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METALLURGICAL SECTION.

PEKO MINES NO LIABILITY.

SECOND REPORT.

SPONTANEOUS COMBUSTION OF COPPER CONCENTRATES.

REPORT ON SHIPMENT OF CONCENTRATES TO JAPAN IN SS "SARIZA". February, 1957.

by

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SPONTANEOUS COMBUSTION OF PEKO CONCENTRATES.

SECOND REPORT.

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SPONTANEOUS COMBUSTION OF COPPER CONCENTRATES. PEKO MINES N.L.

SECOND REPORT.

by

D.W. Read.

-Abstract-

This report covers readings and observations made during the voyage to Japan of a cargo of concentrates from Peko Mines N.L.

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1. SUMMARY.

A study was made of the behaviour of a cargo of concentrates shipped to Japan by Peko Mines N.L. in SS "Sariza", a Greek owned vessel under Panamanian registration.

The following observations were made:

(1) With the moisture content of the concentrates at approximately one percent there was no sign of any reaction which generates heat.

(2) The modified "rice-stow" method of stacking the cargo was very effective and allowed access of cooling air into the centre of the stacks.

(3) High velocity forced ventilation was not necessary. Natural ventilation was sufficent to keep the air in the hold fresh and the cargo cool.

(4) With a dry cargo and similar stowage it may be possible for all ventilators to be sealed off during stormy weather without incurring any danger of excessive overheating. This point however still remains to be demonstrated. If ventilation is insisted on then thought should be given to the provision of "all-weather" ventilators.

(5) The temperature of the cargo was dependent on three factors:

(a) The ambient temperature of the air.

(b) The proximity of local sources of heating such as boilers, engines and hot deck plates.

(c) The proximity to air channels left between the bags of concentrate.

There was no sign of internal heating of the concentrates.

2. INTRODUCTION.

Following experiments on the heating of Peko concentrates, recommendations were made concerning moisture content and ventilation of future shipments (Bollen 1956 (1)).

The conclusions indicated that probably the most important factor was a critical range of moisture content within which there was greater danger of reaction commencing. The most rapid heating occured around six percent moisture and it was apparent that a moisture content of less than four percent would give a slower heating.

Slow heating would also occur above eight percent moisture but the extra freight charges would more than offset the disadvantages of handling a very dry cargo.

It was difficult to assess the effect of the size of the parcel on the rate of heating but it was considered that it would be considerable as had been demonstrated by the actual firing of shipments. In view of the slow heating of ten ton lots it was recommended that further observations be confined to actual shipments.

The Department of Shipping and Transport then authorised a further shipment of concentrates subject to conditions laid down by them. It was requested that a senior member of the Research and Development Branch accompany the ship as observer to study the behaviour of the concentrates when loaded under the above mentioned conditions.

During the voyage a study was made of the temperatures attained in the centre and on the surface of the various stacks, on the effect of forced and natural ventilation on the temperature of the cargo, and of the amount of ventilation obtained with the natural ventilation provided on the ship.

This study of natural ventilation was not conclusive and although a large amount of interesting information was obtained it is not recorded in detail in this report. The results will be tabulated and reported separately for record purposes.

3. STOWAGE OF CARGO.

The vessel SS "Sariza" under Greek ownership and Panamanian registration was a 10,000 ton Liberty ship divided into five holds, each hold consisting of a lower and a tween-deck section. No.1 hold was loaded with a cargo of bran.

TABLE 1.

Size of Holds.

Hold.	Length.	Width.	Depth.	Rated Capacity.
No.2 Lower.	72 ft.	57 ft.	24 ft.	99,000 cu.ft
No.2 Tween.	72	57	11	46,000 " "
No.3 Lower.	50	57	24	68,500 " "
No.3 Tween.	50	57	11	28,000 " "
No.4 Lower.	45	57	18	59,000 " "
No.4 Tween.	45	57	11	35,000 " "
No.5 Lower.	70	57	18	58,000 " "
No.5 Tween.	70	57	11	34,500 " "

The aft end of No.5 hold had drums of scrap iron with bags of concentrate stacked on them. The forward end of the hold had concentrates only. No.4 hold had a deep well, between it and the engine room, which was filled with loose scrap.

The lower holds were stowed with a modification of a method commonly used for shipment of bagged rice. For convenience this will be referred to as a "rice-stow".

It was formed by stowing three layers of bags in a normal fashion and then in the third layer five bags were laid side by side with a space of four to six inches between each lot of five bags. The fourth layer was laid as normal to bridge the gaps between the bags. That is, the appearance of the pile when viewed fore and aft was that of a brick wall in which the sixth, twelvth, eighteenth etc., brick in each third row had been removed. Thus there were air channels running fore and aft through the piles.

The main stacks were each five bags thick and were separated by a distance of one bag. This gap was bridged at every third tier in height and every eighth bag athwart ship by two pieces of 6" x 1' timber on which a filled bag was laid. These were to tie the piles together and stop any movement during rough weather. The gaps left between the stacks acted as crosship ventilation.

Some attempt was made for a similar stow in the tween-decks but with comparatively small tonnages stored in these holds and the clearances that had to be left at the hatches to give access to the lower holds it could not be made with any great degree of success. In these holds however there is less need for such stowage.

The stacks were thus tied together with boards and bags of concentrates. This was highly successful as it was only in about six places at the top edge of the stacks that there was any movement or collapse of bags due to the quite violent pitching experienced on the voyage. The main body of the stack showed no signs of movement.

Dunnage consisting of 3" x 3" timber bearers laid fore and aft and with 6" x 1' timber laid athwartships was provided in No.4 lower hold and tween-deck. In all other holds and tween-decks, bags were placed directly on the ship's decks. Drummed scrap in No.5 lower hold was covered with wood planking before bags of concentrate were loaded on to it.

The amount stowed in each hold as recorded by the Deputy Director of Supply and Shipping is shown in Table 2.

TABLE 2.

Stowage of Cargo.

Hold	Concentrates Tons.	Height of stack.	Space above bags.
No.2			
Lower hold.	2080	27 bags	9 feet.
Tween deck.	712	11 "	4 "
No.3			
Lower hold.	1560	26 "	10 "
Tween deck.	586	12 "	3 "
No.4			
Lower hold.	1440	38 "	8 "
Tween deck.	570	11 "	3½ "
No.5			
Lower hold fore.	568	27 "	12 "
Lower hold aft.	274	10 "	9 "
Tween deck.	240	6 "	6 "

Loading commenced on the 13th February and finished on the 27th. The air temperatures during this period were recorded and are shown in Table 3.

TABLE 3.

Daily Temperatures During Loading.

Date.	Temperature	
	Maximum	Minimum
February 13th	90.7 degrees F.	63.1 degrees F.
14th	99.2	72.0
15th	70.7	61.0
16th	76.3	50.9
17th	83.9	56.3
18th	88.4	70.3
19th	99.3	71.9
20th	79.6	67.3
21st	70.1	58.0
22nd	78.0	56.0
23rd	76.2	54.0
24th	73.0	56.0
25th	76.0	55.5
26th	85.6	60.5
27th	99.0	69.5

The moisture was determined at four different times by opening and sampling 100 bags. The drying during long storage is very apparent.

The results obtained were:

Sampled in October 1956	- 3.58	percent moisture.
Sampled in November 1956	- 2.10	" "
Sampled in January 1957.	- 1.19	" "
Sampled on 15th February 1957	- 0.90	" "

Although the correct figure is not yet available the shipment is estimated to have been despatched at approximately one percent moisture.

4. METHOD OF VENTILATION.

Owing to the dangerous overheating of some cargoes on previous shipments the Department of Shipping and Transport made it a condition of shipment that the air in the holds was to be changed frequently. This was accomplished by removing the ventilators from the mast deck-houses and installing in their place four sets, each of two Meco E.F. 4A, 16 inch fans each of 6000 cubic feet per minute (free air) capacity thus each hold could be exhausted at the rate of 12,000 c.f.m. up the manway access to each hold.

The replacement air was supplied from ventilators on the opposite side of the holds, the main flow being into the lower holds with a portion being bled into and out of the tween-deck holds through holes of approximately 18 x 12 inches size in the ventilators and manways. The fans were of different voltage from the ship's supply and a 75 K.V.A. alternator (440 volt 50 cycle) direct coupled to a 100 H.P. "Meadows" diesel engine was provided. It was expected that the installation would have to be run continuously in order to keep the holds adequately ventilated and cooled. The fans were of the high pressure type with velocity of discharge approximately 90 feet per second. The object was to direct a stream of high velocity air at the surface of the piles of bags and penetrate the pile for

distribution through the fore and aft ventilation openings in the "rice-stow". As will be shown later this idea was not realised in actual practice.

The air flow in the holds is shown in Figure 1.

5. RECORDING OF TEMPERATURES:

5.1 Point of Measurement.

Temperatures in the piles were recorded in the first instance by using pipes at fixed points. Individual bags were also measured to show the variations occuring. Some additional measurements of other temperatures were made.

5.1.1 Fixed Pipes.

Three pipes, two, four and six feet in length respectively, made from 3/4" conduit were buried vertically in each of the lower holds as near as possible to the centre of the middle pile in the hold. The three pipes were placed as close as possible to each other and generally were within a three foot square. The thermometers were lowered into these pipes.

Thus the temperature of the stacks at depths of 2, 4, and 6 feet could be determined to discover any effect due to bulk stacking. The six foot depth would be between one third and one half of the total depth of the stack depending on the depth of the stack.

5.1.2 Individual Bags.

Temperatures were taken by puncturing the bags with a steel spike and pushing the thermometer into the centre of the bag leaving it until the reading had become steady. Between ten and fifteen bags were selected at random from surface bags down to the second or third layer depending on how the loose stacking would permit access to the bags.

A few bags in each hold, such as those directly under a ventilation opening or in a dead space where ventilation was almost impossible, were measured every day for control purposes.

5.1.3 Additional Readings.

When it became apparent that No.3 hold was the critical point, extra four foot pieces of conduit were installed to give a cross-section of the behaviour of the whole of the cargo in the lower hold. Additional readings made in the other holds showed that, although temperature variations up to 10 degrees could be obtained, the general trend of these readings was similar to that occuring at the position of the conduit. The readings at these fixed points were therefore taken as a measure of the behaviour of the whole of the concentrates in that hold.

Other readings such as the temperature of the deck plates, the engine and the boiler room bulk heads were taken. Sea temperatures were taken occasionally. These readings will be referred to in section 9.

5.2 Times of Measurement.

The voyage commenced on February 27th and readings were taken daily from this date. The procedure was to lower the thermometers, encased in metal sheaths, into the conduit pipes leaving them there to attain equilibrium. While this was taking place the temperatures of the bags was being taken.

5.3 Temperatures Recorded.

Method 5.1.1 gave the temperatures of the centres of the piles in positions where the only ventilation possible was through the fore and aft openings in the stow. Method 5.1.2 gave temperatures of bags exposed to air which had free movement or was but little restricted.

The readings in the lower holds are plotted in Figures 2-5. The vertical lines in Figures 6 and 7 are those of the bags taken under section 5.1.2 and the extremities of each line indicate the maximum and minimum readings obtained for that day. The readings from remaining bags will be somewhere on these lines. The smooth curves are to show the general trend of the readings.

6. BEHAVIOUR OF THE CARGO.

Immediately on leaving Adelaide a drop in the air and cargo temperatures was noted. This was followed by a steady increase in temperature until 15-16th March. The equator was crossed on 13th March.

The rise in temperature of the bags was steady and showed no signs whatsoever of any large sudden increases similar to those which would have occured if oxidation, with subsequent internal heating of the concentrates, had taken place. The maximum temperatures reached in each hold are listed in Table 4. These temperatures are the highest recorded in the hold on any one day and do not necessarily refer to readings in any particular position.

TABLE 4.

Maximum Temperatures in Cargo (°F).

DATE:	No.2 Hold		No.3 Hold		No.4 Hold		No.5 Hold		Cabin	
	Lower	Tween	Lower	Tween	Lower	Tween	Lower	Tween	Maximum	Minimum.
February 27th	86	86	95	95	90	86	86	86		
" 28th	84	84	88	86	77	77	78	77	82	76
March 1st	84	80	88	86	80	80	80	74	76	62
2nd	88	76	88	82	84	82	82	78	76	62
3rd	86	80	95	82	82	80	86	76	76	66
4th	90	84	102	86	86	84	86	84	82	68
5th	91	86	104	86	86	86	91	82	76	76
6th	95	82	106	90	91	86	94	88	84	78
7th	95	88	109	96	96	88	91	86	83	78
8th	97	90	108	90	97	94	96	95	82	78
9th	100	92	117	98	102	94	96	92	84	80
10th	100	94	118	102	100	98	98	92	86	82
11th	104	96	122	100	106	102	98	96	90	82
12th	106	100 max.	126	104 max.	108	102	100	98 max.	90	82
13th	104	94	128	100	102	98	98	96	90	82
14th	110	98	130 max.	102	110	102	98	96	88	82
15th	112 max.	98	129	104	104	100	106 max.	94	96	82
16th	110	-	129	104	113	106 max.	104	96	84	80
17th	112	98	128	102	114 max.	106	104	94	82	78
18th	106	94	128	100	110	100	104	98	86	80
19th	111	96	127	98	111	100	104	94	84	78
20th	104	96	124	102	112	102	102	92	80	76
21st	106	94	122	100	110	100	98	88	82	74
22nd	100	90	120	94	102	98	98	80	78	68
23rd	95	92	114	96	100	90	94	78	70	60
24th	90	80	110	82	95	84	87	74	70	60

These temperatures are the highest recorded in the particular holds on any one day and do not necessarily refer to the same position.

The maximum temperatures reached are summarised below:

Hold.	Maximum Temperature.
No.2 Lower.	112°F
Tween.	100°F
No.3 Lower.	130°F
Tween.	104°F
No.4 Lower.	114°F
Tween.	106°F
No.5 Lower.	106°F
Tween.	98°F
Maximum air temperature.	90°F
Minimum air temperature.	60°F
Temperature of deck plates.	126°F (max).
Boiler room bulk head.	136°F (max).

As there was no sign of any internal heating and the cargo had not reached temperatures greater than those prevailing on the deck plates and on the boiler room bulk head, the forced ventilation fans were at first not operated. However on March 7th after discussions with the Captain it was decided to run the fans for two hours per day in 2 and 3 holds only.

After a few days this was increased to 5 hours during the hottest part of the day and the fans were usually run between 10 a.m. - noon and 2 p.m. - 5 p.m. The routine was held until March 16th when it was apparent that the whole cargo was cooling rapidly under the influence of the marked drop in ambient temperature, and the fans were then run for 2 hours only.

They were discontinued after the 19th March.

This method of running the fans in holds 2 and 3 only, gave comparison between similar holds namely:

(a) No.2 hold ventilated.
No.5 hold unventilated.

(b) No.3 hold against boilers-ventilated.
No.4 hold against engine room - unventilated.

The curves showing the comparisons between holds 2 and 5 are shown in Figures 8 and 9. These are plotted as smooth curves and do not show the daily variations.

Following the drop in ambient temperature around the period 15-16th March there was, commencing on March 17th a marked drop in all temperatures being recorded, this being most noticeable in the tween-deck holds.

The drop was noticed even in the centres of the piles, that is the 6 foot temperature readings, showing that the cool air was penetrating into the centre of the piles and thus the effectiveness of the "rice-stow" was demonstrated.

The similarity in all curves between the rise in temperature of the ambient air and the temperature of the cargo followed by the corresponding marked drops, is very apparent and demonstrates very definitely that the change in temperature in the cargo was due almost entirely to atmospheric conditions and not to internal heating of the cargo. Transient drops in atmospheric conditions also caused drops in cargo temperatures (see section 11).

The gradual rise in temperature followed by the sharp drop is graphically shown in the following Figures:

Figures 2 - Hold 2 Lower (Method 5.1.1) 2', 4' and 6'
3 - " 3 " " " "
4 - " 4 " " " "
5 - " 5 " " " "
6 - Hold 2 (Method 5.1.2) Bag Temp. - Lower and tween.
6 - " 3 " " " "
7 - " 4 " " " "
7 - " 5 " " " "

Each of the above figures has the ambient maximum and minimum air temperatures shown for comparison.

Before the voyage commenced it was expected that variations in humidity would probably have a deleterious influence on the behaviour of the cargo. In actual fact the relative

humidity varied only slightly, being over 95 percent for most of the time. Although readings were taken they are not recorded in this report.

On arrival at Kobe the bags were examined as they were being unloaded and appeared to be in perfect condition with no sign of damage or hardening.

7. EFFECT OF VENTILATION IN No.3 HOLD.

As stated in section 5.1.3 it became apparent during the voyage that No.3 hold, which was directly adjacent to the boiler room bulk head, was likely to be the critical point. Extra four feet lengths of conduit were therefore installed in this hold.

The position of these were:

No.1 - Directly under and 10 feet below the discharge of the starboard ventilator.

No.2 - Displaced about 6 feet from position similar to No.1 but on the port side.

No.3 & 4. Similar positions in the port and starboard sections of the centre stack in the hold respectively.

No.5 & 6. Similar positions in the stack near the access manways which were the fan upcast vents. No.6 however was approximately 5 feet closer to the bulk head.

Provided that the ventilators were turned directly into the wind there was always a pronounced airflow underneath the ventilator intakes. When the fans were being run the linear velocity of the air stream striking the bags was 700-800 feet per minute.

When using an anemometer sensitive to an air movement of 9 feet per minute, no air movement could be detected in any of the air passages six feet away from the point of impingement. Some movement of the air however could be detected by the movement of dust particles.

On climbing the access ladder ways no air movement could be detected below a point 2 feet from the tween-deck plating. Above this point the air velocity increased rapidly as the air was sucked into the enclosed manways.

The position of the temperature points and the daily temperatures obtained are shown graphically in Figure 10.

It will be noticed that there was a difference of approximately 6-8 degrees between No.1 point directly below the vent and No.2 point displaced 6 feet, showing that there was a slight benefit to be gained from a position close to an air draft. However, the temperature at No.1 point was no better than that in the surface bags in No.4 tween-deck hold (see Figure 7) where the bags were subjected to natural ventilation only, or to bags at similar depths in the other holds.

There was a marked difference in the temperature at 3 and 4 points which were in similar positions. This is attributed to the fact that there was probably air circulation around 3 point due to close proximity of a fore and aft air way. This view is strengthened by the fact that while there was generally an increase in temperature in the 2', 4' and 6' readings respectively, in some cases there was an inversion, that is, the 6' reading was lower than the 2' reading - again probably due to the proximity of an air vent.

Points 5 and 6 showed readings similar both to each other and to other points in the hold showing that if there was air movement through the stacks it was not enough to cause any marked cooling.

Again as with all other holds there was a marked drop in temperatures following the fall in ambient air temperatures.

8. NATURAL VENTILATION IN HOLDS.

An extended study of the amount of air entering the holds through the ship's ventilators was made. The results were extremely variable and depended not only on the position of the ventilator and its relation to the wind direction, but also on the position of objects relative to the ventilator - deck houses etc. However, the air in the holds was always fresh, and no discomfort, apart from the higher temperatures in No.3 hold, was experienced.

The variations in natural air flow are demonstrated by readings taken from No.5 hold on successive days. The wind directions are referred to the long axis of the ship. The ventilators were in each case turned into the wind.

Direction.	Port Ventilator.	Starboard Ventilator.
Wind 90°	540 cu ft/min down.	660 cu ft/min up.
Wind 45°	1350 " " down.	750 " " down.
Wind 45°	1200 " " down.	900 " " down.
Wind 135°	1200 " " down.	1200 " " up.
Wind 155°	600 " " down.	600 " " up.

The main result noticed was that an average flow of at least 1500 cu ft per minute of air was flowing into each hold.

The main conclusion than can be drawn is that the natural ventilation definitely has a cooling effect on the cargo. With a cargo of low moisture content and stowed with the modified "rice-stow" it seems very probable that, in the event of bad weather, the holds could be sealed off completely and the cargo would not heat up above the temperature of the surroundings i.e. above the boiler room, engine room or deck plates.

This however is an opinion only and would have to be proven by the actual sealing of the ventilators in one or two holds during a voyage.

9. ADDITIONAL TEMPERATURE RECORDS.

When it was realised that any heating of the cargo would come from external sources and not from any internal reactions, various sources of such external heat were checked.

9.1 Temperature of Deck Plates.

As the cargo was in close proximity to the steel deck plates the temperature of these plates was measured daily at noon for two weeks. The temperature was affected by cloud-cover which caused drops of 10-15 degrees. Temperatures at other periods of the day were probably higher than those listed.

TABLE 5.

Deck Plate Temperatures at Noon.

Date.	Temperature.	Date.	Temperature.
March 8th	122 degrees F.	16th	100 degrees F.
9th	126 "	17th	96 "
10th	96 "	18th	92 "
11th	100 "	19th	110 "
12th	120 "	20th	110 "
13th	90 "	21st	96 "
14th	112 "	22nd	70 "
15th	120 "		

9.2 Boiler Room Bulkhead.

The proximity of the boilers had a great influence on the temperatures in No.3 hold which was separated from the engine room and boilers by a single-plate bulkhead reinforced on the hold side by steel angle beams to which were bolted. 6" x 1" timbers to form an open lattice.

The boilers were within five feet of this bulkhead and temperatures taken against the steel work varied from 124°F. to as high as 136°F. According to the engineers these temperatures would at times reach 150°F. The temperature at 2', 4' and 6' reached a maximum of 127, 122 and 118°F. respectively.

while the highest temperature recorded in the hold was at position 4 (see section 7) where a temperature of 130°F was recorded. These readings are close to the maximum readings of the deck plates and well below the readings on the boiler bulkhead.

The heating effect on the engine room and boilers was reflected to a lesser degree in the higher temperatures attained by No.4 hold which was on the aft side of the engines.

The air temperatures in No.3 hold against the wooden planking on the innerside of the bulk-head approximately 18 feed above the oil burners, and against the bulkhead between No.3 and No.2 holds are shown in Table 6.

TABLE 6.

Air Temperatures in No.3 Hold.

Date.	Against Boiler room bulkhead.	Against No.2 hold bulkhead.
March: 12th	114 degrees F.	106 degrees F.
13th	114 "	101 "
14th	110 "	107 "
15th	110 "	104 "
16th	110 "	104 "
17th	106 "	102 "
18th	110 "	104 "
19th	118 "	106 "
20th	110 "	102 "
21st	100 "	102 "
22nd	98 "	90 "
23rd	105 "	88 "

This drop in air temperature across the hold demonstrates the cooling effect of the incoming air.

9.3 Sea temperature.

The sea temperature for the period 8th - 17th March varied between 86-90°F. By the 20th March it had dropped to 76°F and was about 62°F for the last reading.

10. EXAMINATION OF CONCENTRATES.

At the end of the voyage samples of concentrates were taken from places covering wide variations of temperature. These were from directly below the ventilators in No.5 'tween-deck where the bag temperatures did not rise over 95°F and from the two high spots in No.3 hold where temperatures had risen to 126°F and 130°F respectively and from other places where medium temperatures were encountered.

These samples were subsequently examined microscopically with the object of determining whether any difference in mineralogical composition would account for the rise in temperature.

No significant differences could be detected in any of the samples and this lends support to the views expressed that the high temperatures were due to heat being radiated from the boilers.

11. DISCUSSION OF RESULTS.

The temperature curves given in Figures 2 and 5 have a common characteristic, namely a gradual increase in temperature, with the maximum reading being maintained for varying lengths of time. Then follows a much sharper drop in temperature corresponding to but being 24-48 hours behind the drop in ambient minimum air temperatures.

The influence of outside conditions on the temperature of the cargo is shown by the low deck plate temperatures of March 9th and 13th being followed by depressions in the cargo temperature. The effect of the March 13th drop is very marked A further fall on the 18th, is apparent but is not so marked.

From a study of the curves giving the maximum and minimum temperatures in the bags (Figures 6 and 7) it can be seen that curves similar to those of the lower holds can be drawn through the maximum and through the minimum bag readings. That is, a gradual rise is followed by a sharp drop paralleling the ambient air temperatures.

There were no signs whatsoever of any sudden heating of the cargo due to internal reactions.

The effectiveness of the modified "rice-stow" to allow the free access of cooling air into the stacks is demonstrated by the very small time lag between the drop in ambient temperature and the drop in temperatures near the centre of the stacks as shown by the 6 foot readings in Figures 2 and 5. In a closely packed stack with no air access, it would be reasonable to expect that a high temperature would be maintained for several days before any cooling occured.

Figures 8 and 9, which give idealised curves of the temperatures rises in No.2 and No.5 holds and of air temperatures, show that there is no benefit to be gained from forced high-velocity ventilation. In fact the temperature rise in the naturally ventilated No.5 hold was of the same order as that in No.2 hold which had an average of 2,500,000 cu. ft. of air per day blown in during twelve days of the period in the tropics.

The lower temperatures shown in No.5 holds, particularly in the tween deck hold, were most probably due to the smaller tonnages stacked in the hold and the more open stowage.

12. CONCLUSIONS.

The following conclusions can be drawn from the results obtained during the voyage, and from observations made on previous investigations.

(1) Provided the moisture content is below 4 percent, heating by alteration of the concentrate is minimized. At the moisture content at which the present cargo was carried, that is approximatly one percent, heating from decomposition was not detected.

(2) The modified "rice-stow" method of stacking the cargo was very effective and allowed access of cooling air into the centre of the stacks.

(3) High velocity forced ventilation was not necessary.

(4) Natural ventilation sufficient to keep the holds fresh and the cargo cool could be obtained by use of the ship's ventilators. In normal weather an average of at least 1500 cu ft per minute of air could be obtained with the ventilators.

(5) With a dry cargo and similar stowage it should be possible for all ventilators to be sealed off in the event of stormy weather, without any danger of excessive overheating occuring. This point still remains to be demonstrated.

(6) The temperature of the cargo was dependent on three main factors:

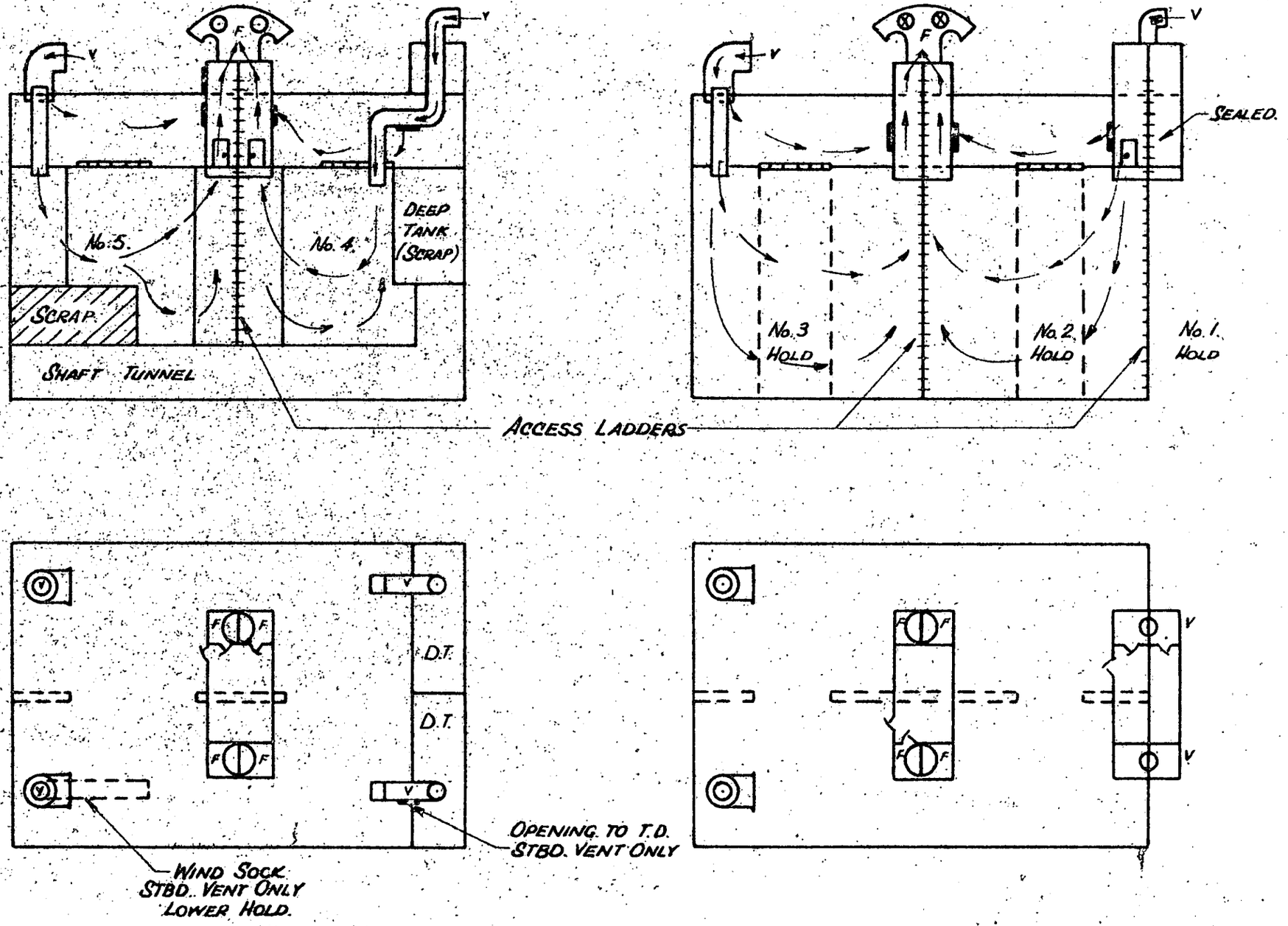
(a) The ambient temperature of the air.
(b) The proximity of local sources of heating such as boilers, engines and hot deck plates.
(c) Proximity of air channels.

Long discussions were held with Dr. Tokunaga who is in charge of Research for the Mitsui Mining and Smelting Company and Dr. Azuma, Professor of Metallurgy at the Tokyo University. Confidential information and reports concerning concentrates shipped to Japan from other sources were made available Subject to the individual requirements of particular types of concentrates, their experience and their conclusions closely parallel ours. They are also of the opinion that, if the concentrates are of a type that will heat spontaneously, then there is a critical moisture range within which heating is most likely to occur.

This report cannot be concluded without reference to the kindness and attention of the Japanese mining companies and all the various agents and representatives who were concerned with the handling of the cargo.

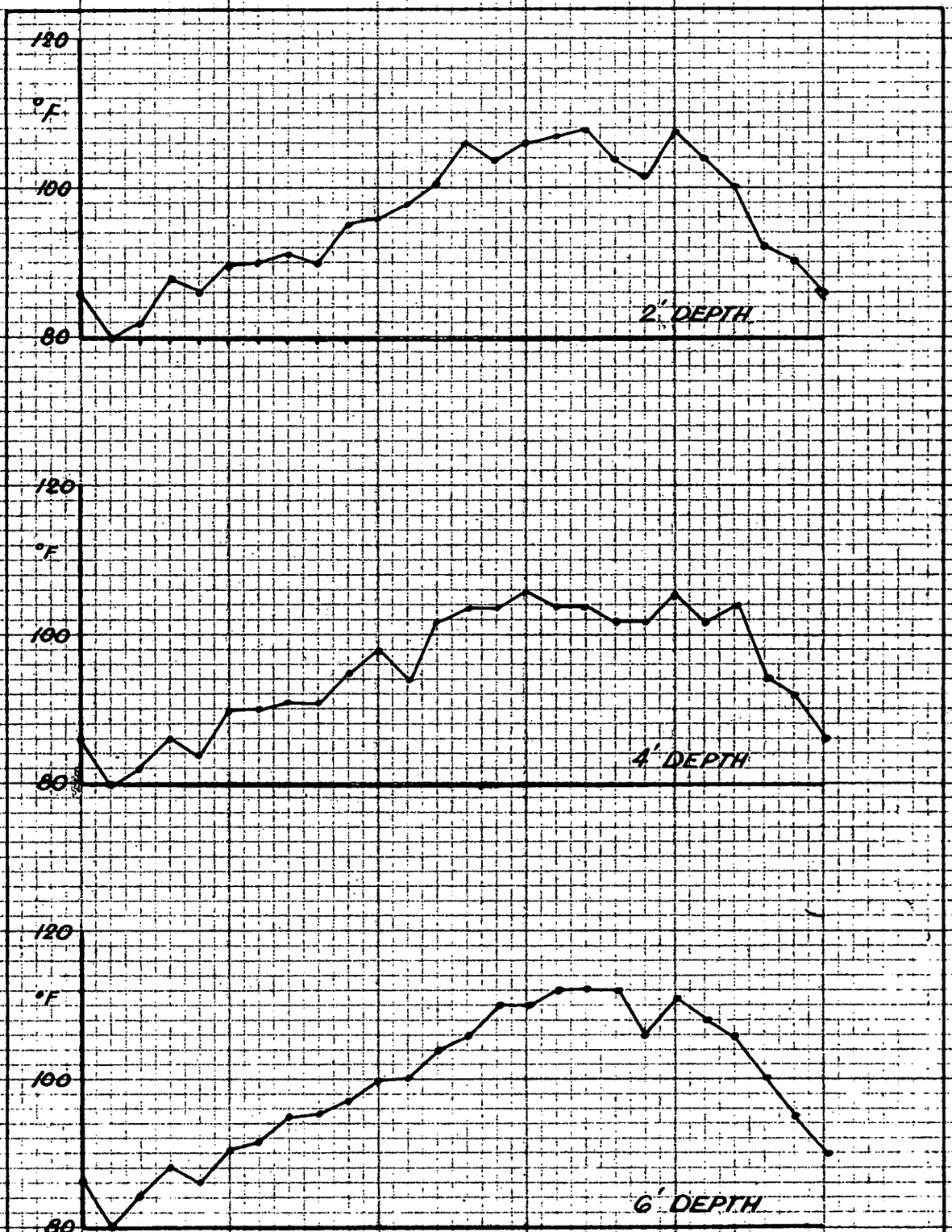
AIR FLOW IN HOLDS

FIGURE 1.

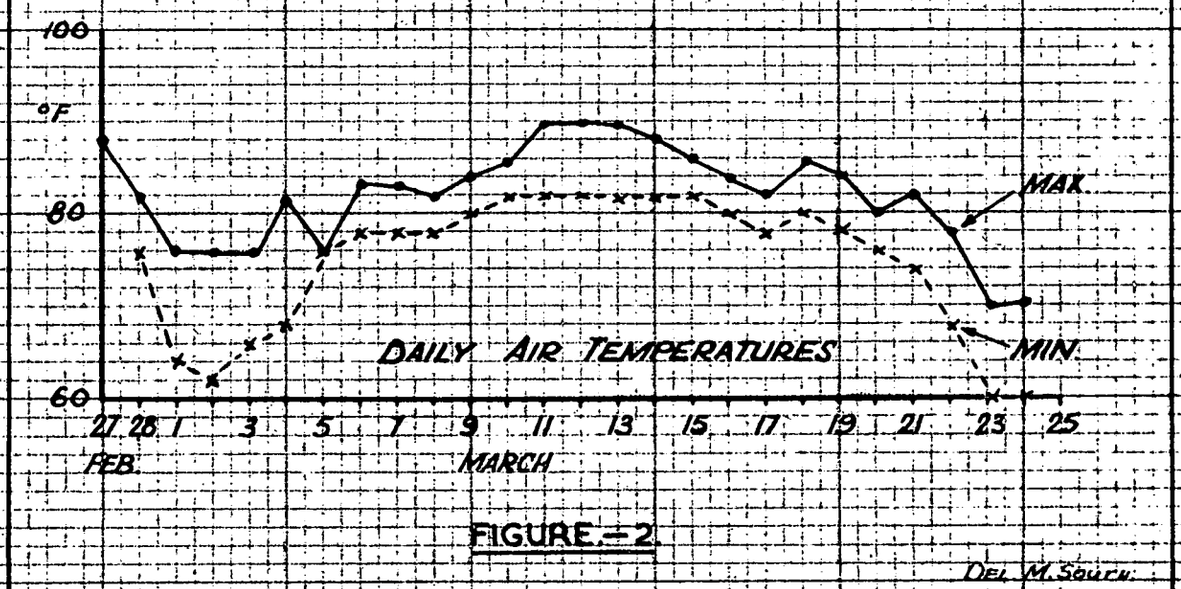


DEL. M. SCOTT.

R.G. 488

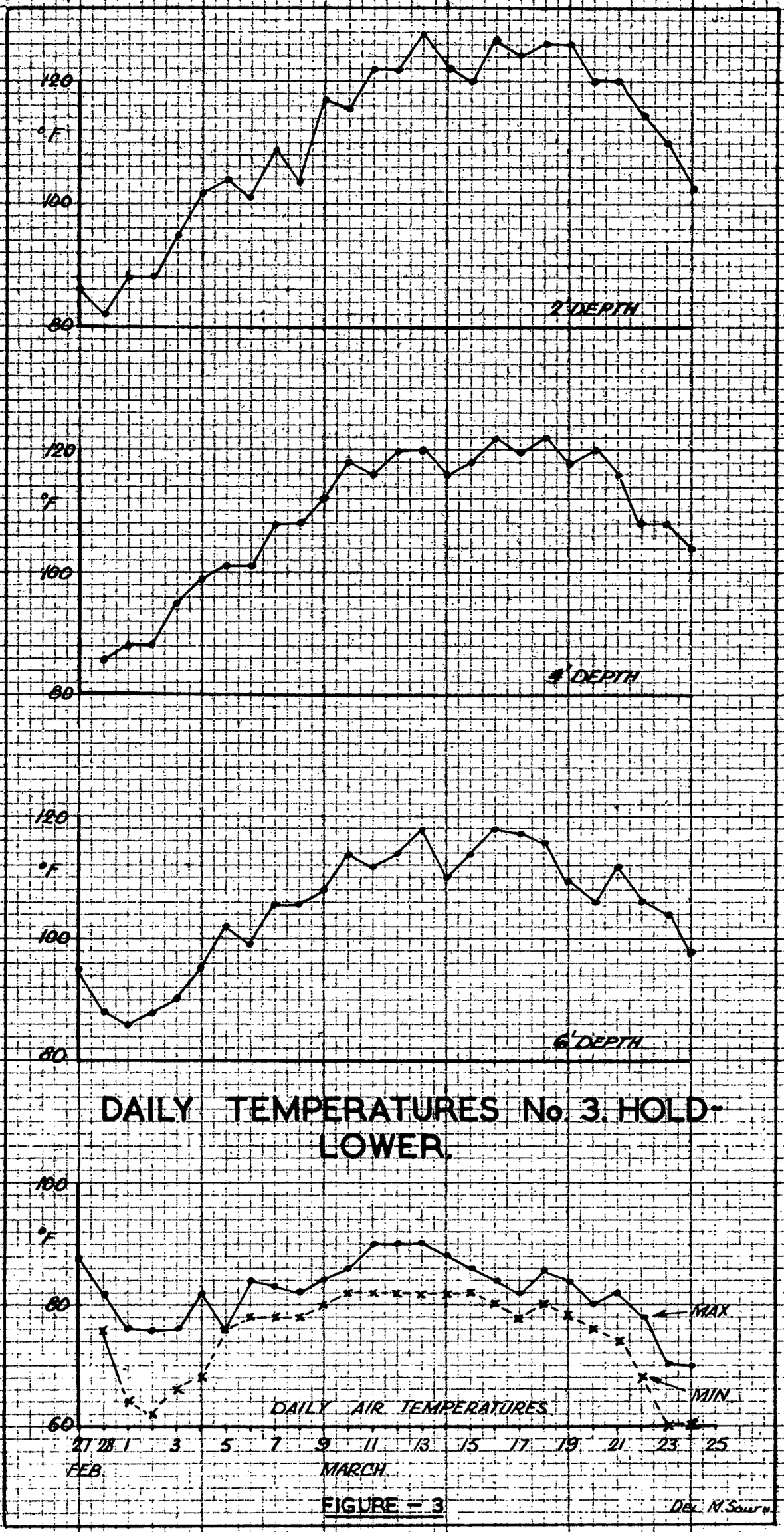


DAILY TEMPERATURES No. 2 HOLD—LOWER



FIGURE—2.

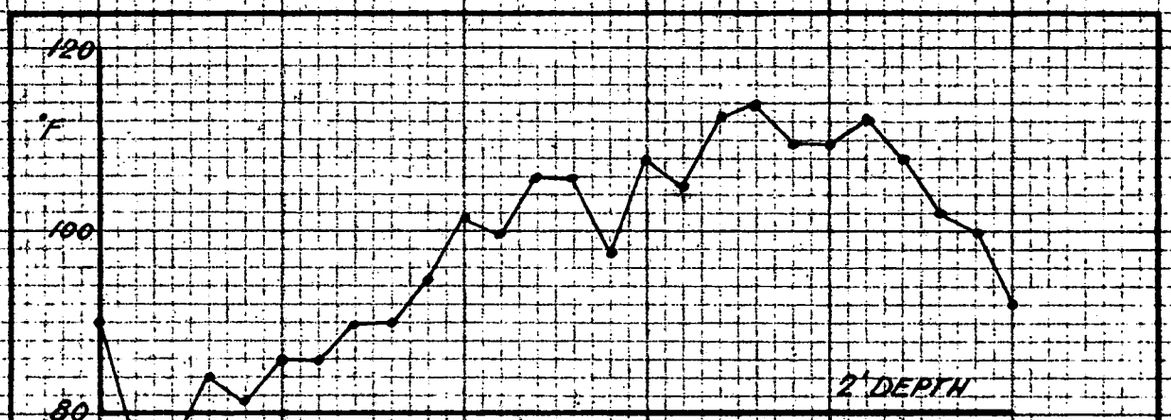
DEL M. SOUTH.

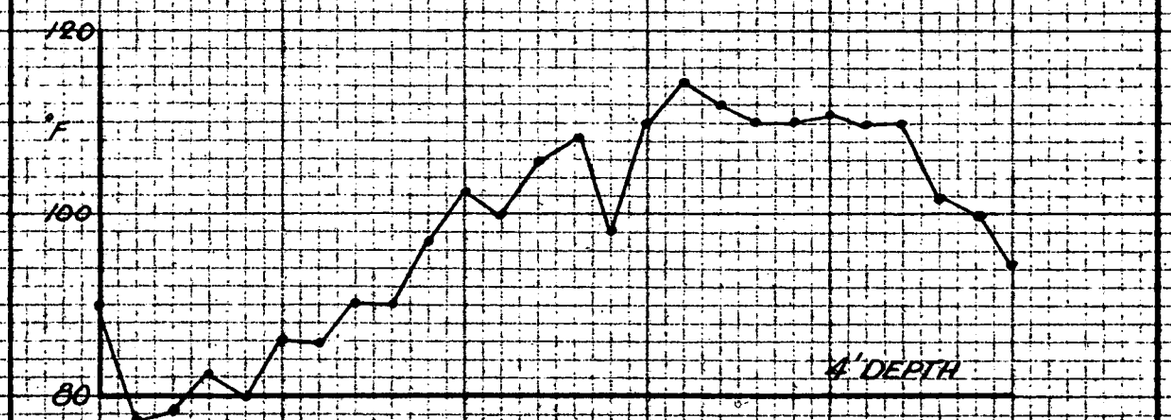


DAILY TEMPERATURES No. 3. HOLD-LOWER.

FIGURE – 3

Del. M. Sourn





DAILY TEMPERATURES No. 4. HOLD-LOWER

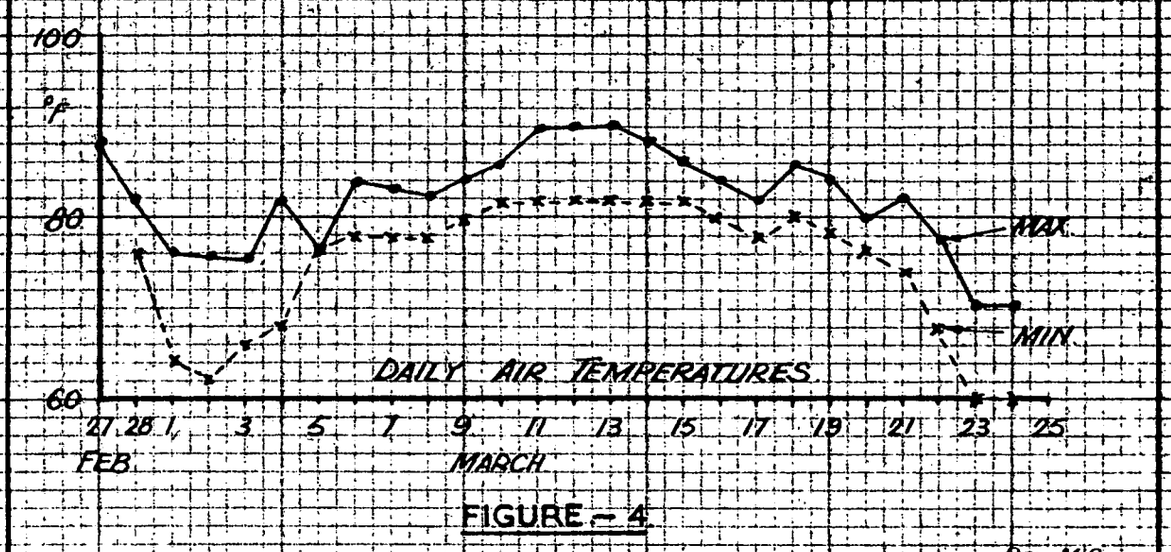


FIGURE — 4.

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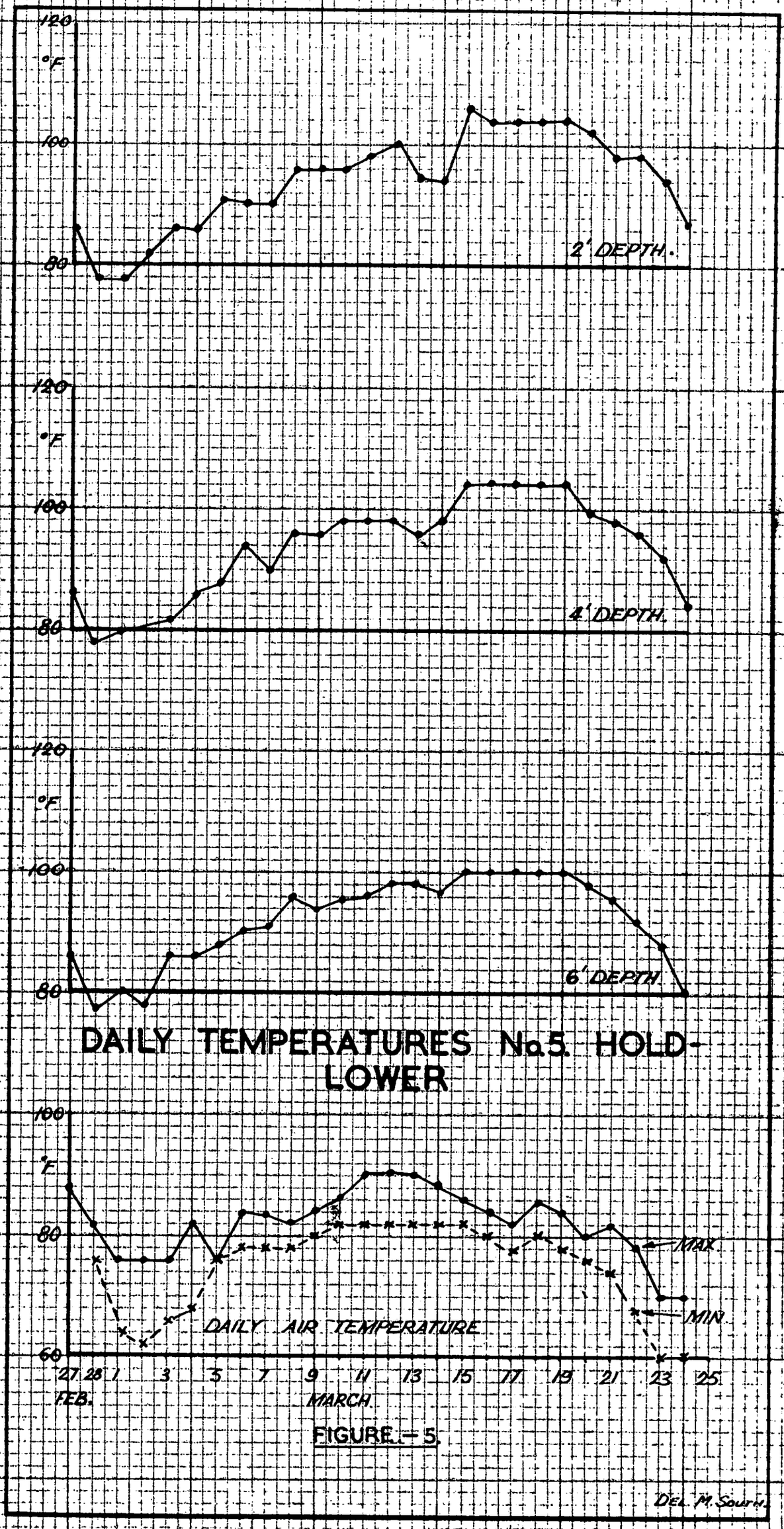

FIGURE.—5.

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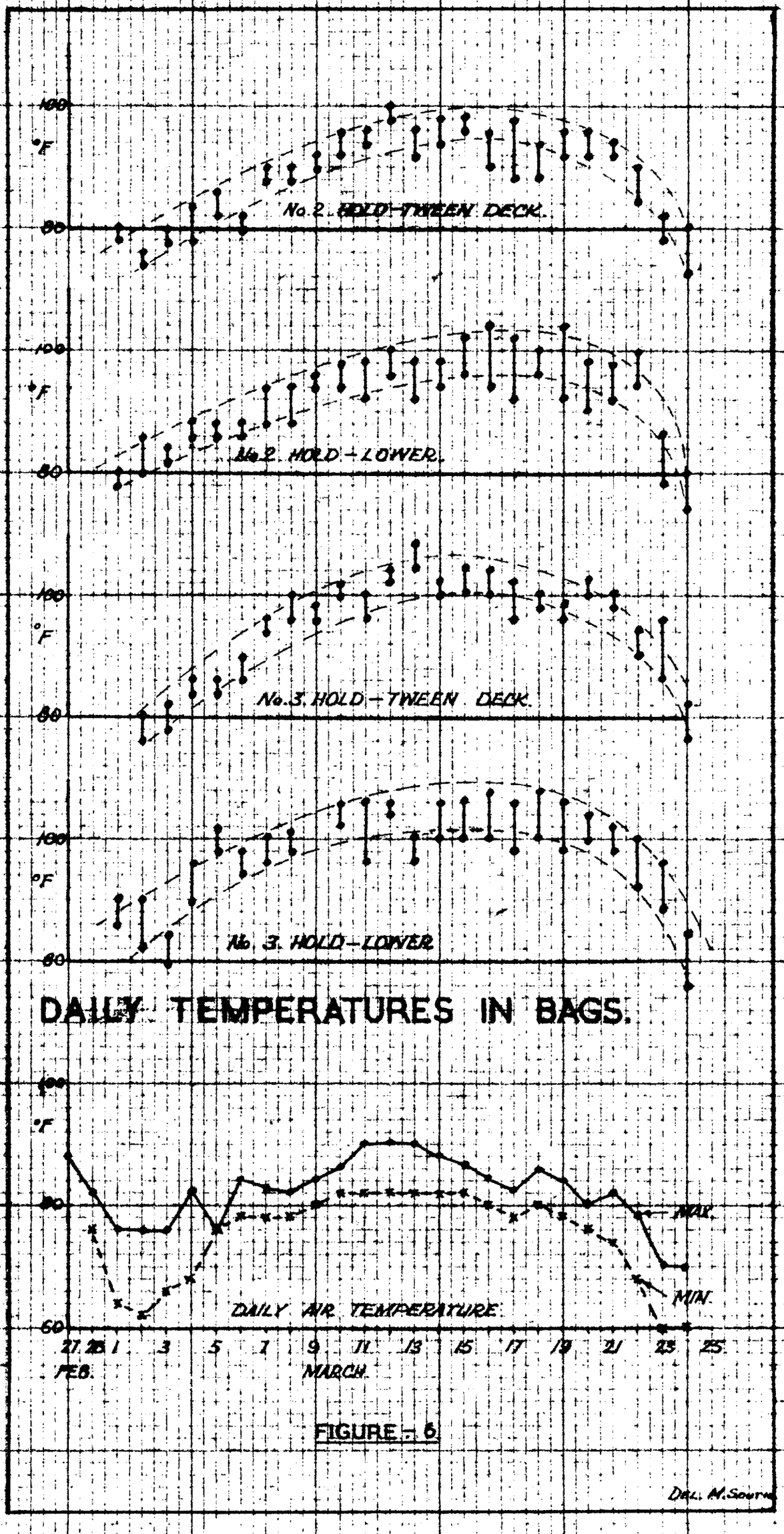
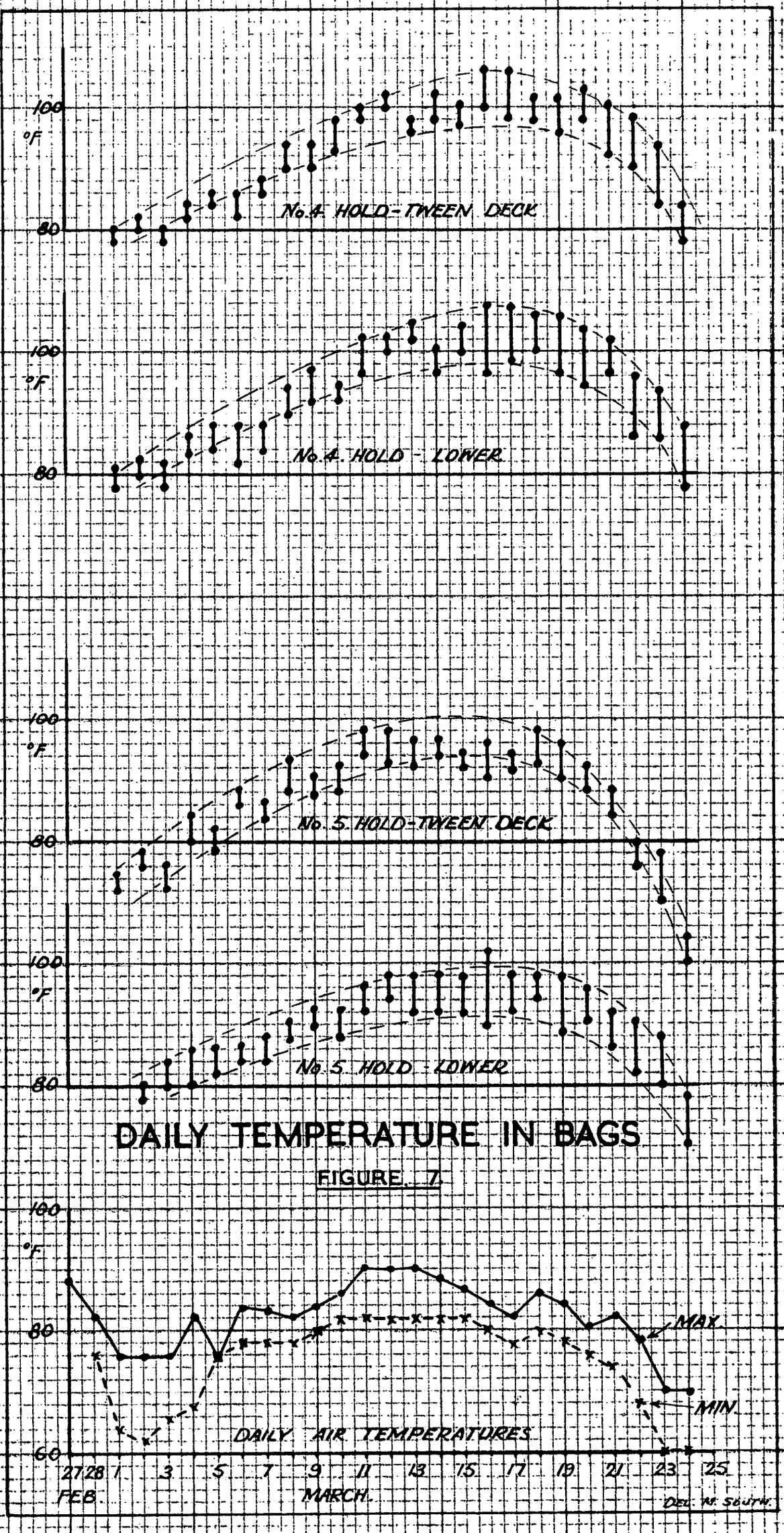


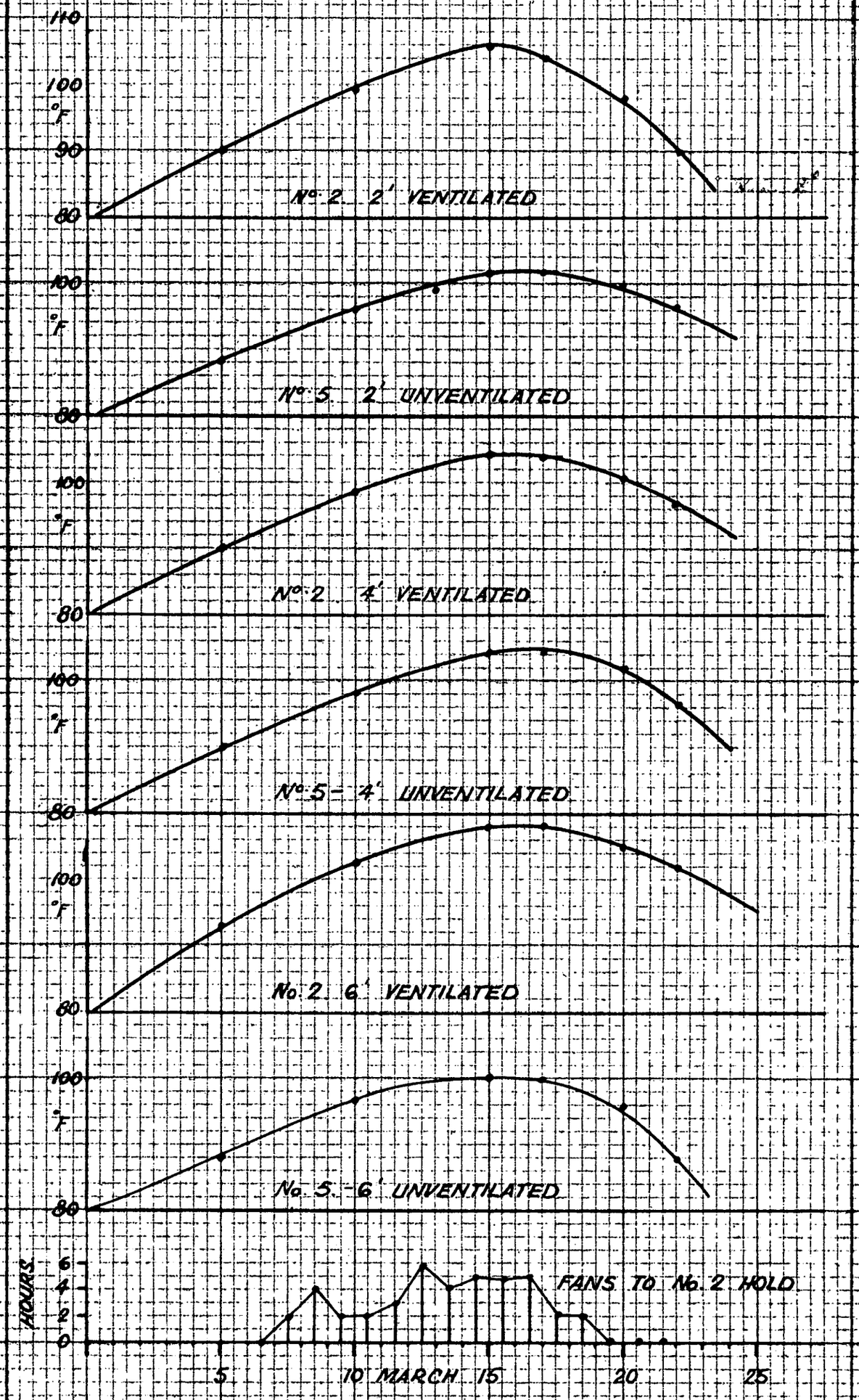
FIGURE - 6

DEL. M. Sourna



DAILY TEMPERATURE IN BAGS

FIGURE 7.



COMPARISON OF No. 2 & No. 5 HOLDS - LOWER

FIGURE - 8

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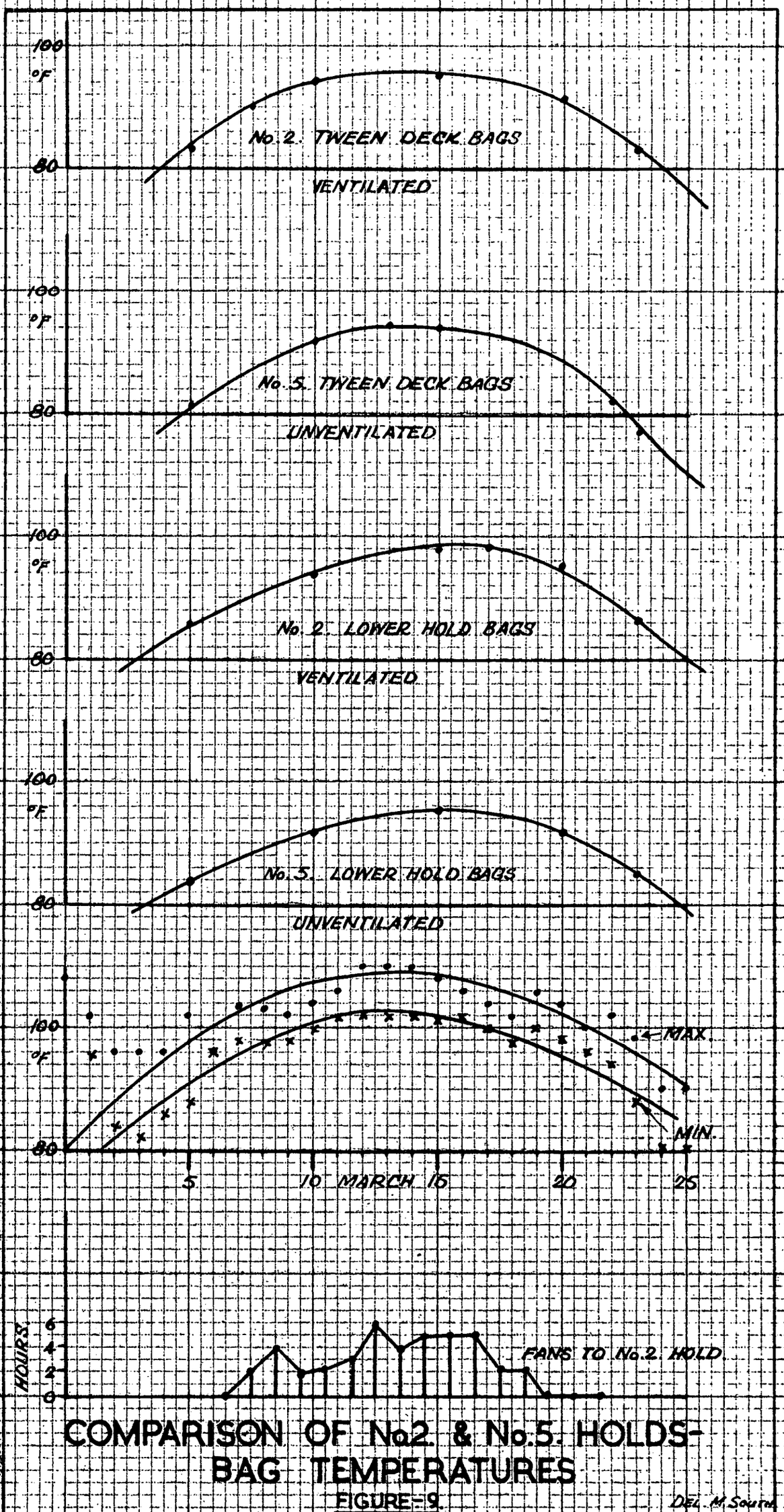

COMPARISON OF No2. & No.5. HOLDS- BAG TEMPERATURES

FIGURE-9

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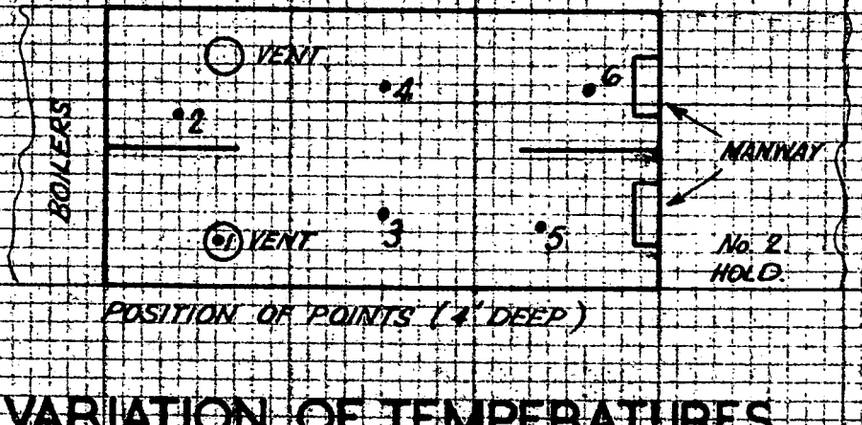

POSITION OF POINTS (4' DEEP)

VARIATION OF TEMPERATURES IN No. 3. HOLD.

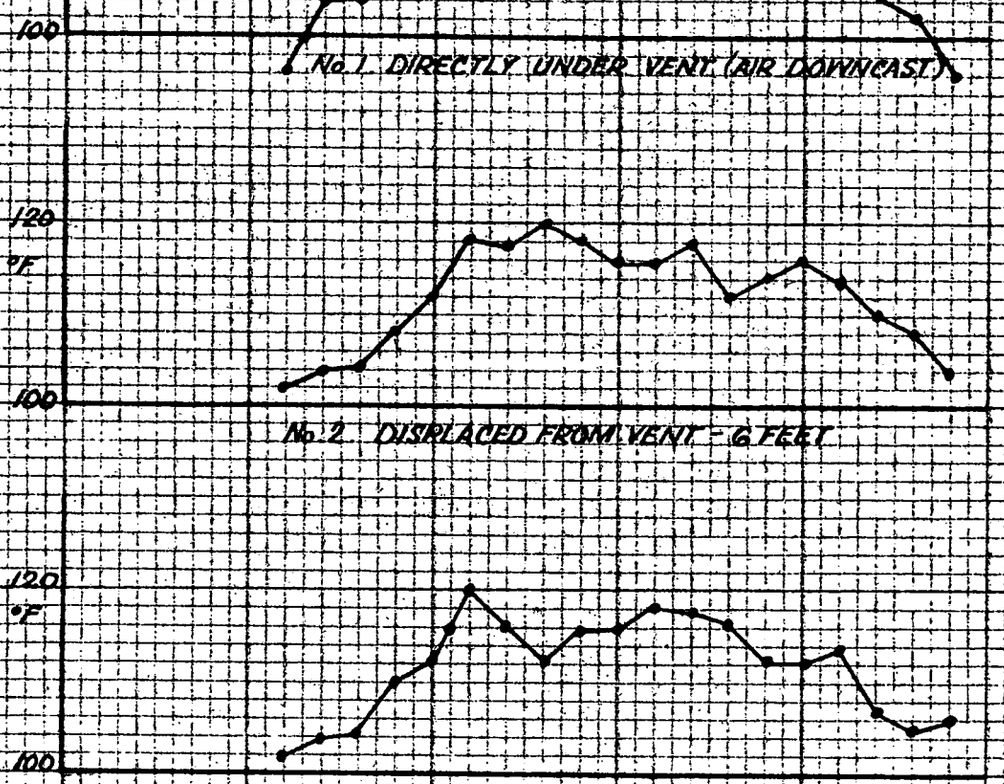

FIGURE-10

DEL. M. Sourn