Sediment sampling and hydrographic
observations off Walvis Baai, S.W. Africa,
dec. 1968 - jan. 1969.

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Introduction

Between december 22, 1968 and january 31, 1969 plankton samples and bottom sediment were collected near Walvis Baai, S.W. Africa, by Dr. M. Brongersma-Sanders (Geological Institute, State University, Leiden), Dr. D. Eisma (Netherlands Institute for Sea Research, Den Helder) and Mr. L. Spaans (Royal Dutch Shell Exploration and Production Laboratory, Rijswijk).

The Walvis Baai area is characterized by the occurrence of upwelling water along the coast. The upwelling water is colder than the surface water of the Atlantic Ocean further west, and it forms the cold Benguela current which generally flows northward along the coast with velocities of up to one knot. As a result of upwelling nutrients are brought to the surface where, under the influence of light and a higher temperature, relatively dense plankton populations develop. Consequently, animal life in general, of benthos as well as of fish, birds and mammals, is rich. The large production of organic matter leads to large amounts of decaying organic matter on or near the bottom and as a result there is large scale consumption of the oxygen dissolved in the water. In an area off Walvis Baai this leads to permanent or near-permanent anoxic conditions near the sea floor which thus is devoid of any benthic life other than anaerobic bacteria. Organic decomposition products accumulate here while, moreover, metals concentrated by the dead plankton may be fixed as sulphides. Thus together with an accumulation of organic compounds there may be an accumulation of metals.

The land bordering the sea around Walvis Baai is a flat desert plain, which south of Walvis Baai, and to a smaller extent also between Walvis Baai and Swakopmund, is covered by high dunes. North of the large dune field which extends southward as far as Orange River, the plain is crossed by a few dry river valleys. The desert is due to the same cause as the upwelling, i.e. the S-SE tradewinds. The wind pattern nearshore is complicated by the heating up during the day of the desert so that, especially during the summer, a strong afternoon breeze blowing for S-SW may develop.

The sampling project carried out in december 1968-january 1969 was set up by M. Brongersma-Sanders in order to collect plankton and bottom sediment for analysis of trace elements and hydrocarbons, and to determine the nature and extent of the "azoïc" zone off Walvis Baai. The bottom sediment sampling on the continental shelf was carried out with the R.S. "Benguela" of the Marine Research Laboratory, Walvis Baai, by D. Eisma and L. Spaans, the letter being responsible for the coring. During this survey also water samples were taken and a bathythermograph lowered at a number of stations in order to get an idea of the hydrographic conditions during the period of sampling. This was made possible by the kind cooperation of Mr. F. Schülein, Mr. J.H. Vorster and Mr. H. Smit, all of the Marine Research Laboratory, Walvis Baai, who carried out the water sampling and also otherwise assisted in every possible way. The oxygen titrations were carried out by Mrs. M. Hellmann.

Field work and methods

Sampling was carried out along the lines A-I indicated in fig. 1. A station list is given in Table I. Bottom samples were collected with a 0.1 m^2 Van Veen grab and a 350 kg gravity corer. From the grab samples two sediment samples were taken and the remainder sieved through a 2 mm sieve. The fraction > 2 mm was preserved on formalin. A short description of sediment and coarse fraction was made on deck and added to the other data on the station list. Halfway on line D the grab was damaged so that on the remaining stations of line D as well as on those of lines F and I only core samples were taken. The grab samples and the cores were partly frozen at -20^oC immediately after having been brought on deck. The cores were kept upright as much as possible.

Water samples were mainly taken with Ekman-Munro reversing water bottles and in some cases with a Nansen-Petterson water bottle. The Ekman-Munro bottles were provided with three protected thermometers and at greater depths one protected thermometer was occasionally exchanged for an unprotected one. From the bottles samples were taken for the determination of salinity and oxygen content. In the laboratory salinity was determined with an Autolab salinometer and oxygen content with the Winckler method without any modification for the presence of H_2S. This means that at low oxygen contents the values found for oxygen may be up to 0.2 ml too low. (Hart and Currie 1960).

A bathy-thermograph was lowered at a number of stations (cf. fig. 1). A Simrad echosounder was put on throughout the sampling period. The bottom profiles along the sampling lines are shown in fig. 2.

Sediment distribution

From the descriptions made of the sediment during sampling a provisional bottom sediment map was made (fig. 3). The following sediment types could be distinguished (the numbers correspond with the numbers on fig. 3):

1(1) dark green fine soft mud with strong H_2S-smell; fish scales and bones.

1(2) soft green mud, weak or no H_2S-smell (usually only a slight smell when the sediment is disturbed for sampling), fish scales and bones, dead mollusks (small Gastropods and Pelecypods) and shell fragments.

1(3) soft green mud with (usually abundant) living macrofauna, chiefly Pelecypods.

2. rather soft green mud with fine sand (foraminifera?) and abundant living macrofauna (predominantly mollusks). Abundant dead yellow-white shells and shell fragments.

3. mostly fine, hard-packed grey sand, sometimes coarse sand and fine gravel. The finer sands have an abundant living macrofauna (worms, mollusks, small crustaceae).

3'. muddy sand with strong H_2S-smell; no living macrofauna.

4. dark grey greenish sediment, rather hard-packed and fine with a coarse admixture (shell fragments), with living macrofauna, mainly Pelecypods.

5. fine stiff light-grey sediment with many shell fragments.

6. rather soft greyish ooze.

Previous collecting of bottom sediment in this area was carried out

a) in 1926-1927 as part of a fisheries survey (Von Bonde 1928, Marchand 1928)
b) by the R.R.S. "William Scoresby" in september-october 1950 (Hart and Currie 1960)
c) by the Danish Deep Sea Expedition (R.S. "Galathea") in december 1951 (cited in Copenhagen 1953).

The results of the 1926/1927 survey are summarized in fig. 4. The following types of sediment were distinguished (the numbers correspond with those in fig. 4):

1. grey sands, mainly fine, sometimes muddy
2. soft (dark) green mud, sometimes with fish bones , always with a bad smell (Von Bonde 1928). Marchand (1928) found abundant remains of diatoms, radiolarians and sometimes sponge spiculae in this sediment. At the edges of the area covered by this sediment, samples occurred containing dead shells (Von Bonde 1928) whereas Marchand (1928) describes "Mixed sediments" containing foraminifera and occasionally quartz grains besides diatoms, radiolarians and sponge needles.

3. soft (dark) green mud with shells (Von Bonde 1928) described by Marchand (1928) as being of fine-medium grade and containing various species of foraminifera.
4. light or yellow-green mud with fine yellow sand (Von Bonde 1928) described by Marchand (1928) as fine sediment consisting mainly of Globigerina.

The area covered by the bad smelling dark green mud was called the "azoic" zone by Von Bonde (1928) and Marchand (1928) due to the absence of macrobenthos. It was found to reach from about 21°30'S to about 24°30'S, extending 25-30 miles west, i.e. up to a depth of 77-84 fathoms. Hart and Currie (1960) found azoic muds, at least patchily, between 25°S and the Kunene river mouth (17°30'S). The Danish Deep Sea expedition however, found an abundant living benthonic macrofauna off Conception Bay and Sandwich Harbour in the "azoic" area (Copenhagen 1953) and Copenhagen (1953) suggested that between 1928 and 1951 probably considerable changes had taken place. Also the results obtained in 1969 show that anoxic conditions near the bottom are far from permanent in the larger part of the "azoic" zone. Only sediment type $1^{(1)}$ is totally devoid of the remains of benthic macrofauna whereas all sediments of type $1^{(2)}$ contain dead mollusks and fragments indicating that at least one prolongued period of oxygenation and benthic mollusk life occurred.

Whether diatomaceous muds occur farther south of 25°S is not clear. The survey list of 1926-1927 mentiones some "green mud"'s. Hart and Currie (1960) suggest that in this area the diatomaceous sediment is kept in an aerobic state.

Thickness of the diatomaceous mud

Subbottom reflections were seen on the echograms on all lines except line I (fig. 5). They occur only in the area covered with the soft muddy sediment of type 1. The topography of the subbottom usually is rather irregular whereas on most lines the surface layer can be seen tapering off towards the sides. The maximum thickness of the surface layer measured along each line are indicated in fig. 5 (in fathoms). On lines A, B, C, D, G and H the subbottom reflections are sharp and usually continuous but those on lines E and F are far less clear and more discontinuous. Especially on line E some of the secondary reflections may not be subbottom reflections at all but indicate difference in the state of consolidation of the mud or irregularities of the instrument. Greater sediment thickness (> 7.5 fathoms) or the formation of gas (H_2S) bubbles in the sediment may also cause the less clear subbottom reflections on lines E and F.

<u>Hydrography</u>

The distribution of temperature, salinity, and oxygensaturation along the lines F, D, E and H are given in fig. 6, 7, 8 and 9.
Two hydrographic processes are important off Walvis Baai (Stander 1962, 1963, 1964, Du Plessis 1967):

a) upwelling

b) thermocline formation.

The upwelling is due to removal of surface oceanwater in an offshore direction by the S-SE trade winds. Water of deeper layers comes up to compensate for this removal. Upwelling occurs all along the south-west African coast between Cape Town (34°S) and the Kunene (17°S) but is strongest between the Orange river (28°30'S) and Lüderitz (26°30'). Between Cape Town and Orange river upwelling is most conspicuous during the summer when this area is under the influence of the S-SE trades, whereas during the winter this area comes regularly under the influence of the west-east moving depressions with predominantly westerly winds. Upwelling is then at a minimum. North of 23°S there is also a reduction: upwelling is at a minimum during late summer and autumn when the influence of the S-SE trades is minimal, and at a maximum during winter and spring. Whereas the upwelling in general is generated by the trade winds the more local winds nearshore probably influence the smaller regional differences and the formation of "cells" (Hart and Currie 1960). Off Walvis Baai however this not clear (Stander 1962): during autumn and winter and spring, the wind is mostly southerly (S-SSE) whereas during the summer there is a shift to SSW. The strongest winds come, in any season, from the southerly directions, the northerly winds being far less frequent and less strong. Stander (1963) found that when the winds are more southerly the surface temperature (0-20 m depth) tends to be lower, suggesting an increase in upwelling. The depth from where water may reach the surface is usually 150-250 m, near Orange river > 350 m but occasionally may be as much as 500 m.

The thermocline forms during the summer when solar radioation is strongest. Thus off Walvis Baai there is an inverse relationship between upwelling and thermocline formation: when upwelling reaches a minimum thermoclines appear most frequently and vice versa. (Du Plessis 1967). South of Orange river the maximum upwelling coïncides with the period of maximum solar radiation but this does not influence much the formation of the thermocline: at 32°-33°S (Lambert Bay - Saldanha Bay) the frequency of thermoclines during summer and autumn is 86-87 % (Duncan 1964), whereas off Walvis Baai (23°S) the summer frequency is 86%. Also the gradients at 32°-33°S are comparable to those off Walvis Baai. It follows that the solar heating up of the surface water during the summer is usually strong enough to counter act the disruptive effects of upwelling.

The profiles given in fig. 6, 7, 8 and 9 thus are typical summer profiles. There is some evidence of upwelling especially visible in the isotherms and the isopycnals, but no deep water directly reaches the surface. Everywhere a thermocline is present especially nearshore (Table III)where the strongest gradients and, except at line E, the highest surface temperatures are found. The salinity distribution indicates some degree of mixing on the shelf: there is a tendency towards a uniform salinity of about 35.05°/oo S. Well mixed water is normal on the shelf off Walvis Baai for the greater part of the year: normally the layering is much less pronounced than found here (Stander 1962). At the shelf edge the surface water has a salinity of about 35.05°/oo, which also is found at about 200 m.

At intermediate depths salinity increases to 35.10 - 35.15 °/oo S. This tongue of more saline water is usually present at the shelf edge off Walvis Baai but occasionally advances well up the shelf (Stander 1962). It forms the edge of the oceanic water that on the shelf has been replaced, and is partly overlain by upwelled water.

The oxygen saturation generally decreases rapidly with depth. Also evident is the decrease in oxygen saturation of the near-bottom water going from the shelf edge towards the coast. Nearshore values of 0-10% are reached. Complete anoxic conditions, however, are only reached on line D.

The TS-relation for the shelf water off Walvis Baai is compared with the TS-relation for the open ocean at 23°S (after Stander 1964) in fig. 10. The shelfwater characteristics can be explained by upwelling of water of 10-12°C and 34.9-35.0 °/oo S. This water is gradually heated up and mixed with saltier water from higher levels. At the surface the temperature increases to 17°-18° C. The water of 10°-12° C and 34.9-35.0 °/oo S is found offshore at a depth of 200-300 m (at line H already at 150 m). The fact that an admixture of water from shallower depths must be assumed in order to explain the characteristics of the shelf water, indicates that as the deeper water moves up it becomes gradually mixed with water from shallower depths. This implies a certain amount of downwelling of the upper water on the shelf.

The formation of the azoic zone

The core of the azoic zone is situated off Walvis Baai - Wlotska baken, whereas the at least temporarily azoic zone lies between Sandwich Harbour and Cape Cross, probably extending from 25°S to 17°30'S. Anoxic conditions in the near bottom water are mainly dependent on the ratio between the rate of oxygen supply and the rate of oxygen consumption. Stander (1964) has shown that azoic conditions tend to develop on the shelf next to an oxygen-poor layer (< 1 ml O_2/l) in the adjacent ocean situated at 200-400 m depth. This is the depth from where the upwelling water most frequently derives. When this water moves up there is no addition of oxygen apart from some admixture of water from shallower depths. Also when more stable conditions develop during the summer aeration is at a minimum because of the thermocline. While thus the possibilities of oxygenation of the bottom shelfwater are minimal, the consumption of oxygen is strongly favoured between 25°S and 17°30'S because of the high productivity of the surface water. This productivity is highest between Walvis Baai and Cape Cross, as can be seen in fig. 11 (after Du Plessis 1967: the numbers indicate million cells per litre), which is probably due to the development of a very pronounced thermocline in this area. Moreover high productivity occurs in the shallow Walvis Baai. It follows that the core of the azoic area is situated where low oxygen supply and high productivity at the surface coïncide.

Plankton

Only small amounts of plankton were found in the open sea during the survey. Nets of different mesh width were lowered when the turbidity or the colour of the water looked promising but only small amounts were collected, i.e. in no sufficient amounts for chemical analysis.

Summary

Preliminary results of a sediment water sampling program carried out off Walvis Baai, S.W. Africa, in dec. 1968 - jan. 1969 were summarized. Grab samples and core samples were collected along nine lines. A provisional bottom map was drawn and the presence of azoic sediment discussed in relation to the hydrography. The distribution of temperature, salinity, density and oxygen concentration was determined along four lines. Typical summer profiles were found with a strong thermocline and relatively inconspicuous upwelling.

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Table I. Station list.

line	station nr.	position	depth (m)	date	stationtime beginning	stationtime end	type of sample	description of sediment	description of coarse fraction	remarks
A	1	21°25'S 14°43'E	14.5	13-1-69	19.35	19.39	grab	fine grey sand	many worms, small Crustaceae	-
A	2	21°25'S 13°43'E	34	13-1-69	19.20	19.25	grab	fine grey sand	worms, mollusks anemones, small Crustaceae	-
A	3	21°25'S 13°39'E	78	13-1-69	18.36	18.52	grab	green mud	worms, Gastropods many fish scales and bones	-
A	4	21°25'S 13°34'E	102	13-1-69	17.58	18.05	grab	green mud, H_2S smell	Pelecypods, Gastropods, many fish scales and bones	-
A	5	21°25'S 13°28'E	110	13-1-69	17.14	17.24	grab	dark greenish grey sediment	Pelecypods, Gastropods, some worms, many shell fragments and grit	-
A	6	21°25'S 13°20.3'E	128	13-1-69	16.22	16.40	grab	fine sandy green mud many shells and fragments	many yellow-white shells and fragments	-
A	7	21°25'S 13°16.7'E	143	13-1-69	15.40	15.50	grab	fine sandy green mud, many shells and fragments	many yellow-white shells and fragments	-
B	1	21°43'S 13°57'E	13	13-1-69	07.00	07.23	grab core	sandy mud, H_2S smell	some worms, seal's hair? fish scales	-
B	2	21°43'S 13°54'E	18	13-1-69	07.55	08.00	grab	sandy mud, H_2S smell	many worms, some Pelecypods, fish scales and bones	-
B	3	21°43'S 13°48'E	69.5	13-1-69	08.30	08.40	grab	green mud	some Gastropods, many fish scales and bones	-

line	station nr.	position	depth (m)	date	stationtime beginning	end	type of sample	description of sediment	description of coarse fraction	remarks
B	4	21°43'S 13°43'E	99	13-1-69	09.12	09.54	grab	green mud	Gastropods, many fish scales and bones, shell fragments	grab did not work properly
B	5	21°43'S 13°37'E	117	13-1-69	10.24	11.05	grab core	green mud	Pelecypods, Gastropods, shell fragments, fish scales	"
B	6	21°43'S 13°32.5'E	128	13-1-69	11.40	11.50	grab	dark greenish grey sediment	many yellow-white shells and fragments	-
B	7	21°43'S 13°27.5'E	146	13-1-69	12.26	13.30	grab core	fine sandy green mud, many shells and fragments	Pelecypods, abundant yellow-white fragments and shells	-
C	1	22°10'S 14°15'E	18	14-1-69	06.27	06.34	grab	thin fine mud layer on hard grey sand and fine gravel	some shell fragments	-
C	2	22°10'S 14°11.5'E	32	14-1-69	06.50	06.55	grab	fine grey gravel	some shell fragments	-
C	3	22°10'S 14°06'E	62	14-1-69	07.26	08.00	grab core	green mud slight H_2S smell	some dead shells and fragments, many fish scales and bones	-
C	4	22°10'S 14°00'E	88	14-1-69	08.34	08.52	grab	green mud slight H_2S smell	shell fragments many fish scales and bones	-
C	5	22°10'S 13°54.5'E	101	14-1-69	09.24	09.34	grab	green mud slight H_2S smell	shell fragments many fish scales and bones	grab did not work properly

line	station nr.	position	depth (m)	date	stationtime beginning	stationtime end	type of sample	description of sediment	description of coarse fraction	remarks
C	6	22°10'S 13°49'E	115	14-1-69	10.08	10.14	grab	green mud slight H_2S smell	Pelecypods, Gastropods, many fish scales and bones	-
C	7	22°10'S 13°44'E	126	14-1-69	10.48	11.18	grab	dark greenish grey sediment	Pelecypods, Gastropods, shell fragments	-
C	8	22°10'S 13°38'E	143	14-1-69	11.54	12.04	grab	fine sandy green mud	Pelecypods, many worms, abundant yellow-white shell fragments	-
C	9	22°10'S 13°33.5'E	162	14-1-69	12.36	13.12	grab	fine sandy green mud	abundant yellow-white shell fragments	-
C	10	22°10'S 13°28.5'E	198	14-1-69	13.44	14.00	grab	fine sandy green mud	Pelecypods, some worms, fine yellow-white shell fragments	-
C	11	22°10'S 13°17.2'E	225	14-1-69	14.55	15.20	grab	fine sandy green mud	Pelecypods, many worms, fine yellow-white shell fragments	-
C	12	22°10'S 13°08'E	310	14-1-69	16.21	16.48	grab	fine sandy green mud	Pelecypods, fine yellow-white shell fragments	-
D	1	22°30'S 14°26'E	16.5	18-1-69	11.35	11.52	grab core water	muddy greenish grey sand and fine gravel	shells and shell fragments, fish scales	-
D	2	22°30'S 14°24'E	26	18-1-69	12.11	-	grab BT	coarse grey sand and fine gravel	some shell fragments	-
D	3	22°30'S 14°21.5'E	40	18-1-69	12.38	12.55	grab water BT	fine grey gravel	some shell fragments	-

line	station nr.	position	depth (m)	date	stationtime beginning	stationtime end	type of sample	description of sediment	description of coarse fraction	remarks
D	4	22°30'S 14°15.3'E	63	18-1-69	13.28	13.55	grab core BT	green mud H_2S smell	fish scales and bones	-
D	5	22°30'S 14°10.6'E	90	18-1-69	14.26	14.46	grab water BT	green mud H_2S smell	fish scales and bones	-
D	6	22°30'S 14°05.7'E	106	18-1-69	15.20	15.52	grab core BT	green mud weak H_2S smell	some shells and shell fragments some fish scales	-
D	7	22°30'S 14°00'E	117	18-1-69	16.29	17.07	grab water BT	green mud	some Gastropods, shells and fragments, some fish scales	grab did not work properly
D	8	22°30'S 13°55'E	122.5	18-1-69	17.42	18.10	grab core BT	green mud	-	grab broken
D	9	22°30'S 13°50'E	128	18-1-69	18.43	19.11	core water BT	green mud	-	-
D	10	22°30'S 13°45'E	132	18-1-69	20.00	20.08	core BT	fine sandy green mud	some Pelecypods, shell fragments	-
D	11	22°30'S 13°40'E	145	18-1-69	20.43	21.17	core water BT	fine sandy green mud	abundant shells and fragments	-
D	12	22°30'S 14°27'E	185	18-1-69	21.51	22.05	core BT	fine sandy green mud	-	-
E	1	22°52.5'S 14°23'E	29	11-1-69	-	-	grab core water	dark green mud H_2S smell	many fish scales	sediment sampled on 8-1-69
E	2	22°52.5'S 14°20'E	60	11-1-69	09.12	09.45	grab water	dark green mud H_2S smell	fish scales, some small bones and shell fragments	-
E	3	22°52.5'S 14°17'E	76	11-1-69	10.05	10.35	grab	green mud H_2S smell	a few fish scales	-

line	station nr.	position	depth (m)	date	stationtime beginning	end	type of sample	description of sediment	description of coarse fraction	remarks
E	4	22°52.5'S 14°14.5'E	91.5	11-1-69	10.54	11.20	grab core	green mud H_2S smell	fish scales and bones, some shell fragments	-
E	5	22°52.5'S 14°12'E	104	11-1-69	11.40	11.45	grab	green mud	some small shells and fragments many fish scales and bones	-
E	6	22°52.5'S 14°09'E	113	11-1-69	12.04	12.11	grab	green mud	Gastropods, some shells and fragments many fish scales	-
E	7	22°52.5'S 14°06'E	118	11-1-69	12.29	13.10	grab core	green mud	Gastropods, some fish scales, fish eggs(?)	-
E	8	22°52.5'S 14°01.5'E	124	11-1-69	15.20	15.40	grab	-	-	grab did not work properly
E	9	22°52.5'S 13°55.5'E	133	11-1-69	16.20	16.55	grab core	green mud	Gastropods, some fish scales	-
E	10	22°52.5'S 13°45'E	137	11-1-69	18.04	18.45	grab core	fine sandy green mud	Pelecypods, yellow-white shells and fragments	-
E	11	22°52.5'S 13°40'E	137	11-1-69	19.20	20.10	grab water	fine sandy green mud	abundant yellow-white shell fragments	-
F	1	23°15'S 14°26.3'E	22	20-1-69	08.35	08.48	core water	green mud H_2S smell	-	-
F	2	23°15'S 14°24'E	33	20-1-69	08.06	08.14	core BT	green mud H_2S smell	-	-
F	3	23°15'S 14°21.5'E	51	20-1-69	07.25	07.51	core water BT	green mud H_2S smell	-	-

line	station nr.	position	depth (m)	date	stationtime beginning	end	type of sample	description of sediment	description of coarse fraction	remarks
F	4	23°15'S 14°16'E	73	20-1-69	06.55	07.08	core BT	green mud H_2S smell	-	-
F	5	23°15'S 14°10'E	110	20-1-69	06.02	06.24	core water BT	green mud H_2S smell	-	-
F	6	23°15'S 14°05.5'E	128	20-1-69	05.10	05.31	core BT	green mud H_2S smell	-	-
F	7	23°15'S 14°00'E	132	20-1-69	03.52	04.39	core water BT	green mud H_2S smell	-	-
F	8	23°15'5 13°55'E	143	20-1-69	03.00	03.23	core	green mud	-	-
F	9	23°15'S 13°49.9'E	146	20-1-69	02.00	02.30	core water BT	green mud	-	-
F	10	23°15'S 13°44'E	150	20-1-69	01.15	01.32	core	fine sandy green mud	yellow-white shell fragments	-
F	11	23°15'S 13°39'E	152	20-1-69	00.03	00.40	core water BT	sandy dark green sediment	-	-
F	12	23°15'S 13°34'E	188	19-1-69	23.12	23.33	core BT	fine sandy green mud	-	-
F	13	23°15'S 13°23'E	337	19-1-69	21.03	22.10	water BT	(fine grey ooze)	-	core pipe broken several times
F	14	23°15'S 13°13'E	374	19-1-69	19.40	20.00	BT	-	-	core pipe broken several times
G	1	23°35'S 14°26'E	26	15-1-69	10.52	10.55	grab	fine grey sand	many worms, anemones small Crustaceae	-

line	station nr.	position	depth (m)	date	stationtime beginning	stationtime end	type of sample	description of sediment	description of coarse fraction	remarks
G	2	23°35'S 14°24.6'E	53	15-1-69	10.18	10.30	grab	green mud	many worms, large Pelecypods, some fish bones, shell fragments	-
G	3	23°35'S 14°21.5'E	77	15-1-69	09.53	10.00	grab	green mud	Gastropods, Pelecypods, many fish scales and bones	-
G	4	23°35'S 14°16'E	113	15-1-69	09.00	09.19	grab	green mud	Gastropods, small shells and fragments, some fish scales	-
G	5	23°35'S 14°11'E	145	15-1-69	08.14	08.25	grab	fine sandy green mud	Gastropods, Pelecypods, yellow-white shells and shell fragments, a few fish scales	-
G	6	23°35'S 14°04'E	153	15-1-69	07.23	07.37	grab	fine sandy green mud	Pelecypods, worms, yellow-white shell fragments	-
G	7	23°35'S 13°59'E	166	15-1-69	06.35	06.52	grab	fine sandy green mud	Pelecypods, worms, abundant yellow-white shell fragments	-
H	1	23°56'S 14°27.5'E	29	12-1-69	06.40	07.28	grab core water	fine grey sand	Gastropods, worms, shell fragments	-
H	2	23°56'S 14°24.5'E	62	12-1-69	07.55	08.35	grab core	green mud	large Pelecypods, shell fragments, some fish scales and bones	-

line	station nr.	position	depth (m)	date	stationtime beginning	stationtime end	type of sample	description of sediment	description of coarse fraction	remarks
H	3	23°56'S 14°22.6'E	81	12-1-69	08.57	09.40	grab water	green mud	large Pelecypods Gastropods, shell fragments, fish scales	-
H	4	23°56'S 14°18.8'E	92	12-1-69	09.58	10.04	grab	green mud	Pelecypods, Gastropods, many fish scales and bones	-
H	5	23°56'S 14°15.8'E	110	12-1-69	10.22	11.15	grab	dark green mud	Pelecypods, Gastropods, shells and shell fragments	-
H	6	23°56'S 14°13'E	128	12-1-69	11.34	11.57	grab	fine sandy green mud	yellow-white shells and fragments	-
H	7	23°56'S 14°10'E	139	12-1-69	12.17	12.22	grab	fine sandy green mud	Pelecypods, yellow-white shells and fragments	-
H	8	23°56'S 14°06.9'E	157	12-1-69	12.42	14.25	grab core water	fine sandy green mud	yellow-white shells and fragments	-
I	1	24°15'S 14°28.5'E	22	19-1-69	08.57	09.34	grab	fine grey sand	many worms	-
I	2	24°15'S 14°25.5'E	57	19-1-69	09.53	10.07	core BT	green mud on coarse shelly gravel	-	-
I	3	24°15'S 14°23'E	82	19-1-69	10.25	10.31	core	green mud, slight H_2S smell	-	-
I	4	24°15'S 14°20.2'E	108	19-1-69	10.48	10.53	core	green mud slight H_2S smell	shells and shell fragments	-

line	station nr.	position	depth (m)	date	stationtime beginning	end	type of sample	description of sediment	description of coarse fraction	remarks
I	5	24°15'S 14°17.5'E	123	19-1-69	11.12	11.30	core	stiff light grey sandy clay	many shell fragments	-
I	6	24°15'S 14°14.5'E	128	19-1-69	11.47	11.54	core	stiff light grey sandy clay	many shells and fragments	-
I	7	24°15'S 14°10'E	165	19-1-69	12.28	12.37	core BT	dark greenish grey sediment	-	-
I	8	24°15'S 14°04.8'E	219	19-1-69	13.10	13.20	core	fine sandy green mud	yellow-white shell fragments	-

Table II. Wind data and air temperature.

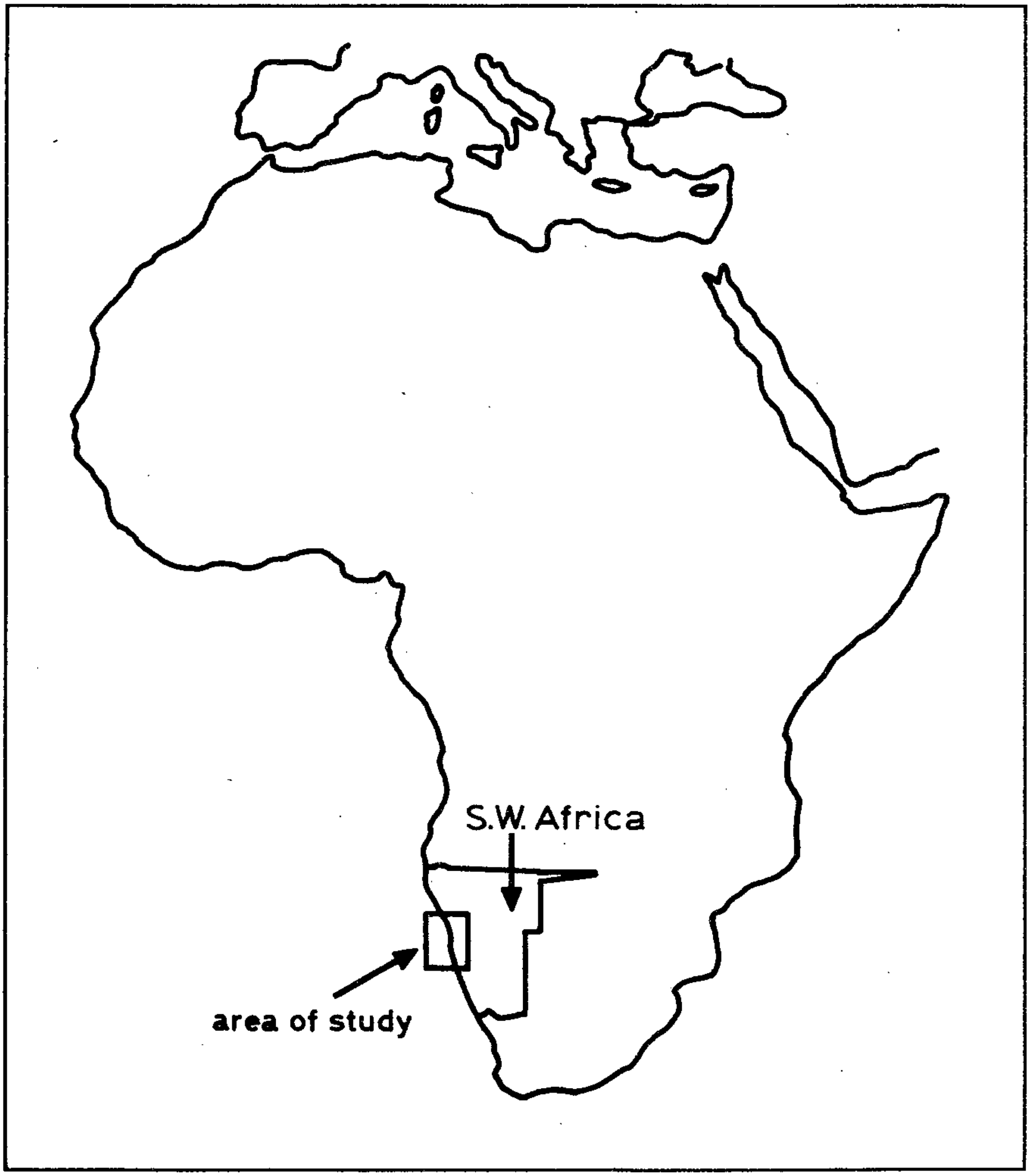
date	time	wind direction	wind force (knots)	air temperature (°C)	station
11-1-69	09.12	-	calm	19.5	E 2
	10.05	-	"	19.0	E 3
	10.54	-	"	20.5	E 4
	11.40	-	"	20.7	E 5
	12.04	220°	8	18.0	E 6
	12.29	200°	8-10	19.0	E 7
	15.20	200°	9	20.5	E 8
	16.20	200°	8-9	21.0	E 9
	18.04	200°	9	20.7	E 10
	19.20	200°	6-7	19.5	E 11
12-1-69	06.40	-	calm	17.0	H 1
	07.55	-	calm	15.5	H 2
	08.57	190°	8	17.3	H 3
	09.58	190°	18	18.0	H 4
	10.22	190°	18	18.2	H 5
	11.34	190°	20-21	18.2	H 6
	12.17	200°	19-20	18.5	H 7
	12.42	200°	18-19	18.0	H 8
13-1-69	07.00	-	calm	16.3	B 1
	07.55	-	calm	16.5	B 2
	08.30	-	calm	17.0	B 3
	09.12	-	calm	19.3	B 4
	10.24	210°	10	19.6	B 5
	11.40	210°	10	19.5	B 6
	12.26	210°	10-11	20.0	B 7
	15.40	210°	7-8	21.0	A 7
	16.22	210°	7-8	20.0	A 6
	17.14	210°	7-8	20.0	A 5
	17.58	210°	6-7	20.5	A 4
	18.36	200°	5	19.5	A 3
	19.20	200°	1-2	19.0	A 2
	19.35	200°	5	18.5	A 1
14-1-69	06.27	000°	2	17.0	C 1
	06.50	000°	4	17.0	C 2
	07.26	000°	6	17.8	C 3

date	time	wind direction	wind force (knots)	air temperature (°C)	station
(14-1-69)					
	08.34	000°	1	19.0	C 4
	09.24	220°	8-9	21.5	C 5
	10.08	220°	11-12	19.2	C 6
	10.48	210°	11-12	19.5	C 7
	11.54	210°	13-14	20.0	C 8
	11.54	210°	13-14	20.0	C 8
	12.36	210°	12-14	21.1	C 9
	13.44	210°	17	20.8	C 10
	14.55	210°	20	20.1	C 11
	16.21	200°	22	21.0	C 12
15-1-69	06.35	180°	15	16.5	G 7
	07.23	180°	15	16.5	G 6
	08.14	180°	13	17.0	G 5
	09.00	180°	12	17.8	G 4
	09.53	180°	11-12	17.5	G 3
	10.18	180°	8-9	17.5	G 2
	10.52	180°	6	17.8	G 1
18-1-69	09.48	330°	8	18.5	K
	11.35	330°	6	19.0	D 1
	12.11	330°	6	19.5	D 2
	12.38	330°	5	22.0	D 3
	13.28	330°	3-5	21.9	D 4
	14.26	330°	3-5	20.5	D 5
	15.20	330°	3-5	20.5	D 6
	16.29	250°	3-5	19.0	D 7
	17.42	250°	11	18.0	D 8
	18.43	240°	6-8	16.0	D 9
	20.00	200°	8	16.3	D 10
	20.43	200°	14	16.3	D 11
	21.51	200°	15	16.3	D 12
19-1-69	08.57	000°	1	16.5	I 1
	09.53	180°	3	16.3	I 2
	10.25	200°	7	17.0	I 3
	10.48	200°	7	17.0	I 4
	11.12	200°	8	18.1	I 5

date	time	wind direction	wind force (knots)	air temperature (°C)	station
(19-1-69)					
	11.47	200°	5	19.0	I 6
	12.28	200°	-	20.5	I 7
	13.10	200°	-	20.0	I 8
	19.40	180°	20	18.0	F 14
	21.03	180°	17	18.0	F 13
	23.12	180°	10	18.0	F 12
20-1-69	00.03	180°	10	17.0	F 11
	01.15	180°	-	20.0	F 10
	02.00	180°	-	20.2	F 9
	03.00	180°	-	21.2	F 8
	03.52	180°	-	19.0	F 7
	05.10	180°	8-10	19.2	F 6
	06.02	180°	8	17.5	F 5
	06.55	180°	3	17.5	F 4
	07.25	-	calm	17.0	F 3
	08.06	360°	6	18.0	F 2
	08.35	360°	6	18.5	F 1

Table III. Thermocline-data.

Station	depth-limits of thermocline (m)	temperature difference (°C)	Δ_t
D 1	0-7	5.0	0.71
D 3	0-8	4.9	0.61
D 4	0-12	4.5	0.37
D 5	0-14	4.5	0.32
D 6	0-9	4.4	0.49
	9-25	0.8	0.05
	[0-25]	[5.2]	[0.21]
D 7	5-15	3.8	0.38
D 8	0-8	0.8	0.10
	8-14	2.2	0.37
D 9	9-19	2.6	0.26
D 10	8-13	1.9	0.38
	13-20	0.5	0.07
	[8-20]	[2.4]	[0.20]
D 11	9-17	1.8	0.22
	17-34	1.2	0.07
D 12	10-14	1.8	0.45
	14-20	0.5	0.08
	[10-20]	[2.3]	[0.23]
F 2	0-4	2.1	0.52
	4-13	0.9	0.10
F 3	0-8	2.6	0.32
F 4	0-4	1.9	0.48
F 5	11-18	1.8	0.26
F 6	3-14	1.5	0.14
F 7	9-14	1.8	0.36
F 9	11-35	2.2	0.09
F 11	10-39	2.1	0.07
F 12	19-34	2.1	0.14
F 13	20-36	1.9	0.12
F 14	19-47	2.8	0.10
I 2	0-4	5.2	1.30
I 7	0-4	4.1	1.02
	24-32	1.3	0.16


S.W. Africa
area of study

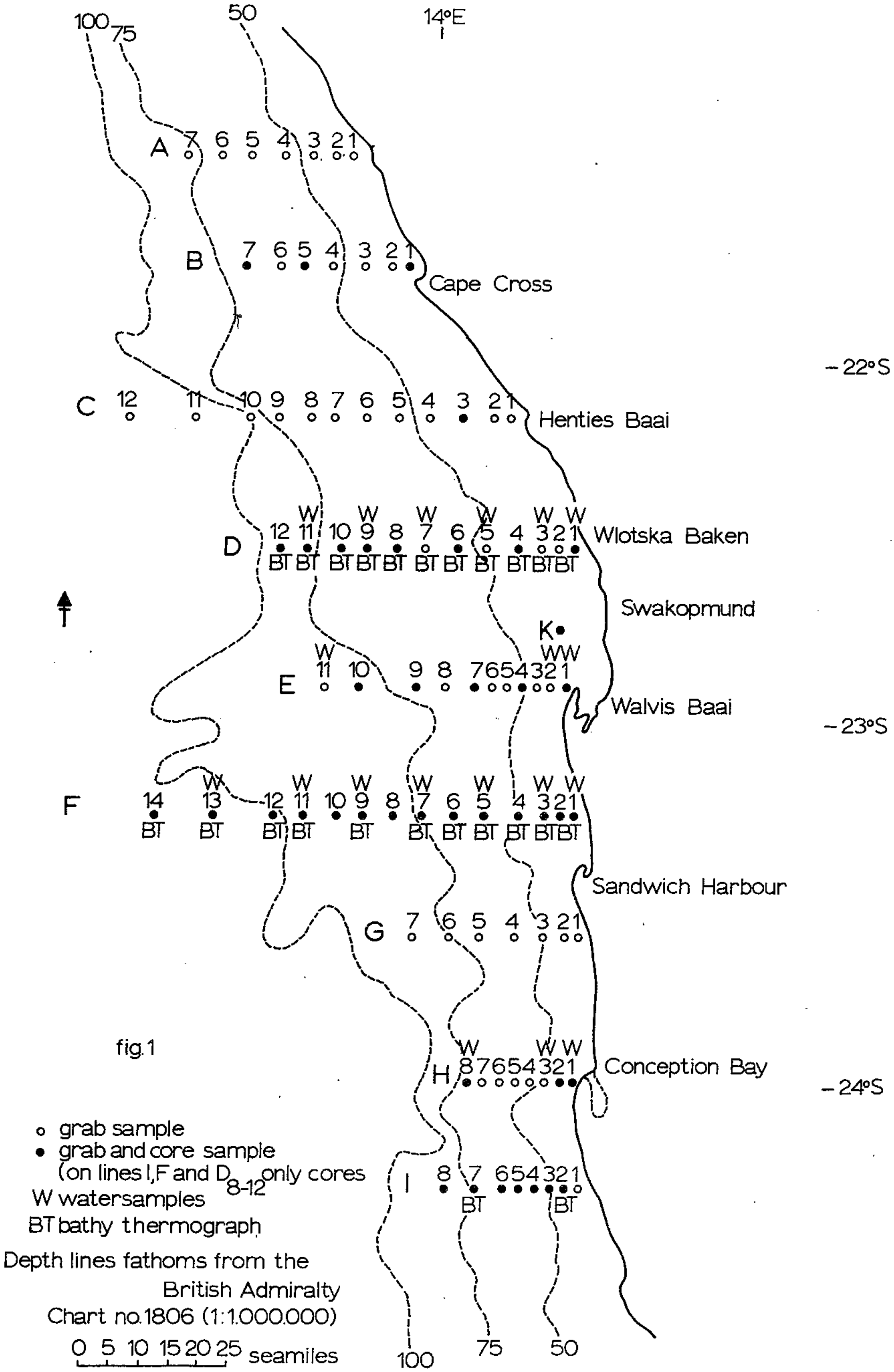

100
75
50
14°E
A
B
Cape Cross
−22°S
C
Henties Baai
D
Wlotska Baken
Swakopmund
K
E
Walvis Baai
−23°S
F
Sandwich Harbour
G
H
Conception Bay
−24°S
I
W
BT
o grab sample
• grab and core sample
(on lines I, F and D 8-12 only cores
W watersamples
BT bathy thermograph
Depth lines fathoms from the
British Admiralty
Chart no. 1806 (1:1.000.000)
0 5 10 15 20 25 seamiles
100
75
50

fig. 1

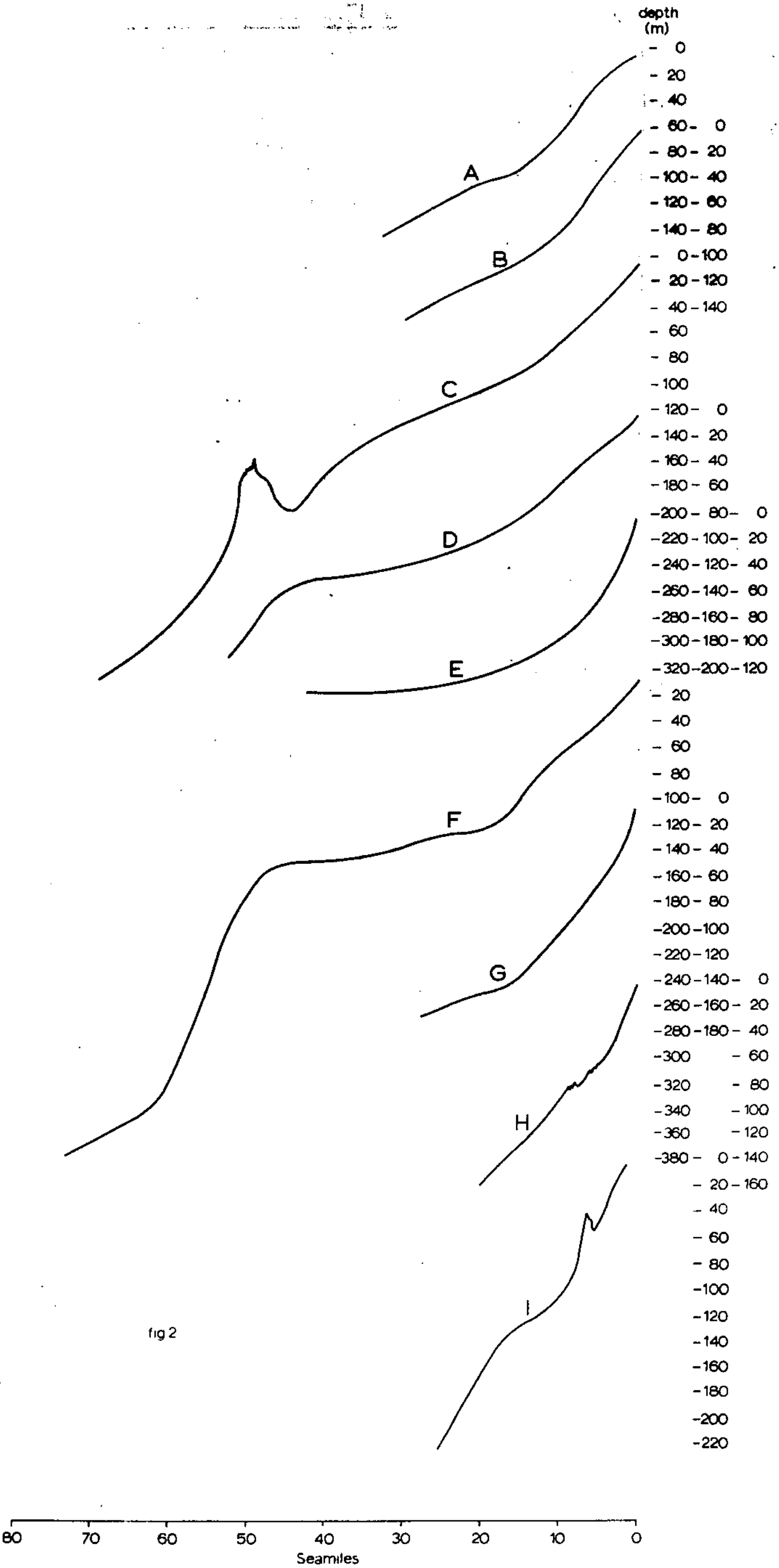


fig 2

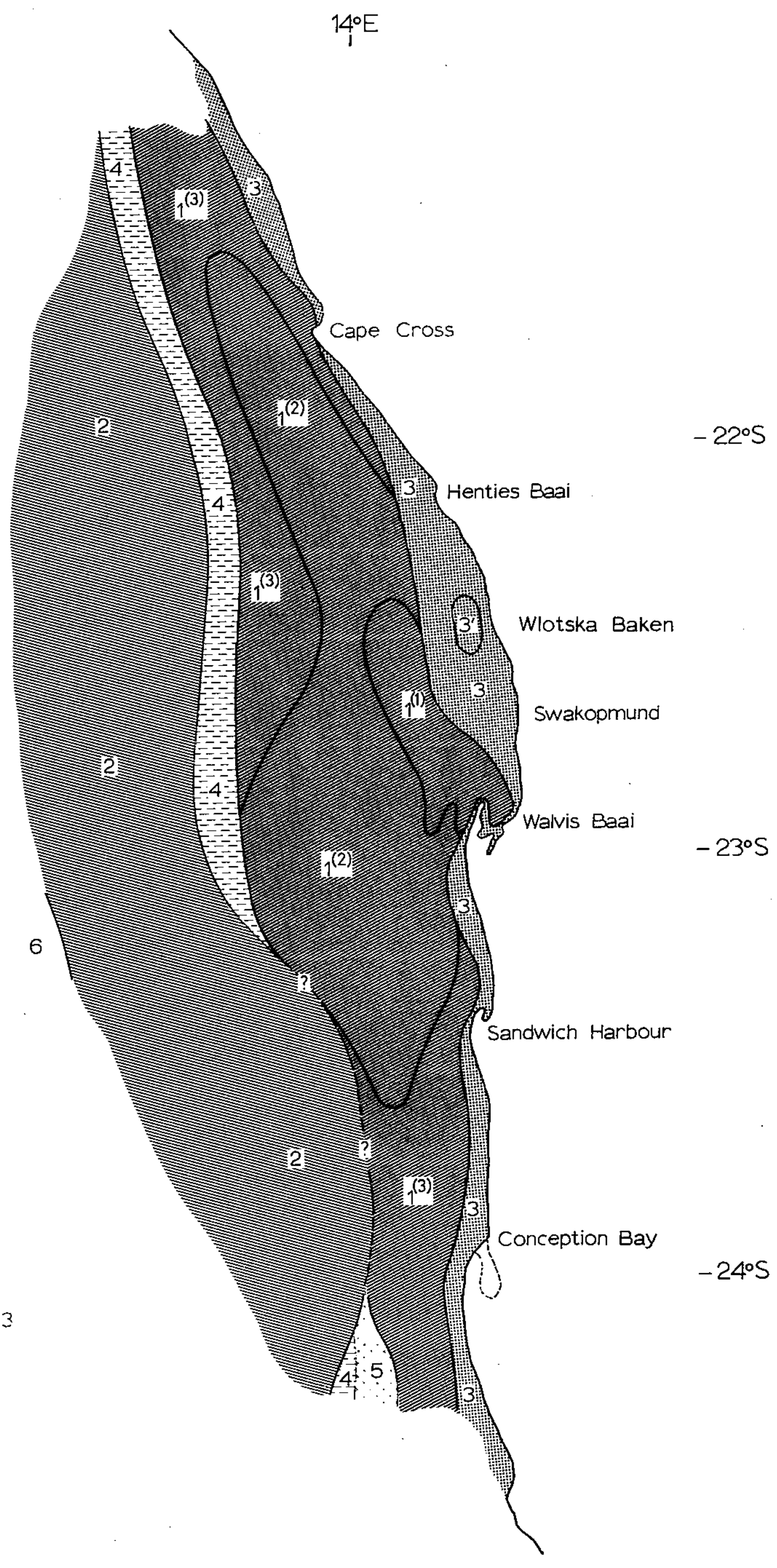

14°E
Cape Cross
-22°S
Henties Baai
Wlotska Baken
Swakopmund
Walvis Baai
-23°S
Sandwich Harbour
Conception Bay
-24°S

fig 3

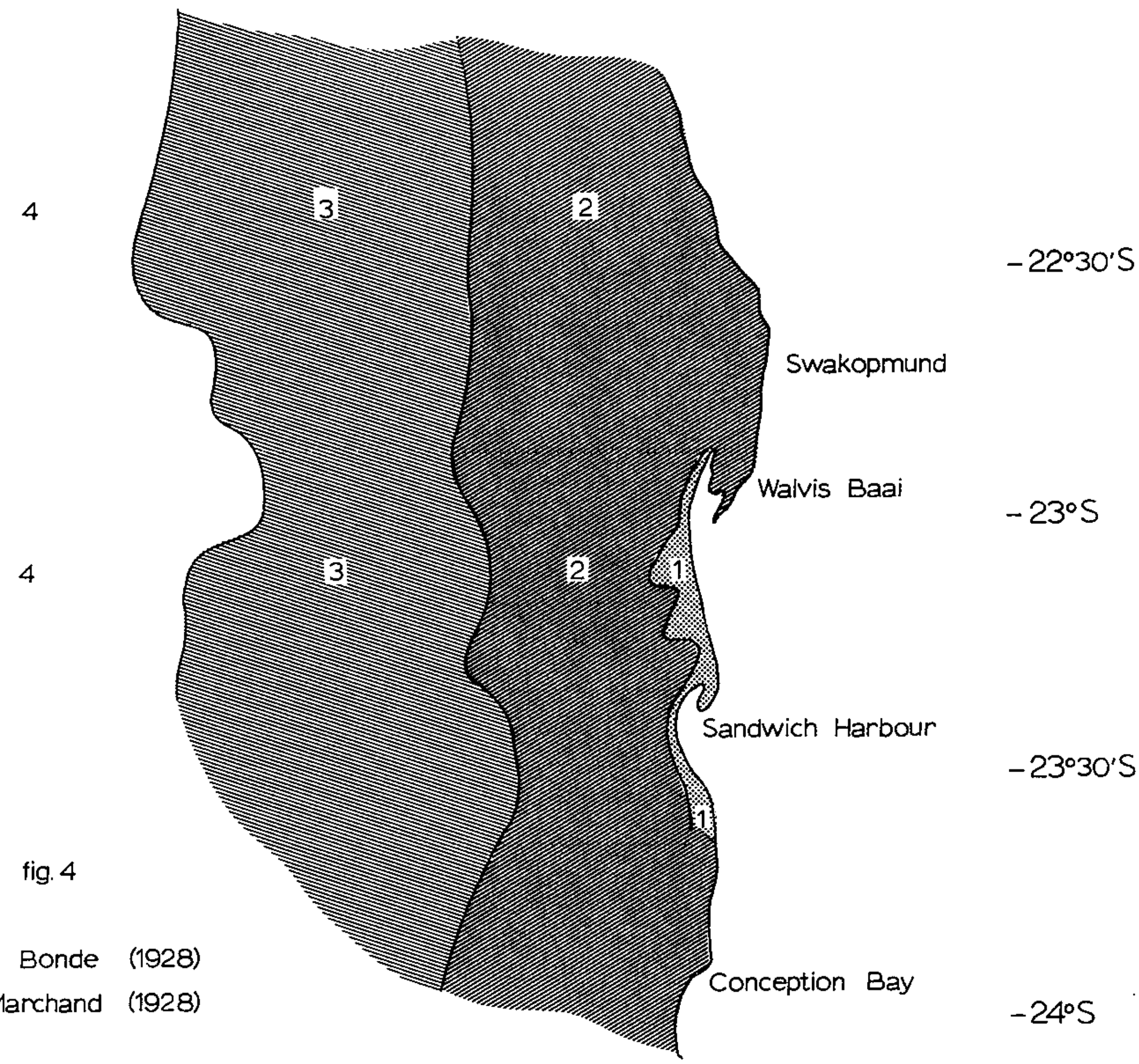


fig. 4

After Von Bonde (1928)
Marchand (1928)

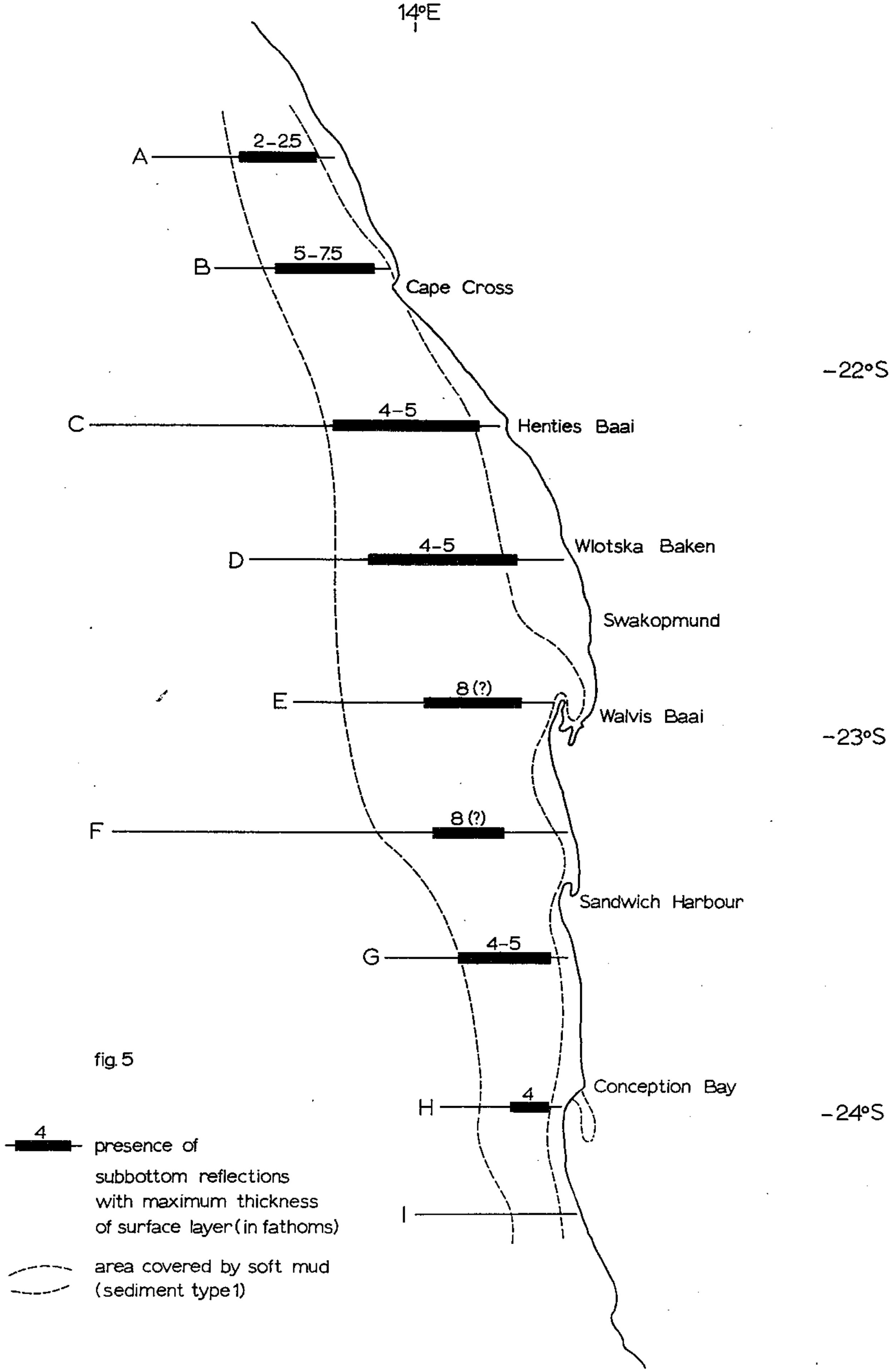

14°E
-22°S
-23°S
-24°S
A
2-2.5
B
5-7.5
Cape Cross
C
4-5
Henties Baai
D
4-5
Wlotska Baken
Swakopmund
E
8 (?)
Walvis Baai
F
8 (?)
Sandwich Harbour
G
4-5
Conception Bay
H
4
I
4
presence of subbottom reflections with maximum thickness of surface layer (in fathoms)
area covered by soft mud (sediment type 1)

fig. 5

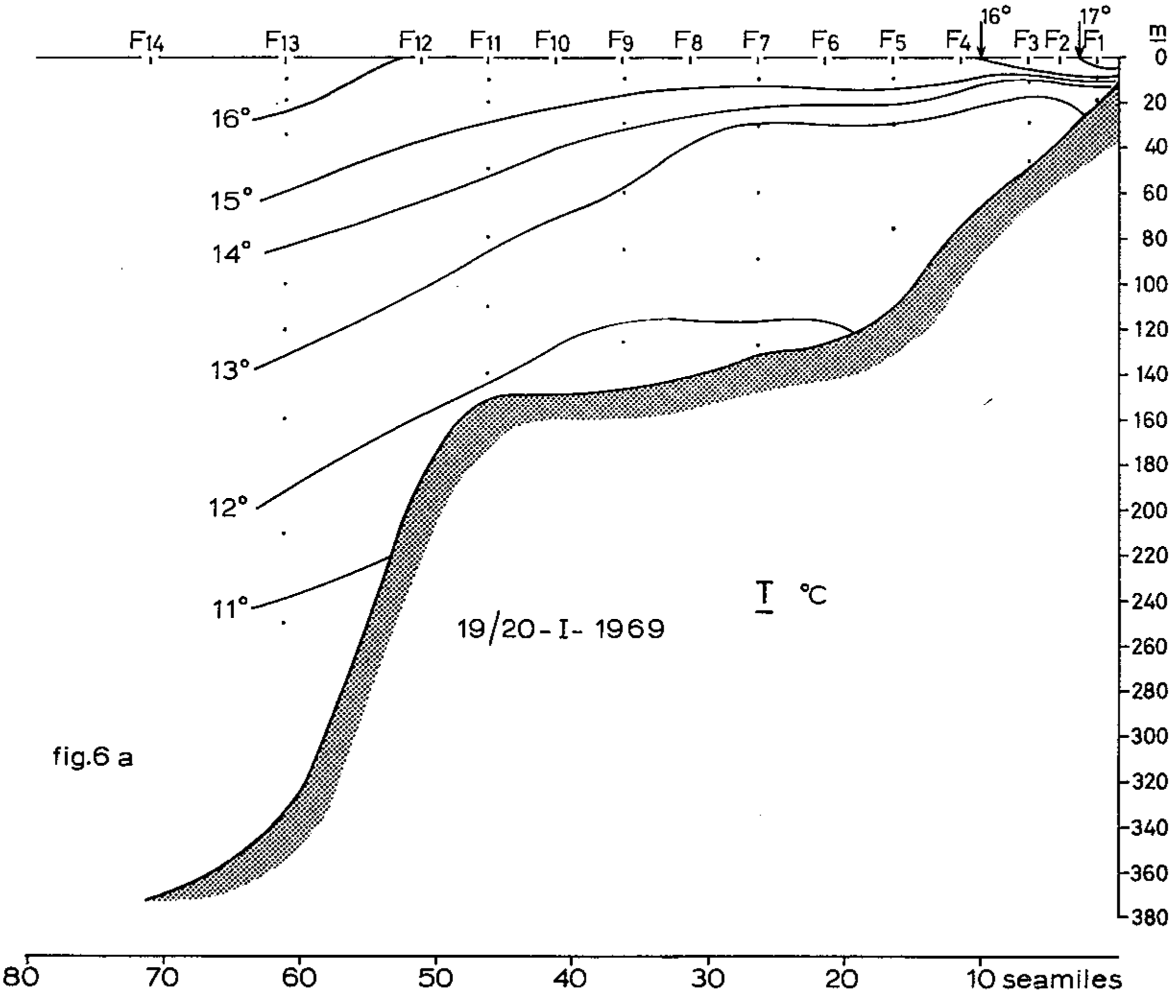


fig.6 a

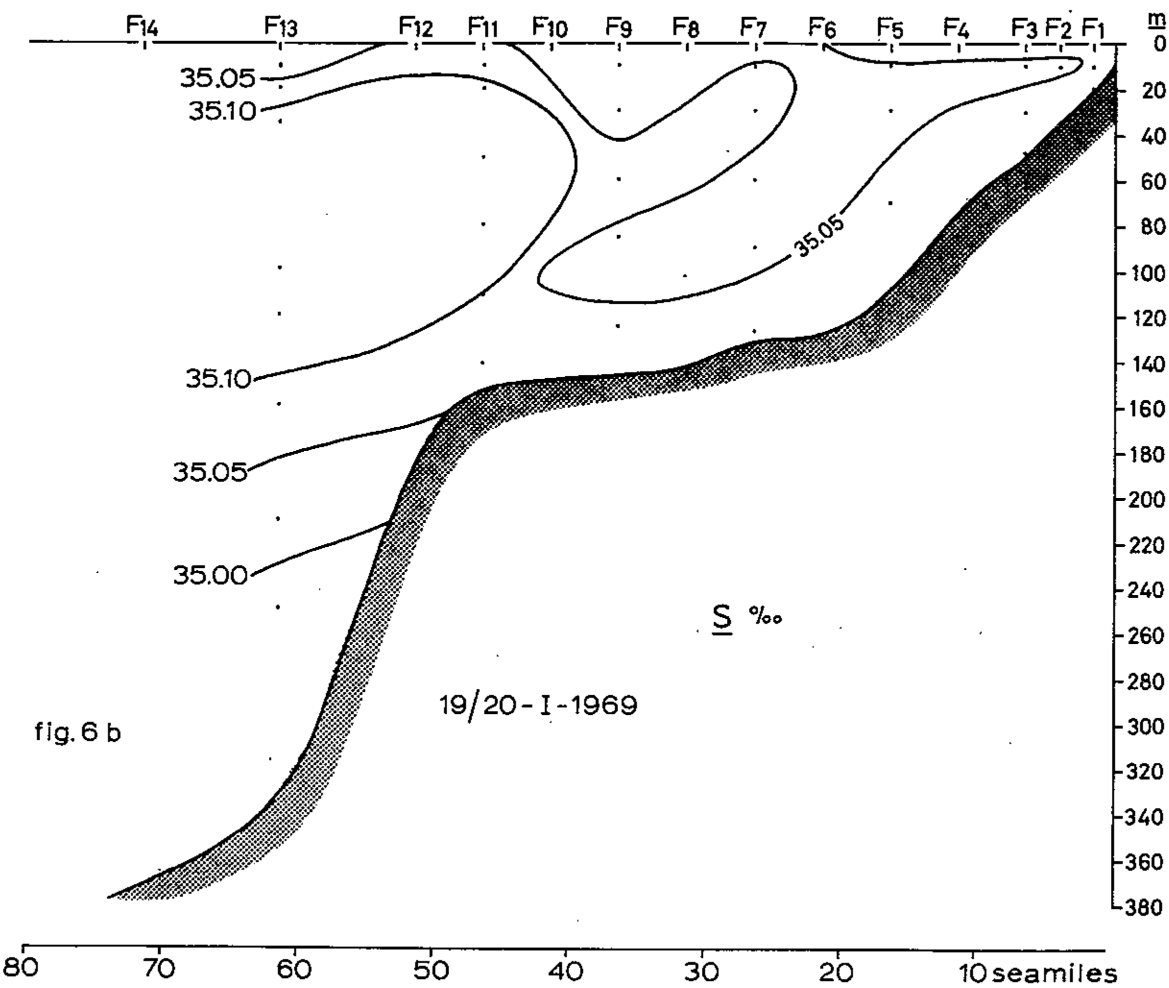
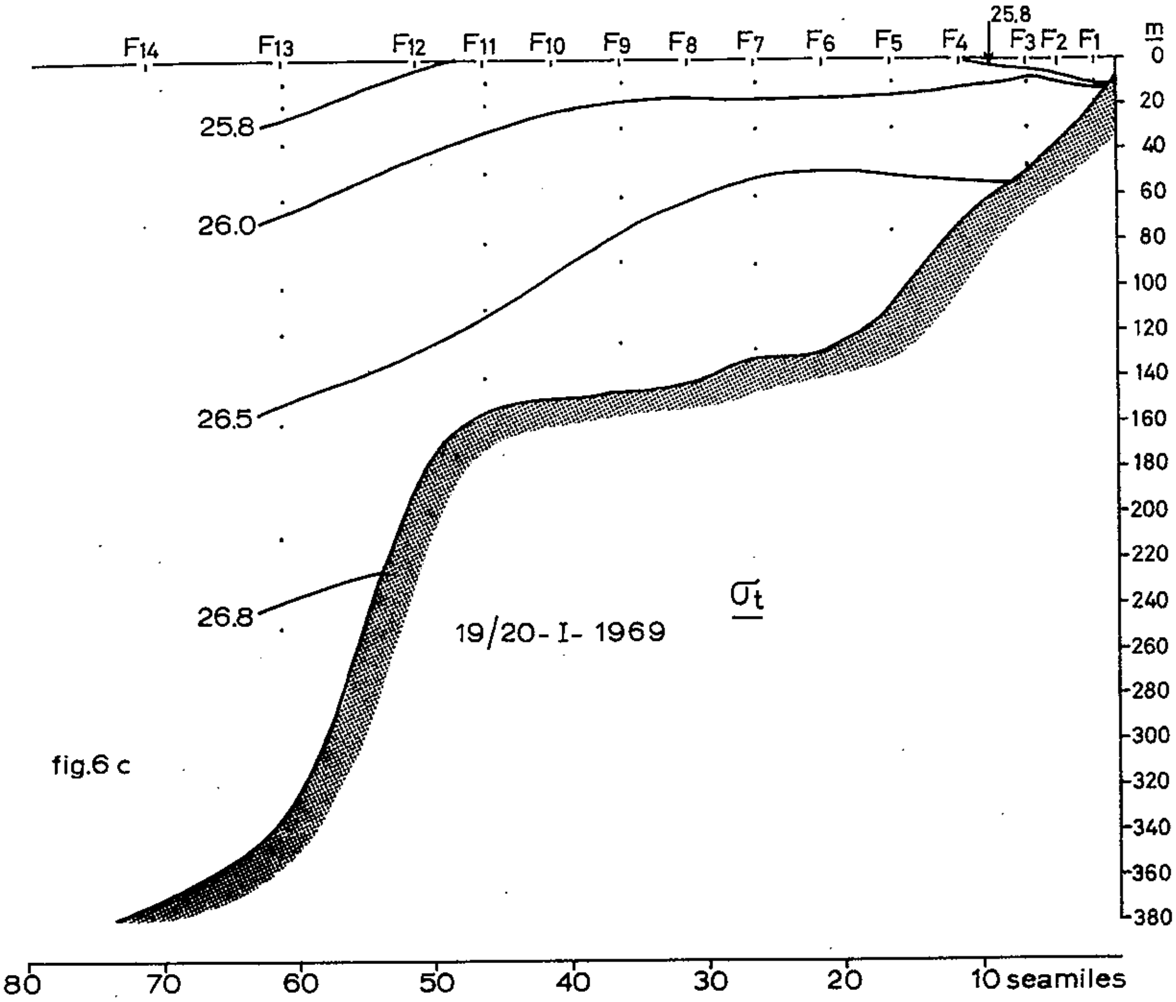
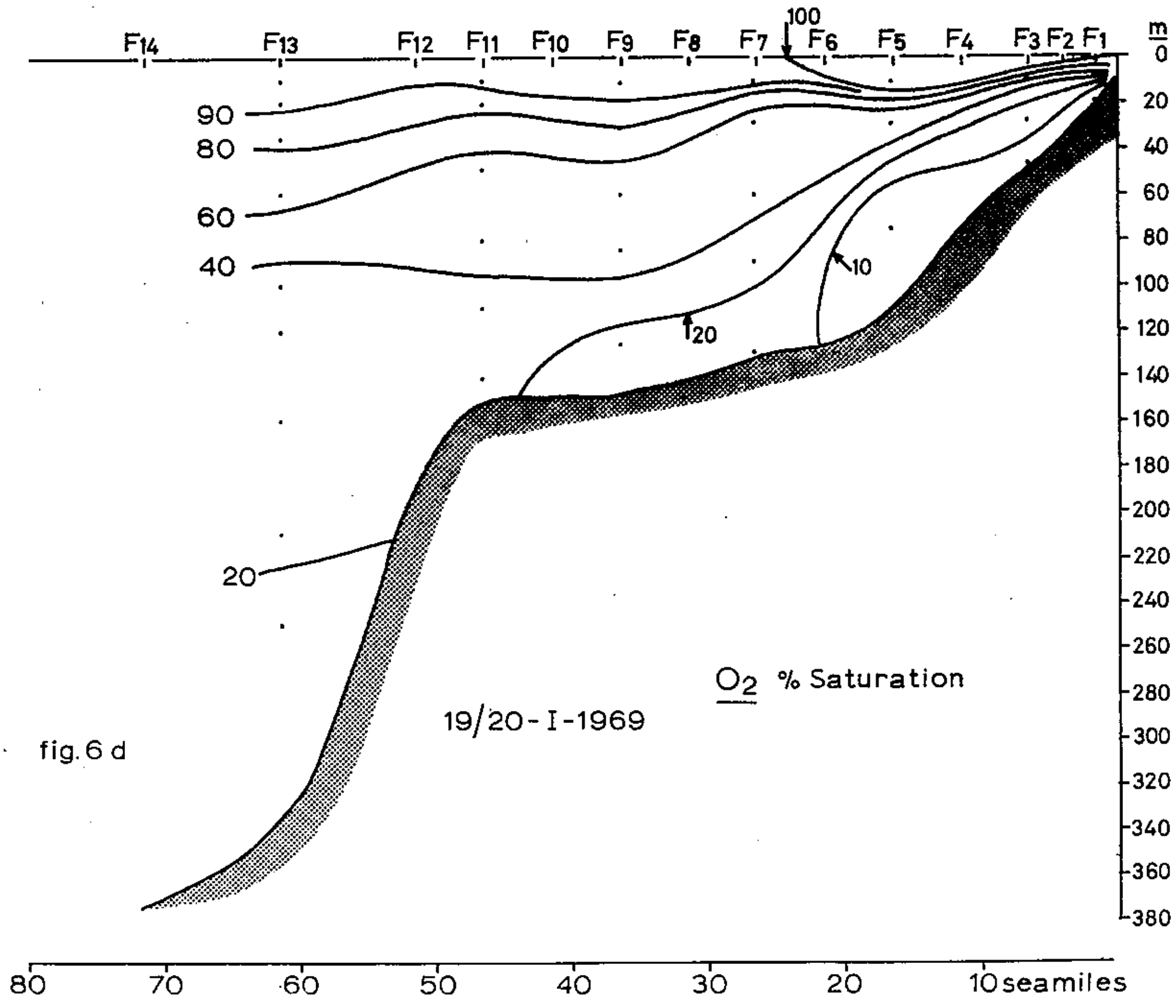
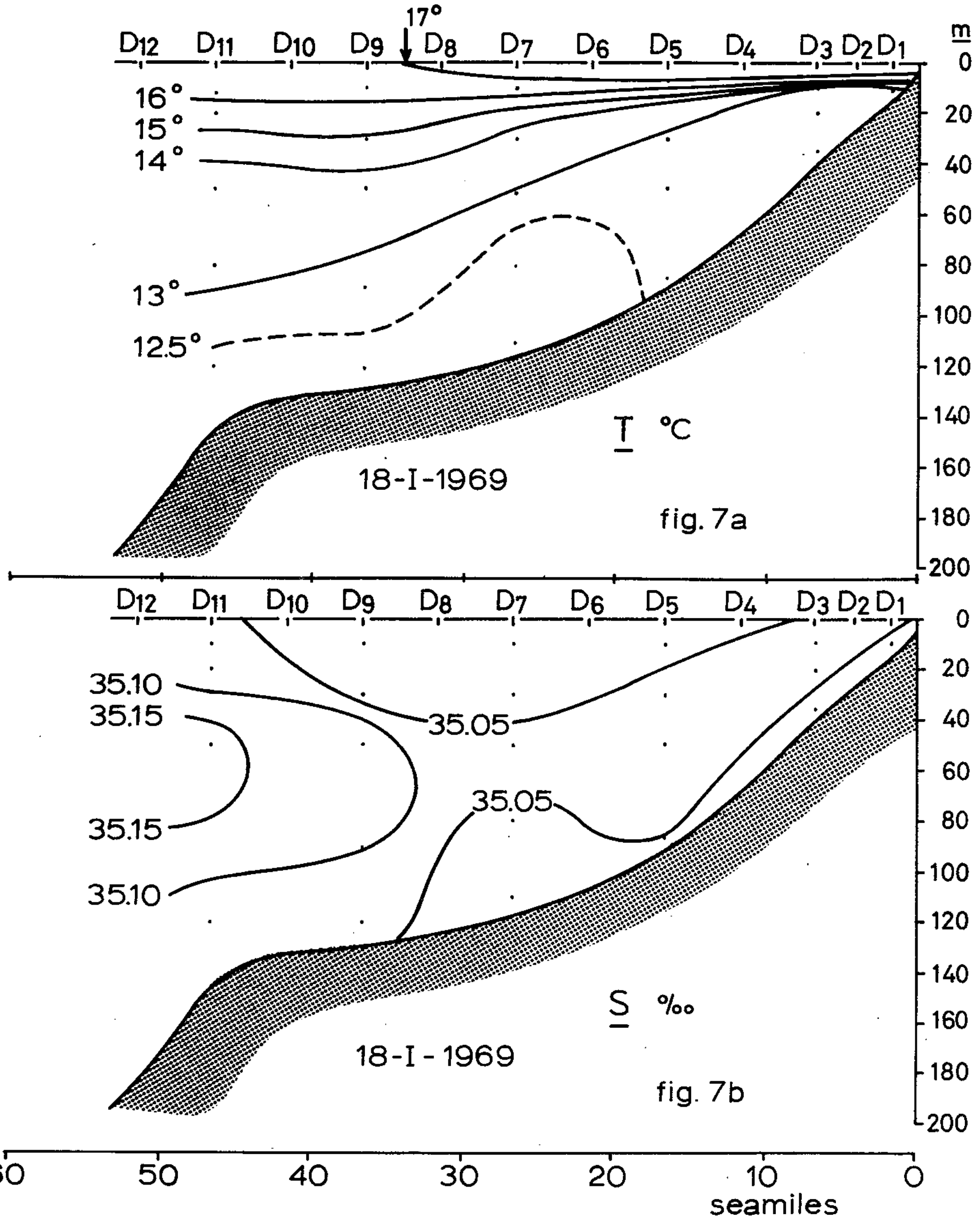


fig. 6 b

I


F14 F13 F12 F11 F10 F9 F8 F7 F6 F5 F4 F3 F2 F1
25.8
m
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380
25.8
26.0
26.5
26.8
σ_t
19/20-I-1969
fig.6 c
80 70 60 50 40 30 20 10 seamiles


F14 F13 F12 F11 F10 F9 F8 F7 F6 F5 F4 F3 F2 F1
100
m
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380
90
80
60
40
10
20
20
O_2 % Saturation
19/20-I-1969
fig. 6 d
80 70 60 50 40 30 20 10 seamiles


17°
D12 D11 D10 D9 D8 D7 D6 D5 D4 D3 D2 D1
m
0
20
40
60
80
100
120
140
160
180
200
16°
15°
14°
13°
12.5°
T °C
18-I-1969
fig. 7a
D12 D11 D10 D9 D8 D7 D6 D5 D4 D3 D2 D1
35.10
35.15
35.05
35.05
35.15
35.10
S ‰
18-I-1969
fig. 7b
60 50 40 30 20 10 0
seamiles

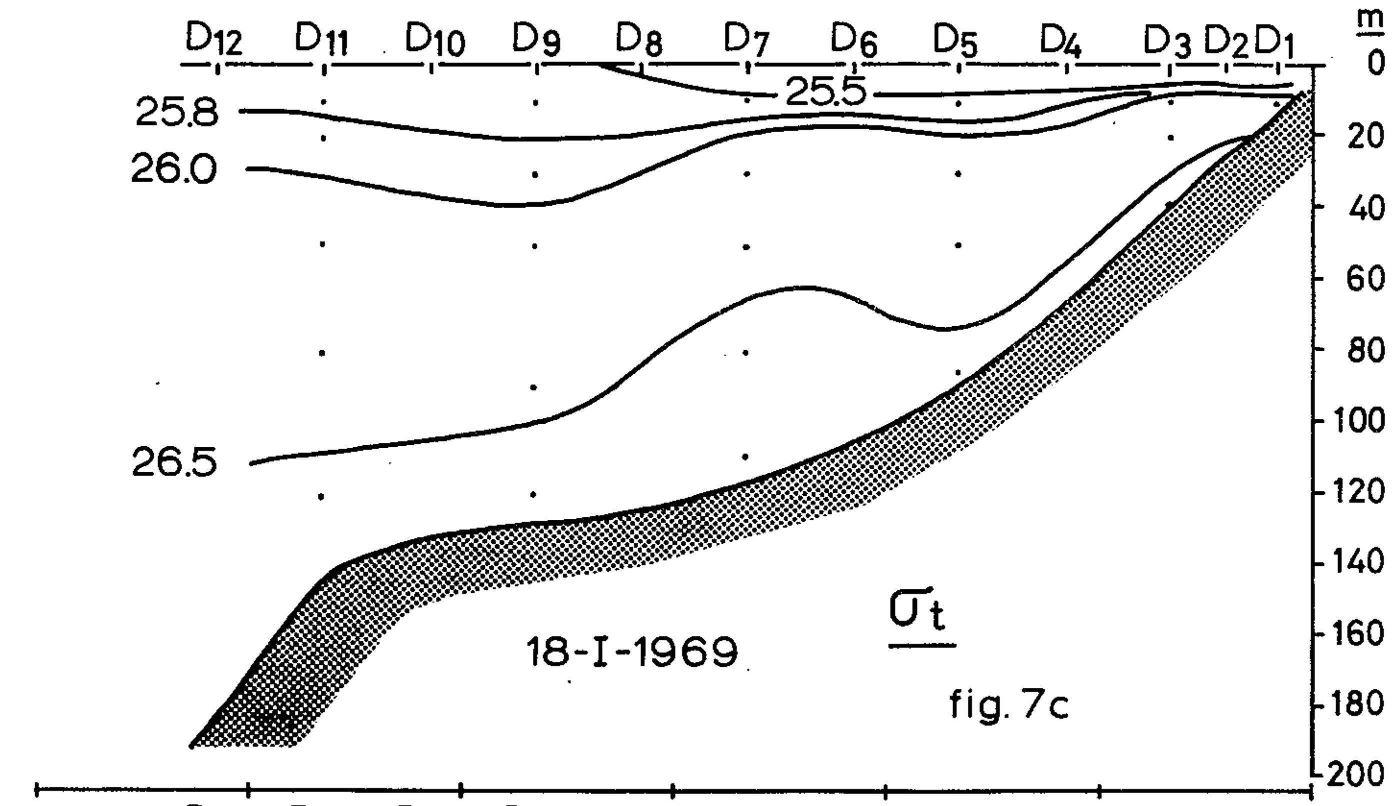

D12 D11 D10 D9 D8 D7 D6 D5 D4 D3 D2 D1
m
0
20
40
60
80
100
120
140
160
180
200
25.5
25.8
26.0
26.5
σt
18-I-1969

fig. 7c

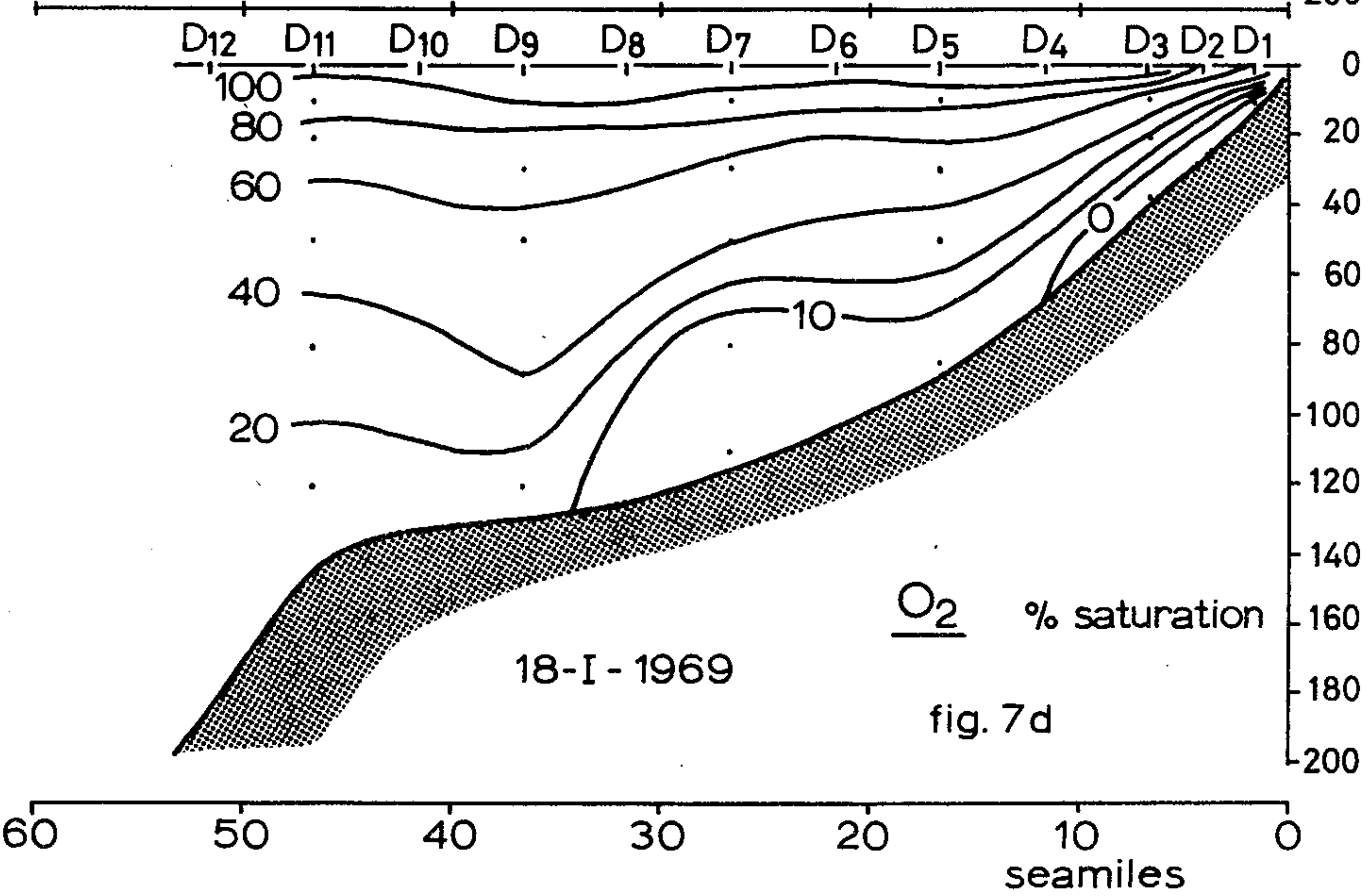
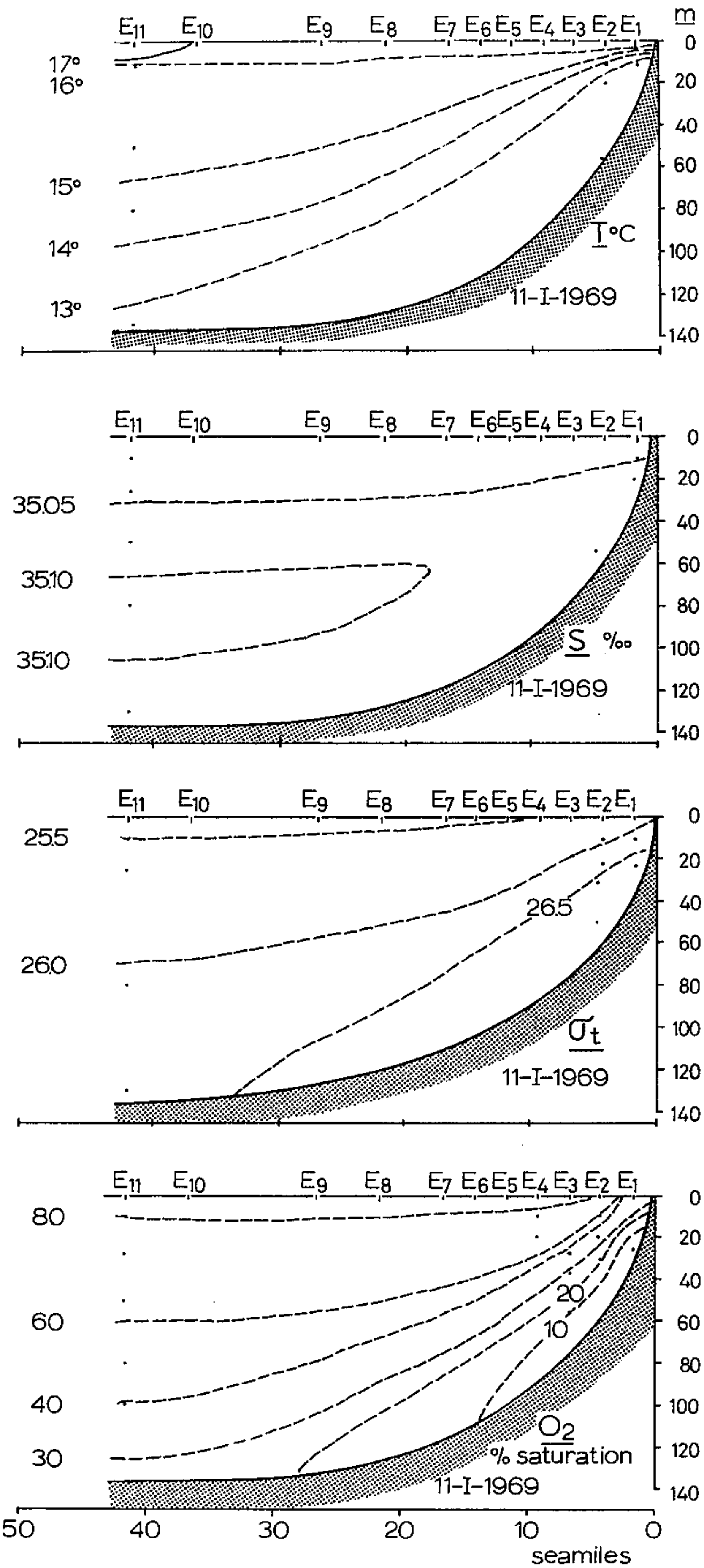
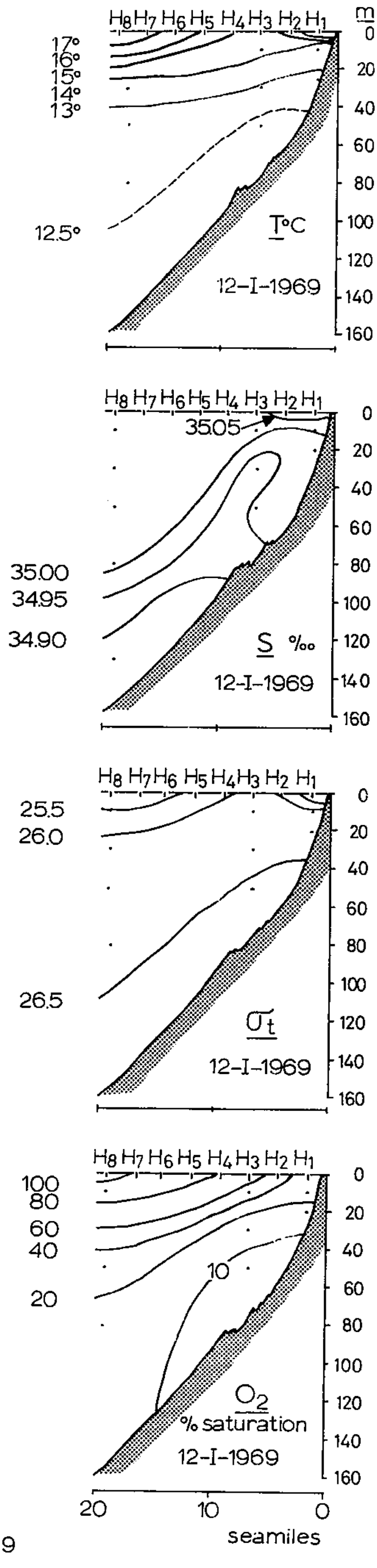

D12 D11 D10 D9 D8 D7 D6 D5 D4 D3 D2 D1
0
20
40
60
80
100
120
140
160
180
200
100
80
60
40
20
10
0
O2 % saturation
18-I-1969
60 50 40 30 20 10 0
seamiles

fig. 7d



E11 E10 E9 E8 E7 E6 E5 E4 E3 E2 E1
m
17°
16°
15°
14°
13°
T °C
11-I-1969
35.05
35.10
35.10
S ‰
11-I-1969
25.5
26.0
26.5
σt
11-I-1969
80
60
40
30
20
10
O2
% saturation
11-I-1969
0 20 40 60 80 100 120 140
50 40 30 20 10 0
seamiles

fig. 8



H8 H7 H6 H5 H4 H3 H2 H1
m
0
20
40
60
80
100
120
140
160
17°
16°
15°
14°
13°
12.5°
T°C
12-I-1969
35.05
35.00
34.95
34.90
S ‰
12-I-1969
25.5
26.0
26.5
σt
12-I-1969
100
80
60
40
20
10
O2
% saturation
12-I-1969
20
10
0
seamiles

fig. 9

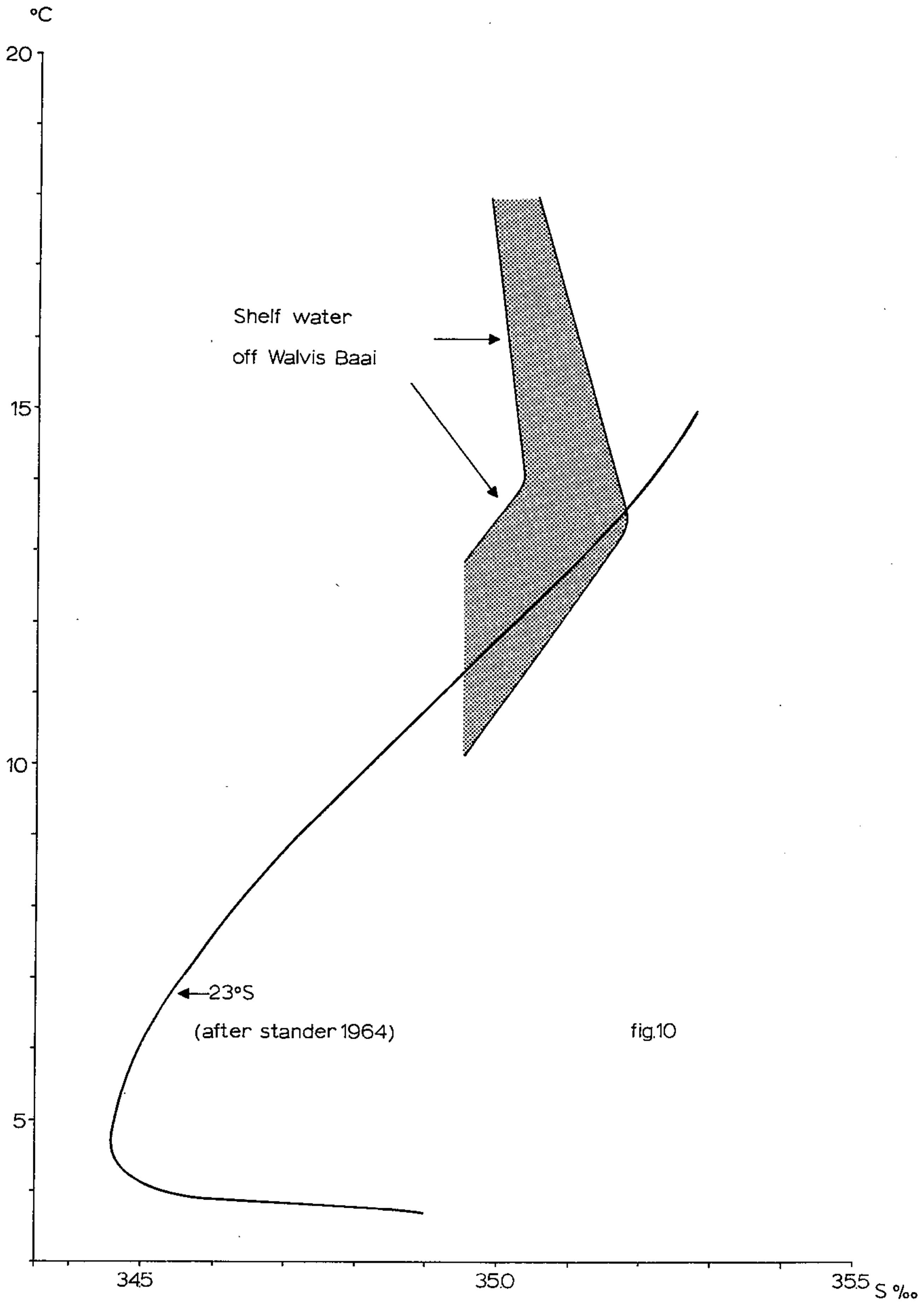

°C
20
15
10
5
Shelf water
off Walvis Baai
←23°S
(after stander 1964)
34.5
35.0
35.5
S ‰

fig.10

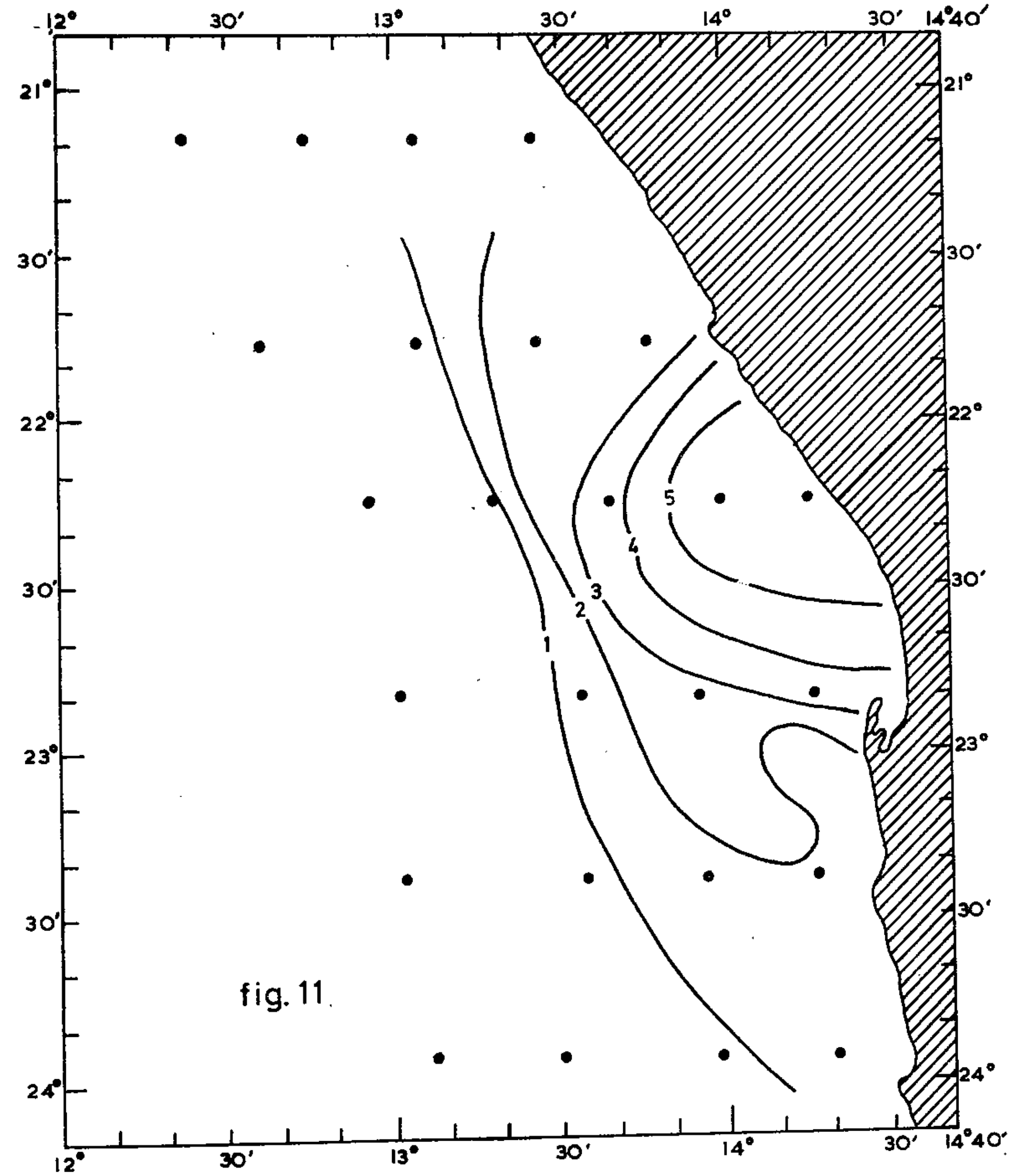


fig. 11