HISTORISCH-MEERESKUNDLICHES JAHRBUCH

(HISTORY OF OCEANOGRAPHY YEARBOOK)

**Schriftenreihe des Deutschen Meeresmuseums (DMM)
und der Deutschen Gesellschaft für Meeresforschung e. V. (DGM)**

Band 11

Herausgeber:
Deutsches Meeresmuseum
Stralsund
2005

German research on the Agulhas Current system between the World Wars; a lost scientific achievement

Johann R. E. Lütjeharms and Gerhard Kortum

The greater Agulhas Current system is currently the centre of substantial international interest because of its perceived role in the inter-ocean exchange of water between the South Indian Ocean and the South Atlantic Ocean. This exchange forms a fundamental link in the global thermohaline circulation. German researchers paid considerable attention to the circulation in the South West Indian Ocean during the 1930s and they can be considered to have been the contemporary experts on this region. More than 30 scientific papers or books on the subject were produced by German oceanographers between 1929 and 1941; a major achievement at the time. After the Second World War this knowledge was used in a few major texts, but shortly afterwards largely disappeared from sight. By the time of the International Indian Ocean Expedition in the 1960s no further mention was made of this preceding German work. Using a bibliographic investigation we here track the manner in which this knowledge was lost and speculate on its causes.

Deutsche Beiträge zur Erforschung des Agulhas-Stromsystems zwischen den Weltkriegen: Ein verlorenes wissenschaftliches Erbe. Das Agulhas-Stromsystem östlich von Südafrika spielt in der gegenwärtigen Forschung eine sehr wichtige Rolle in der wissenschaftlichen Diskussion, da es für den Wassertransport vom Indischen in den Atlantischen Ozean verantwortlich ist. Diese Verbindung ist für die globale thermohaline Gesamtzirkulation von sehr großer Bedeutung. Es waren deutsche Meeresforscher, die sich in den 1930er Jahren erstmals intensiver mit den hydrographischen Verhältnissen des südwestlichen Indischen Ozeans befassten. Sie galten seinerzeit als Experten für diese Region. Insgesamt wurden von deutscher Seite von 1929 bis 1941 mehr als 30 Publikationen vorgelegt. Nach dem Zweiten Weltkrieg wird auf die wichtigen, hauptsächlich vom Berliner Institut für Meereskunde erarbeiteten Ergebnisse nur noch gelegentlich verwiesen. Zur Zeit der International Indian Ocean Expedition Mitte der 60er Jahre war das wissenschaftliche Erbe der deutschen Beiträge vollständig vergessen. – Der vorliegende Beitrag diskutiert die alten deutschen Beiträge und weist auf die Hauptpersonen und Institutionen hin, die diesen Forschungsprozess trugen. Es werden einige Gründe angeführt, die zum Vergessen der damaligen Forschungsarbeiten geführt haben.

1. Introduction

Data, knowledge and concepts on the circulation of the South West Indian Ocean have increased rapidly since the 1970s (Figure 1). This is particularly the case for knowledge on the greater Agulhas Current system and its influence on the South Atlantic Ocean (e.g. Boebel et al., 1997; Lutjeharms et al., 2000). The reasons for this growth in interest are manifold and complex and have, to some extent, been discussed elsewhere (Lutjeharms, 1991). A study of the development of knowledge on the circulation of the South West Indian Ocean since the beginning of the 20th century shows that a substantial amount of important and groundbreaking work was done in the 1920s and 1930s (viz. Figure 1). This work was carried out

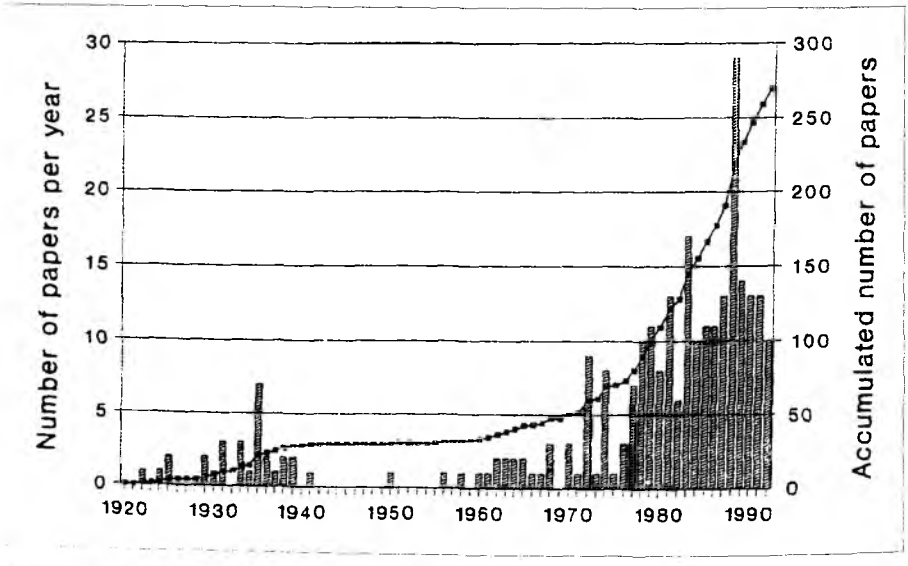

Figure 1: The number of scientific publications per year on the South West Indian Ocean (left hand ordinate) from 1920 to 1992 as a histogram and the accumulated total of such publications as a continuous curve (right hand ordinate). The largest number of publications during the 1930s came from Germany with the number coming from the United Kingdom a close second (viz. Lutjeharms and Kortum, 2004).

almost exclusively by scientists from two countries, Germany and the United Kingdom (Lutjeharms & Kortum, 2004s). The British contribution consisted mainly of reports on the results gained from cruises by the vessels *Discovery* and *William Scoresby* (e.g. Deacon, 1933, 1937) in the Southern Ocean, but extending north to Cape Town. In fact a large part of this contribution consisted of cruise and data reports (viz. Lutjeharms, 1982; his Figure 2). The German contribution to this peak in publications at the time had a much higher component of research papers, as will be seen below. However, this major epoch in the history of oceanographic

endeavour – particularly the German component – is relatively unknown at present and most of the publications of this period seem to have been erased from the collective scientific consciousness.

We describe here the key German publications of this period, the findings expressed in them and the influence these findings had on further work in the region. Some thoughts are put forward on why this rich and potentially very solid base of knowledge was not adequately used as a foundation for subsequent investigations.

Historical studies on this aspect of the scientific enterprise are of more than purely historical interest as they address one of the very basic tenets of research philosophy. The so-called scientific method is supposed to be a very efficient mechanism for accumulating knowledge, since all new information that is submitted is thoroughly evaluated for factual content and that which passes this screening process becomes part of the established knowledge base. In this process no valuable knowledge should be lost. Ideally the scientific method should furthermore be a totally logical, cerebral practise in which emotions such as prejudice or partisanship should have no part.

In practise this is not always the case nor has it been so in the past. Deacon (1971), in her major study on the development of marine science from 1650 to 1900, has demonstrated that the growth of understanding has gone through a number of distinct peaks in development. During the times between these periods of high intellectual activity most work on the ocean came to a complete standstill. There also seems to be hardly any apparent connection between work that was carried out during one active period and the next, so that many new research activities – initiated during one period of high activity – reflected no awareness of any research on the topic that had been carried out before. Worse, many of the previous advances in knowledge and understanding were no longer known and had to be rediscovered at great pains and cost.

This historical portrayal (Deacon, 1971) of the scientific enterprise in marine studies is in direct conflict with that of the ideal of the classical scientific method taught to most undergraduates studying science. How could such an inefficient system of passing on knowledge come about? Deacon (1971) shows that the peaks in ocean research were usually due to immediate operational requirements of shipping or of a national navy. These requirements lead to increases in funding that enabled enthusiastic investigators to pursue their marine interests. During the past 150 years such peaks may also have been by-products of the dominant political processes at the time, as has been proposed by Tomczak (1980) in discussing the classification of deep-sea expeditions by Wüst (1964). If scientists did not produce a crop of students who could propagate the new concepts, ideas and results into the next era, these results were usually lost, even when they had been printed and amply distributed (Deacon, 1971).

This hypothesis on the processes involved in keeping scientific results known are in essential agreement with the results of a historical investigation on inter-basin leakage of water south of Africa (Lutjeharms et al., 1992). Since about 1930 the concept of a direct flow of the Agulhas Current from the South Indian

Ocean to the South Atlantic Ocean has had to compete with the idea of a total recurvature of the current, carrying all its water back into the South Indian. A compromise has held that there exists a bifurcation of the current by which part of the current would go in either direction. This conflict was finally resolved when new data showed unequivocally (Bang, 1970) that the Agulhas Current did turn back on itself, henceforth signified by the term *retroflection*. Inter-ocean transfer of water was assumed to come about by the shedding of Agulhas rings through loop occlusion at the retroflection. This process was eventually observed in thermal infrared satellite imagery (Lutjeharms, 1981) and subsequently confirmed by observations at sea (Lutjeharms & Gordon, 1987).

However, the primary concept of a near-total retroflection of the Agulhas Current, with only sporadic leakage into the South Atlantic, had already been put forward by Rennell in 1832! His proposal naturally had a very narrow data base, but this base was considerably widened by Dutch workers in the 1850s and in particular by one Andrau (van Gogh, 1857) who used a vast collection of ships' drift data. These results from the KNMI (*Koninklijk Nederlandsch Meteorologisch Instituut*, Royal Dutch Meteorological Institute) clearly showed a total retroflection of the current (viz. Lutjeharms et al., 1992), supported by surface currents and by sea surface temperatures. Although this work was fairly well known in certain influential oceanographic circles and quoted by some at the time (e.g. Petermann, 1865; Findlay; 1866, Krümmel, 1887), it was soon lost and played no significant part in subsequent fundamental work on the Agulhas Current (e.g. Michaelis, 1923; Clowes, 1950; Darbyshire, 1964). The whole concept of retroflection had, as it were, to be rediscovered. How can one account for such scientific inefficiency?

As mentioned above, Deacon (1971) holds that the process in the development of scientific thinking that causes such a total loss of information is due mainly to a long period during which knowledge of this information in not maintained, i.e. passed from teacher to pupil. In the case of the concept of retroflection, this hypothesis of Deacon's may indeed be appropriate, since about 45 years had elapsed since the publication of the early Dutch results and the next substantial research effort on the currents of the region (Michaelis, 1923). The researchers involved were employed by a state institution, the KNMI, and thus probably had little access to students to carry there research result into the future.
A study of the German research during the 1930s and the subsequent loss of this information may shed light on whether this debilitating process on scientific progress also operates on shorter time scales.

2. Pre-war German research on the South-west Indian Ocean

German interest in its marine environment has a long history the roots of which can be traced back more than 300 years (e.g. Institut für Meereskunde, 1994; Kortum, 1980; Peterson et al., 1996; Lenz, 1997; Schott, 1987). As in many countries with such a long tradition of ocean studies, true research started with geographical investigations and early pioneers such as Krümmel (1854-1912) were geographers

(Ulrich & Kortum, 1997). Well-known naturalists such as Alexander von Humboldt (1769-1859) also wrote on ocean currents (Kortum, 1990) and there is evidence that he, Rennell (viz. Rennell, 1832) and Maury (1856) met and corresponded (Kortum & Schwarz, 2004). Rennell can be considered to be one of the pioneers of research on the Agulhas Current (Frenzel, 1904) and seems to have had a decisive role in the forming of some of the concepts of ocean currents held by Humboldt. Kortum (1990) has shown that in many ways Humboldt adopted Rennell's notions, particularly on the influence of the Agulhas Current on the surface circulation of the Atlantic Ocean. Kortum (1993, p. 614) has also pointed out that Humboldt was one of the first to propose that ships be specially equipped as research platforms for work on the ocean.

Notwithstanding the geographic origins of the early marine interest in Germany, other aspects also started to play a role. Ehrenberg (1864), for instance, discussed the bottom sediments on the Agulhas Bank, south of Africa, and the pelagic organism found in the water column there. Ehrenberg was another pioneer of German oceanography (Engelmann, 1969) who pushed for the use of deep-sea soundings on German expeditions. Tragically this proposal was only accepted for the first time during the oceanographic expedition of the vessel *Gazelle* in 1874-1876, two years before Ehrenberg's death in 1876. Others (Anonymous, 1883) discussed the physical oceanography (*physische Oceanographie*) and the meteorology around the southern part of South Africa in some detail. But the geographical aspect of this work continued and in a way culminated in the publication of Schott's famous monographies on the world ocean (e.g. Schott, 1935, 1944). Lenz (1986) and Schultz (1936) have both indicated the important role Schott played in the development of the marine sciences in Germany. It is indicative of his role that James (1936) reviewed Schott's work under the title of *The geography of the oceans.* A great impetus to the whole oceanographic endeavour in Germany came with the establishment of a dedicated institution, the *Institut für Meereskunde* at the University of Berlin.

The history of the founding of this institute has been ably described by Engelmann (1997), Lüdecke (1997) and by Roll (1990), as has the role of Ferdinand von Richthofen in its establishment (Kortum, 1983). This institute and its members played a key role in Germany at the time, not only in planning deep-sea expeditions, but also in teaching (Brosin, 1997) and in educating the public (Neubert, 1997). Even after the war when the institute had been destroyed and its existence terminated, the rebuilding of the oceanographic enterprise in Germany was carried out by persons who had received their training in this establishment (Lenz & Streicher, 1997). Most of the scientific activities of the destroyed institute were subsequently transferred to the new *Institut für Meereskunde* in Kiel (Krauß, 1990). The original institute was also very important from another point of view. It was here that the change from a purely geographical point of view to that of a quantitative science based on mathematical physics was achieved (Mills, 1997). This new point of view fundamentally changed oceanography not only in Germany, but also in the rest of the world. From this institute came a large number of research publications, published largely in the *Veröffentlichungen des Insituts für*

Meereskunde and the *Annalen der Hydrographie und Maritimen Meteorology*. These series were considered of sufficient importance that renowned foreigners, such as George Deacon from the UK, also had contributions published in them (Deacon, 1934). From these publications only those pertaining to the South West Indian Ocean, or the greater Agulhas Current system, are of interest here. A full list is given in Table 1.

Table 1: A List of all publication on the South West Indian Ocean by German oceanographers during the years 1920 to 1941.

Becker, R. (1938). Über den jährlichen Temperaturgang auf dem Indischen und Stillen Ozean. *Annalen der Hydrographie und Maritimen Meteorologie*, Berlin, 66(7): 338-340.

Defant, A. (1932-1960). *Wissenschaftliche Ergebnisse der deutschen Atlantischen Expedition auf dem Forschung- und Vermessungsschiff „Meteor" 1925-1927.* Bände I-XVI, Berlin.

Defant, A. (1936). Ausbreitung- und Vermischungsvorgänge im antarktischen Bodenstrom und im subantarktischen Zwischenwasser. *Wissenschaftlichen Ergebnisse der deutschen Atlantischen Expedition auf dem Forschung- und Vermessungsschiff „Meteor" 1925-1927*, 6(2): 53-96.

Defant, A. (1941). Die absolute Topographie des physikalischen Meeresniveaus und der Druckflächen sowie die Wasserbewegung im Atlantischen Ozean. *Wissenschaftlichen Ergebnisse der deutschen Atlantischen Expedition auf dem Forschung- und Vermessungsschiff „Meteor" 1925-1927*, 6(2): 191-260.

Defant, A. (1941). Die relative Topographie einzelner Druckflächen im Atlantischen Ozean. *'Meteor' Forschungsergebnisse*, 6(2/4): 183-190.

Dietrich, G. (1935). Aufbau und Dynamik des südlichen Agulhasstromgebietes. *Veröffentlichungen des Institut für Meereskunde an der Universität Berlin*, N. F. A(27): 79 pp.

Dietrich, G. (1935). Zur Dynamik des Atlantischen Zweiges des Agulhasstromes. *Annalen der Hydrographie und Maritimen Meteorologie*, 63: 383-387.

Dietrich, G. (1936). Aufbau und Bewegung von Golfstrom und Agulhasstrom, eine vergleichende Betrachtung. *Naturwissenschaften*, 24(15): 225-230.

Harries, H. D. (1932). Über die Veränderlichkeit von Monatswerten meteorologischer und hydrologischer Elementen der Äquatorialsee. *Annalen der Hydrographie und Maritimen Meteorologie, Berlin*, 60(12): 496-499.

Michaelis, G. (1923). Die Wasserbewegung an der Oberfläche des Indischen Ozeans im Januar und Juli. *Veröffentlichungen des Instituts für Meereskunde an der Universität Berlin*, N. F. A8(16): 32 pp.

Möller, L. (1929). Die Zirkulation des Indischen Ozeans; auf Grund von Temperatur- und Salzgehaltstiefenmessungen und Oberflächenstrombeobachtungen. *Veröffentlichungen des Instituts für Meereskunde an der Universität Berlin*, N. F. A21: 48 pp.

Möller, L. (1933). Zur Frage der Tiefenzirkulation im Indischen Ozean. *Annalen des Hydrographie und Maritimen Meteorologie Berlin*, 61(8,9): 233-236.

Paech, H. (1926). Die Oberflächenströmungen um Madagaskar in ihrem jährlichen Gang. *Veröffentlichungen des Instituts für Meereskunde an der Universität Berlin*, N. F. A(16): 39 pp.

Römer, E. (1939). Der Gegenstrom unter der süd- und südostafrikanischen Küste. *Seewart*, 8(6).

Römer, E. (1939). The counter current off the south and southeast African coast. *Hydrographic Review*, 16: 88-91.

One of the first noteworthy papers in this list was one on the surface motion of the Indian Ocean in the months January and July (Michaelis, 1923). These months were selected as representative of the summer and winter months with the specific aim of showing the abrupt changes to currents that are under the monsoonal influence. Michaelis did not gather new data but brought together all the measurements he could find in previous publications, particularly in atlases based

Schott, G. (1926). Die Tiefenwasserbewegung des Indischen Ozeans. *Annalen der Hydrographie und Maritimen Meteorologie, Berlin*, 54(2): 417-431.

Schott, G. (1928). Die Verteilung des Salzgehaltes im Oberflachenwasser der Ozeane. *Annalen der Hydrographie und Marittimen Meteorologie, Berlin*, 5: 145-166.

Schott, G. (1935). *Geographie des Indischen und Stillen Ozeans.* C. Boysen, Hamburg, 413 pp., 37 plates.

Schott, G. (1944). *Geographie des Atlantischen Ozeans.* (4 th edit.),C. Boysen, Hamburg, 438 pp., 38 plates. (1 st edit. 1912, 2 nd edit. 1926, 3 rd edit. 1942)

Thomsen, H. (1933). The circulation in the depths of the Indian Ocean. *Journal Cons. Perm. Int. Explor. Mer* 8(1): 73-79.

Thomsen, H. (1935). Entstehung und Verbreitung einiger charakteristischer Wassermassen in dem Indischen und südlichen Pazifischen Ozean. *Annalen der Hydrographie und Maritimen Meteorologie, Berlin* 63(8): 293-305.

Van Riel, P. M. (1932). Einige ozeanographische Beobachtungen im Roten Meer, Golf von Aden und Indischen Ozean. *Annalen der Hydrographie und Maritimen Meteorologie, Berlin*, 60(10): 401-407.

Von Drygalski, E. (1935). Das Indischen Ozeanreich. Festrede, Bayerische Akademie der Wissenschaften zur Feier des 176. Stiftungsfestes am 19 Juni 1935, München, 19 pp.

Wattenberg, H. (1933). Kalziumkarbonat- und Kohlensäuregehalt des Meereswassers. *Wissenschaftlichen Ergebnisse der deutschen Atlantischen* Expedition auf dem Forschung- und Vermessungschiff „Meteor" 1925-1927, 8: 233 pp.

Wellman, F. (1936). Östliche Stromversetzung and der südostafrikansiche Küste im Juli. *Seewart*, 5(2).

Willimzik, M. (1929). Die Strömungen im Subtropischen Konvergenzgebiet des Indischen Ozeans. *Veröffentlichungen des Instituts für Meereskunde an der Universität Berlin*, N. F. A (14): 1-27.

Wüst, G. (1930). Meridionale Schichtungen und Tiefenzirkulation in den Westhälften der drei Ozeane. *Journal Cons. Perm. Int. Explor. Mer.*, 5(1): 7-21.

Wüst, G. (1934). Anzeichen von Beziehungen zwischen Bodenstrom und Relief in der Tiefsee des Indischen Ozeans. *Naturwissenschaften*, 22(16): 241-244.

Wüst, G. (1935). Die Ausbreitung des antarktischen Bodenwassers im Atlantischen und Indischen Ozean. *Zeitschrift zur Geophysik*, 11: 40-49.

Wüst, G. (1935). Zur Frage des Indischen Tiefenstroms. *Naturwissenschaften*, 23(9): 137-139.

Wüst, G. (1938). Bodentemperatur und Bodenstrom in der atlantischen, indischen und pazifischen Tiefsee. *Beiträge zur Geophysik*, 54: 1-8.

Table 2: A matrix of the main German papers on the South West Indian Ocean of the 1920s and the 1930s (abscissa) and the most important subsequent international papers up to the 1970s on the same ocean region (ordinate). The latter are organised according to country, in descending order: the USA, the Soviet Union, France, the United Kingdom and South Africa. Bibliographic detail on the papers indicated on each axis can be found in the reference list.

		1938	1936	1941a	1941b	1935a	1935b	1932	1923	1929	1933	1926	1926	1928	1935	1936	1933	1935	1932	1933	1929	1930	1934	1935a	1935b	1938
		Becker	Defant	Defant	Defant	Dietrich	Dietrich	Harries	Michaelis	Möller	Möller	Pusch	Schott	Schott	Schott	Schott	Thomsen	Thomsen	Van Riel	Wattenberg	Willimzik	Wüst	Wüst	Wüst	Wüst	Wüst	Wüst
Sverdrup et al.	1942		✓	✓		✓				✓	✓				✓		✓	✓	✓								
Pollak	1958																									
le Pichon	1960																									
Taft	1963			✓																						
Hamon	1967																									
Schell	1968																									
Muromtsev	1958																									
Zaklinskii	1968																									
Sheherbinin	1969																									
Kuksa	1972																									
Menaché	1963																									
Donguy & Piton	1969																✓									
Deacon	1934																									
Clowes	1950					✓				✓	✓	✓		✓	✓	✓		✓	✓			✓		✓			
Darbyshire	1964																									
Darbyshire	1966																									
Visser & Niekerk	1965					✓						✓														
Mostert	1966																									
Duncan	1968					✓																				
Duncan	1970					✓																				
Bang	1970					✓																				
Harris	1972																									
Bang	1973																									

on ships' drift observations. He found the atlases produced by the Dutch KNMI especially useful. His maps show detail of the wind direction, wind persistence, average sea surface temperatures, and mean current speeds and directions over the full extent of the Indian Ocean. Current patterns off Madagascar and the east coast of South Africa are quite realistic. The retroflection of the Agulhas Current can be inferred, but is not explicit. Based largely on current atlases of the time, the results are instructive, but not particularly novel.

VERÖFFENTLICHUNGEN DES
INSTITUTS FÜR MEERESKUNDE
AN DER UNIVERSITÄT BERLIN
NEUE FOLGE
A. Geographisch-naturwissenschaftliche Reihe. Heft 16

Juni 1926

DIE OBERFLÄCHENSTRÖMUNGEN UM MADAGASKAR IN IHREM JÄHRLICHEN GANG

VON

DR. HARRY PAECH

Mit 6 Abbildungen im Text und 1 Kartenbeilage

E. S. MITTLER & SOHN, BERLIN SW 68, KOCHSTRASSE 68—71

Figure 2: Cover page from a paper by Harry Paech as published in the Veröffentlichungen des Instituts für Meereskunde an der Universität Berlin in 1926. This is characteristic for a whole series of papers that came from that institution at that time.

This type of re-analysis of other published data was also carried out in the planning of the *Meteor* expedition (e.g. Merz, 1925) and produced some prescient depictions of the seasonal changes in the configuration of the Subtropical Convergence south of Africa (Merz, 1925; Figure 4). The influence of the Agulhas Current could be seen quite clearly and the meridional excursions in this front were quite representative. The currents at the Agulhas Current termination are very attractively portrayed, but are considerably more speculative (Merz, 1925; Figure 5).

Part of the Agulhas Current is portrayed as flowing directly into the South Atlantic Ocean, while another part is absorbed into a large gyre south of the continent. Nevertheless, the detail given is quite suggestive. This portrayal of streamlines was taken over from the analysis by Willimzik (1929) and was – perhaps for reasons of its attractiveness – subsequently taken over by Defant (1929) and published in his textbook on the atmosphere. A more detailed analysis of the surface currents was published by Paech (1926).

Paech (1926; Figure 2) started his analysis in the institute in Berlin under the tutelage of Merz, but completed the work at the *Geographisches Institut* at the University of Frankfurt. As source material he again used all the observations gathered by the Dutch KNMI and added a number of German observations of ships' drift and sea surface temperature. He concentrated on the region around Madagascar and drew maps of sea surface temperature for the Mozambique Channel (Paech, 1926; Figure 5) and attempted to infer seasonal changes in the current structure in this channel (Figure 6). He expressed some pride in the fact that he did not only show current directions as shown in atlases of the time, but constructed streamlines in the manner pioneered at the institute by Willimzik (1929). This was a dangerous thing to do because it combined eulerian observations into a lagrangian portrayal of assumed streamlines with all the dangers inherent in such a transfer. One of the clear examples of this error, that has subsequently persisted over many years, has been the depiction of an intense current in the Mozambique Channel, called the Mozambique Current. This inferred current was shown to be the precursor to the Agulhas Current, only the change in name indicating where the one started and the other began. It has taken nearly 80 years to show that this concept was totally in error (Ridderinkhof et al., 2001) and to prove that the flow in the Mozambique Channel consists of a train of eddies moving poleward (De Ruijter et al., 2002). However, the richness of detail and the analyses of sea surface temperature are of substantial interest. With this publication the German studies of the surface circulations were more or less concluded and the water masses as a whole started receiving greater attention. One of the first to do this was Lotte Möller (Figure 3).

Möller had studied geography as well as physics and mathematics at the University of Berlin (Nöthlich, 1974) and was appointed junior research assistant at the *Institut für Meereskunde* in 1923. She received her doctoral degree in geography, but with an oceanographic research topic. She played an increasingly important role in the institute and eventually became the head of one of the research units. In her first paper on the Indian Ocean (Möller, 1929) she extended the work on surface currents considerably by including many vertical sections (viz. Figure 4). In this way she gave a very solid description of the water masses at different depths in the Indian Ocean, right up to Antarctica, and indicated the origin of many of the water types, including Antarctic Bottom Water. In this way she adumbrated some of the work from the *Discovery*. She used largely hydrographic data gathered by German vessels such as the *Gazelle*, the *Valdivia*, *Planet*, *Gauß* and the *Möwe*, but included Austrian, Russian, French and British data as well. This publication can be considered a new standard in the hydrography of the Indian

Ocean. When data from more deep stations became available due to the expeditions on the *Snellius* (van Riel, 1932) and the *Dana* (Schmidt, 1932; Thomsen, 1933) she was quick to modify her previous work (Möller, 1933) in this region and to enhance her previous work on the deep circulation of the Indian Ocean. Thomsen published some of his work in German journals (Thomsen, 1935); some in other journals (Thomsen, 1933). His work largely supported and complemented

Figure 3: Prof. Dr. Lotte Möller (1893-1973), an active participant in the study of the Indian Ocean in the 1920s and 1930s.

that of Möller's (1929). He dealt mostly with the different water masses in the Indian Ocean and their perceived origins. Schott (1926) had also dabbled in this question of the deep water movement of the Indian Ocean, particularly as it related to the formation regions in the Southern Ocean. He stressed the formation of water that occurred at the Antarctic Polar Front (called the *Meinardus Linie* in his publications). It is clear that the perception currently held by most oceanographers in the Anglo-Saxon world that our understanding of the Southern Ocean is based on totally new concepts generated by the *Discovery* cruises (Deacon, 1933, 1937) is incorrect. Gerhard Schott was a geographer of the ocean who had an enormous influence.

Schott was not a desk-bound oceanographer, but had sailed on the famous *Valdivia* cruise as well as with the *Croatia* (Schulz, 1936). His major contribution

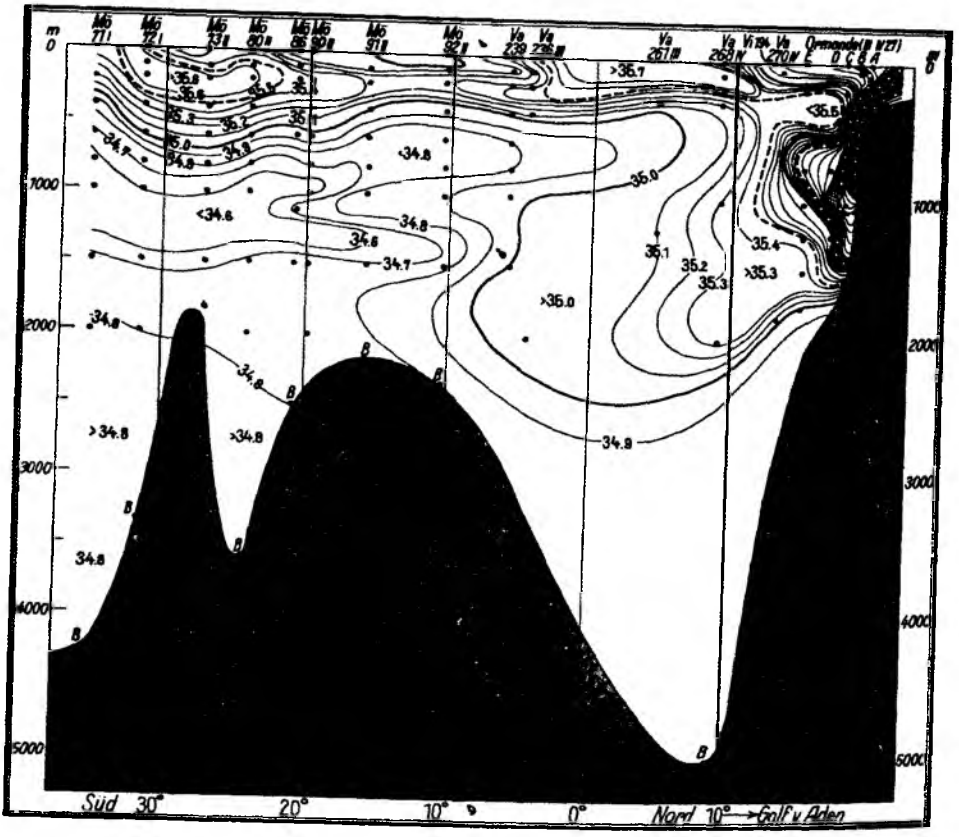

Figure 4: An illustration from a publication by Lotte Möller (Möller, 1929) showing the salinity distribution along a vertical section from the latitude of Cape Town, through the Mozambique Channel to the Gulf of Aden. Dots indicate the locations where observations were taken with reversing bottles. Station indicators show the ship's name and the station number. Mö stands for the Möwe; Va for Valdivia.

was a series of ocean monographies (Schott, Atlantic Ocean 4 eds. 1912-44, Pacific and Indian Ocean 1935) and work stemming from these volumes (e.g. Schott, 1936). These books included detailed maps on sea surface temperatures, surface salinities, surface densities, sea surface currents for different seasons and even temperatures at 200 m and 400 m depths. The latter were an innovation in such publications. The currents depicted in the South West Indian Ocean differed little from that shown in the work by Michaelis (1923), with some of the detail removed and with some of the same erroneous interpretations. These atlases were enormously influential at the time. They were used in the main textbook of the time (Sverdrup et al., 1942) and in many other textbooks and popular publications as well (without proper reference).

The person who should have had the greatest impact on subsequent work on the Agulhas Current - and more particularly on research concerning its southern reaches - was Günther Dietrich (Figure 5). For his Ph. D. dissertation he assembled all the hydrographic data that had been gathered by deep-sea cruises in the region and analysed this using principles of dynamic oceanography (Dietrich, 1935a). It was only possible to do this because of the number of deep-sea cruises that had passed though the region during the preceding few decades. In the end he used 151 stations, but the largest number still came from the *Meteor* expedition.

Figure 5: Prof. Dr Günter Dietrich (1911-1972), the German pioneer of Aghulas Current Research, photo taken around 1962 before International Indian Ocean Expedition (Foto: Edith Mempel; Quelle: Archiv IFM-Geomar)

He was exceedingly careful to use only the very best hydrographic data, portraying the water masses in a number of vertical sections of temperature and salinity, calculating velocities as well as the water transport. His portrayal of the dynamical topography of the region relative to a level of no motion at 1000 db is shown in Figure 6. This picture correctly shows the tight isolines that typify the Agulhas Current proper off the South African east coast and a strong Agulhas Return Cur-

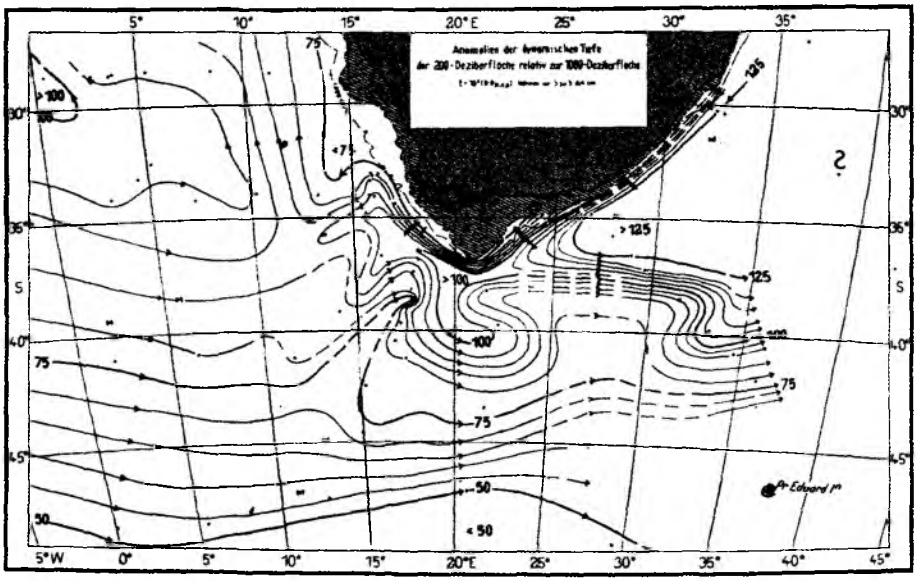

Figure 6: The southern Agulhas Current as depicted in a seminal publication by Dietrich (Dietrich, 1935a) on the Aufbau und Dynamik des südlichen Agulhasstromgebietes (his Figure 55). It depicts, for the first time, the anomaly of the dynamic depth of the 200 db surface relative to 1000 db and indicates a complex kind of retroflection of the current. It is based on a substantial collection of hydrographic stations from many different ships assembled for this purpose by Dietrich.

rent (as it is known today; Lutjeharms & Ansorge, 2001) with the latter's typical equatorward excursion over the Agulhas Plateau at about 28° E. The Agulhas retroflection can be inferred, but the lack of hydrographic stations south-west of Cape Town made it difficult to decide on the contouring. The strong current shown setting equatorward of Cape Town (*Kapstadt* in Figure 6) is probably misinterpreted, as is clear from his next paper in which Dietrich (1935b) calls this the Atlantic branch of the Agulhas Current (*atlantische Zweiges des Agulhasstromes*, Figure 7). This almost certainly is coastal upwelled water and not a branch of the Agulhas Current. Nevertheless, the portrayal of the cold water region and the upwelling front is very realistic (Shannon, 1985). Even some detail, such as an eddy in the upwelling front (Dietrich, 1935b; Figure 2; viz. Figure 7)) has only recently been described in more detail using satellite imagery (Lutjeharms & Matthysen, 1995). After this initial focus on the Agulhas Current, Dietrich's interest returned to more northern regions (Böhnecke & Bückmann, 1973) and he played a crucial role in re-establishing oceanography in Germany after the Second World War and in building up the new *Institut für Meereskunde* in Kiel (Krauß, 1990). He taught a whole new generation of German oceanographers (Dietrich & Kalle, 1957) and died unexpectedly in 1972 (Institut für Meereskunde, 1973).

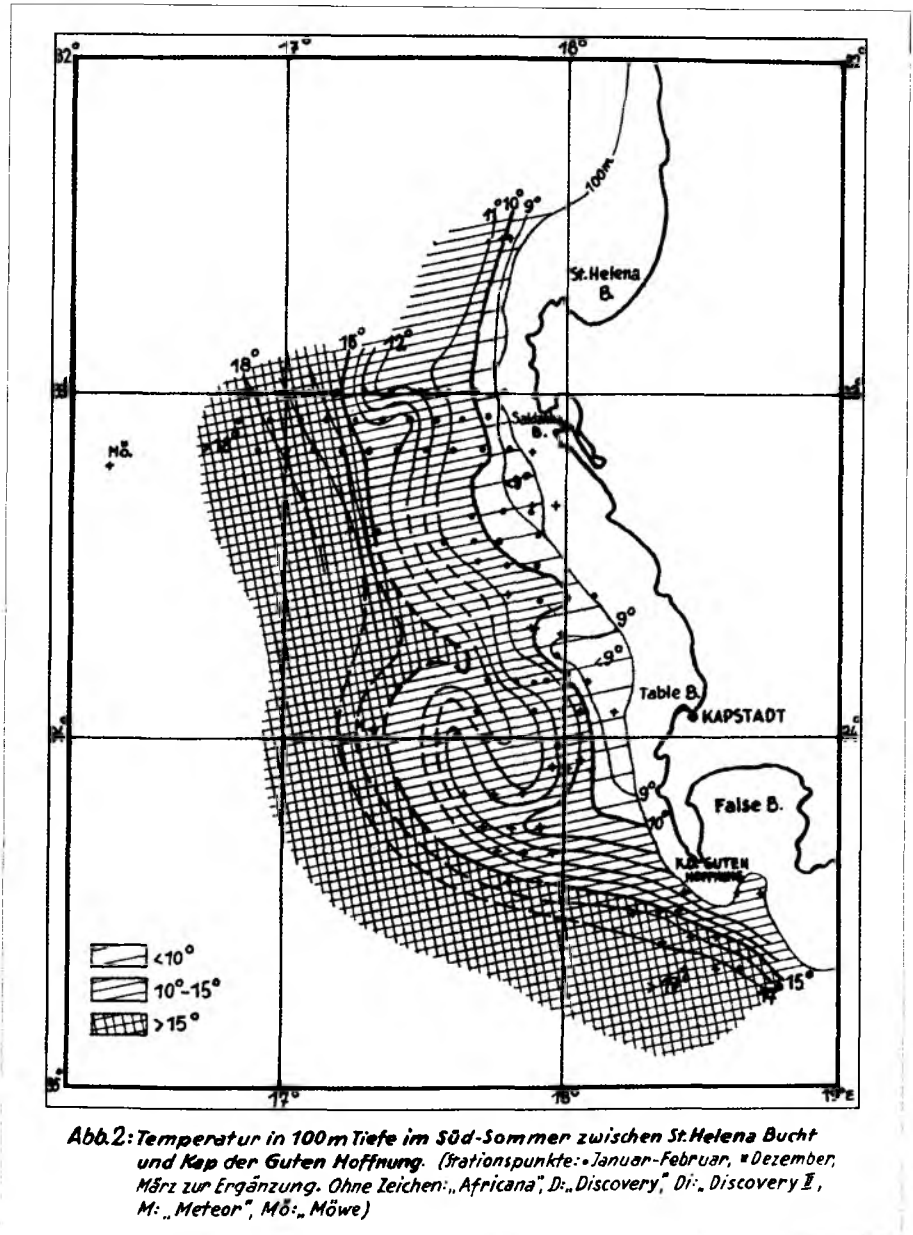

Abb. 2: Temperatur in 100 m Tiefe im Süd-Sommer zwischen St. Helena Bucht und Kap der Guten Hoffnung. (Stationspunkte: • Januar-Februar, ▪ Dezember, März zur Ergänzung. Ohne Zeichen: „Africana", D: „Discovery", DII: „Discovery II", M: „Meteor", Mö: „Möwe")

Figure 7: The sea temperatures, in °C, at 100 m depth off Cape Town as portrayed in Dynamik des atlantischen Zweiges des Agulhasstromes by Dietrich (1935b). Hydrographic data came from the vessels Africana, Discovery, Discovery II, Meteor and the Möwe. This clear depiction of the wind-driven, coastal upwelling was mistaken by Dietrich for a branch of the Agulhas Current.

It is therefore abundantly clear that this body of German research constitutes a considerable advance on what was known before on the South West Indian Ocean. What influence did this have on the planning and execution of subsequent research in the region?

3. Use made of German research findings after the Second World War

A bibliographic analysis gives a strong indication of the subsequent impact of the German research school at the *Institut für Meereskunde* at the University of Berlin. It is shown in Table 2. The papers on the abscissa constitute the most important of the 1920-1940 era that had anything to do with the South West Indian Ocean or the greater Agulhas Current system. A number (e.g. Defant, 1932-1960, 1936, 1941a and 1941b) were directly related to the exploratory cruise of the *Meteor* in the Atlantic and may seem an awkward choice here. However, the station distribution of the *Meteor* extended around the Cape of Good Hope into the South Indian Ocean and most of the results of this expedition thus included an important part of the Agulhas Current system as well. With hindsight some of these papers may be considered to be more important than others; we are convinced that this set gives a solid and representative coverage of the German oceanographic products of the time. The selection of papers on the ordinate may be more disputable. It consists of a collection of papers that appeared largely after the Second World War in a number of different countries when interest in the Indian Ocean again picked up. Some of these papers may be considered more important than others; clearly the selection has had to be somewhat subjective. Papers have been binned according to country in order to explore the possibility of a country bias. Even this is fraught with difficulties. Deacon clearly was British; the Darbyshires also, but they did their work on the Agulhas Current (Darbyshire, 1964; Darbyshire, 1966) in South Africa. Since the attitude to the German publications and research may have been cultural, we decided to place them with the British. Similarly, Duncan (1970) wrote his Ph.D. thesis in the US, but since he was South African and returned to that country after studying under Prof. Klaus Wyrtki at the University of Hawaii, we left his work in the section with that of other South Africans. The matrix of Table 2 shows some interesting results.

First, two individuals stand out for their citations of German research publications: Sverdrup and Clowes. They have some aspects in common. Both their publications can be considered reviews of what was known as the time; Sverdrup's monumental handbook (Sverdrup et al., 1942) covering the globe; that of Clowes (1950) covering only South African waters. Clowes had been educated in the UK, had played an active role in the *Discovery* cruises (e.g. Clowes & Deacon, 1935) and had taken up a position with the then Division of Sea Fisheries in South Africa (Lutjeharms & Shannon, 1997). It is possible that he wrote this review as a self-educational exercise on South African waters. A subsequent review of this nature was compiled only in 1966 (Shannon, 1966), but concentrated more on the coastal regions. More extensive reviews followed in the 1980s (e.g. Shannon, 1985).

Another factor that the publications of Sverdrup (Sverdrup et al., 1942) and Clowes (1950) have in common is that they both appeared relatively early when compared to the rest of the publication used in this table (Table 2). Figure 1 shows why this is the case. It was only in the later 1960s when there was again an increased interest in this ocean region. Lutjeharms (1982) has shown that this new interest started of with cruise proposals and news items, was followed about two years later with cruise and data reports which in turn were followed by research papers only after that. This means that a lot of the research papers appeared late in the 1960s or only in the 1970s (Table 2) extending the time between the German work of the 1930s to the new work of the 1970s even further.

A second characteristic of the citations to be seen in Table 2 shows that of all the German oceanographers of the 1920s and 1930s, Dietrich was most cited by far, but only his paper of 1935 on the southern termination of the Agulhas Current (Dietrich, 1935a). With the exception of Sverdrup, all the people who cited Dietrich's work were working in South Africa. This makes sense, since this particular paper was the best at the time to deal with this region. Nevertheless, it is interesting to note that Harris (1972), Mostert (1966) and the Darbyshires (Darbyshire, 1964; Darbyshire, 1966), also working in South Africa on the Agulhas Current system, did not quote this important work at all.

Apart therefore from Sverdrup (Sverdrup et al., 1942) and Clowes (1950) who used the German work extensively, and a number of South Africans who used one paper by Dietrich heavily, the near-total neglect of this German work is clear (Table 2). The effect this had on subsequent investigations and planning is difficult to establish. It could not but have had a negative effect. Lutjeharms and Kortum (2004) have pointed out that the influence of German oceanographic research has been small on South African oceanography precisely because so little use was made of the results achieved in the 1920s and 1930s in Germany.

4. Discussion

From the above analysis it is apparent that the work of German oceanographers in the period 1923 to 1941 established a clear benchmark for knowledge on the South West Indian Ocean. It is also clear that this whole body of work did not subsequently become part of oceanographic understanding to the degree that one would expect. What may have caused this? A number of possible reasons present themselves.

First, the period between this German work and the initiation of new research on the South West Indian Ocean may have been too long and the original papers therefore had been forgotten. This proposition is not entirely unlikely. The peak in publications in the 1930's was only exceeded on a permanent basis in the 1980s (Figure 1). However, the major impetus for research on this ocean region was the International Indian Ocean Expedition of the 1960s (Wüst, 1960), twenty years after the German effort. This does not seem a long enough period for work to be almost completely forgotten, but with the all-encompassing break caused by

the Second World War and all that this entailed, this might nevertheless be considered a lengthy period in science, particularly since hardly any publications on the region had appeared from about 1940 to 1960 (viz. Figure 1). During this intermediate period interest in the ocean region had disappeared and the total break with previous work thus caused a very sharp discontinuity. However, there are some facts that argue against this supposition of the period between the German and subsequent work being too long.

First, there is the use of many of these German publications in the textbook by Sverdrup et al. (1942). More than 9 papers were cited (Table 2) and much of what was written in this textbook on the South West Indian Ocean rested firmly on the German foundation. This book was used to train at least two post-war generations of ocean scientist and the original source of this information should therefore have become well known for a much longer period. One of the authors himself had to study this book in the late 1960s as part of post-graduate education at the University of Cape Town. Another piece of evidence that this German research remained well-known and was considered very important (Lutjeharms & Shannon, 1997) after the war is to be seen by its extensive use in the review on South African waters published by Clowes (1950), as can be seen in Table 2. Another possibility why it was so soon forgotten may be due to its scientific attributes.

Much of the German work was of a purely descriptive nature (e.g. Michaelis, 1923) and based mainly on accumulated ships' drift observations and sea surface temperatures taken from commercial vessels. By the 1960s ocean studies from such a strong geographic perspective held limited interest. A significant number of these German papers (viz. Table 1) were, however, based on hydrographic observations and showed the location of water masses and their movement (e.g. Figure 4). All this information was still of substantial use in the 1960s. It is perhaps significant that a vertical salinity section through the Mozambique Channel (Figure 4) from Möller (1933) was not referred to again, while a similar – but arguable poorer section – published by Clowes and Deacon (1935) at more or less the same time was cited for a long time afterwards. Emery (1980) has pointed out that the volumes describing the results of the *Meteor* expedition (Defant, 1932-1960) after the war "lay untouched and unread in various libraries while modern oceanographers struggled to rediscover some of their findings". The results of the *Meteor* cruises can hardly be considered to be purely geographical. The contention that the mainly geographic work by the Germans had by the 1960 lost all scientific value is therefore demonstrably false.

This is particularly true for the region directly south of Africa where the work by Dietrich (1935a, 1935b, 1938) remained the only solid oceanographic work till the 1960s. This is also clear from the use made of this work by subsequent researchers in the region such as Visser and van Niekerk (1965), Duncan (1968, 1970) and Bang (1970), as can be seen in Table 2. The case of Bang is interesting since he did cite Dietrich (1935a) in his 1970 paper, but by 1973 had stopped doing so. Had too much new information from the 1960s and the International Indian Ocean Expedition perhaps made the 1930s results redundant? Why did Dietrich's 1935a paper receive so much attention under South African

oceanographers compared to the whole body of other work by Germans in the 1930s? One of the reasons might have been that Dietrich had many personal contacts in South Africa from his visits to the country and from international meetings. However, his other publications on the same subject (Dietrich, 1935b, 1936) were never cited in subsequent influential papers, even in South Africa.

Another possibility for the neglect of the research results from the German school of oceanography could be that most of it was published in German. By the 1960s the shift of the main science language from German to English was almost complete and a decreasing number of oceanographers in the UK, South African or the US would still have been able to read German. Even so, Schell was German, though resident in the US at the time, but his 1968 paper on the west coast waters of southern Africa makes no mention of the paper by Dietrich (1935b) on a similar subject, nor to any of the other German papers of the 1930s. An interesting hypothesis on a contributing factor to a collective loss of oceanographic memory has been mentioned by Deacon (1990). She contends that, since the scale and pace of oceanographic research is so much greater now than previously, many oceanographers have largely lost contact with what has been achieved before. This has given rise in the oceanographic community to the idea that knowledge of the deep ocean in particular was minimal until the late 1950s. This in turn may lead to a total dismissal of previous work. At least one other possibility for the neglect of the pre-war German work, less appealing, is left.

Having not eliminated, but perhaps cast some doubt on some of the other reasons that can be proposed why the German oceanography of the 1930s had so little post-war impact, shear antipathy or chauvinism after the war remains as a possible cause. This is impossible to determine rigorously or to quantify, but cannot be entirely excluded. Lenz and Streicher (1997) have suggested that since the aims of the *Institut und Museum für Meereskunde* had a somewhat imperialist and militaristic nuance, the memory of the institute and its works was purposefully neglected after the Second World War. This political aspect to the institute does become apparent when one views photographs of the exhibitions in the museum at the time (Röhr, 1981) that include a large navy component.

Perhaps a large degree of ignorance due to a combination of factors is the key. In scientific terms a considerable time had passed, the papers were in a language that was foreign to most new oceanographers and Germans did not play as solid a part in the subsequent research in the South West Indian Ocean as once they had (e.g. Lutjeharms, 1982).

5. Summary and conclusions

A study of the historical development of scientific concepts concerning the greater Agulhas Current shows some quite remarkable spurts in growth of knowledge. However, an unconscionable loss of important concepts and information during certain periods has also occurred. This includes the loss of the concept of the retroflection of the Agulhas Current at its southern termination that had been so

able described by Dutch investigators in the 19th century. It also includes the loss of the whole body of work carried out in Germany in the 1930s, particularly at the *Institut für Meereskunde* in Berlin. There are some indications that in the latter case plain chauvinistic partisanship after the Second World War may have played a part in the fate that these German oceanographic results suffered. This short historical review shows that such non-scientific factors may have a considerable impeding effect on the growth of scientific knowledge.

It therefore seems clear that the loss of a body of scientific knowledge is not an archaic occurrence that cannot occur in the present age of global communication. Continuous vigilance is a necessary characteristic of good scientific practice in order to prevent the repetition of such failures of the true scientific method.

Both from an historical perspective and also for cultural reasons it seems important that the oceanographic research carried out in Germany before the Second World War starts receiving the recognition that it deserves.

Acknowledgements

This paper was prepared during a short visit by JREL to the *Leibniz-Insitut für Meereswissenschaften an der Christian-Albrechts-Universität zu Kiel* at the invitation of Prof. Dr. Gerold Siedler. It is based on an invited talk presented at the *Deutscher Wissenschaftshistorikertag* in Berlin in September of 1996. JREL thanks both these hosts for their support and hospitality

References

Anonymous, 1883: Die physische Oceanographie und Meteorologie der das Kap der Guten Hoffnung umgebenden Meerestheile im Südatlantischen und Indischen Ocean, zwischen 30° bis 50° S-Br und 10° bis 40° O-Lg. Annl. Hydrogr. mar. Meteorol., 11: 1-5, 63-69.

Bang, N. D., 1970: Dynamic interpretations of a detailed surface temperature chart of the Agulhas Current retroflexion (sic) and fragmentation area. S. Afr. geogr. J., 52: 67-76.

Bang, N. D., 1973: Oceanography: Oceanographic environment of Southern Africa. In: J. J. Spies and P. C. du Plessis (eds). Standard Encyclopedia of Southern Africa, Vol. 8, Nasou, Cape Town: 282-286.

Becker, R., 1938: Über den jährlichen Temperaturgang auf dem Indischen und Stillen Ozean. Annl Hydrogr. und Marit. Meteorol., Berlin, 66: 338-340.

Boebel, O., C. Duncombe Rae, S. Garzoli, J. Lutjeharms, P. Richardson, T. Rossby, C. Schmid & W. Zenk, 1997: Float experiment studies interocean exchanges at the tip of Africa. Eos, Trans. Am. Geophys. Un., 79, 1: 7-8.

Böhnecke, G. & A. Bückmann, 1973: Günther Dietrich † 15.11.1911 – 2.10.1972. Berich. Deut. Wissensch. Komm. Meeresforsch., 22: 463-471.

Brosin, H.-J., 1997: Meereskundliche Vorlesungen und Übungen am Institut für Meereskunde 1900-1946. Historisch-meereskundliches Jahrbuch, 4: 71- 87.

Clowes, A. J., 1950: An introduction to the hydrology of South African waters. Investl Rep. Fish. Mar. boil. Surv. Div. Un. S. Afr., 12: 42 pp.

Clowes, A. J. & G. E. R. Deacon, 1935: The deep-water circulation of the Indian Ocean. Nature, London, 136: 936-938.

Darbyshire, J., 1964: A hydrological investigation of the Agulhas Current area. Deep-Sea Res., 11: 781-815.

Darbyshire, M., 1966: Agulhas Current (and Mozambique Current). In: R. W. Fairbridge (ed), The Encyclopedia of Oceanography, Reinhold Publ. Corp., New York: 23-28.

Deacon, G. E. R., 1933: A general account of the hydrology of the South Atlantic Ocean. Discovery Rep., 7: 171-238.

Deacon, G. E. R., 1937: The hydrology of the Southern Ocean. Discovery Rep. 15, 124 pp.

Deacon, G. E. R., 1934: Die Nordgrenzen antarktischen und subantarktischen Wasser im Weltmeer. Annl Hydrogr.und Marit. Meteorol., Berlin 62, 129. [Translated as: The northern boundaries of Antarctic and subantarctic waters at the surface of the world ocean. In: M. B. Deacon (ed), Oceanography; concepts and history, Benchmark Papers in Geology 35, Dowden, Hutchinson and Ross Inc., Stroudsburg, 1978: 89-97.]

Deacon, M., 1971: Scientists and the Sea 1650-1900; a study of marine science. Acdemic Press, London: xvi + 445 pp.

Deacon, M., 1990: Preface; On the State of the Art. In: W. Lenz & M. Deacon (eds), Ocean Sciences: their history and relation to man. Dt. Hydrogr. Z. Erg.-H. B, Nr. 22: VII-X.

Defant, A., 1928: Statik und Dynamik der Atmosphäre. Handbuch der Experimentalphysik, Geophysik I. Leipzig: 1-56.

Defant, A., 1932-1960: Wissenschaftlichen Ergebnisse der Deutschen Atlantischen Expedition auf dem Forschung- und Vermessungschiff „Meteor" 1925-1927. Bände I-XVI, Berlin.

Defant, A., 1936: Ausbreitung- und Vermischungsvorgänge im antarktischen Bodenstrom und im subantarktischen Zwischenwasser. Wissenschaftliche Ergebnisse der deutschen Atlantischen Expedition auf dem Forschung- und Vermessungsschiff „Meteor" 1925-1927, 6: 53-96.

Defant, A., 1941a: Die absolute Topographie des physikalischen Meeresniveaus und der Druckflächen sowie die Wasserbewegung im Atlantischen Ozean. Wissenschaftliche Ergebnisse der deutschen Atlantischen Expedition auf dem Forschung- und Vermessungschiff „Meteor" 1925-1927, 6: 191-260.

Defant, A., 1941b: Die relative Topographie einzelner Druckflächen im Atlantischen Ozean. Wissenschaftliche Ergebnisse der deutschen Atlantischen Expedition auf dem Forschung- und Vermessungschiff „Meteor" 1925-1927, 6: 183-190.

De Ruijter, W. P. M., H. Ridderinkhof , J. R. E. Lutjeharms, M. W. Schouten & C. Veth, 2002: Observations of the flow in the Mozambique Channel. Geophys. Res. Lett.. 29: 1401-1403.

Dietrich, G., 1935a: Aufbau und Dynamik des südlichen Agulhasstromgebietes. Veröffentl. Inst. Meeresk. Uni. Berlin , N.F. A27: 79 pp.

Dietrich, G., 1935b: Zur Dynamik des Atlantischen Zweiges des Agulhasstromes. Annl Hydrogr.und Marit. Meteorol., 63: 383-387.

Dietrich, G., 1936: Aufbau und Bewegung von Golfstrom und Agulhasstrom, eine vergleichende Betrachtung. Naturwissenschaften, 24: 225-230.

Dietrich, G., & K. Kalle, 1957: Allgemeine Meereskunde; eine Einführung in die Ozeanographie. Gebr. Borntträger, Berlin-Nikolassee: 492 pp.

Donguy, J. R. & B. Piton, 1969: A perçu des conditions hydrologiques de la partie nord du canal de Mozambique. Cah. ORSTOM Oceanogr. 7: 3-26.

Duncan, C. P., 1968: An eddy in the subtropical convergence southwest of South Africa. J. Geophys. Res. 73: 531-534.

Duncan, C. P., 1970: The Agulhas Current. Ph.D. dissertation, University of Hawaii: 76 pp.

Ehrenberg, (C. G.), 1864: Beitrag zur Kenntiniss der unterssischen Agulhas-Bank and der Südspitze Afrikas als eines sich kundgebenden grünsandigen Polythalamine-Kalkfelsens. Monatsberichte Königl. Preuss. Akad. Wissensch. Berlin: 379-394.

Emery, W. J., 1980: The *Meteor* expedition , an ocean survey. In: M. Sears & D. Merriman (eds), Oceanography. The Past, Springer-Verlag, New York: 690- 703.

Engelmann, G., 1969: Christian Gottfried Ehrenberg; ein Wegbereiter der deutschen Tiefseeforschung. Deut. Hydrogr. Z. 22: 145-157.

Engelmann, G., 1997: Die Gründungsgeschichte des Instituts und Museum für Meereskunde in Berlin 1899-1906. Historisch-meereskundliches Jahrbuch, 4: 105-122.

Findlay, A. G., 1866: A directory for the navigation of the Indian Ocean. Richard Holmes Laurie, London: 113 pp.

Frenzel, C. A., 1904: Major James Rennel; der Schöpfer der neueren englishen Geographie. Inaugural Dissertation, Universität Leipzig: 191 pp.

Hamon, B. V., 1967: Medium-scale temperature and salinity structure in the upper 1500 m. in the Indian Ocean. Deep-Sea Res. 14: 169-182.

Harries, H. D., 1932: Über die Veränderlichkeit von Monatswerten meteorologischer und hydrologischer Elementen der Äquatorialsee. Annl Hydrogr. Berlin 60: 496-499.

Harris, T. F. W., 1972: Sources of the Agulhas Current in the spring of 1964. Deep-Sea Res. 19: 633-650.

Institut für Meereskunde, 1973: Günther Dietrich † 2. Oktober 1972. Christina Albertina, Kieler Uni.-Zeitschr. 15: 92-93.

Institut für Meereskunde, 1994: 300 Jahre Meeresforschung an der Universität Kiel; ein historischer Rückblick. Bericht. Instit. Meeresk. Christian-Abrechts-Uni. Kiel 246: 58 pp.

James, P. E., 1936: The geography of the oceans; a review of the work of Gerhard Schott. Geogr. Rev. 26: 664-669.

Kortum, G., 1980: Frühe deutsche Ansätze zur physischen Geographie des Meeres. In: M. Büttner (Hrsg.). Abhandlungen und Quellen zur Geschichte der Geographie und Kosmologie. Band 2. Ferdinand Schoningh Verlag, Paderborn: 221-256.

Kortum, G., 1983: Ferdinand von Richthofen (1833-1905) und die Kunde vom Meer. Schr. Naturwiss. Ver. Schlesw.-Holst. 53: 1-32.

Kortum, G., 1990: An unpublished manuscript of Alexander von Humboldt on the Gulf Stream. In: W. Lenz & M. Deacon (eds), Ocean Sciences: their history and relation to man, Dt. Hydrogr. Z. Erg.-H. B. Nr. 22: 122-129.

Kortum, G., 1993: Überfahrten in die Neue Welt – Die Atlantikquerungen von Christoph Kolumbus (1492) und Alexander von Humboldt (1799) im ozeanographiegeschichtlichen Vergleich. Z. geol. Wiss. 21.: 605-616.

Kortum, G. & I. Schwarz, 2004: Alexander von Humboldt und Matthew Fontaine Maury- two pioneers of marine sciences. Historisch-meereskundliches Jahrbuch, 10: 157- 185.

Krauß, W., 1990: The Institute of Marine Research in Kiel. In: W. Lenz & M. Deacon (eds), Ocean Sciences: their history and relation to man. Dt. Hydrogr. Z. Erg.-H. B, Nr. 22: 131-140.

Krümmel, O., 1887. Die Bewegungsformen des Meeres. Handbuch der Ozeanographie, Band II. J. Engelhorn, Stuttgart: 592 pp.

Kuksa, V. I., 1972: Some peculiarities of the formation and distribution of intermediate layers in the Indian Ocean. Oceanol., 12: 21-30.

Lenz, W., 1986: Gerhard Schott 1866-1961. DGM-Mitteil., 1/86: 19-22.

Lenz, W., & S. Streicher, 1997: Vorwort der Schriftleitung. Historisch-meereskundliches Jahrbuch, 4: 7.

Lenz, W., 1997: Über die Entwicklung maritimer Interesse Preußens und seiner Meeresforschung 1640 bis 1900. Historisch-meereskundliches Jahrbuch, 4: 9-18.

Le Pichon, X., 1960: The Deep Water circulation in the Southwest Indian Ocean. J. Geophys. Res., 65: 4061-4074.

Lüdecke, C., 1997: Erich von Drygalski und die Gründung des Instituts und Museums für Meereskunde. Historisch-meereskundliches Jahrbuch, 4: 19-36.

Lutjeharms, J. R. E., 1981: Features of the southern Agulhas Current circulation from satellite remote sensing. S. Afr. J. Sci., 77: 231-236.

Lutjeharms, J. R. E., 1982: Die geskiedkundige ontwikkeling van fisiese navorsing oor die oseane grensend aan Suider-Afrika. S.-Afr. Tydskr. Natuurwet. Tegnol. 1: 42-52.

Lutjeharms, J. R. E. & A. L. Gordon, 1987: Shedding of an Agulhas Ring observed at sea. Nature, London: 138-140.

Lutjeharms, J. R. E., 1991: Twintig jaar fisiese oseanografie in Suid-Afrika: 'n persoonlike beskouing. S. Afr. Tydskrif Seewet., 10: 305-320.

Lutjeharms, J. R. E., W. P. M. de Ruijter & R. G. Peterson, 1992: Interbasin exchange and the Agulhas retroflection; the development of some oceanographic concepts. Deep-Sea Res., 39: 1791-1807.

Lutjeharms, J. R. E. & C. P. Matthysen, 1995: A recurrent eddy in the upwelling front off Cape Town. *S. Afr. J. Sc.*, 91: 355-357.

Lutjeharms, J. R. E. & L. V. Shannon, 1997: A century of physical oceanography in South Africa; in search of the legacy of John D. Gilchrist. In: A. I. L. Payne & J. R. E. Lutjeharms (eds). A Century of Marine Science in South Africa. Sea Fisheries Research Institute, Royal Society of South Africa: 17-30.

Lutjeharms, J. R. E., W. P. M. de Ruijter, H. Ridderinkhof, H. van Aken, C. Veth, P. J. van Leeuwen, S. S. Drijfhout, J. H. F. Jansen & G.-J. A. Brummer, 2000: MARE and ACSEX: new research programmes on the Agulhas Current system. S. Afr. J. Sci., 96: 105-110.

Lutjeharms, J. R. E. & I. J. Ansorge, 2001: The Agulhas Return Current. *J. mar. Syst.*, 30: 115-138.

Lutjeharms, J. R. E. & G. Kortum, 2004: On the influence of German marine research on South African physical oceanography since 1890. In: S. Morcos et al. (eds), Ocean sciences bridging the millenia. A spectrum of historical accounts. UNESCO & China Ocean Press: 229-250.

Marcinek, J., 1997: Albrecht Penck – Förderer der Kunde vom Meer. Historisch-meereskundliches Jahrbuch, 4: 37-44.

Maury, M. F., 1856: The physical geography of the sea. Sampson Low, London: 348 pp., 13 plates.

Menaché, M., 1966: Première campagne océanographie du "Commandant Robert Giraud" dans le canal de Mozambique 11 octobre – 28 novembre 1957. Cah. Océanogr., 15: 224-235.

Merz, A., 1925: Vorbericht. Die Deutsche Atlantische Expedition auf dem Vermessungs- und Forschungsschiff "Meteor". Preussische Akademie der Wissenschaften, 31: 562-586.

Michaelis, G., 1923: Die Wasserbewegung an der Oberfläche des Indischen Ozeans im Januar und Juli. Veröffentl. Inst. Meeresk. Uni. Berlin N. F. A8: 32 pp.

Mills, E., 1997: "Physikalische Meereskunde": from geography to dynamical oceanography in the Institut für Meereskunde. Historisch-meereskundliches Jahrbuch, 4: 45-70.

Möller, L., 1929: Die Zirkulation des Indischen Ozeans; auf Grund von Temperatur- und Salzgehaltstiefenmessungen und Oberflächenstrombeobachtungen. Veröffentl. Inst. Meeresk. Uni. Berlin N. F. A21: 48 pp.

Möller, L., 1933: Zur Frage der Tiefenzirkulation im Indischen Ozean. Annl Hydrogr. und Marit. Meteorol. Berlin 61: 233-236.

Mostert, S. A., 1966: Distribution of inorganic phosphate and dissolved oxygen in the South West Indian Ocean. Investl Rep. Div. Sea Fish. S. Afr., 54: 24 pp.

Muromtsev, A. M., 1958: Plotnost' vody na poverkhnosti Indiiskogo Okeana. (Water density on the surface of the Indian Ocean.) Dokl. Akad. Nauk SSSR, 123: 1014-1017.

Neubert, H.-J., 1997: Das öffentliche Vortragswesen des Instituts für Meereskunde. Historisch-meereskundliches Jahrbuch, 4: 88-94.

Nöthlich, K., 1974: Professor Dr. Lotte Möller zum Gedächtnis. Arch. Hydrobiol., 74: 133-136.

Orren, M. J., 1963: Hydrological observations in the South West Indian Ocean. Invest. Rep. Div. Sea Fish. S. Afr., 45: 61 pp.

Paech, H., 1926: Die Oberflächenströmungen um Madagascar in ihrem jährlichen Gang. Veröffentl. Inst. Meeresk. Uni. Berlin N. F. A16: 39 pp.

Payne, A. I. L. & J. R. E. Lutjeharms (eds), 1997: A Century of Marine Science in South Africa. Sea Fisheries Research Institute, Royal Society of South Africa: 252 pp.

Petermann, A., 1865: Karte der aktische und antarktischen Regionen zur Übersicht des geographischen Standpunktes im Jahre 1865. Petermanns Geograph. Mitt., Tafel 5, Gotha.

Peterson, R. G., L. Stramma & G. Kortum, 1996: Early concepts and charts of ocean circulation. Progr. Oceanogr., 37: 115 pp.

Rennell, J., 1832: An investigation of the currents of the Atlantic Ocean, and of those which prevail between the Indian Ocean and the Atlantic. J. G. and F. Rivington, London, editor J. Purdy: viii + 359 pp. + 2 folding maps.

Ridderinkhof, H., J. R. E. Lutjeharms & W. P. M. de Ruijter, 2001: A research cruise to investigate the Mozambique Current. S. Afr. J. Sci., 97: 461 - 464.

Röhr, A., 1981: Bilder aus dem Museum für Meereskunde in Berlin 1906-1945. Deutsches Schiffahrtsmuseum Bremerhaven: 72 pp.

Roll, H. U., 1990: On the roots of oceanography in Germany. In: W. Lenz & M. Deacon, Ocean Sciences: their history and relation to man. Dt. Hydrogr. Z. Erg.-H. B, Nr., 22: 3-19.

Römer, E., 1939: The countercurrent off the south and southeast African coast. Hydrogr. Rev., 16: 88-91.

Schell, I. I., 1968: On the relation between the winds off southwest Africa and the Benguela Current and the Agulhas Current penetration in the South Atlantic. Dt Hydrogr. Z., 21: 109-117.

Schmidt, J., 1932: Dana's togt omkring Jorden 1928-1930. Kopenhagen: 255 ff.

Schott, G., 1926: Die Tiefenwasserbewegung des Indischen Ozeans. Annl Hydrogr. und Marit. Meteorol. Berlin, 54: 417-431.

Schott, G., 1928: Die Verteilung des Salzgehaltes im Oberflachenwasser der Ozeane. Annl Hydrogr. und Marit. Meteorologie. Berlin, 5: 145-166.

Schott, G., 1935: Geographie des Indischen und Stillen Ozeans. C. Boysen: 413 pp., 37 plates.

Schott, G., 1936; Die Aufteilung der drei Ozeane in natürliche Regionen. Petermanns Geogr. Mitt., 82: 165-170.

Schott, G., 1944: Geographie des Atlantischen Ozeans, 3rd Edit., C. Boysen: 438 pp., 38 plates.

Schott, W., 1987: Early German oceanographic institutions, expeditions and oceanographers. Deutsches Hydrographisches Institut: 50 pp.

Schulz, B., 1936: Zur Vollendung des 70. Lebensjahres von Gerhard Schott. Ann. Hydrogr. Mar. Meteorol., 8: 329-335.

Shannon, L. V., 1966: Hydrology of the south and west coasts of South Africa. Invest. Rep. Div. Sea. Fish. S. Afr., 58: 62 pp.

Shannon, L. V., 1985: The Benguela Ecosystem. 1. Evolution of the Benguela, physical features and processes. Oceanogr. mar. Biol. Annl Rev., 23: 105-182.

Shcherbinin, A. D., 1969: Water structure of the equatorial Indian Ocean. Oceanol., 9: 487-495.

Sverdrup, L. V., H. W. Johnson & R. H. Flemming, 1942: The Oceans; their Physics, Chenistry and General Biology. Prentice Hall, Englewood cliffs: 1087 pp.

Taft, B. A., 1963: Distribution of salinity and dissolved oxygen on surfaces of uniform potential specific volume in the South Atlantic, South Pacific, and Indian Oceans. J. mar. Res., 21: 129-146.

Thomsen, H., 1933: The circulation in the depths of the Indian Ocean. J. Cons. Perm. Int. Explor. Mer, 8 : 73-79.

Thomsen, H., 1935: Entstehung und Verbreitung einiger charakteristischer Wassermassen in dem Indischen und südlichen Pazifischen Ozean. Annl Hydrogr. und Marit. Meteorol., 63: 293-305.

Tomczak, M., 1980: A review of Wüsts classification of the major deep-sea expeditions 1873-1960 and its extension to recent oceanographic research programs. In: M. Sears & D. Merriman (eds), Oceanography: the Past. New York: 188-194.

Ulrich, J., & G. Kortum, 1997. Otto Krümmel (1854-1912): Geograph und Wegbereiter der Ozeanographie. Kieler geogr. Schr., 93: 310 pp. + 8 plates.

Van Gogh, J., 1857: Uitkomsten van Wetenskap en Ervaring aangaande winden en zeestromingen in sommige gedeelten van den oseaan. Koninkl. Ned. Meteorol. Inst., Bosch en Zoon: 74 pp.

Van Riel, P. M., 1932: Einige ozeanographische Beobachtungen im Roten Meer, Golf van Aden und Indischen Ozean. Annl. Hydrogr. und Marit. Meteorol., Berlin, 60: 401-407.

Visser, G. A. & M. M. van Niekerk, 1965: Ocean currents and water masses at 1,000, 1,500 and 3,000 metres in the South-West Indian Ocean. Invest. Rep. Div. Sea Fish. S. Afr., 52: 46 pp.

Wattenberg, H., 1933: Kalziumkarbonat- und Kohlensäuregehalt des Meereswassers. Wissenschaftlichen Ergebnisse der deutschen Atlantischen Expedition auf dem Forschung- und Vermessungschiff „Meteor" 1925-1927, 8: 233 pp.

Wellman, F., 1936: Östliche Stromversetzung and der südostafrikansiche Küste im Juli. Seewart, 5.

Willimzik, M., 1929: Die Strömungen im Subtropischen Konvergenzgebiet des Indischen Ozeans. Veröffentl. Inst. Meeresk. Uni. Berlin N. F. A14: 1-27.

Wüst, G., 1930: Meridionale Schichtungen und Tiefenzirkulation in den Westhälften der drei Ozeane. J. cons. Perm. Int. Explor. Mer., 5: 7-21.

Wüst, G., 1934; Anzeichen von Beziehungen zwischen Bodenstrom und Relief in der Tiefsee des Indischen Ozeans. Naturwissenschaften, 22: 241-244.

Wüst, G., 1935a: Die Ausbreitung des antarktischen Bodenwassers im Atlantischen und Indischen Ozean. Zeitschr.Geophys., 11: 40-49.

Wüst, G., 1935b: Zur Frage des Indischen Tiefenstroms. Naturwissenschaften, 23: 137-139.

Wüst, G., 1938: Bodentemperatur und Bodenstrom in der atlantischen, indischen und pazifischen Tiefsee. Beitr. Geophys., 54: 1-8.

Wüst, G., 1960: Proposed International Indian Ocean Expedition, 1962-1963. Deep-Sea Res., 6: 245-249.

Wüst, G., 1964: The major deep-sea expeditions and research vessels 1873-1960; a contribution to the history of oceanography. Progr. Oceanogr., 2: 3-52.

Zaklinskii, G. B., 1963: Deep circulation of water in the Indian Ocean. Deep-Sea Res., 11: 286-293.