-known expeditions such as those of the North Atlantic Polar Front Survey during the IGY (International Geophysical Year) in 1957-58, the Overflow Expedition of 1960, the new *R/V Meteor* participation (1964-65) in the Indian Ocean Expedition, not to mention his numerous cruises in the Atlantic and the North Sea.

In addition to his activities in connection with oceanographic exercises, both on a national and international scale, he also served on various international committees. From 1966 to 1969 he served as Chairman of the Hydrography Committee of ICES (International Council for the Exploration of the Sea) and from 1967 to 1970 he was President of IAPSO (International Association for the Physical Sciences of the Ocean).

Dietrich was elected the first Chairman of the Joint Panel on the Equation of State of Seawater (later renamed the Joint Panel on Oceanographic Tables and Standards) and was therefore closely involved in the formulation of its tasks. It is widely felt that without his excellent chairmanship, the efforts of the Panel might not have culminated so rapidly in the development of the new equation of state of seawater and the definition of practical salinity. An early death denied Dietrich the satisfaction of seeing the product of a JPOTS project started under his guidance.

J. Gieskes and S. Morcos

... Roland Arthur Cox (1923-1967)

(Chairman of JPOTS from 1964 to 1966)

Born in Lincoln, England, Roland Cox was educated at City School in Lincoln and subsequently at Imperial College, London University, where he graduated in 1944 with a specialization in chemistry. After three years in industry he engaged in research work on the oxidation of hydrocarbons at Imperial College and was awarded the degrees of Ph.D. and D.I.C. (Diploma of Membership of the Imperial College of Science and Technology). In 1950 he joined the staff of the National Institute of Oceanography (NIO, now the Institute of Oceanographic Sciences).

Although he was basically an analytical chemist (and known as a careful and competent one) Cox did much of his oceanographic research on the physical properties of seawater. His earlier work included the design of a portable salinometer, based on a variable density float, and the redetermination of the specific heat of seawater.

It was during their work on the design and development of the NIO Thermostat Salinity Meter that Cox and others realized the limitations in the existing relationships between the physical properties of seawater and its composition. As electrical conductivity was beginning to replace chlorinity as a measure of salinity, there was an urgent need to redetermine conductivity/salinity/temperature relationships for use with bench salinometers. In addition, it was considered that the density/salinity relationships, established sixty years previously on a small number of samples by Knudsen *et al.*, should be re-examined.

The Joint Panel on the Equation of State of Seawater was set up to consider these problems and advise on procedures, but the bulk of the investigation was undertaken by Cox. This involved the formidable task of organizing the collection, by many laboratories, of about 400 samples of seawater from all major oceans, followed by measurements of physical properties of the highest precision he could achieve. One major outcome of this work was the joint publication by Unesco and NIO of the International Oceanographic Tables, which did much to standardize the determination of salinity by bench salinometers.

As one of the founding members of the Joint Panel, Roland Cox played a major role in stimulating interest in the problems of salinity and the equation of state of seawater. Over the years more advanced or better methods than the one used by Cox have become available for the determination of density in the laboratory. The increasing use of *in situ* salinometers has generated new problems. New minds have been applied to the question of salinity and to what should be used as the basis for new measurements.

As a result of these developments, a different basic approach has been adopted in establishing new relationships to replace the old. Nevertheless, Roland Cox will be remembered as one of the pioneers in a difficult field where every single approach will probably have its critics.

F. Culkin

Editor's note

Anyone interested in reading more about the life and work of the former JPOTS chairmen may consult the following references:

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Figure 2. The first four Chairs of JPOTS were ICES scientists on its Hydrography (Hydrographical) Committee (from Wright and Morcos, 1982).

... Frede Evan Hermann (1917-1977)

(Chairman of JPOTS from 1967 to 1969)

Frede Hermann was born in North Jutland, Denmark and educated at the local grammar school and the University of Copenhagen where he graduated in physics in 1941. In his student days he developed an interest in oceanography and worked as a part-time assistant under Professor Martin Knudsen in the Hydrographic Laboratory of the Danish Institute for Marine Research. Hermann's career was mainly in physical oceanography, in which he published numerous papers. He regularly attended the Statutory Meetings of ICES and for 26 years was one of the Danish representatives on the Hydrography Committee. However, it was probably in his work as Director of the Standard Seawater Service that he made his most widely felt contribution to oceanography.

Salinity and temperature are the two most frequently studied parameters of seawater, and physical oceanographers have come to rely heavily on their accurate measurement. The fact that salinity data from different sources can be compared with a high degree of confidence is due, to a considerable extent, to the international use of a single standard, an idea conceived by Knudsen at the end of last century. Knudsen directed the Standard Seawater Service, which supplies this standard, from 1908 until 1948. Towards the end of this period, Hermann took part in the preparation and calibration of the standard. When Knudsen retired, Hermann continued this work and eventually succeded Helge Thomsen as Director of the Service in 1960.

The following years brought many problems. Worldwide expansion in oceanographic studies led to an increase in the demand for standard seawater from 8000 ampoules in 1960 to 30,000 in 1967, which meant finding larger premises and scaling up the equipment. Preparing several thousand ampoules of seawater of uniform quality, with the help of friends and colleagues employed on a part-time basis, was an organizational achievement in itself; but in the calibration of the standards Hermann also displayed admirable talents as an analytical chemist. He replaced the tedious Volhard method for the determination of chlorinity with a combined gravimetric/potentiometric method using an ingenious electrode system which, used in conjunction with weight burettes of his own design, gave a standard deviation of 3×10^{-4} in chlorinity. This impressive accomplishment was achieved by the same dedication and attention to detail which he also displayed in 1974 when he calibrated a new Primary Standard Seawater against pure silver by adapting a method which had previously been used for atomic weight determinations.

Hermann's experience as a hydrographer and with the Standard Seawater Service made him a natural choice as one of the first members of the Joint Panel, to which he made valuable contributions for eleven years. The fact that standard seawater was chosen as the basis for the Practical Salinity Scale and the International Equation of State of Seawater is a tribute to his efforts in maintaining a high quality standard over many years, and it was fitting that he was awarded the Prince Albert I Medal in 1975 by the Institut Océanographique in Paris for services rendered to the field of oceanography.

F. Culkin

... Klaus Grasshoff (1932-1981)

(Chairman of JPOTS from 1969 to 1977)

Klaus Grasshoff was born in Swinemünde (now Swinoujscie, Poland). During the war, he was taken to Kiel, Schleswig-Holstein. He received his primary and secondary schooling in Kiel and Plön, after which he attended the universities of Kiel and Würzburg, Federal Republic of Germany, from 1953 to 1960. In Kiel he obtained a doctorate in chemistry for his research work in polarography, and from 1959 to 1961 he held a post as research assistant at the University of Würzburg.

Returning to Kiel, he worked in the Institut für Meereskunde. Professor G. Dietrich, who was appointed Director of the Institute in 1959, was expanding this establishment into new research disciplines, and invited Grasshoff to apply modern analytical chemistry to oceanography. This venture proved to be highly successful, as a small working group was raised to a well established department of chemical oceanography of world reputation. In 1968, Grasshoff did his "habilitation" at the University of Kiel with a study on the chemistry of the Red Sea and Gulf of Aden. In 1971 he was appointed professor of chemical oceanography. He died on 11 March 1981, at the age of 48.

As an analytical chemist, Klaus Grasshoff introduced many new methods, concepts and approaches, notably in the determination of dissolved gases and nutrient salts. His multi-author book 'Methods of Seawater Analysis' is a standard text in chemical oceanography. He soon realized the importance of automated analysis in clinical chemistry, and developed this system in order to give accurate and continuous determination of several nutrient salts on moving ships. In the last year of his short life, he had the satisfaction of seeing his system become instrumental in the detection of chemical anomalies within less than one nautical mile.

Klaus Grasshoff was also a staunch supporter of the promotion of marine sciences in developing countries, and in this area his help and advice were greatly appreciated. He participated in several Unesco meetings and, as a Unesco consultant, in projects for the development of marine sciences in the Red Sea and the Gulf, as well as in the People's Democratic Republic of Yemen, Oman, the United Arab Emirates, Syria, Egypt and Thailand. He contributed significantly to the regional study of marine pollution in the Baltic Sea and to activities which culminated in the provisions of the Helsinki Convention of the Protection of the Baltic Sea Area. He was an active member of SCOPE (Scientific Committee on Problems of the Environment) and chairman of his national committee.

Grasshoff atteded the JPOTS meeting, from 1964, became a member in 1967 and was chairman from 1969 to 1977. His ability as an analytical chemist and his interest in dissolved gases helped to reconcile opinions and approaches on independent measurements of oxygen solubility. As a result, the table on oxygen solubility in seawater was published in 1973 in Volume 2 of the International Oceanographic Tables. In addition and at the Panel's request, he prepared the conversion table for salinity/chlorosity at 20 and 25 degrees centigrade, which also appeared in Vol. 2.

Under his chairmanship, JPOTS brought about the change in the fundamental concepts of salinity definition in favour of the Practical Salinity Scale, and accomplished the bulk of the work involved in the establishment of the new International Equation of State of Seawater.

M. Ménaché and S. Morcos

(cont'd from p. 3)

The big problem encountered when seeking accuracy with an *in situ* salinometer is to ensure that the data obtained in the laboratory calibration carries over to the *in situ* situation. For instance, conditions in a practical calibration tank, of necessity, represent near static conditions while the *in situ* salinometer must perform the *in situ* measurement with arbitrary water flow and time variation of temperature, conductivity and pressure, at the sensors and at both varying and unknown probe-circuit temperature. A knowledge of the respective time constants and meticulous attention to circuit drift in the original design are essential. Even then the salinity determination incorporates the errors of all three parameters, including their thermal drift and hysteresis, so it is not surprising that for precise work at present the deep-cast water bottle is the rule rather than the exception. Given a few reference points, however, the *in situ* salinometer can give an excellent picture of salinity variations within any body of water.

T. M. Dauphinee

Presidents of IAPO and SCOR, "we intend to establish such a Panel and convene it as soon as possible", and that "funds to support this group will be found within UNESCO's Regular Program" (Wooster, 1961).

The Joint Panel on the Equation of State of Seawater (JPESS) met for the first time at UNESCO in Paris in May 1962 and elected Günther Dietrich (nominated by SCOR) as Chair. After its second meeting in Berkeley, California, in August 1963, the Panel changed its name to the Joint Panel on Oceanographic Tables and Standards (JPOTS) upon a recommendation by IAPO. Under its new name, another nine meetings of the Panel were held between 1964 and 1980. UNESCO financially supported the meetings from its inception up until the seventh meeting in Grenoble, France, in 1975. Afterwards, expenses were shared between UNESCO, ICES, and SCOR/IAPSO, each share proportionate to the number of their nominated members in attendance at each meeting.

JPOTS is credited with the adoption of the Practical Salinity Scale (1978) used today (UNESCO, 1981), after being endorsed by the four sponsoring bodies and IOC. The adoption of the International Equation of State of Seawater (1980) marked the replacement, after 80 years, of the traditional equation of state of seawater used in the Hydrographical Tables, and the equation of state of seawater at elevated pressure published in 1908 by V. W. Ekman, a pioneering ICES scientist in the Central Laboratory in Kristiania. Both equations were used for the calculation of density of seawater from temperature and salinity at surface or at depth, respectively.

JPOTS continued its activities after the 10th plenary meeting in Sidney, BC, Canada in 1980, by specialized sub-panels such as the Joint Editorial Panel on the Oceanographic Station Data Manual which was published by UNESCO in 1992. Other sub-panels were those of thermodynamics of the carbon dioxide system, and standards for carbon dioxide measurements. The reports and studies of JPOTS were published in the series *UNESCO Technical Papers in Marine Science.*

In conclusion, it is fitting to remember that the first four chairs of JPOTS were ICES scientists on the Hydrography (Hydrographical) Committee: Günther Dietrich (Kiel, 1962–1964, SCOR nominee), Roland Cox (Wormley, 1964–1967, ICES nominee), Frede Hermann (Copenhagen, 1967–1969, ICES nominee), and Klaus Grasshoff (Kiel, 1969–1977, SCOR nominee). Figure 2 is presented as a tribute to those leading scientists and to the ICES contribution to oceanography and to our understanding of seawater properties.

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