Investigations into the Behavior of Polish Coal When Exposed to Tropical Conditions

by W. Olpinski, J. Krajewski

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INVESTIGATIONS INTO THE BEHAVIOR OF POLISH COAL WHEN EXPOSED TO TROPICAL CONDITIONS

Dr. Wojciech Olpinski and Jan Krajewski

Contents: A Shipload of Polish Coal has been Furnished with Control Apparatus in order to Gather Detailed Data about its Behavior when Transported and Stored in Tropical Latitudes. A Description of the Quality and Method of Loading of the Investigated Coal. A Description of how the Control Apparatus has been Placed in the Ship. The Results of the Measurements of Coal, Water, and Air. The Wind Directions, and the Method of Ventilating the Cargo Holds on the Danzig-Karachi Route. A Description of the Behavior of Polish Coal Piled up in Sahdara near Lahore. By Analysis of the Gathered Observations, it has been Found that Polish Coal from Mines Selected for Export to Tropical Countries Bears itself Well in the Climatic Conditions of These Countries.

It is generally known from experience in the storing and transporting of coal that it possesses a dangerous propensity for spontaneous combustion (self-ignition). This propensity varies in intensity depending upon the kind and assortment of coal as well as on external conditions, such as the method of loading it into bins or cargo holds, temperature, humidity, and the velocity of the air flow. Since several years, investigations into causes of spontaneous combustion and research leading to a re-classification of coals from the viewpoint of this property have been conducted by the Mining Works and by the Chemical Processing Division of the Main Institute of Mining. These investigations have confirmed statistically a fact, long known to our experts, that Polish coal is not any more dangerous than foreign coal if proper types of it are selected for comparison.

Recognizing that a comparison between the laboratory conclusion and the observations of large coal cargoes would enhance the surety of decision on technical questions pertaining to export of coal, the Central Bureau of Coal Sales has organized and financed with the help of the Ministry of Foreign Trade and of the Ministry of Mining, investigations into the behavior of the average shipload. It entrusted the conduct of these investigations to the Main Institute of Mining. The investigations were conducted upon a British vessel, the SS Ionian Sea, during May and June of this year, that is, during a period when highest temperatures could be expected on the projected route. The observations made on the ship, the observations of old banks of Polish coal piled up in Pakistan, and the conversations with the Pakistani technicians, have made it possible to confirm the theory that Polish coal originating from mines exporting to tropical countries show a distinct resistance to spontaneous combustion.

The aim of the investigations was chiefly to gather detailed data on the behavior of polish coal during its transportation through the following climatic zones:

(a) above Cape Finisterre

(b) in the Mediterranean Sea

(c) in the Red Sea

(d) in the Indian Ocean

(e) during its unloading and on banks in Pakistan

In order to perform these investigations, we used equipment supplied to us by the Central Bureau of Coal Sales (nineteen distance thermometers, Orsat gas analysis and air testing apparatus, cans for taking coal samples), by the Main Institute of Mining (chemicals), and by the First Aid Mining Station (Drager's hollow rod indicators of carbon monoxide content).

The loading of the ship commenced on 24 April 1950. She was an old freighter with a capacity of 8,500 tons, and she had five cargo holds covered with impregnated boards at her false floor height, and five upper cargo holds lying above the false floor (between-deck).

An inspection of the ship, conducted before she was loaded with cargo, showed that the cargo holds and the false floors were dry and clean, if small quantities of the remains of the previously transported oil cakes are not taken into consideration. The sides of the ship were laid inside with 20 centimeter-wide boards. Electric wires under the deck were inspected, and it was found that they were secured and insulated; as to the steam conductors, they all lay above the deck.

The equipment for loading coal from railroad cars into the cargo holds was used very carefully. Coal from the cars was scooped up by an automatic scoop with a capacity of 3,000 kilograms and unloaded into the cargo holds. The scoop was not released until it was lowered to the height of half a meter from the surface of the coal. Large lumps of coal were unloaded upon a half-meter high layer of cobbled coal; then both these assortments were unloaded indiscriminately depending upon what railroad car came next. The coal assigned for the loading was supplied by the previously selected mines. They were unloaded separately into different cargo holds. Table I indicates the results of the inspection of individual cars carrying cobbled coal from each mine.

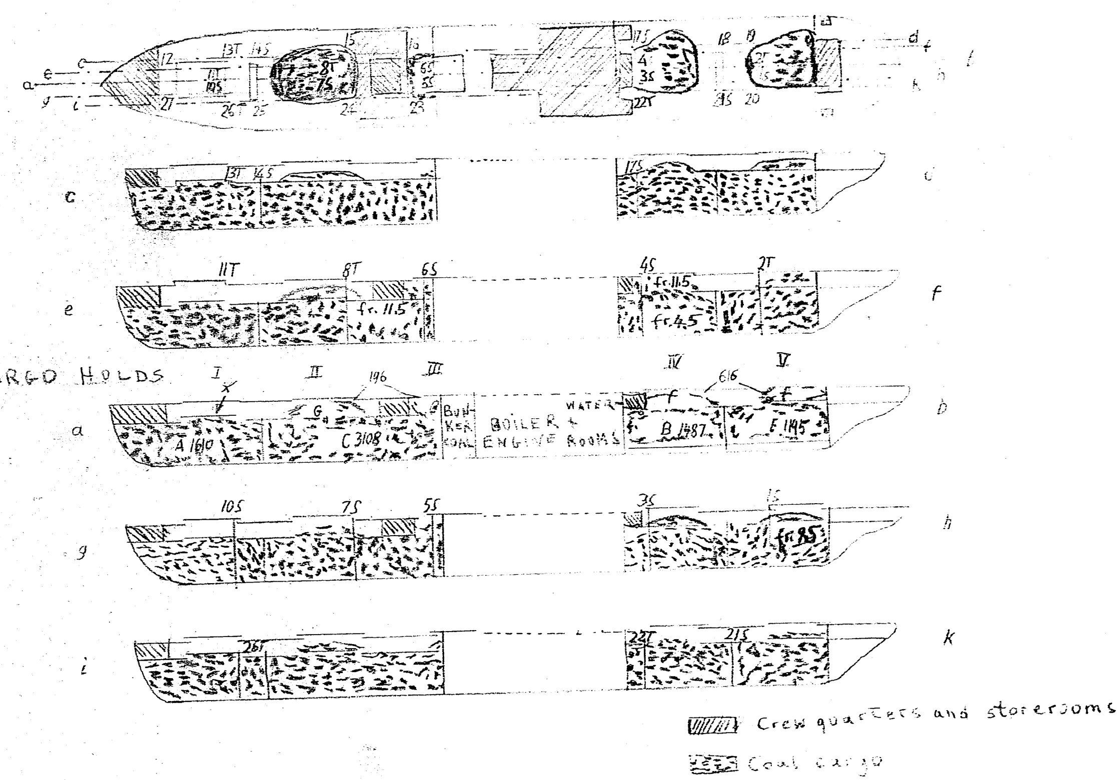
TABLE I

No of	Mine	Percentage of			
		Stone	Coarse grain	Fine grain	Coal dust
1	A	3.9	16.9	11.6	3.0
2	B	1.7	10.3	9.6	2.0
3	C	8.3	9.0	7.0	2.0
4	D	0.7	-	18.4	5.0
5	E	3.0	3.2	12.1	1.6
6	A	1.2	16.6	15.7	2.0
7	C	1.6	15.5	15.8	3.6
8	E	4.3	12.7	11.2	2.5
9	F	2.2	11.4	15.4	1.7

The location and the sizes of the cargo holds are shown on Figure 1 [See following page] (cross sections from A to K). These holds were divided into two parts by a false floor; a main lower part and a smaller upper part. 1610 tons of coal from Mine A were unloaded into the hold No 1, lying nearest to the forecastle. The upper part of that hold was left vacant in order not to overload the ship. Holds No II and III were filled with 3108 tons of coal from Mine C. After the surface of the coal was leveled, and after the hatch had

FIG. 1

LOCATIONS OF Cargo And of Points of Measurement



been covered with boards, 196 tons of coal from Mine G were unloaded into the false floor hold. Hold No IV was filled with 1487 tons of coal from Mine B. The hatch of that hold was left open and coal from Mine F was unloaded directly onto its upper part. Hold No V was filled with 1195 tons of coal from Mine E. That hold had a hatch covered with boards, and coal from Mine F was unloaded onto these boards. The upper part of Holds No IV and V contained altogether 616 tons of coal from Mine F.

Figure 1 shows the scope in which coal was unloaded onto the false floor.

The freighter carried bunker coal from England. That coal was extracted in Durham, and it contained large quantities of coal dust (about 50 percent).

During the loading, average samples of coal were taken from each cargo hold and sent for chemical analysis which showed results summarized in Table 2. [See Table 3 on Following pages]

Altogether, the conditions under which the ship was loaded were adverse. The placing of sounding pipes in the hatches, in order to measure temperatures by remote reading thermometer connection, made the uniform filling of the whole hold with coal more difficult: in conjunction with this, certain larger than usual quantities of pulverized coal had accumulated. Atmospheric conditions were also adverse. For at least three-fourths of the loading time, rain was falling. The data on the rainfall during the loading, as given by the Seacoast Division of the State Meteorological Institute, have been compiled in Table 3.

TABLE 2

Name of Sample	Moisture		Ash	Volatiles	Spontaneous Combustion		Carbon	Hydrogen	Carbon	Hydrogen	Sulphur		
	Lab	Trans										Ash	Pyrite
	M	M^{a}*	A^{a}	V^{a}	SC^{a}	SC^{b}**	Ca	Ha	Cb	Hb	S_c^a	S_A^a	S_p^a
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]
1. Mine A, Average from 1610 tons	0.97	1.78	3.86	30.65	69	72	80.15	4.94	84.04	5.24	0.72	0.17	0.44
2. Mine A, Sample from Cars	0.97	1.63	3.73	31.05	69	72	81.35	4.83	85.96	5.10	0.67	0.20	0.41
3. Mine A, Sample from 2 Cars	1.38	2.38	4.44	32.54	85	89	77.88	4.78	83.55	5.13	0.69	0.28	0.27
4. Mine E, Hold No I, 1195 tons	0.72	1.72	3.88	30.98	70	73	80.64	4.88	85.43	5.17	0.64	0.26	0.34

TABLE 2 (cont'd)

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]
5. Mine E, Sample from 2 Cars	0.71	1.63	3.55	31.81	67	70	81.43	4.91	85.86	5.18	0.60	0.17	0.40
6. Mine B, Hold No IV 1489 tons	1.48	2.77	4.78	33.52	90	94	76.06	4.83	82.27	5.22	0.84	0.24	0.52
7. Mine B, Sample from 2 cars	1.48	2.90	4.84	33.49	85	89	76.93	4.80	83.39	5.20	0.87	0.24	0.47
8. Mine F, Hold No IV, False floor Iv+V, 516 tons	0.57	2.31	4.42	30.57	67	70	78.24	4.72	83.89	5.06	0.82	0.18	0.57
9. Mine G, Hold No 4, False floor, 196 tons	0.94	2.42	2.97	31.58	80	82	80.26	4.81	84.26	5.08	0.65	0.15	0.40
10. Mine C, Hold No II, 3,100 tons	1.50	2.17	4.41	32.07	85	89	77.45	4.83	82.90	4.94	0.71	0.27	0.45

* Dry-air Sample
** Waterless and Ashless Sample

Chemical Analysis of Coal Samples

TABLE 3

Date	Weather
24 April	Scattered rain with few interruptions during the night and in the morning until 8:30 AM, and from 12:30 PM till evening.
25 April	Rain of mean intensity from 10:40 AM to 1:50 PM, and scattered rain from 3 to 4 PM.
26 April	Cloudy to clear, no rainfall.
27 April	Rain of moderate intensity from 2:15 PM to 5 PM
28 April	Scattered, passing rain with interruptions, from 2:30 PM to 3:25 PM
29 April	Rain mostly scattered, from 11 AM till evening
30 April	Cloudy to clear, no rainfall

The loading itself took a very long time, owing to many causes, chiefly to the installation of sounding pipes and to filling the cargo holds with coal separately from each mine.

Figure 1 shows the location of sounding pipes and thermometers in the cargo holds. A bird's eye view makes obvious the location of sounding pipes on the level, the cross-sectional areas C-D, E-F, G-H, J-K, and their positions within the coal cargo. The sounding pipes were placed in the corners of the hatchways and in the entrances to the false floors. These pipes were made from 2 inch pipes 9 to 11 meters long, depending on the distance between the deck and the bottom of the ship.

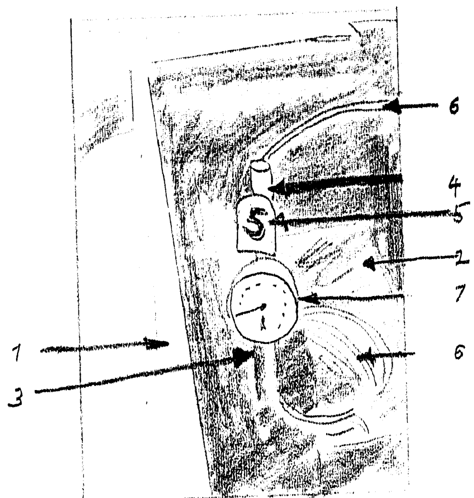
In Figure 1, points provided with numerals denote sounding pipes. The letter T denotes that a thermometer has been placed in the sounding pipe, and the letter S denotes that the thermometer has been connected to the signalizing system.

A greater quantity of pipes than of thermometers had been provided for, so that if a sudden rise in temperature were observed we could concentrate our investigations on the threatened sections. Figure 2 shows us a view of the opening of the pipe and of the thermometer dial. [See Figure 2 on following page]

The thermometers were placed in sounding pipes at different levels, so that of temperature readings could be taken at different heights of the coal layer. They were placed partly in sounding pipes installed in corners of the hatchways (Figure 1, cross sections E-F and G-H), and partly in the entrances to the false floors (Figure 1, cross sections C-D and J-K).

Continuity of observation was assured in such a way that, if during a storm or for another reason the hatchways were covered with boards and tarpaulin, then we could still take readings of the thermometers accessible in the false floors. But, if even those thermometers became inaccessible because of dangerous quantities of generated carbon monoxide, then readings would be taken automatically with the help of the installed system of signalization. We would set it for an expected temperature and if that temperature and if that temperature were reached then a bell would ring and indicate the identification number of the thermometer automati-

FIG. 2
METHOD OF INSTALLING THERMOMETERS



1- EDGE OF HATCH. 2- SURFACE OF COAL CARGO. 3- SOUNDING PIPE 4- WOODEN SOUNDING PIPE PLUG 5- RECOGNIZING TABLE OF SOUNDING PIPE. 6- THERMOMETER WIRE. 7- THERMOMETER GAGE

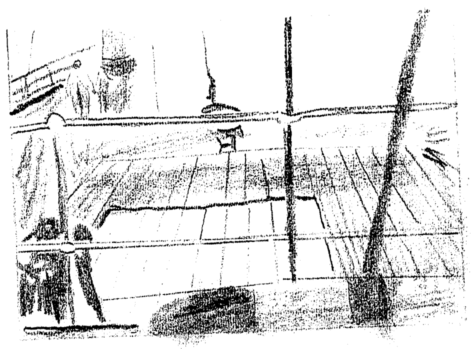


FIG. 3 - HATCH COVERED WITH BOARDS. TARPAULIN REMOVED BEFORE UNLOADING

cally. The electric signalization wires were installed all along the hull and embraced the whole coal cargo. The hatchways, after the holds were filled with coal, were boarded up and doubly covered with tarpaulin which sheltered the coal from the sun and water.

OBSERVATIONS MADE DURING THE TRANSPORTATION OF COAL

The ship left Danzig on 30 April, at 12 AM. Her daily positions, according to data supplied by her officers, have been compiled in Table 4. [See following pages for Table 4]

The ship was in these points bordering the individual zones on the following days:

(a)	Cape Finisterre	7 May
(b)	Gibraltar	9 May
(c)	Port Said	18 May
(d)	Perim 28	28 May

and she arrived at Karachi on 6 June, at 4 PM.

During the voyage in the Atlantic Ocean and in the middle part of the Mediterranean Sea the weather was sunny, while in the Baltic Sea and in the remaining parts of the Mediterranean it was chilly and cloudy. On the other hand, beginning with our arrival in Port Said and continuing through our sojourn in Pakistan, we had hot and cloudless weather. Stronger storms took place from 10th to 12th and from 17th to 18th of May, causing the wetting of the hatchways with sea water and compelling a more thorough covering with tarpaulins.

Owing to defective engines, and to the bad quality of the

TABLE 4

TEMPERATURES OF AIR IN THE SHADOW AT 12 AM

Date	Northern Latitude (at 12. AM every day)	Longitude (at 12. AM every day)	Weather	Difference between the local time and the Middle-European Time
[1]	[2]	[3]	[4]	[5]
April 30	Port Danzig		sunny, quiet sea	
May 1	55° 7'	13o 51'E	fog until noon, afternoon sunny, quiet sea	
May 2	Kiel Canal		scattered rain from 12:30 AM, to 2 PM, otherwise sunny	
May 3	54° 18'	5° 00' E	sunny until noon, afternoon cloudy, no rain	- 1 hour
May 4	10 Km from Dover		cloudy to clear, passing rains, fog in the evening	
May 5	49° 12'	3° 43' W	cloudy until noon, sometimes clear, sunny after noon, bigger billows	- 1 hour 33 minutes
May 6	46° 09'	7° 12' W	sunny, billowing sea	

TABLE 4 (cont'd)

[1]	[2]	[3]	[4]	[5]
May 7	42° 42'	9° 31' W	sunny, billowing sea	
May 8	38° 44'	9° 35'W	sunny, rough sea in the evening	
May 9	36° 05'	6° 46 ' W	sunny, quite quiet sea	
May 10	36° 25'	1° 51' W	sunny, very strong breeze	- 30 minutes
May 11	36° 54'	2° 15' E	cloudy to clear, after noon strong breeze, billowing sea	
May 12	37° 10'	6° 31' E	very cloudy to clear, breeze in the afternoon weaker	- 15 minutes
May 13	37° 15'	10° 57' E	sunny, sea almost quiet	
May 14	35° 49'	15° 37'E	cloudy until noon, afterwards sunny	- 20 minutes
May 15	34° 43'	20° 10' E	sunny, slight breeze	
May 16	33° 37'	24° 41' E	sunny, strong breeze	- 50 minutes
May 17	32° 40'	28° 54' E	cloudy to clear from 4 PM, sea very rough	
May 18	Port Said		cloudy morning with scattered rains, later sunny	
May 19	Port Suez		sunny	- 1 hour 10 minutes
May 20	27° 48'	33° 57' E	sunny	- 1 hour 20 minutes
May 21	24° 47'	35° 59' E	sunny, billowing sea	- 1 hour 30 minutes
May 22	23° 05'	37° 00' E	sunny	
May 23	19° 58'	37° 33' E	sunny	

Table 4 (cont'd)

[1]	[2]	[3]	[4]	[5]
May 24		Port Sudan	sunny	
May 25	Po	Port Sudan	sunny	
May 26	18° 53'	36° 02' E	sunny	
May 27	16° 21'	41° 03' E	sunny	
May 28	13° 56'	42° 52' E	sunny, cloudy in the evening, lightnings	- 2 hours
May 29	12° 29'	44° 54' E	sunny	- 2 hours 30 minutes
May 30	13° 26'	48° 03' E	sunny	
May 31	14° 18'	50° 50' E	sunny, stronger breeze	- 3 hours
June 1	15° 31'	54° 08' E	sunny	
June 2	16° 59'	56° 33' E	sunny, very rough sea	- 3 hours 10 minutes
June 3	19° 06'	59° 12' E	sunny	
June 4	20° 58'	61° 45' E	sunny, slight breeze	
June 5	22° 05'	64° 15' E	sunny, slight breeze	- 5 hours 30 minutes
June 6		Karachi	sunny	

bunker coal, the arrival at Karachi, which the captain of the ship planned for the 27th of May, was delayed by 10 days. The sojourn of the ship in the tropical zone was prolonged by just that period, so that the value of the observations made by us were enhanced. Air temperatures (in the shade) at 12 AM are shown on Table 5. [See Table 5 on following pages]. Until the Bay of Biscay, the average temperature was 15 degrees Centigrade, and in the Mediterranean Sea it was 23 degrees Centigrade. It rose to 27 degrees Centigrade in Port Said and to 33 degrees Centigrade in the Red Sea, but it fell to 30 degrees Centigrade in the Indian Ocean. As a result of the heating of the black-painted deck by the sun rays, the temperature of air under the deck was considerably higher, reaching 42 degrees Centigrade in the Red Sea.

The temperature of sea water (See Table 5) which averaged 8 degrees Centigrade in the Baltic Sea, rose on the average by 1 degree Centigrade daily, and reached 30 degrees Centigrade in Port Sudan. Then it remained at 30 degrees Centigrade throughout the rest of the voyage.

VENTILATION

The data pertaining to the ventilation of the cargo have been gathered in Figure 4. [See Figure 4 immediately following Table 5].

The pipe ventilators designated with numerals, which one can see on Figure 4 (1 May) opened above the deck horizontally, and their openings could be turned to any direction. On the drawings of Figure 4, small arrows near the ventilators show the direction

TABLE 5

TEMPERATURES OF AIR AND CARGOES [Left Upper Section]

Hold No	Mine	No	Depth in meters	Cape Finisterre							Gibraltar			Mediterranean Sea								
				30 April	1 May	2	3	4	5	6	7 May	8	9	10 May	11	12	13	14	15	16	17	18
[1]	[2]	[3]	[4[	[5]							[6]			[7]								
I	A	10S	6.2	15	11	7	11	11	11	10		9	9	10			10	11	10	10	12	
		11f	2.6	12	9	10	10	11	11	11	12	12	13	12	13	13	14	14	15	15	16	
		13T	2.4	12	11	12	12	12	13	13		13	14	14			16	16	16	17	18	18
		26T	6.2	12	10	10	11	10	11	11		11	12	11	12	13	14	13	13	16	15	15
II	C	7S	8.3	12	10	7	11	10	11	10		9	9	10			12	11	11	13	13	
		8T	to 11.5 8.1 to 11.5 1.2		10	7	11	12	11	11	12	12	11	11	17	17	17	17	17	17	17	
		14S	6.4	12	9	10	10	10	11	11		11	12	11	11	12	13	13	13	14	15	15
		6S	6.0	12	9	8	10	12	11	11	12	10	12	11	12	11	12	11	11	10	12	11
III		5S	8.0	7	7	7	7	7	9	8		9	10	10							12	

(cont'd)

TABLE 5 (cont'd) [Left lower section]

[1]	[2]	[3]	[4]	[5]							[6]			[7]								
II III	G	5S	1.0																23	24	24	
IV	B	17S	5.4		6	7	8	9	10	9		9	12	11	11	12	13	13	13	15	15	15
		4S	to 4.5 8.3 4.5 -10.5 5.3	12	10	7	8	10	11	11	11	12	12	11								
		3S	8.2	8	11	7	9	10	10	11	11	10	10	10			11	10	10	12	13	
		22 T	6.2											12	12	12	12	13	13	14	14	15
IV, V	F	4S	1.6												17	19	18	19	20	20	21	
V	E	2T	7.6		12	11	12	12	11	12	12	12	13	11	12	12	13	13	12	13	14	
		1S	to 9.5 7.1 to 9.5 3.1	8	7	6	6	6	7	8	7	8	10	13			16	16	16	16	16	
		21S	6.8		11	11	11	11	11	11				11	13	12	13	13	14	15	15	15
Temperatures		Air			14.5	22	15	12	13	15	20	19	22	20	21	21	22	23	23	22	22	22
at 12AM		Water			8	8	9	11	12	14	14	15	16	18	18	18	18	19	19	20	20	21
		engine room			23	30	32	30	33	34	30	35	32	36	34	35	39	41	40	39	40	40
		air under the layer															33			29	27	

Table 5 (cont'd)

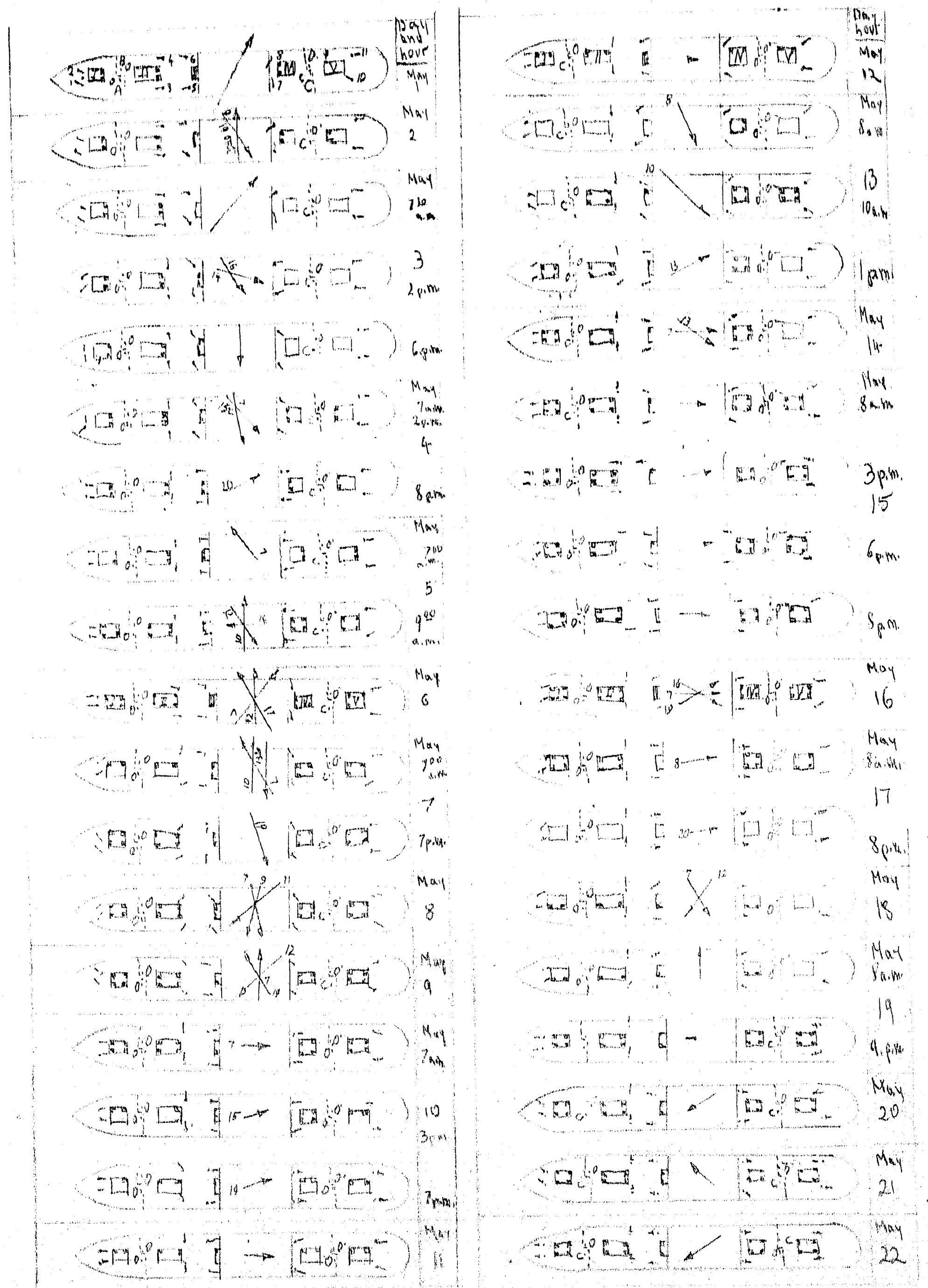
[Right, upper section]

Red Sea										Indian Ocean							
19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5
May										May			June				
[8]										[9]							
10	11	11	11	11	11	12	12	13	14	15	13	17	17	18	18	18	18
16	17	18	18	19	20	20	22	23	24	25	25	26	27	28	28	28	28
18	18	18	19	19	21	22	24	24	24	24	25	25	25	25	25	25	25
15	15	15	15	16	16	18	19	20	20	21	21	22	23	24	24	24	25
12	13	12	12	13	13	15	15	15	17	18	19	20	20	21	21	22	22
16	20	20	22	23	23	23	24	25	26	26	28	26	26	26	26	26	26
15	15	16	16	17	17	18	19	19	20	20	21	23	23	24	24	24	24
12	12	13	12	13	14	15	17	17	18	18	19	21	22	22	22	23	24
14	14	14	15	15	15	18	18	18	20	21	22	22	22	23	23		

TABLE 5 (cont'd) [Right, lower section]

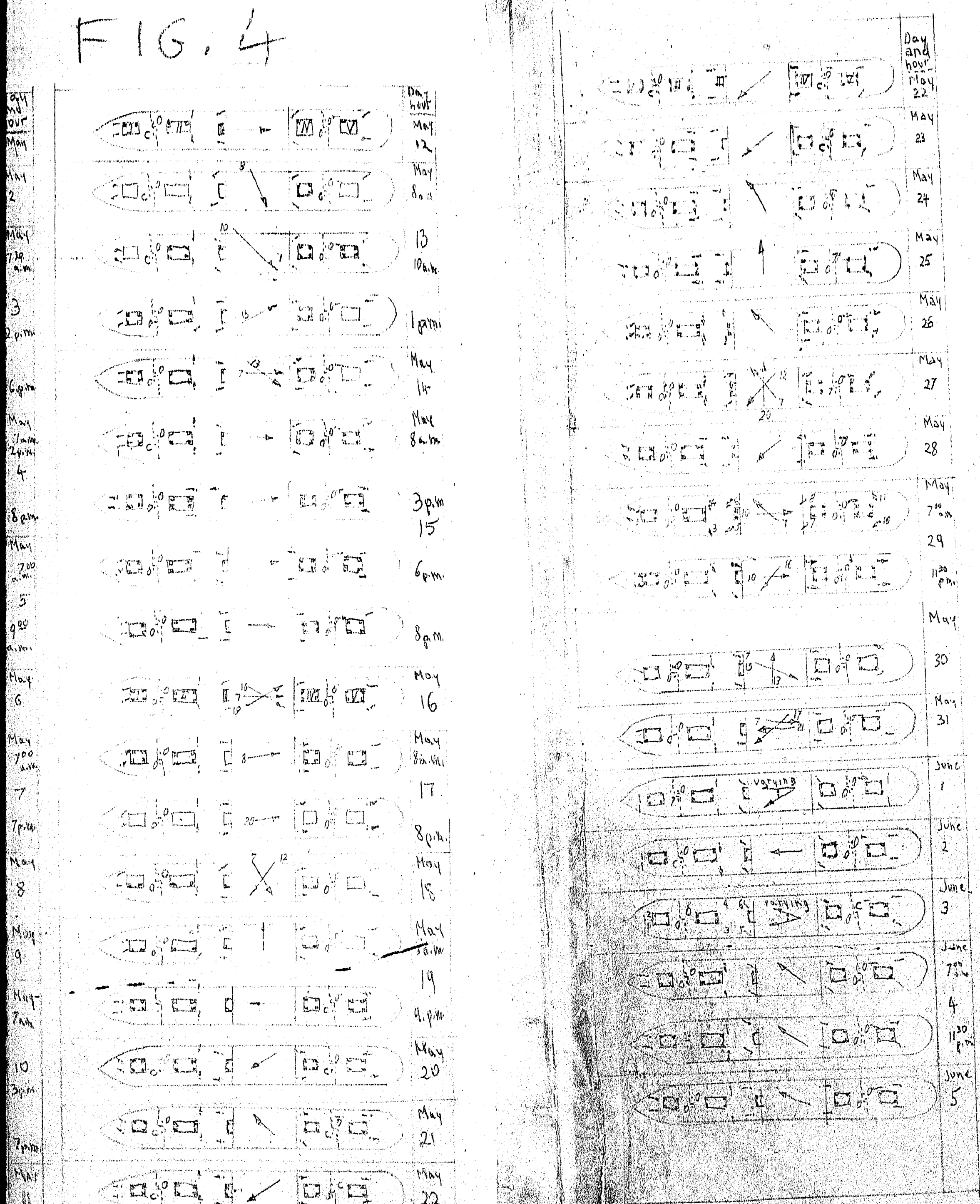
[8]										[9]							
															23	24	24
16	17	17	17	18	19	21	22	24	25	25	25	25	25	25	25	25	25
13	15	14	14	15	15	18	18	18	19	20	21	21	23	23	24	25	25
15	16	17	17	18	20	20	21	22	22	23	24	25	25	25			
21	22	24	24	25	25	26	26	27	29	30	30	30	30	30	30	30	29
14	14	15	15	15	15	16	17	17	17	17	17	20	22	22	22	22	22
17	17	17	20	21	22	21	23	24	25	25	25	25	25	25	25	25	25
15	15	15	17	16	16	20	19	20	20	20	23	23	24	25	25	25	25
28	26	28	29	32	32	32	33	33	33	32	32	29	30	31	32	30	31
24	23	27	28	29	29	30	30	30	30	30	31	30	29	29	29	28	29
43	38	36	50	54	52	44	42	41	44	43	48	46	42	43	43	43	43
37	32	36	40	42	39	39		43	43	40	42	39	41	41			

FIG. 4



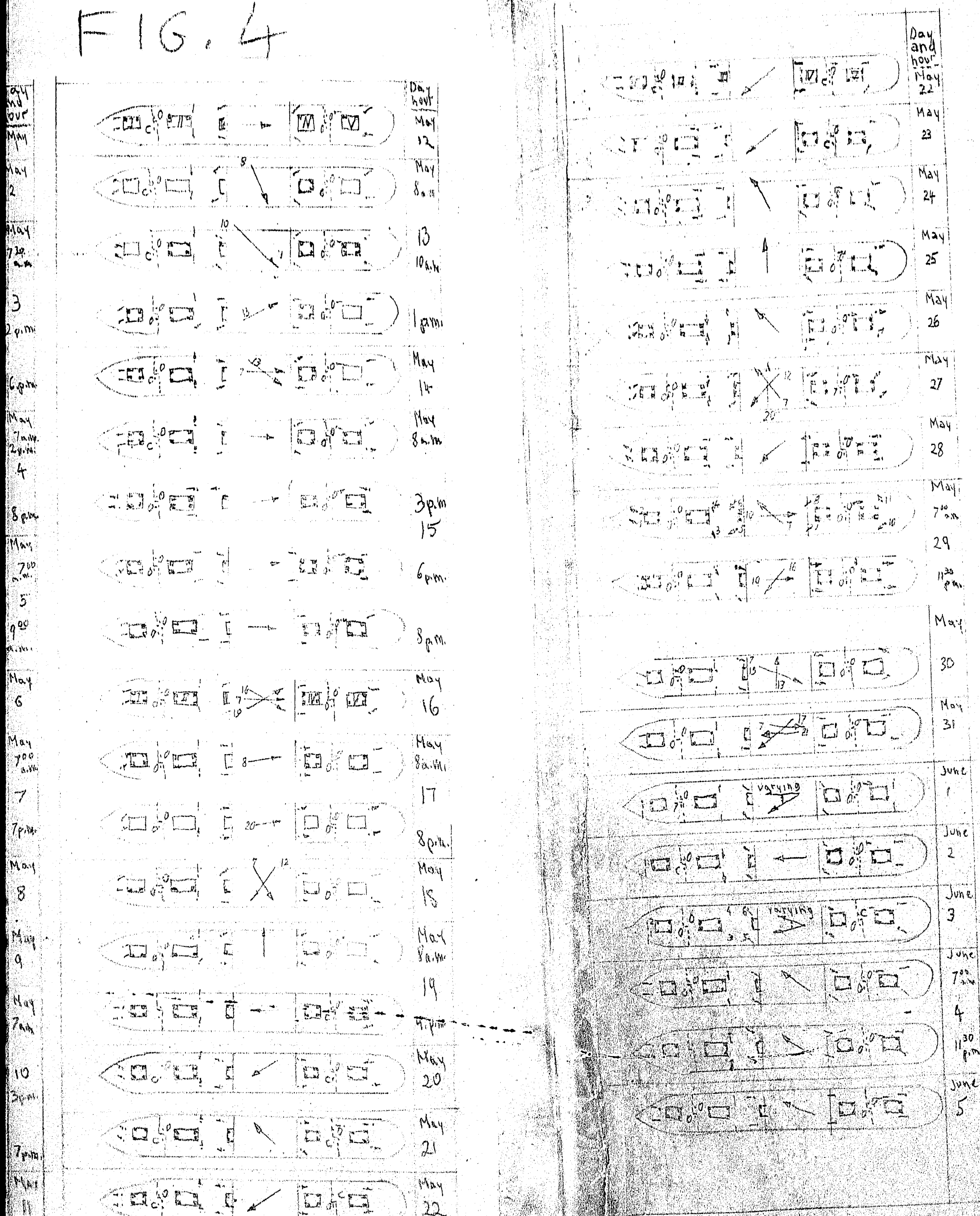
WIND DIRECTION, POSITION OF VENTILA

FIG. 4



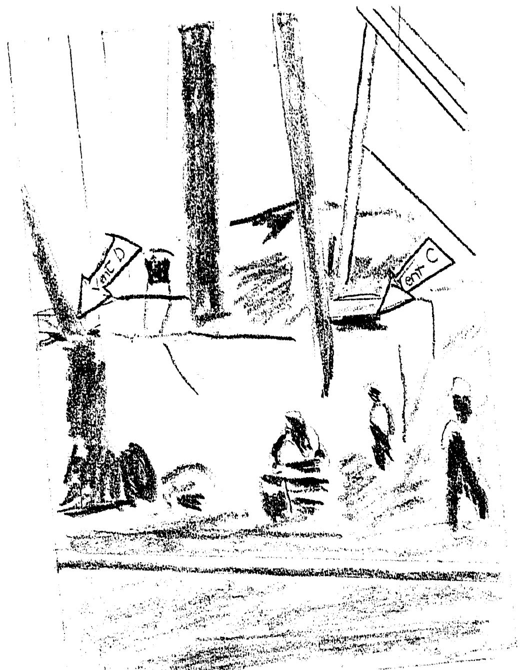
…ION, POSITION OF VENTILATORS, UNCOVERING OF HATCHES

FIG. 4



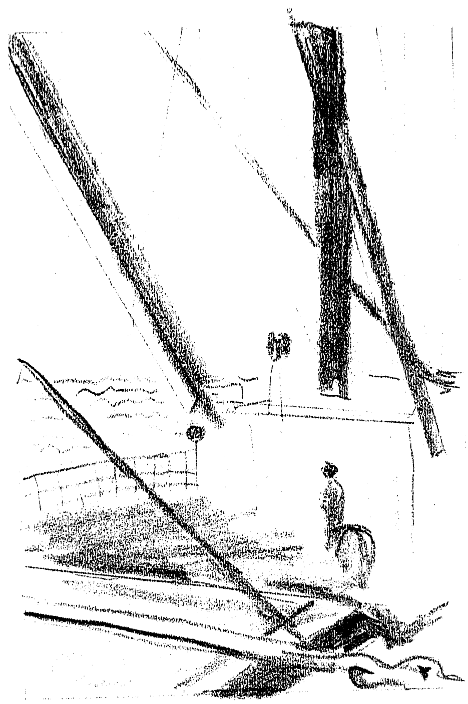
...LLA, POSITION OF VENTILATORS, UNCOVERING OF HATCHES in which their openings were turned. The ventilators A, B, C, and D has (see Figure 5) [Figure 5 on following page] an opening which could not be regulated. Within these ventilators, the sides of which measured 0.5 x 0.5 meters, there was a ladder leading to the false floor and to the bottom. The entrances to these ventilators made possible an additional flow of air, so that these entrances were designated on the drawings with letters O or C, showing whether they were open or closed. All the ventilators, except for No 9, reached to the false floor and ventilated simultaneously all the corresponding cargo holds above and under that floor. Ventilator No 9 pierced the deck only the ventilated holds No IV and V above the false floor. Cross lines (Figure 4) indicate the separate walls between the cargo holds, full lines indicate that the wall extends from deck to bottom, and dotted lines indicate that the wall extends from false floor to bottom. Large arrows in the middle of the drawings show wind directions and/or ship direction. Lack of a number near the arrow means that change in wind direction was not observed. Blackened corners of hatchways denote uncovered corners. On the right margin of each drawing, are shown the day to which the drawing pertains and the hour at which the change in the direction of the ventilators or in the covering of the hatches by the crew was observed. It was found that the crew generally used to turn the openings of the ventilators away from the wind, e.g. on 4 May, at 4 PM; on 7 May, at 7 PM; on 10, 11, 12, and 13 May. If, however, the wind changed its direction too often, then the openings of the ventilators were not tampered with, e. g., on 8, 9, and 27 May. Sometimes the maneuvering of the ventilators was quite incomprehensible, e. g., om 15 May. (The captain is responsible for the

FIG 5



A VIEW OF VENTILATORS

FIG 6



UNCOVERED CORNERS OF HATCHES

proper arrangement of the cargo, and so it is he alone who commands the loading and the airing of the cargo.)

The corners of the hatchways were initially partly covered. On 5 May they were all uncovered, and henceforth they were covered only during a storm, but only on the sides from which flooding by sea water was threatened.

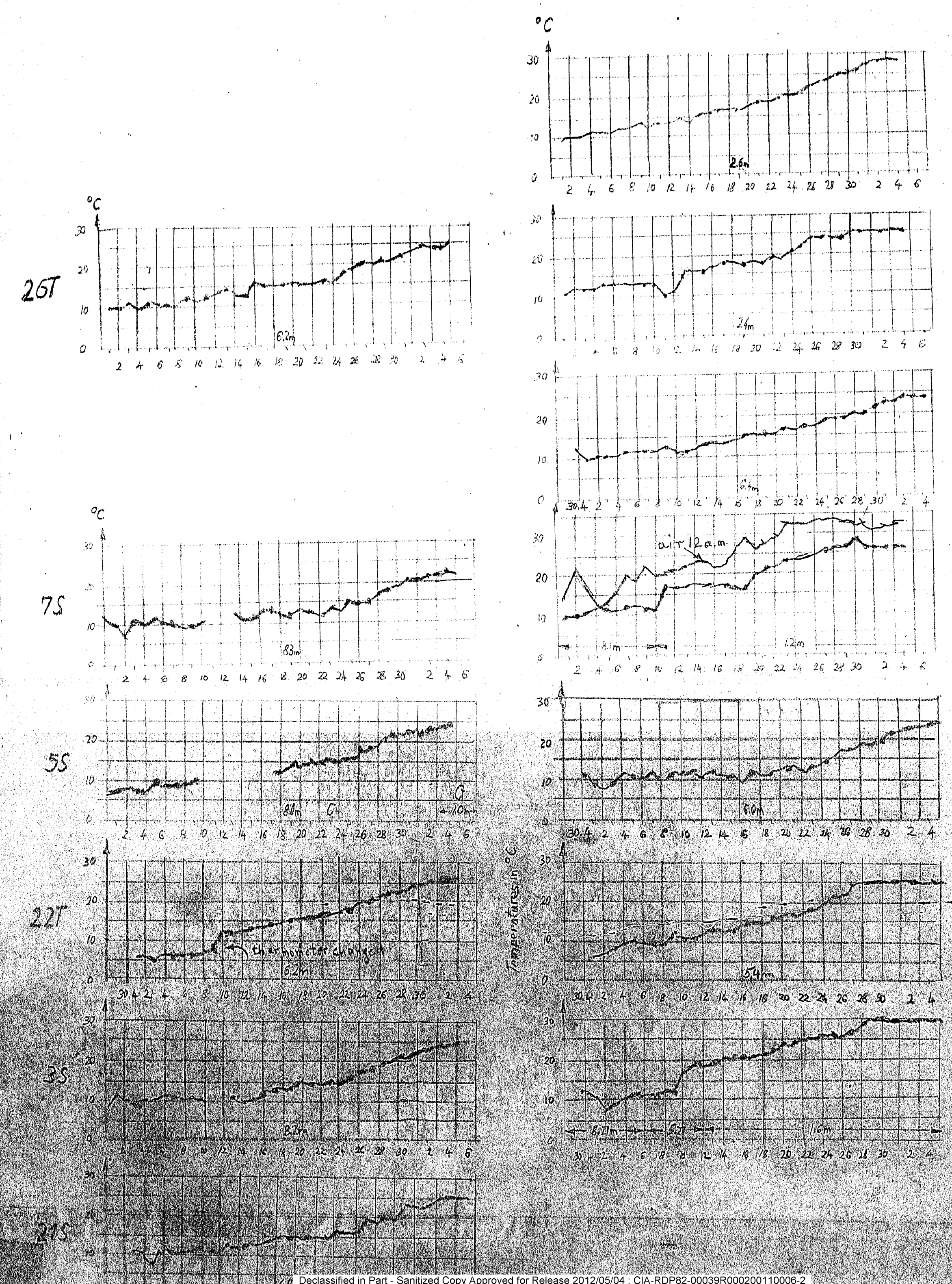
As we will show below, the temperature of air under the deck exceeded considerably the external air temperature. Cooler air entered under the deck by the corners of the hatchways, and hot air left by these corners. Without this, the temperature would rise much more quickly. Air entered under the false floor by the somewhat uncovered (because of the installation of thermometers) entrance doors, and left by ventilators or in an opposite direction if the ventilator openings were turned towards the wind, which happened quite frequently in the abaft holds, e. g., on 5 May at 3 and 6 PM, on 19 May at 8 PM, and on 26 May.

AIR AND CARGO TEMPERATURES

These temperatures have been compiled in Table 5 and in Figure 7. [See Figure 7 on following page]

Observation of thermometers at the beginning of the voyage and during the subsequent period of heat spells proved that even these thermometers which were placed 1 meter deep under the surface of coal did not become subject to any noticeable changes in temperature during a 24-hour period.

Hence, the dials of all the accessible thermometers were



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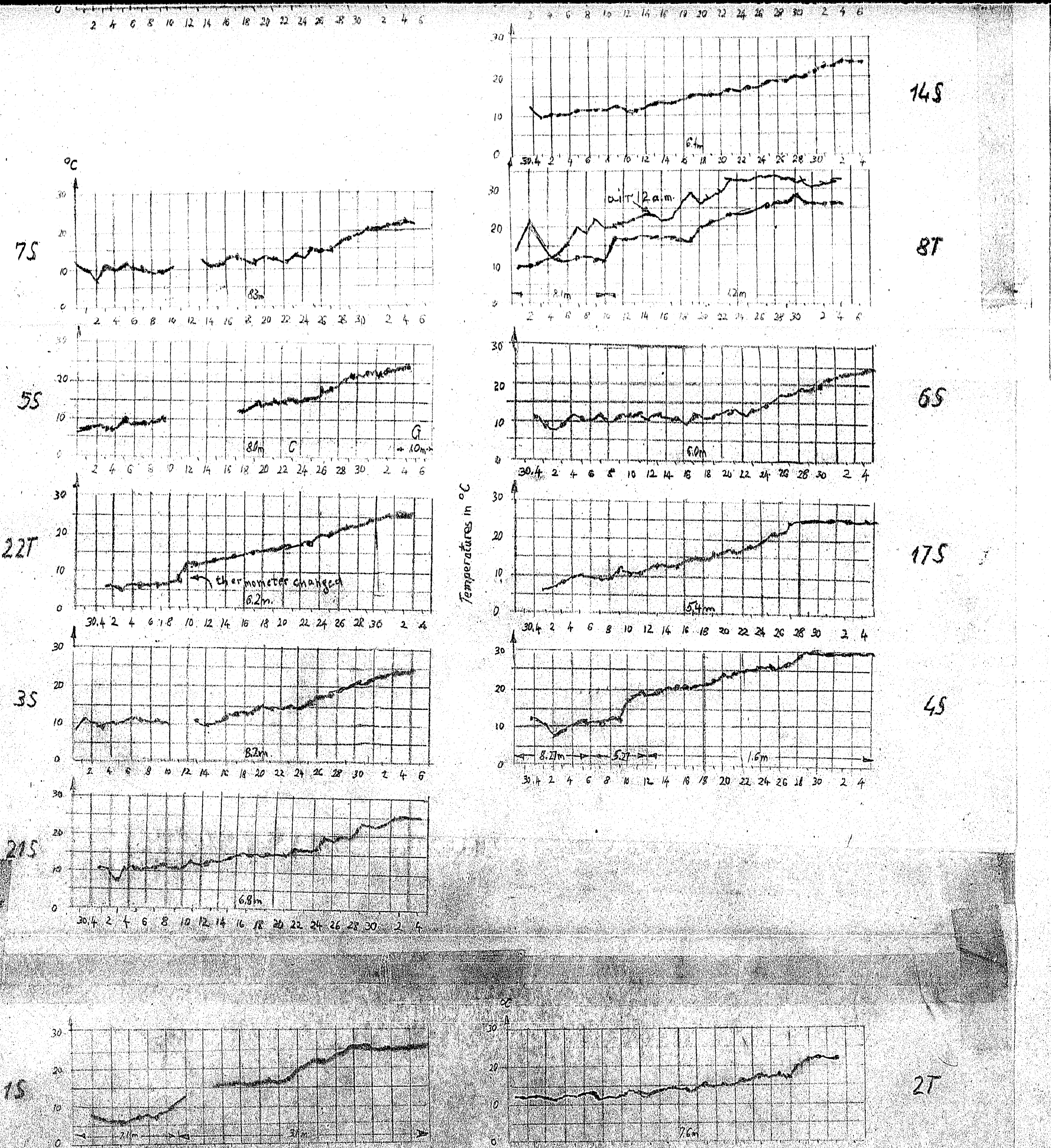


Fig. 7 - Changes in the temperature of the cargo

read but once daily, at about 8 AM. On 30 April, 7, 8, and 11 May, the thermometers placed in the hatches could not be read because the hatches were covered up. The mechanism of thermometer No 10 stopped working and indicated a too low temperature (in comparison with thermometer 26 T, placed in the same coal and at the same depth) hence it was not shown on Figure 7. It was also found that thermometer 22T in hold No IV was also damaged; the readings in that place can be regarded as valid only from 10 May, when it was replaced by a reserve thermometer. By reading repeatedly the same thermometers, it was found that the error in reading the thermometers with a scale of 0-250 degrees Centigrade reached 3 degrees Centigrade. We had only two more exact thermometers, both with a 0-50 degrees Centigrade scale and with a margin of error 0.5 degrees Centigrade. One of them was used to replace the damaged 22T, and the other was used to read the temperature of the air under the deck in the tropical zone. We tried to change the position of the thermometers as rarely as possible in order not to damage the metal conducting pipes.

The placing of thermometers at different depths made possible to take quickly temperature readings of the whole ship load. For checking purposes, the temperatures of the thermometers 8 T and 4S were taken twice at 1 meter distances. 8T was selected because it lay near to the middle point of the forward cargo hold, and 4S was selected because it lay near the engine room.

TEMPERATURES OF THE CARGO IN INDIVIDUAL CLIMATIC ZONES

On the day of embarkation at Danzig, the temperature of the cargo was 7 - 12 degrees Centigrade, (if the doubtful 10S is omitted) and it remained at that temperature until Cape Finisterre. On 2 May the temperatures of 8T and 4S were measured by moving vertically these thermometers within the sounding pipes and leaving them at a given level for an hour, in order to level out their temperatures with the temperature of their surroundings. The measurements (Table 6) indicate an unchanging steady temperature of the cargo (10 - 11 degrees Centigrade) which rises to 14 degrees Centigrade in 8T and to 12 degrees Centigrade in 4S only when on surface.

TABLE 6

8T		4S	
Distance from surface in meters	Temperature in °C	Distance from surface in meters	Temperature in °C
8.1	10	8.3	8
6.1	11	6.3	10
4.1	11	5.3	10
3.1	11	4.3	9
2.1	11	2.3	10
0.1	14	0.3	12

On the Atlantic Ocean

Between Cape Finisterre and Gibraltar, the temperatures at distinctly cool locations (5S, 17S, 1S, and thermometers placed near to the surface -- 11T and 13T) rose by 2 - 3 degrees Centigrade. The temperature readings in the place 8T and 4S indicated (Table 7) that the heating of the cargo had reached a little deeper.

TABLE 7

TEMPERATURE OF THE CARGO ON THE ATLANTIC OCEAN

8T		4S	
Distance from Surface in meters	Temperature in °C	Distance from Surface in meters	Temperature in °C
8.1	11	5.2	11
6.1	11	4.2	11
5.1	12	3.2	11
4.1	13	2.2	13
3.1	14	1.2	16
2.1	16	0.7	17
1.1	18		

Mediterranean Sea

The temperature of the sections lying near to the bottom, as shown in 26T, 14S, 6S, 5S, 17S, 22T, 2T, 21S, rose to 12 - 15 degrees Centigrade, while, nearer to the surface, 13T, 8T, and 1S reached 18 degrees Centigrade, and 4S even to 21 degrees Centigrade. The rapid rise in temperature of 4S (F) worried us, but later we found that nothing dangerous had developed.

Red Sea

In this region the temperatures of both the deep and the shallow layers rose. The average rise was about 1 degree Centigrade daily, uniformly throughout the whole depth. At the end of that period, the temperature at the bottom reached 19 degrees Centigrade (6S, 3S) and in the upper layers 26 degrees Centigrade (8T). The 4S, with a temperature of 29 degrees Centigrade continued to be the most heated of all.

Indian Ocean

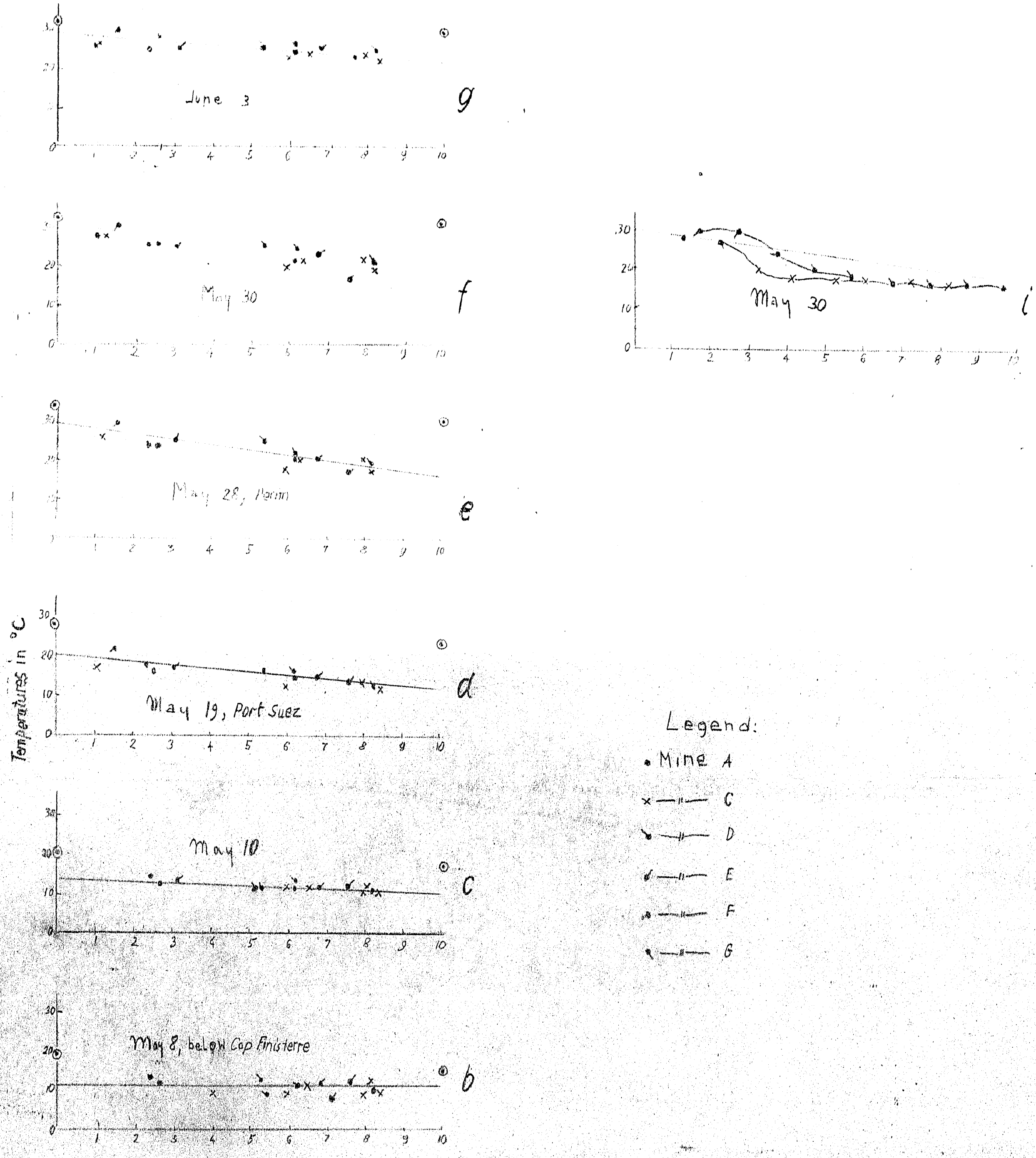
As the temperatures of air and sea ceased to rise, so also ceased to rise the temperature near the surface (4S, 8T, 17S, 1S), but, nearer to the bottom, the temperature still continued to rise (26T, 7S, 14S, 6S, 3S, 2T, 21S). At any rate, the rise was slow, and in no place the temperature of the coal did exceed the temperature of air.

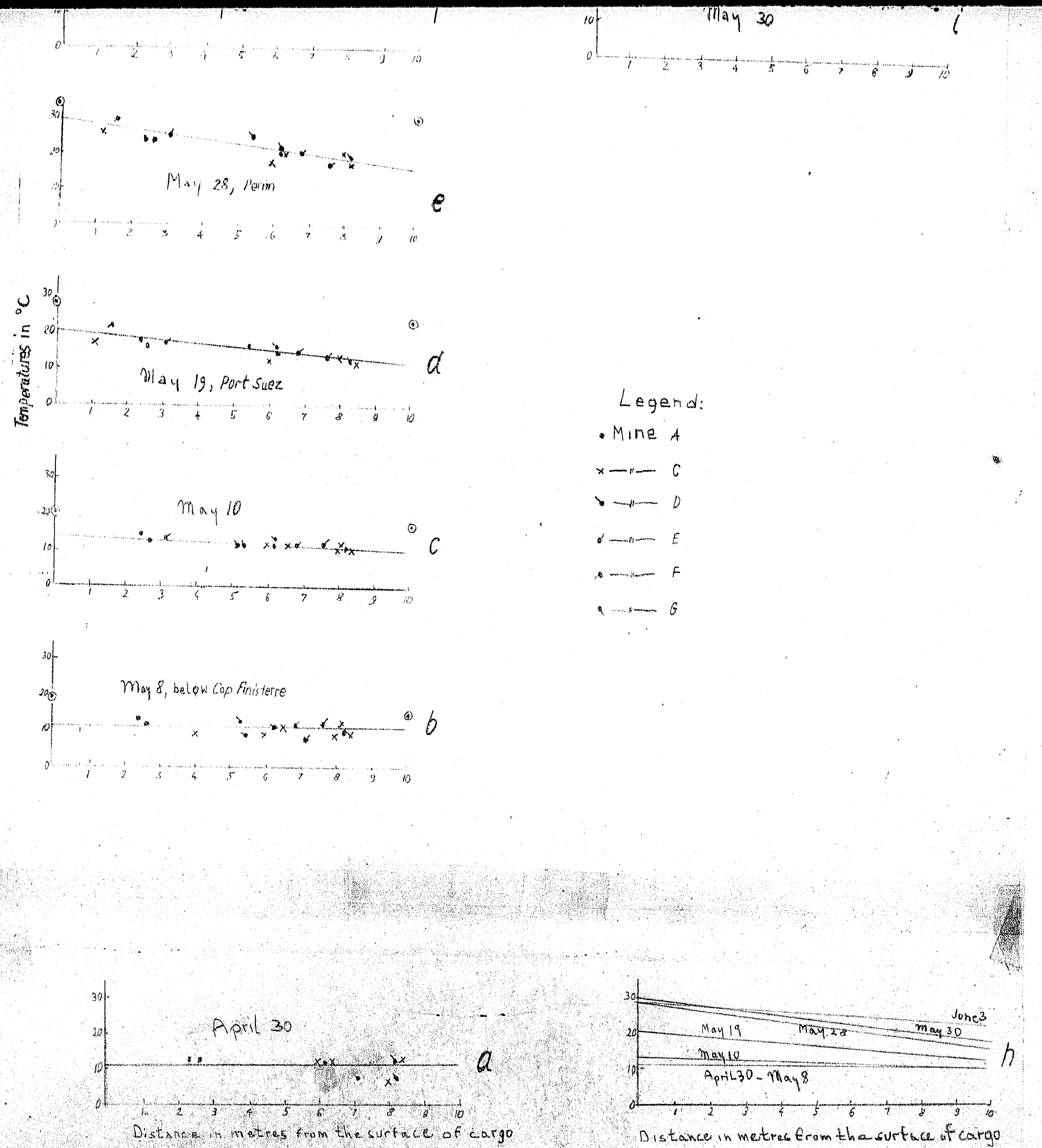
On 30 May, the temperatures were again measured with thermometers 8T and 4S. Temperature readings are shown in Table 8 and on Figure 8, disgram 1. [See Figure 8 on following page] [Also see Table 8 on second following page]

ANALYSIS OF THE RESULTS OF TEMPERATURE MEASUREMENTS

Figure 8 shows the results of measurements made near the borders of individual climatic zones. Individual diagrams of that figure show the dependence of the temperature of the coal cargo upon the distance between the place of measurement and the surface of the cargo, and upon the mine from which the coal had originated. These diagrams include straight lines which show the dependence of

FIG 8


June 3
g
May 30
f
May 28,
e
Temperatures in °C
May 19, Port Suez
d
May 10
c
May 8, below Cap Finisterre
b
May 30
i
Legend:
Mine A
C
D
E
F
G



Dependence of Temperature Upon The Kind of Coal and Upon Distance From Surface

TABLE 8

TEMPERATURE OF THE CARGO ON THE INDIAN OCEAN

8T		4S	
Distance from surface in meters	Temperature in °C	Distance from surface in meters	Temperature in °C
8.2	17	9.7	17
7.2	18	8.7	17
6.2	18	7.7	17
5.2	18	6.7	17
4.2	20	5.7	19
3.2	20	4.7	20
2.2	27	3.7	24
1.2	28	2.7	30
		1.7	30

the temperature of the cargo upon depth, on a given day. A comparison of the locations of temperatures, as considered upon these lines should make it possible to discover the differences in the degree of the propensity to spontaneous combustion, shown by coal from different mines. The observation of the changes in the position of the lines of average temperatures may give us a clearer picture of how the cargo behaved on the whole. Generally speaking, it may be noted that the temperatures of the cargo, which were very varied at the beginning of the voyage (diagrams A and B), probably owing to differences in temperature during the loading time, approach distinctly the lines of average temperatures during the first ten days of the voyage (diagram C).

Until then, therefore, the properties of individual types of coal cannot be investigated. During the following periods (Diagrams D-G), the plotted points are scattered widely again. One should remember, though, that this might result not only from differences in propensity of coals for spontaneous combustion but also from varying extraneous factors near the place of measurement (flow of air, distance from the engine room, etc). According to Table 2, the average samples of coal from the cargo of the SS Ionian Sea indicated the following propensities for spontaneous combustion:

F	70	G	82
A	72	C	89
	73	D	94

Which all points up that these different types of coal belong to a group of hardly self-combustible coals.

The least self-combustible coal F was unloaded onto the most self-combustible D, into hold No IV, in the neighborhood of the engine room. Probably owing to an easier access of air into its upper layer, this coal oxidized itself as rapidly as the more self-combustible D, which had a limited access to air, so that the temperatures of both these types of coal were, as shown on diagram D-G, above the average. The coals A and E, which react similarly as coal F, are predominantly found below the average line, or on it. The temperatures of coal C lie plainly above the average line.

Concluding: in accordance with the laboratory findings about their propensity for spontaneous combustion, the A, E, and D coals preserved themselves well, the F coal heated itself too much, the

G and C coals heated themselves too little. The probable -- in our opinion -- cause of the higher heating of coal has already been discussed above. We measured the temperature of G coal only in one place and that only during the last three days of the voyage, because its quantity was small (196 tons) so that no serious conclusion could be drawn from these measurements. The C coal was investigated thoroughly (5 places of measurement), yet we cannot state with certainty whether its slower self-heating was due to its properties or to the better conditions under which it was loaded. By a comparison of the behavior of coals A, C, and D, we would say that coal in forward cargo holds heats itself more slowly, and that it heats itself quicker in the abaft holds, but such a conclusion is not warranted because of the fact that we observed the most abaft hold, containing E coal, heated itself very slowly. If we omit G coal, we may, on the basis of the observations discussed here, divide the investigated coals into two sufficiently discernible groups: the hardly self-combustible A, C, and E, and the easily self-combustible F and D coals.

Considering that the temperatures of the coal did not exceed the temperature of air, we would say that the above-mentioned differences result rather from somewhat differing conditions in individual cargo holds than from differences in propensity for spontaneous combustion. The lines of average temperatures have been gathered together in diagram H, Figure 7. There, it is clearly evident that the temperature of the surface of the cargo rises initially more rapidly, that, after crossing the Suez Canal, (May 19) the lines move almost horizontally, and that beginning with 30 May the temperature of the bottom layers continues to rise, while the temperature at a distance above 2 meters from the bottom begins to fall off.

Besides the temperatures of the interior of the cargo, we have also measured in the tropical zone the temperatures 15 centimeters below the surface and the temperatures of air above that section of the cargo (under the deck) in the "x" place, Figure 1, hold No IV. Because we had at our disposal for this purpose only one trustworthy distance thermometer, for the first two days we measured with it the temperature of air above the surface of coal, and for the following two days the temperature of coal itself. The external conditions were sufficiently stable, so that the results of these measurements may be compared, even if they were not performed simultaneously. The result is shown on Table 9. [See Table 9 on following page]

From Table 9, it may be seen that, already at a distance of 15 centimeters from the surface, the differences in temperature amount only to 3 degrees Centigrade, in spite of the differences in air temperatures amounting to as much as 13 degrees Centigrade. It is also evident that it is the deck which generates the heat and not the oxidation of coal, because temperature in the evening, after the deck cools, falls to about the same level as the previous day.

Investigations into the content of carbon monoxide in the air above the surface of the sargo also corroborate a conclusion that oxidation reactions play a relatively insignificant part here. These investigations were conducted five times with the aid of Dräger's indicators. The first to be investigated was the air within the closed hatehes of the false floor, 17S and 22T, i.e., in the locations of highest temperatures. On 5 May, carbon monoxide was found neither in 17S nor in 22T. On 12 and 27 May, only the 17S was checked and no carbon-monoxide was found there on 12 May, but a small trace of Co was found there on 27 May. Considering such result, on May 29

TABLE 9

SURFACE TEMPERATURES

Day	Hour	Temperature in °C: 15 cm under the surface of coal	Temperature in °C: of air above the surface of coal	Temperature in °C: of air above the deck at 12 AM
[1]	[2]	[3]	[4]	[5]
May 31	A.M. 7:00		30.2	
	8:30		30	
	12:00		39.5	32
	P. M. 3:00		42.2	
	9:00		32.2	
June 1 A.M	7:00		30.5	
	8:30		32	
	12:00		40.0	30
	P.M. 3:00		43	
	10:00		31.5	
June 2 A.M	7:00		30.2	
	8:30		32.5	
	12:00		41	31
	P.M. 7:30		32.7	
	7:45	34.4		
	9:15	34.4		
June 3 A.M.	7:00	31.6		
	8:30	32		
	12:00	32.9		
	P.M. 3:00	34.5		
	7:00	34.6		

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[1]	[2]	[3]	[4]	[5]
	9:00	33.9		
June 4 A.M.	7:00	32.5		
	8:30	33.0		
	12:00	33.6		

we investigated the 17S, 21S, 22T, and the air in those ventilators into which we were able to plunge a sounding pipe through chinks in their nets (Numbering of the ventilators: Figure 4). On 29 May, at 7: AM, (the measurement was performed between 7 and 8 AM), it was found that ventilator No 1 (left, hold No I) contained the greatest amount of CO, but even there the coloring of the indicator was much more weak than the lowest valve of the scale, which amounts to 0.04 percent of CO, so that it may be said that traces of CO were found in ventilator No 1, and still smaller traces in other ventilators. Here, the intensity diminished in this succession: 1, 2, 10, 17S, 7, and 22T. The remaining ventilators were not investigated owing to their inaccessibility. On 3 May, no CO was found in ventilators No 1 and 5, but slight traces of it were found in No 4 and 3. The discovery of the presence of traces of CO indicates that, after all, the oxidation of coal did take place, but to such small a degree that it did not contribute to any serious rise in temperature.

During our sojourn in Pakistan, we held a conversation with the Coal Commissar of Pakistan. The Commissar emphasized that he is very satisfied with the punctuality of supplies as well as with the calorific content of Polish coal. Certain difficulties are caused by a greater content of volatile matter (South-African coals contain only

17 - 27 percent of volatile matter and Pakistani boiler rooms are not geared to receive coals containing more than 30 percent of volatile matter). The Coal Commissar directed us to the Sahdara power-station near Lahore, so that we might have a look at Polish coal from previous transports. We discussed Pakistani coal, and the Commissar mentioned that these types of coal (from the Puetta District in Baluchistan and from the Punjab District) are young coals with a high content of sulphur amounting to as much as 6 percent. Their seams are thin (60 centimeters), and they are extracted by mining galleries. They are quite frequently subject to spontaneous combustion.

On 20 June we arrived in the Sahdara power station near Lahore, where 2,000 tons of Polish coal lay piled up since 2 months. The coal was piled up on an embankment reaching a height of 3 meters in some places. On that day, the air temperature was 49 degrees Centigrade. The coal was very heated by the sun, but it betrayed no marks of spontaneous combustion. Many large lumps were observed, and they did show some loss in solidity and mechanical endurance. When thrown down from a height of 0.5 meters, they shatter. Nearby lay South-African coal which differs from Polish coal by its grayish-dull appearance. Within the power station, coal is crushed manually by hammers until pulverized, and then fired on grates in Babcock boilers.

Meteorological Data

In order to ascertain whether the temperature conditions during the voyage, which is the subject of this article, differ from the temperatures normally encountered in these locations, and in order to inform ourselves about the temperatures on the way to Chittagong and within the area of Pakistan, we received from the Pakistani Meteorological Office a few data which show that May, June, and July are the hottest months, and that highest temperatures prevail during that period in Punjab, in the vicinity of Peshawar, and in Lahore.

Besides the observations of the Meteorological Office, compiled in Table 2, we were also provided with the mean monthly and maximum temperatures (Table 10) excerpted from the following books: Bartholomew, J. G., and A. J. Herbertson, Atlas of Meteorology, Edinburgh, 1899, and Kendrow, W. G. The Climates of the Continents, Oxford University Press, 1947.

TABLE 10

MEAN MONTHLY AND MAXIMAL TEMPERATURES

Month	Mean Monthly Temperatures in degrees Centigrade			
	Mediterranean Sea	Red Sea	Arabic Sea	Pakistan
May	15.5 - 21	21 - 27	27 - 32	above 32
June	21 - 27	27 - 32	27 - 32	above 32
July	21 - 27	27 - 32	27 - 32	above 32
August	21 - 27	27 - 32	27 - 32	27 - 32
September	21 - 27	27 - 32	27 - 32	27 - 32
	Maximum	Temperature		
	35 - 40	40 - 45	near 40	40 - 45

A comparison of the data in Table 2 with Table 10 indicates that during our voyage we had a temperature of the air that was higher than the mean May temperature, and rather like June temperature - and June is one of the three hottest months. We did not encounter any maximum temperatures (Table 10, last line).

GENERAL CONCLUSIONS

The heretofore cited conclusions from our observations indicate that coal from mines selected for export to tropical countries has a very high resistance to spontaneous combustion. In the holds, of the ship as well as on embankments on land, the coal showed no obvious tendency to spontaneous combustion, and it lost only some ot its mechanical endurance. This conclusion was confirmed by conversations with dock workers and other workers employed at the re-loading and piling up of Polish coal in Pakistan.