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Atmospheric Humidity Atlas - Northern Hemisphere

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Abstract

This atlas presents 120 plates showing the distribution of water vapor in the atmosphere of the Northern Hemisphere. There are 20 plates in terms of mixing ratio at the surface and 100 plates in terms of dew point at the surface and at the 850-, 700-, 500-, and 400-mb levels. The distributions of other measures of moisture, including vapor pressure, frost point, water-vapor density, and mixing ratio aloft, are readily obtainable from the distribution of the dew points. The plates will be useful to designers faced with the problem of estimating the effects of atmospheric water vapor on aerospace hardware and for those concerned with the operation and storage of equipment. The plates of frequency distributions, from 5 to 95 percent, are especially useful for estimating the duration or persistence of moist conditions, as illustrated by several examples.

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Preface

The work on this atlas was initiated in 1962 by a letter from the Air Force Cambridge Research Laboratories (AFCRL) to the Air Weather Service's Climatic Center (now designated the Environmental Technical Applications Center [ETAC] USAF) which stated that a compilation of atmospheric-moisture data for the world and their representation on charts would be of great benefit to AFCRL research as well as to designers and engineers of the Air Force aerospace systems. In subsequent conferences, it was decided to present the data for midseason months in terms of the mixing ratio at the earth's surface and the dew point at the earth's surface and at the 850-, 700-, 500-, and 400-mb levels.

Since the frequency distribution as a measure of the probability of high and low moisture content could not be usefully approximated by the Gaussian normal distribution, charts of averages and standard deviations would not suffice. Moisture in the air tends to be bimodally distributed by alternate outbreaks of dry polar air and advances of moist warm air. In tropical regions, above the level of the subsidence inversion, the bimodality of moisture content is particularly well marked; therefore, a set of percentiles representing the frequency distribution of the moisture content, level by level, was required. The percentiles could begin effectively at 5 percent and end effectively with 95 percent. The in-between percentiles were chosen at 25, 50, and 75 percent.

For the purpose of the atlas, the "world" was limited to the Northern Hemisphere, it being felt that the station networks and lengths of records were adequate for a workable representation of the moisture distribution. An effort was made to have one station per 5-deg square. At each station the latest 5 years of record, up to the initiation of this project in 1962, were used to give the climatic frequency. Older records were not used, partly because the humidity-measuring instruments used to obtain the data were less reliable than present-day instruments, and partly because the difficulties of data recall from early years and the transformation of the data into a uniform computer language would have seriously delayed the project.

The first step in acquiring data for the computation of the atlas required the ETAC-USAF to select the stations, some 1500 for surface data (Figure 1) and some 400 for upper-air data (Figure 2). The data had to be summarized by month and the distribution of data obtained to yield the five chosen percentiles, which values were then plotted automatically on computer paper representing a polar stereographic projection, scale 1:30,000,000 at latitude 60°N.

When the data sheets were ready the analysis was accomplished at AFCRL. Final drafting was done at ETAC, and the writing, editing, and printing of the report was made the responsibility of AFCRL.

Atmospheric Humidity Atlas—Northern Hemisphere

1. INTRODUCTION

This atlas contains 120 plates, or charts, showing the distribution of water vapor in the atmosphere of the Northern Hemisphere. Each chart is for a mid-season month — January, April, July or October -- and for a cumulative relative frequency of 0.05, 0.25, 0.50, 0.75, or 0.95. Charts 1 to 20 show isopleths for the mixing ratio at the surface of the earth; Charts 21 to 40 show isopleths for the dew point at the earth's surface; Charts 41 to 60 show isopleths for the dew point at the 850-mb level; Charts 61 to 80 show isopleths for the dew point at the 700-mb level; Charts 81 to 100 show isopleths for the dew point at the 500-mb level; and Charts 101 to 120 show isopleths for the dew point at the 400-mb level.

On Charts 1 to 20, the mixing ratio (w) is defined as

$$w = 0.622\ e/(p-e)$$

where p is the ambient pressure of the atmosphere and e is the water-vapor pressure. The formula gives mixing ratio in grams of water vapor per kilogram of dry air. For Charts 21 to 120, the dew point is defined as the temperature to which a given parcel of air at constant pressure and constant water-vapor content must be cooled for saturation to occur with respect to a liquid-water surface. Dew points

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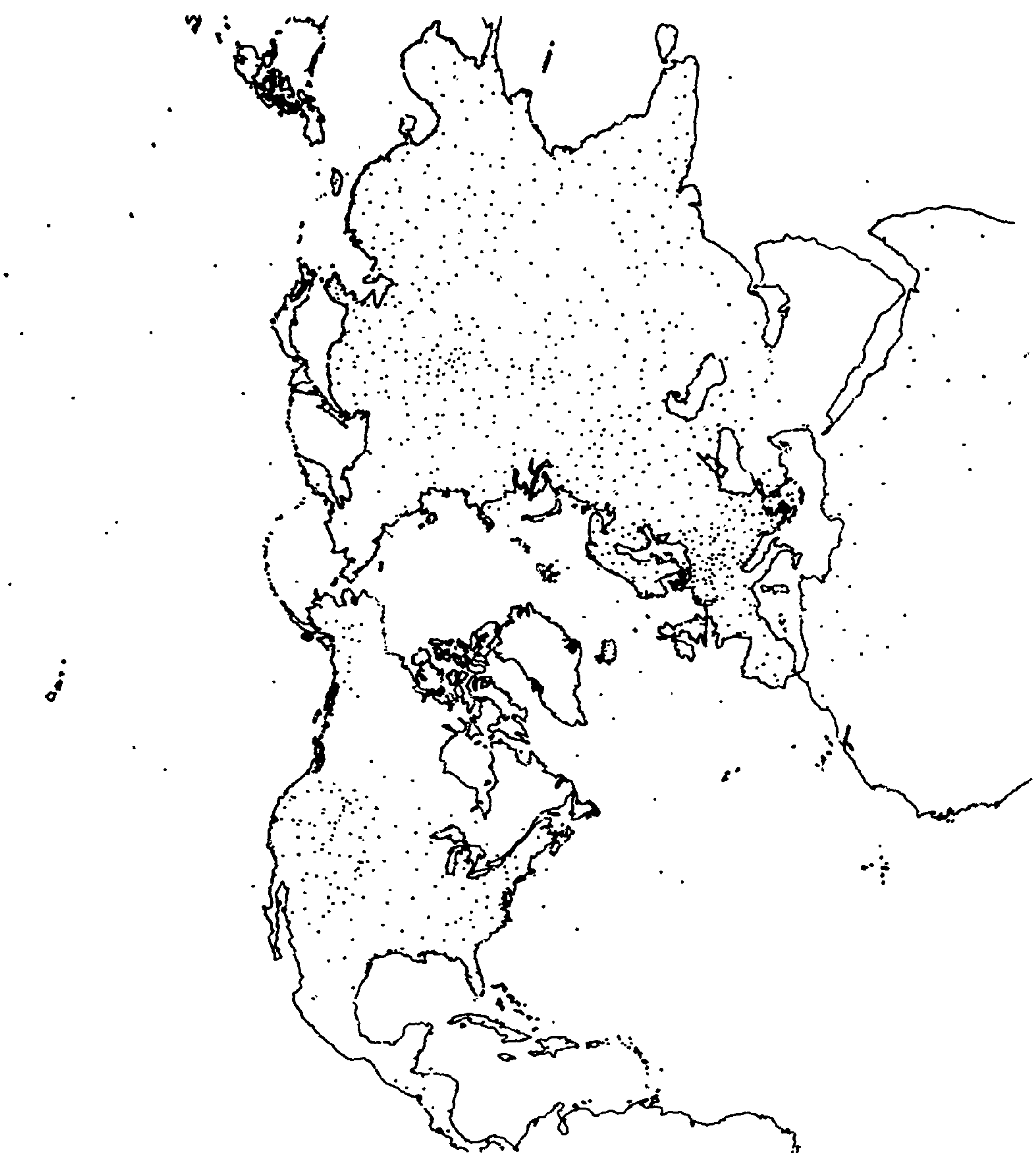

Figure 1. Map of the Northern Hemisphere Showing Location of 1500 Stations Where Surface Observations of Atmospheric Water Vapor Were Made

lower than -40°C are fictitious, but the isopleths so labeled have real meaning in specifying the moisture content (see below).

The preparation of this atlas was undertaken for several reasons. For the upper levels, it was primarily done to provide moisture-content data that could be used to calculate precipitable water-vapor content of the atmosphere along a given line of sight, it being known that moisture in the form of water vapor causes attenuation of infrared signals. (Clouds are virtually opaque.) The atlas was not extended to altitudes above the 400-mb level (approximately 24,000 ft) because of

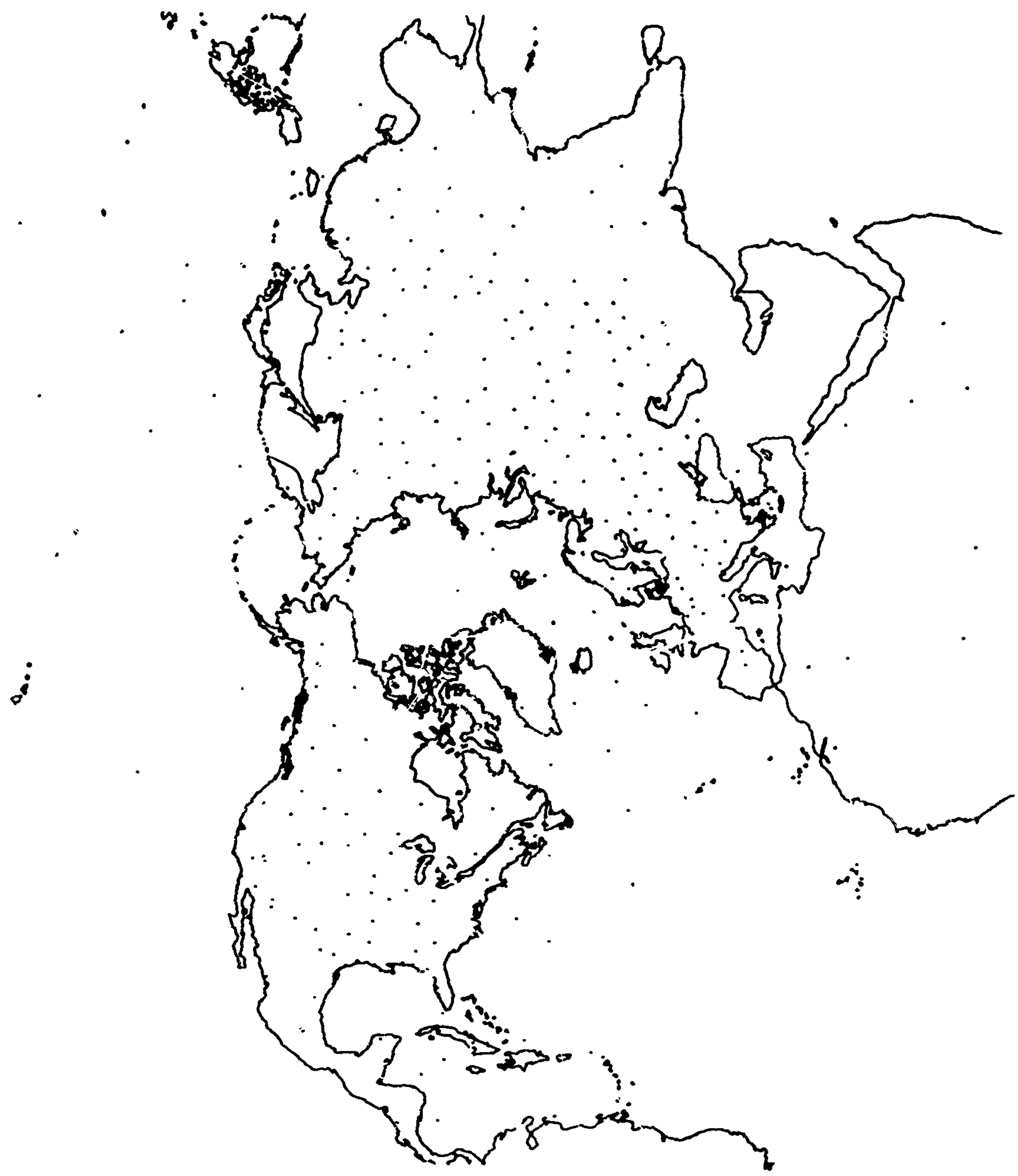

Figure 2. Map of the Northern Hemisphere Showing Location of 400 Stations Where Upper-air Observations of Relative Humidity Were Made

limitations of radiosonde sensors. Unfortunately, however, the greatest concentration of moisture, and therefore the greatest attenuation, is in the lower layers of the atmosphere.

The use of data pertaining to moisture at the surface of the earth is more obvious. The need for humidity control and air conditioning – for human comfort as well as for equipment in use or in storage – is governed by the frequency and duration of high moisture content. Toward this goal, the charts of frequency distribution of moisture content have proved most useful (see below). Reitan (1963) related the surface dew point to the precipitable water, using some 15 stations in the United States to develop the relationship. Given the frequency distribution of a dew point at a station, the corresponding distribution of precipitable water can be estimated.

2. PREVIOUS CHARTS, TABLES, AND REFERENCES

The first and obvious source for information on world-wide moisture distribution is "Monthly Climatic Data of the World" (1966 and previous years), sponsored by the World Meteorological Organization in cooperation with the U.S. Weather Bureau, which gives, for each first-class station, the average dew point for each month, thus providing for the distribution of monthly averages. Peixoto and Crisi (1965) drew isopleths of annual averages (for 1950 and 1958) of specific humidity and calculated the standard deviation of the winter and summer specific humidity at 1000, 700, and 500 mb. Bannon and Steele (1960) prepared maps of the world showing the average amounts of integrated water-vapor content above the earth's surface and at 850-, 700-, and 500-mb altitudes, using 5 years of data (1951 to 1955). Landsberg (1964), taking advantage of the several previous sources, drew isopleths showing the mean water-vapor pressure over the earth in January and July.

Covering more specific areas, maps of mean vapor pressure at the surface are included in the "Climatological Atlas of Canada" (Thomas, 1953), and maps of specific humidity over Africa are presented by Peixoto and Obasi (1965) and Thompson (1965). The U.S. Weather Bureau, in cooperation with the U.S. Navy Hydrographic Office (1957, 1961) published, in three volumes, a marine climatic atlas of the North Atlantic, North Pacific, and Indian Oceans; these volumes include monthly averages of surface dew point. In at least one early edition, frequency distributions of moisture were given for individual stations. Monthly averages and standard deviations of surface dew points for the United States were published by the U.S. Army Natick Laboratories (Dodd, 1965); they also published (Bennett et al., 1964) data on extreme wet-bulb temperatures measured throughout the world.

While the above-mentioned references contribute abundantly toward our knowledge of hemispheric moisture distribution, they do not give sufficient information on the temporal distribution and they have geographical limitations.

3. DATA SOURCES AND PROCESSING

From the archives of data at the National Weather Records Center, and the ETAC Data Processing Division, Asheville, North Carolina, ETAC-USAF extracted upper-air radiosonde information on some 400 stations distributed throughout the

Northern Hemisphere (Figure 2). From this data, a distribution of dew point by month was obtained for each station. About 1/12 of the stations had provided four observations per day for the 5-year period selected, usually 1958-1962. The bulk, about 2/3 of the stations, had provided two observations per day, about 1/6 had provided one observation per day, and about 1/12 of the stations had provided less than one observation per day. For some stations, for example in India, especially for the 500- and 400-mb levels, there were only one or two observations on record.

The ETAC tabulations showed the number of observations made so that the reliability of the percentile values could be judged. It was expected that there would be no significant differences between intradiurnal observations aloft, except at coastal stations at the 850-mb level where sea and land breezes should make the difference. The tacit assumption is made that the distribution of all available measures of the dew point over a single station at a given level serves as an estimate of the distribution of hourly values.

Upper-air measurements of moisture are made in terms of relative humidity (r) over a water surface. These, in turn, give the vapor pressure (e) by the formula

$$e = r . e_s(T)$$

where $e_s(T)$ is the saturation vapor pressure over water at temperature (T) of the ambient air. For this atlas the dew point (T_d) was obtained to satisfy the Magnus formula (Holmboe et al., 1945)

$$\log e = -2937.4/T_d - 4.9283 \log T_d + 23.5518$$

where e is measured in millibars, T_d is in degrees Kelvin, and logarithms are taken to base 10. The dew points thus obtained were plotted on the charts even when they were less than -40°C.

Whenever the ambient temperature was less than -40°C, the relative humidity (r) was assumed to be 50 percent. Whenever "motor boating" occurred at higher temperatures during radiosonde ascents, the following values of relative humidity were assumed, given the ambient temperature range (T):

T (°C)	Rel Hum (%)
-40 to -37	22
-36 to -34	21
-33 to -30	20
-29 to -26	19
-25 to -21	18
-20 to -16	17
-15 to -11	16
-10 to - 5	15
- 4 to 2	14
3 to 7	13
8 to 12	12

Regrettably, the above rules had to be used often. In a sample of 12 representative stations, from Anchorage, Alaska, to Miami, Florida, for the 1956 to 1960 period, more than half of the humidities reported on punched cards for the 400-mb level were "statistical" values, that is, values substituted for real values where the humidity couldn't be measured.

With regard to surface moisture, the information recorded in the archives was as follows: 340 stations had made hourly observations, and the distribution at each station was based on 700 or more observations per month. Approximately 280 of the stations had made 8 to 20 observations a day; 630 stations had made 4 a day, 130 stations had made 3 a day, and 120 stations had made 2 observations a day. Pressure observations were missing for 133 stations, so the mixing ratios were not determined.

The instruments used to make surface observations varied from country to country and for the period of record. For the most part, psychrometers were used to obtain wet-bulb temperatures. The temperatures so obtained were converted to dew point temperatures by using ambient temperatures and hygrometric tables. The mixing ratio was obtained by converting the dew point temperatures, using tables such as the Smithsonian (List, 1963) and taking into account the surface pressure. Alternatively, the dew point was used to find the saturation vapor pressure over water, which in turn was used to find the mixing ratio obtained by the formula:

$$w = 0.622\ r\ e_s/(p-e_s)$$

where p is the station pressure.

The 5, 25, 50, 75, and 95 percentiles of the distribution of values of dew points or mixing ratios were estimated in all cases, even when there was only one observation. Beginning with the lowest observation, the ith of N ordered observations (T_i) was chosen as the estimate of the P-percentile as soon as

$$i/N \geqslant P.$$

The P-percentile of each station, given the constant-pressure surface and month, was plotted, with a computer, alongside the station on a polar stereographic chart, scale 1:30,000,000. For orientation, a cross was plotted at the north pole and at geographic coordinates (25°N, 10°E) and (25°N, 170°W). Each computer-plotted sheet of data was superimposed over a polar stereographic chart on a light table and the analysis and drawing of isopleths done.

4. THE ANALYSIS

Since the median value is subject to the least random variation of sampling, the first chart analyzed for each season and level was that for the 50 percentile of dew point. Then the 25- and 75-percentile charts were analyzed, care being taken to make the isotherms consistent with those on the 50-percentile chart. Lastly, the 5- and 95-percentile charts were analyzed. The isotherms for the United States were drawn first because the density of observations was great and a complete 5-year period of record reasonably well assured.

Over the wide expanse of ocean, where stations are lacking, the 50-percentile surface dew-point lines were made generally parallel to the mean dew-point lines given in USWB-Navy publications. The 50-percentile isopleths of surface mixing ratio were drawn using the 50-percentile dew point as a guide. The 25- and 75-percentile charts were analyzed and made consistent with the 50-percentile charts, and the 5- and 95-percentile charts were analyzed and made consistent with the 25- and 75-percentile charts.

At the surface of the earth, high-elevation stations adjacent to low-elevation stations gave contrasting figures for moisture content. The contrast was especially strong in the vicinity of the geographic boundaries between India and Pakistan on one side and Nepal, Bhutan, and Tibet on the other side. In the Sahara Desert there are two stations, Ouallene and In Salah, Algeria, where the dew points were consistently higher than expected. This observation is consistent with another, that the minimum temperature at Ouallene is higher than that at neighboring stations by 7 to 11°F; hence the phenomenon is accepted as real.

One of the large data gaps in the Northern Hemisphere may soon be closed by the work of the International Indian Ocean Expedition (Ramage, 1963). Results of this work are expected to lead to considerable revision of the plates contained herein for those areas where there is an exceptionally high moisture content. In the regions of Africa, the Arabian Desert, and the Arabian Sea the recently published work sponsored by the Munitalp Foundation (Thompson, 1965) was of considerable help in checking the analyses of 50-percentile charts.

The analyst had difficulty in smoothing the isopleths. In many instances, especially in areas of flat horizontal gradients of moisture, it was impossible to draw isopleths to satisfy all plotted data. Usually, the first-drawn isopleths were erratic, and the analyst had to use his judgment to smooth the lines. Even so, many of the final lines appear too wiggly and unevenly spaced. This feature, however, should not detract from the usefulness of the maps.

With regard to the upper-air charts, the data coverage was better at 850 mb than at 700 mb, which in turn was better than at 500 mb. The coverage and accuracy at the 400-mb level are poor. The 700-mb charts were used as a guide to the drawing of the 500-mb charts, and the latter were used as an important guide to the drawing of the 400-mb charts.

In some instances, the percentile values plotted on the charts were based on fewer than 10 observations. In such instances the data tabulation was a guide to the reliability of the sample, and the isopleths were drawn with greater dependence upon stations with better coverage. The final drafting was completed on polar stereographic charts, using the base map prepared for the Air Weather Service by the Aeronautical Chart and Information Center.

The analyzed data revealed many noteworthy features. In the Trade Wind belt, at 850 mb and aloft, the atmosphere appears dry, with an occasional invasion of moist air (Gutnick, 1958). The dry and moist air differ in frequency from station to station but the content is roughly uniform. For example (Figure 3), the frequency of dry air having a dew point less than -15°C is 20 percent at Palau Island (lat 7°21' N, long. 134°29' E) but 50 percent at Guam (lat 13°29' N, long. 144° 48' E); the frequency of moist air having a dew point greater than 5°C is 25 percent at Palau Island, but 5 percent at Guam.

For some hemispheric stations the percentiles suggest a nearly normal or Gaussian distribution of the dew point. But, for the most part, there is a bimodality or a skewness of the distribution. At some stations, especially in southern latitudes, the moisture content varies little with time, but at other stations, especially in the subpolar regions, the moisture content, as given by the dew point, can vary widely. The highest moisture content in the Northern Hemisphere appears in the atmosphere over the Arabian Sea, the Red Sea, the Persian Gulf, and West Pakistan (Ramage, 1966). Extreme desert conditions prevail over the Arabian Peninsula, even though it is surrounded by the Red Sea and the Persian Gulf.

Regrettably, southeast Asia is poorly covered by this moisture atlas, it being at the periphery of the coverage. The greatest uncertainty in our plates is for the moisture content over India and the adjacent bodies of water. Conditions over the Indochina peninsula are variable, as are those over the Indian Peninsula, making it desirable that a special study be made to bring the information on moisture distribution up to date in that part of the world.

5. USES AND APPLICATIONS

In spite of the difficulties encountered in assembling and analyzing the moisture-distribution data, the atlas is considered sufficiently accurate for practical use. The percentiles of the distribution are needed for determining the duration or persistence of moist conditions, as explained in Section 5.2 below.

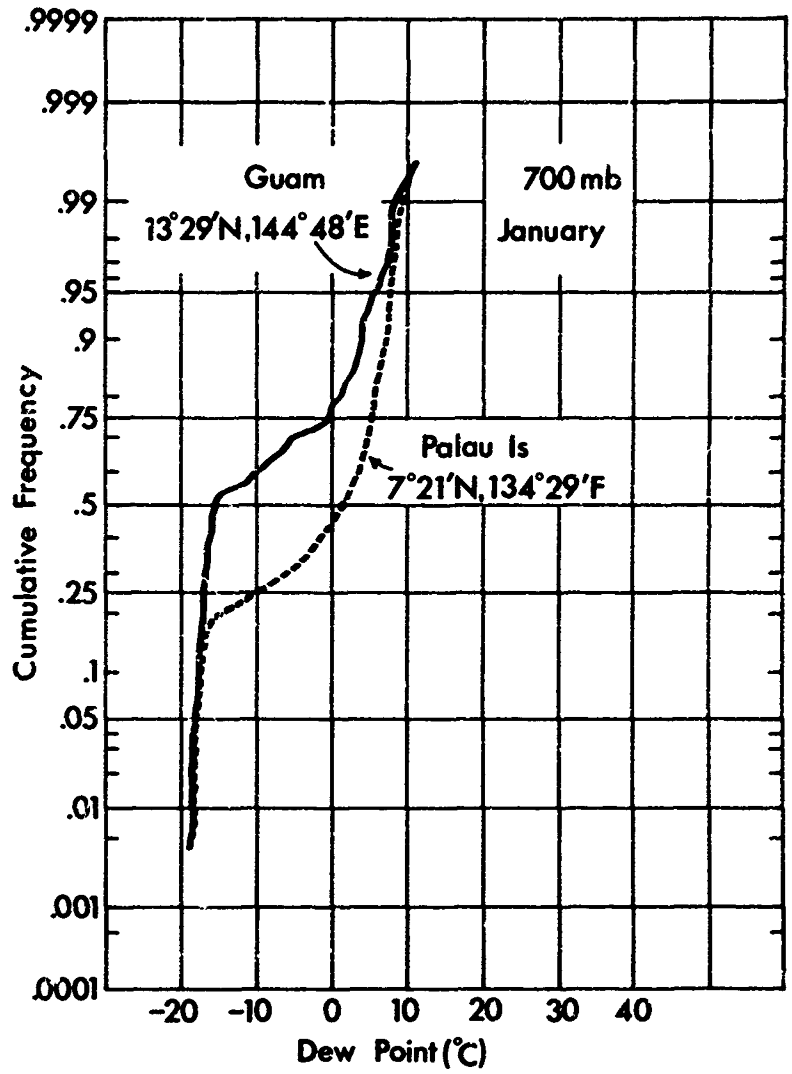

Figure 3. The Cumulative Relative Frequency of Dew Point (°C) at Two Pacific Stations at 700 mb in January

5.1 Other Measures of Moisture Content

Table 1 gives the conversion of dew points into frost points, where applicable, and to vapor pressure, absolute humidity (or density) at dew-point temperature, and mixing ratio, the latter requiring that the constant-pressure surface be given. There is a one-to-one correspondence between the P-percentile of dew point and the P-percentile of the other measures of water-vapor content. For example, in Plate No. 41 of the 5-percentile dew point at 850 mb, the isotherm of 0°C can also be labeled as the isopleth of 6.1 mb vapor pressure, or 4.8 g/m^3 absolute humidity, or 4.5 g/kg mixing ratio. One measure of moisture content not considered in this study is relative humidity.

Table 1. The Conversion of Dew Point (°C) to Other Measures of Moisture Content (Based on Smithsonian Meteorological Tables)

Dew Point (°C)	Frost Point (°C)	Vapor Pressure (mb)	Abs Humidity (g/m^3)	Mixing Ratio (g/kg) 850 mb	700 mb	500 mb	400 mb
-60	-55.5	.0197	.0197	.0146	.0176	.0246	.0326
-55	-50.7	.0362	.035	.0264	.0321	.0449	.0561
-50	-46.0	.0636	.0617	.0467	.0567	.0793	.099
-45	-41.2	.1111	.1055	.0817	.0991	.1386	.1732
-40	-36.5	.1891	.1757	.1390	.1687	.2360	.2948
-35	-31.8	.3139	.2856	.2308	.2801	.3918	.4896
-30	-27.2	.5088	.4534	.3742	.4540	.6352	.7938
-25	-22.5	.8070	.7047	.5936	.7204	1.008	1.260
-20	-18.0	1.2540	1.074	.9227	1.120	1.568	1.960
-15	-13.4	1.9118	1.605	1.408	1.709	2.393	2.993
-10	- 8.9	2.8627	2.358	2.11	2.56	3.59	4.492
- 5	- 4.5	4.2148	3.407	3.11	3.78	5.30	6.637
0	0	6.1078	4.847	4.52	5.49	7.71	9.664
5		8.7192	6.797	6.47	7.87	11.07	13.89
10		12.272	9.399	9.15	11.13	15.69	19.73
15		17.044	12.83	12.78	15.57	22.01	27.75
20		23.373	17.30	17.66	21.56	30.59	38.70
25		31.671	23.05	24.17	29.59	42.19	53.63
30		42.430	30.38	32.82	40.29	57.86	
35		56.236	39.63	44.27	54.56	79.10	
40		73.777	51.19	59.41	73.61		

5.2 Estimating the Duration of Moist or Dry Conditions

Gringorten (1966) developed a stochastic model of duration of a weather element based on the assumption of a simple Markov process. For determining the duration of dew point at the surface or aloft, a constant hour-to-hour correlation of 0.98 was proved acceptable for the variate when it was normalized. Figure 4 shows the duration of values of a normalized variate y that has a mean of zero and a variance of 1.0 with an hour-to-hour correlation of 0.98 as the probability distribution of the m-hour minimum of y for m equal to 1 hour through 24 hours and up to 768 hours (32 days). Figure 5 shows the probability distribution of the highest m-hour minimum of y in 24 hours. Figure 6 shows the distribution of the highest m-hour minimum of y in 192 hours (8 days), and Figure 7 shows the probability distribution of the highest m-hour minimum of y in 768 hours. The use of Figures 4 to 7 for studying the duration of moisture patterns is explained in the following example.

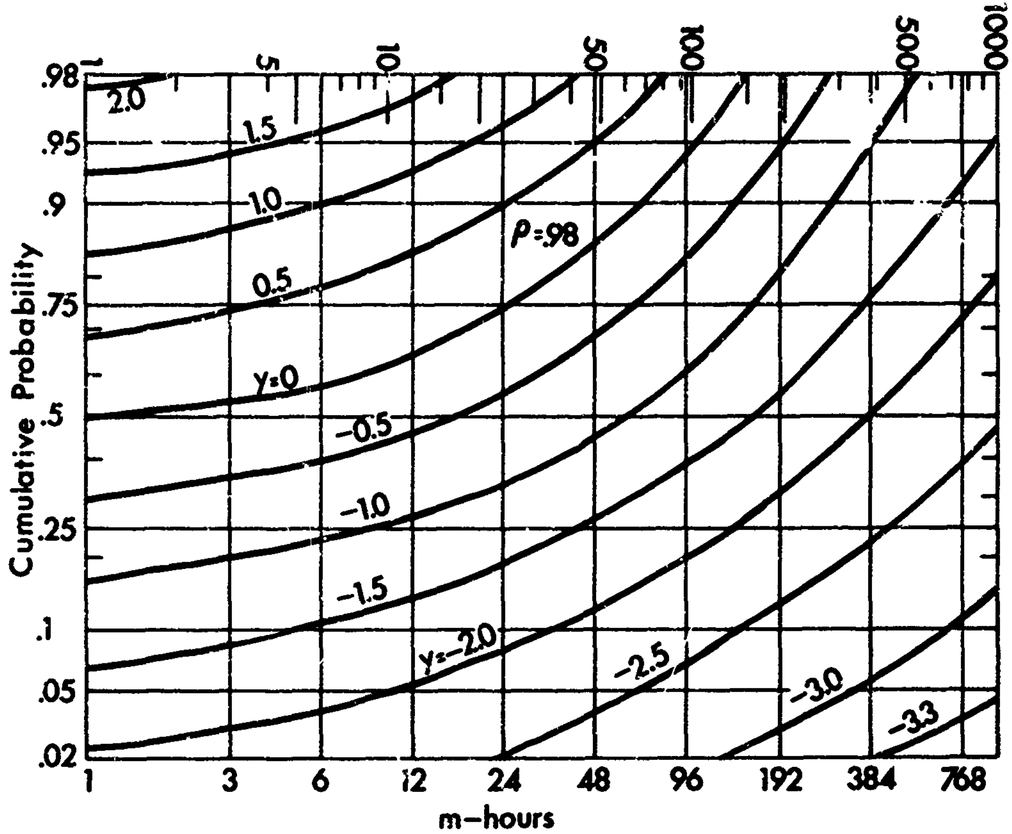

Figure 4. The Probability Distribution of m-Hour Minimum of the Normalized Variate y or the m-Hour Maximum of -y in a Markov Chain With Hour-to-Hour Correlation, $\rho = 0.98$

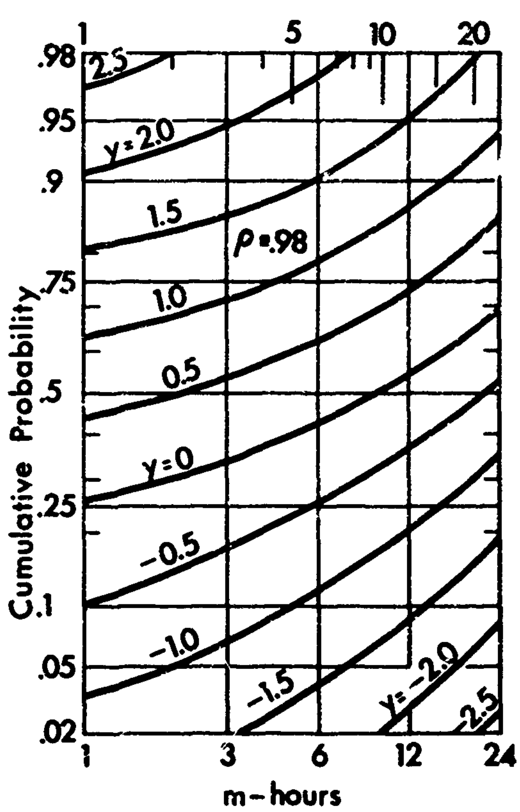

Figure 5. The Probability Distribution of the Highest m-Hour Minimum of y, or the Lowest m-Hour Maximum of -y, in 24 Hours

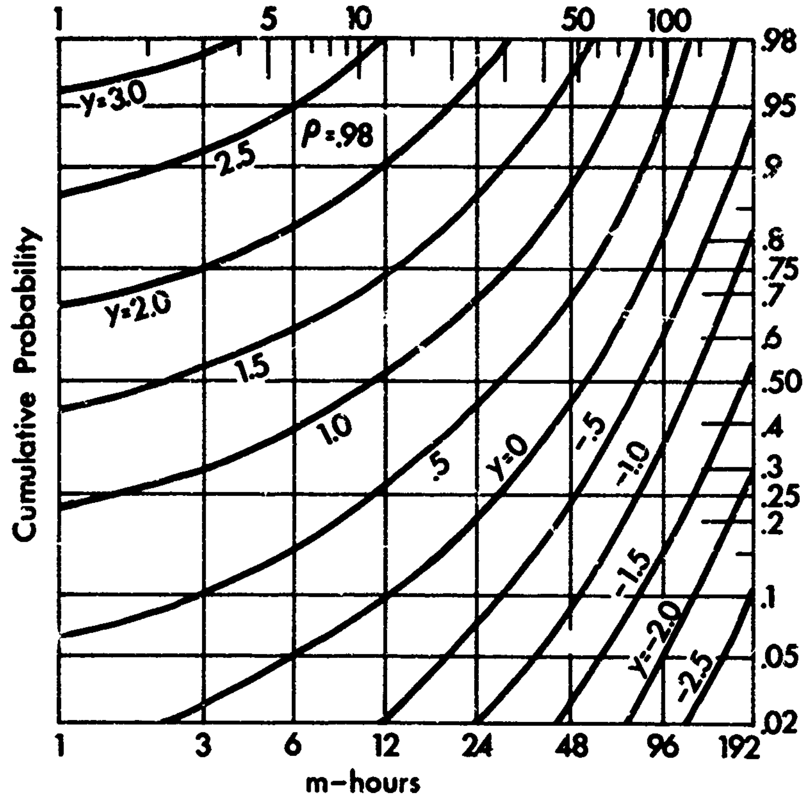

Figure 6. The Probability Distribution of the Highest m-Hour Minimum of y, or the Lowest m-Hour Maximum of -y, in 192 Hours

5.2.1 EXAMPLE 1

A random procedure was used to select a month (April) and a station (Denver, Colorado) in western United States. Plates 26 to 30 give the 5 to 95 percentiles which are the circled values of dew point (°F) on normal probability graph paper (Figure 8). If normal, the frequency distribution would have appeared as a straight line. Since it was not normal, interpolation and extrapolation of the distribution was made by eye. (A future refinement of the Atlas might include plots of the rare events given as 99, 99.9, or even 99.99 percentiles.)

Figure 8 shows the transformation of the dew point T_d into the normalized variate y. For example, the 32°F dew point at Denver in April corresponds to y = 0.65. With such a one-to-one correspondence it is possible to label all the isopleths in Figures 4 to 7 in terms of the Denver dew point in April. For example, the line y = 2.0 can be labeled T_d = 42°F, the line y = 1.5 can be labeled 39°F, and so on. Thus we are able to read any percentile of an m-hour minimum or the highest in n-hours of m-hour minima of T_d. Table 2 lists the results of extreme (2.5 percent) high moisture content. It shows that there is a 2.5 percent

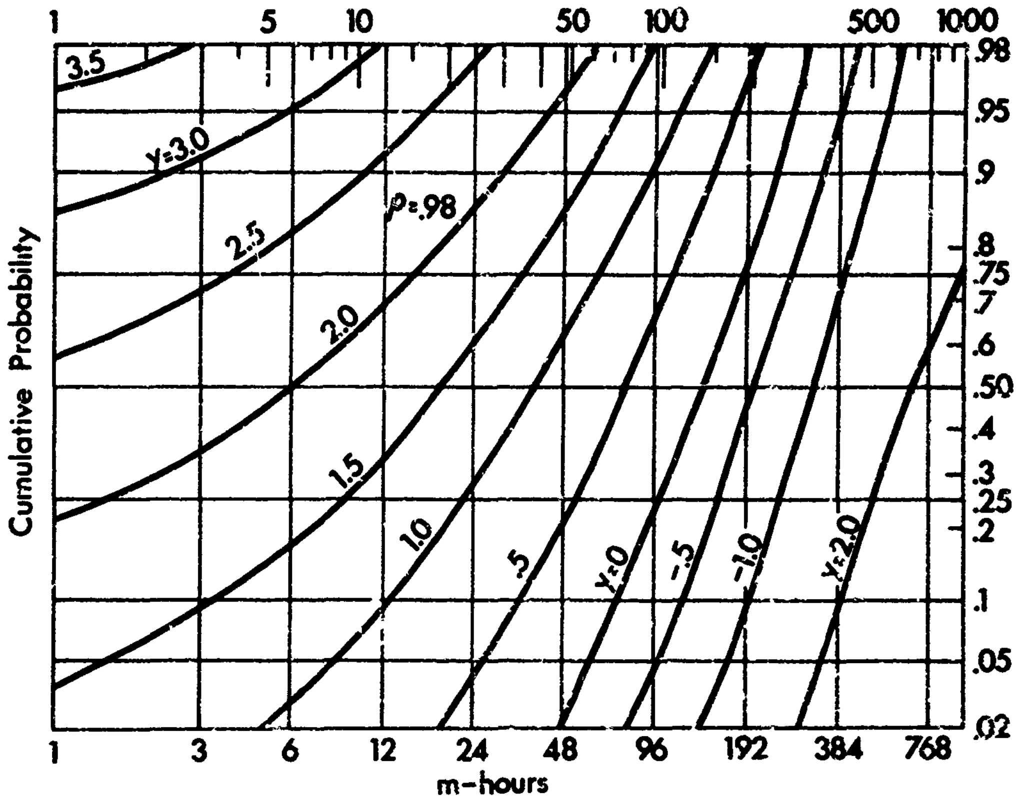

Figure 7. The Probability Distribution of the Highest m-Hour Minimum of y, or the Lowest m-Hour Maximum of -y, in 768 Hours

chance that, for any random 12-hour period in April, the dew point will remain at or above 39°F. In any 24-hour period there is a 2.5 percent chance that, for 12 hours within the 24-hour period, the dew point will remain at or above 40°F. In 8 days there is a 2.5 percent chance that there will be 12 consecutive hours when the dew point will remain at or above 46°F and in the whole month (32 days) there is a 2.5 percent chance that there will be 12 consecutive hours when the dew point will remain at or above 50°F.

The estimates of Table 2 have not been verified directly. However, a report published by the U.S. Weather Bureau (1948), based on 41 years of data (1905 to 1945), gives estimates of the highest minimum dew point that was equaled or exceeded in a 10-day period in mid-April at Denver for durations of 12, 24, 48, 96, or 120 hours. These dew points are, respectively, 46°F, 45°F, 43°F, 40°F, and 38°F. The proximity of these figures to figures of comparable probability in Table 2 is remarkable, especially since the USWB study was based on observations taken 2, 3, or 4 times a day instead of 24 times each day. Thus a 12-hour "persistence" is actually persistence indicated by only two or three observations.

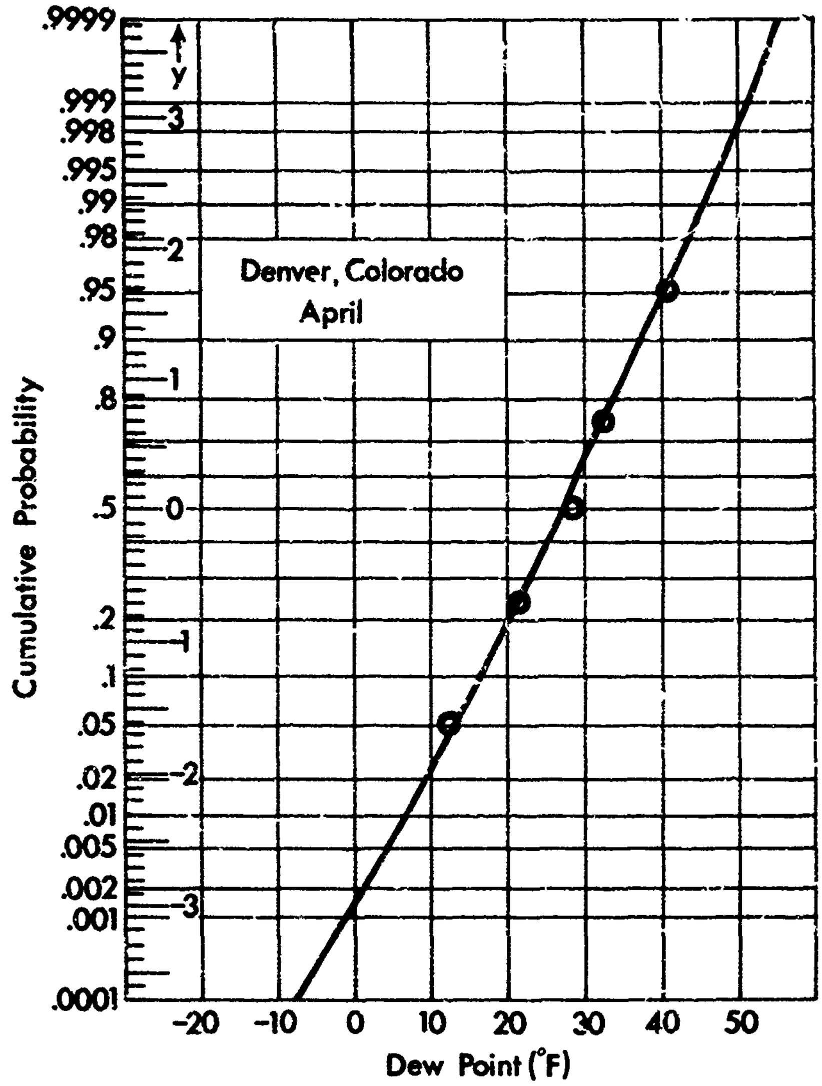

Figure 8. The Frequency Distribution of Hourly Values of Surface Dew Point (°F) at Denver, Colorado, in April

Figure 4, which gives the probability distribution of the m-hour minimum of y, can also be used to give the probability distribution of the m-hour maximum of -y. For example, the point in Figure 4 that gives y = 0.5 as the 75 percentile of the 4-hour minimum also gives y = -0.5 as the 25 percentile of the 4-hour maximum. Or, the point that gives y = -1.0 as the 20 percentile of the 3-hour minimum also gives y = 1.0 as the 80 percentile of the 3-hour maximum. Likewise, the figures (Figures 5, 6, and 7) that give the probability distribution of the highest m-hour minimum of y in n hours also gives the probability distribution of the lowest m-hour maximum of -y in n hours. Thus we are able to use Figures 4, 5, 6, and 7 to yield the estimates of Table 3 for the extreme (2.5 percent) dry conditions at Denver, Colorado, in April.

Table 2. Estimates of the 2.5 Percentiles of Dew Point (°F) Showing High Moisture Content, Duration From 1 to 768 Hours (32 Days) at Denver, Colorado, for April

Item	Duration m (Hours)										
	1	3	6	12	24	48	96	120	192	384	768
m-hour minimum	43	42	40	39	36	33	29	28	25	21	17
highest in 24 hr of m-hour minima	46	44	43	40							
highest in 8 days of m-hour minima	51	50	48	46	44	40	33	31			
highest in 32 days of m-hour minima	54	53	51	50	46	44	38	37	32	25	
USWB 40-yr record of highest in 10 middle days of month of m-hour minima (1905-1945)				46	45	43	40	38			

Table 3. Estimates of the 2.5 Percentiles of Surface Dew Point (°F) Showing Low Moisture Content, Duration From 1 to 768 Hours (32 Days) at Denver, Colorado, for April

Item	Duration m (Hours)									
	1	3	6	12	24	48	96	192	384	768
m-hour maximum	9	11	12	14	17	20	[illegible]	29	33	37
lowest in 24 hr of m-hour maxima	4	6	9	12						
lowest in 8 days of m-hour maxima	-1	0	2	5	8	13	21			
lowest in 32 days of m-hour maxima	-6	-4	[illegible]	0	4	8	14	22	30	

5.2.2 EXAMPLE 2

In the course of this study 5 years of upper-air dew point temperatures were collected on the m-hour minima for five stations: Montgomery, Alabama, 1958 to 1962; Nantucket, Massachusetts, 1956 to 1960; Tucson, Arizona, 1958 to 1962; Oakland, California, 1956 to 1960; and Washington, D.C., 1955 to 1959. The data at these stations were collected at the 850-, 700-, 500-, and 400-mb levels for January, April, July, and October. All observations were 12 hourly, yielding a basic distribution that is assumed to be the distribution of hourly dew points.

Assuming an hour-to-hour correlation of 0.98, it was possible to make the estimates by tne duration model. Table 4 gives examples of the estimates of dew points that have a 50-50 chance of being equaled or exceeded in m consecutive hours. The station, season, and level were randomly selected, but the random process was continued until all stations, seasons, and levels were represented. Table 4 also gives, for comparison, the estimates made directly from the 5-year samples.

Table 4. Estimates of the 50 Percentile of m-Hour Minimum of Dew Point (°C). The A-column consists of estimates made by drawing the distributions to the values taken from Plates 41 to 120 and using Figure 4. The B-column consists of direct estimates from samples of observations over 5 years (see text)

Hours	Nantucket, Mass. January 500 mb		Oakland, Calif. January 500 mb		Montgomery, Ala. October 400 mb		Tucson, Ariz. July 850 mb		Washington, D.C. April 700 mb	
m	A	B	A	B	A	B	A	B	A	B
1	-36		-32		-32		3		-14	
3	-37		-33		-38		8		-15	
6	-38		-34		-38		7		-16	
12	-39		-35		-39		6		-18	
24	-41	-42	-37	-38	-40	-40	5	8	-20	-21
48	-42	-43	-38	-39	-41	-41	4	6	-22	-24
96	-44	-45	-40	-40	-42	-42	2	4	-26	-27
192	-46	-47	-42	-41	-43	-43	-1	1	-30	-28
384	-48	-50	-43	-42	-44	-45	-3	-4	-34	-30
768	-49		-44		-45		-5		-37	

5.2.3 EXAMPLE 3

For Minneapolis, Minnesota, dew point temperatures were collected from 1949 to 1958 for the midseason months; these temperatures were processed to yield directly the sample estimates of frequencies of m-hour minima and maxima. Table 5 gives the P percentiles of the m-hour minimum of dew points obtained from the data and, for comparison, the P percentiles estimated by the model using the dew point values of Plates 21 to 40. Each value of P was chosen from a table of random numbers. The root mean square difference of these estimates of high moisture content is 1.8°F. Table 6 gives the P percentile of the m-hour maximum. The root mean square difference of estimates of low moisture content is 2.7°F.

Table 5. Estimates of the Upper P Percent in the Distribution of m-Hour Minimum of Dew Point (°F) at Minneapolis, Minnesota. P was chosen at random. The A-column consists of estimates made by drawing the distribution to the values taken from Plates 21 to 40 and using Figure 4. The B-column consists of direct estimates from the 10-year sample, 1949-1958

Days	Hours m	January P = 0.39 A	B	April P = 0.65 A	B	July P = 0.36 A	B	October P = 0.63 A	B
	1	12	13	26	27	61	63	36	34
	3	10	12	25	26	60	62	34	33
	6	9	10	24	25	60	61	33	32
	12	6	7	22	24	59	60	32	31
1	24	1	3	20	21	56	58	30	30
2	48	- 4	- 1	18	19	53	55	27	28
4	96	-10	- 8	15	16	50	52	24	25
8	192	-17	-14	12	13	48	49	21	23
16	384	-25	-23	8	11	46	47	18	21
32	768	-31	-27	6	4	43	46	15	14

Table 6. Estimates of the Lower P Percent in the Distribution of m-Hour Maximum of Dew Point (°F) at Minneapolis, Minnesota. P was chosen at random. The A-column consists of estimates made by drawing the distribution to the values taken from Plates 21 to 40 and using Figure 4. The B-column consists of direct estimates from the 10-year sample, 1949-1958

Days	Hours m	January P = 0.03 A	B	April P = 0.68 A	B	July P = 0.03 A	B	October P = 0.13 A	B
	1	-27	-26	35	36	45	48	28	27
	3	-24	-24	36	37	46	48	29	29
	6	-22	-22	37	38	46	50	30	30
	12	-19	-20	39	39	47	51	32	31
1	24	-13	-15	41	41	49	53	35	33
2	48	- 6	-11	43	44	52	56	38	36
4	96	3	- 4	45	47	57	60	42	40
8	192	12	6	49	50	61	63	46	44
16	384	19	23	52	56	65	66	50	49
32	768	23	29	55	59	68	69	54	54

5.3 Estimate of Precipitable Water Vapor Along a Line of Sight

Water vapor in the atmosphere causes serious attenuation of infrared signals. By far, the greatest concentration of the moisture is in the lower layers. The plates in this atlas show data to 400 mb, it being assumed that the water vapor content above that level is negligible by comparison with the amounts below.

It is possible to estimate the amount of precipitable water vapor along a line of observation of given length. But the usefulness of this atlas for the problem of attenuation or blocking of infrared signals is badly restricted because the frequency of cloud buildup with each percentile of moisture content is not given or estimated. Moreover, no known model exists to correlate the frequency of moisture content at one station with that of another, using zero time lag. Without a model, theory, or empirical relationship, the plates of this report cannot be used to derive a frequency distribution of precipitable water along a given path; however, they can be used to estimate the average amount of precipitable water along any given straight-line path, if we assume that the average at each station is approximated by the 50 percentile.

For a ray that skims the earth at an initial point, the tangential distance s from the initial point to the point that is p mb above the surface of the earth is approximated (Table 7) by assuming that the radius of the earth is 6, 371, 221 m.

Table 7. The Distribution of Mean Water Vapor Content Along a Straight-line Path Tangential to the Surface of the Earth at Omaha, Nebraska, in July

Pressure p (mb)	Path Distance s (m)	Dew Point* T_d (°C)	Absolute Humidity at the Dew Point** ρ_d (g/m^3)	Mean Temperature*** T (°C)	Absolute Humidity ρ_T (g/m^3)
Surface	0.00×10^5	18	15.	25.2	14.7
850	1.40×10^5	11	10.	18.9	9.7
700	2.29×10^5	- 1	4.5	9.4	4.3
500	2.93×10^5	-25	0.7	- 7.9	0.7
400	3.06×10^5	-36	0.3	-19.4	0.3

* From Plates 33, 53, 73, 93, 113
** From Table 1
*** From Ratner (1958)

The absolute humidity (ρ_T) at the temperature (T) of the air is given in terms of the absolute humidity (ρ_d) at the dew point (T_d) by the formula

$$\rho_T = \rho_d \cdot T_d/T .$$

For example, the average amount of precipitable water in a path 200 nautical miles long, which equals 3.6×10^5 m, can be obtained by graphical integration of the area under the curve of density (absolute humidity) plotted against tangential distance. For the example of Table 7, this gives 2.53×10^6 g/m^2 or 2.53 m of precipitable water along the path.

Acknowledgments

The authors acknowledge the considerable assistance of their associates. Arnold Court* and Norman Sissenwine, AFCRL, originated the idea of a moisture atlas and initiated the project together with M. Gutnick** and R.H. Ferrell, ETAC-USAF. Lt. Col. John McCabe, ETAC-USAF, participated in most of the later planning of the atlas, and the final drafting was accomplished by Robert Hunton, ETAC-USAF.

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** Now retired

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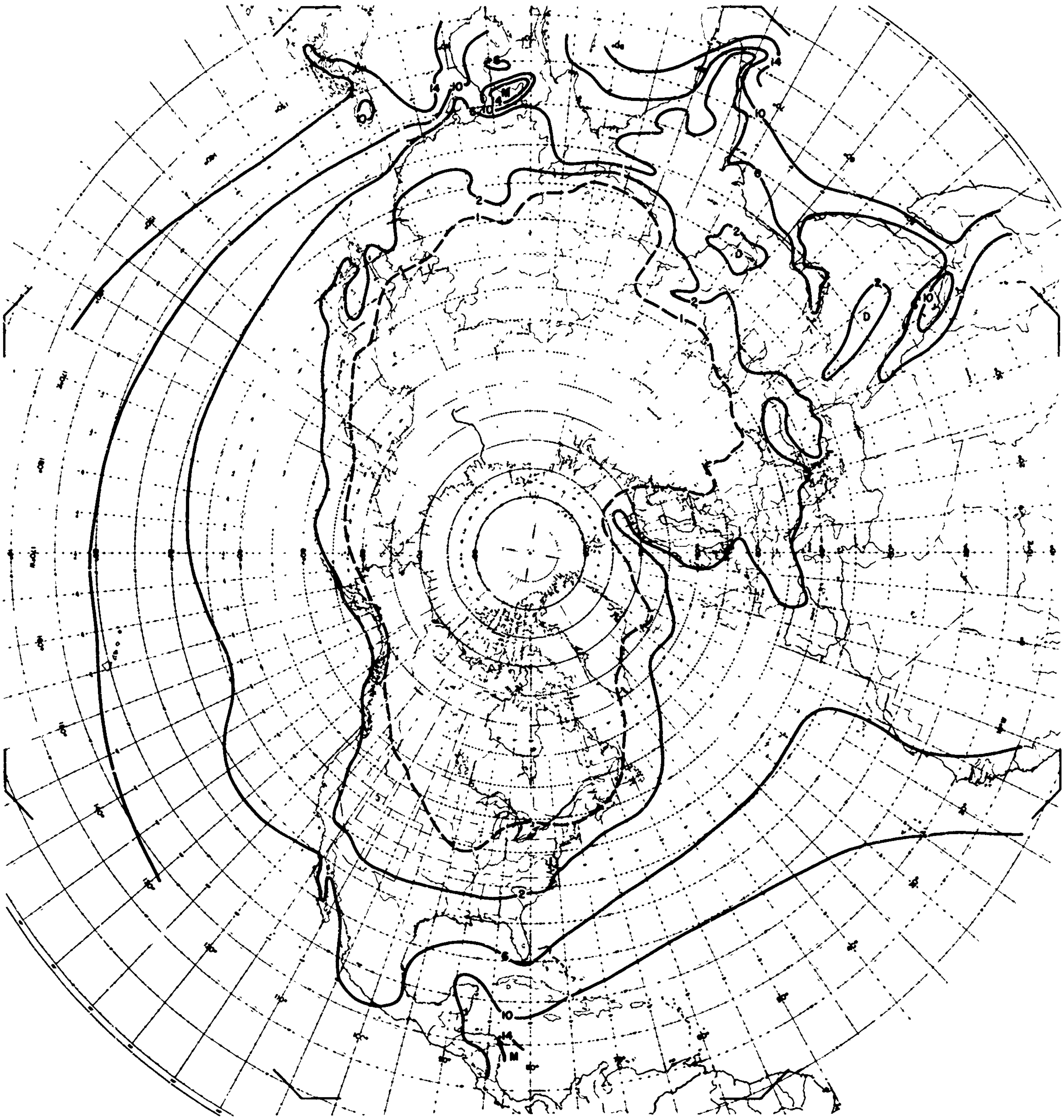

Plate 1. Mixing Ratio at the Surface in January, 5 Percentile

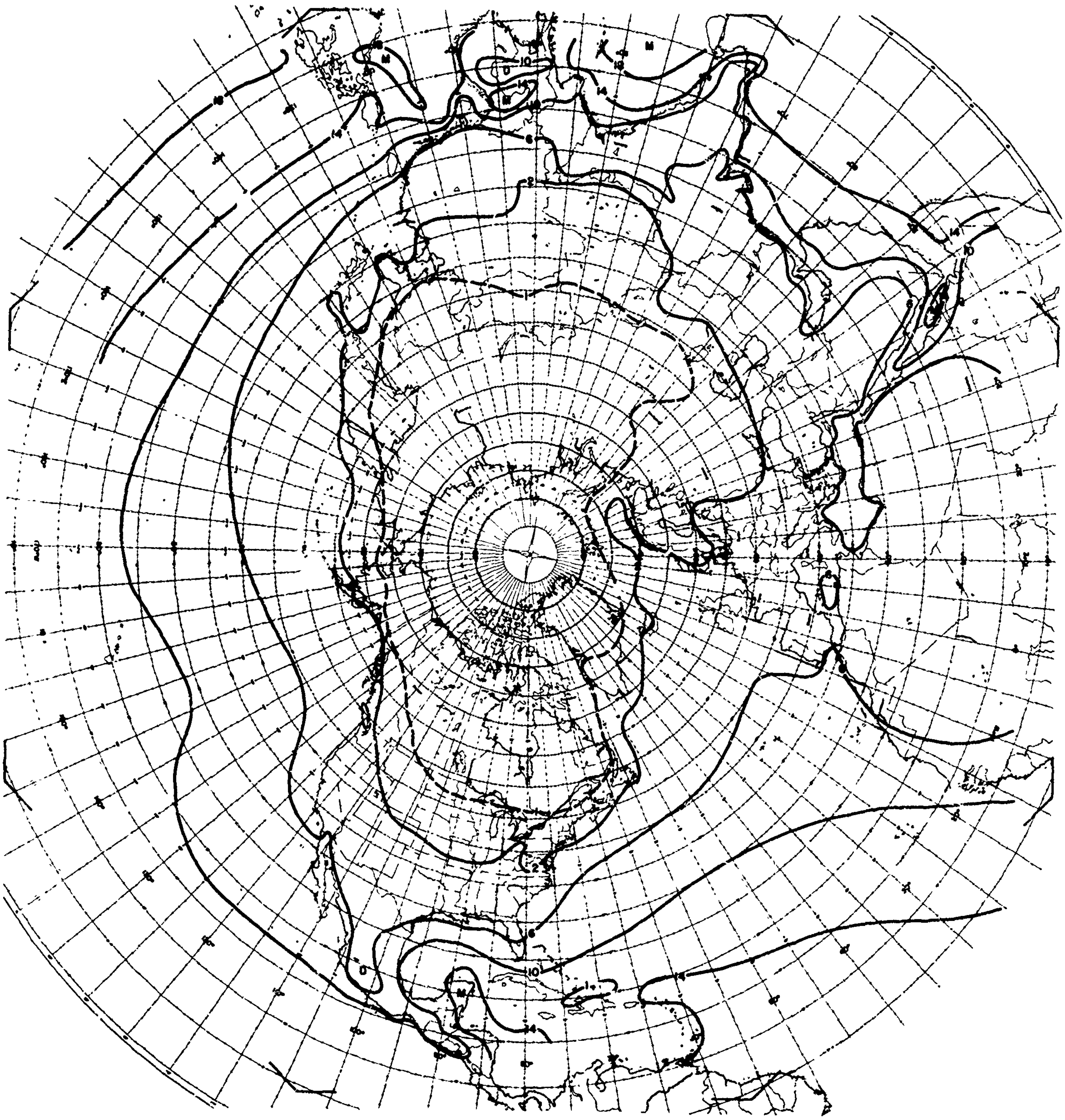

Plate 2. Mixing Ratio at the Surface in January, 25 Percentile

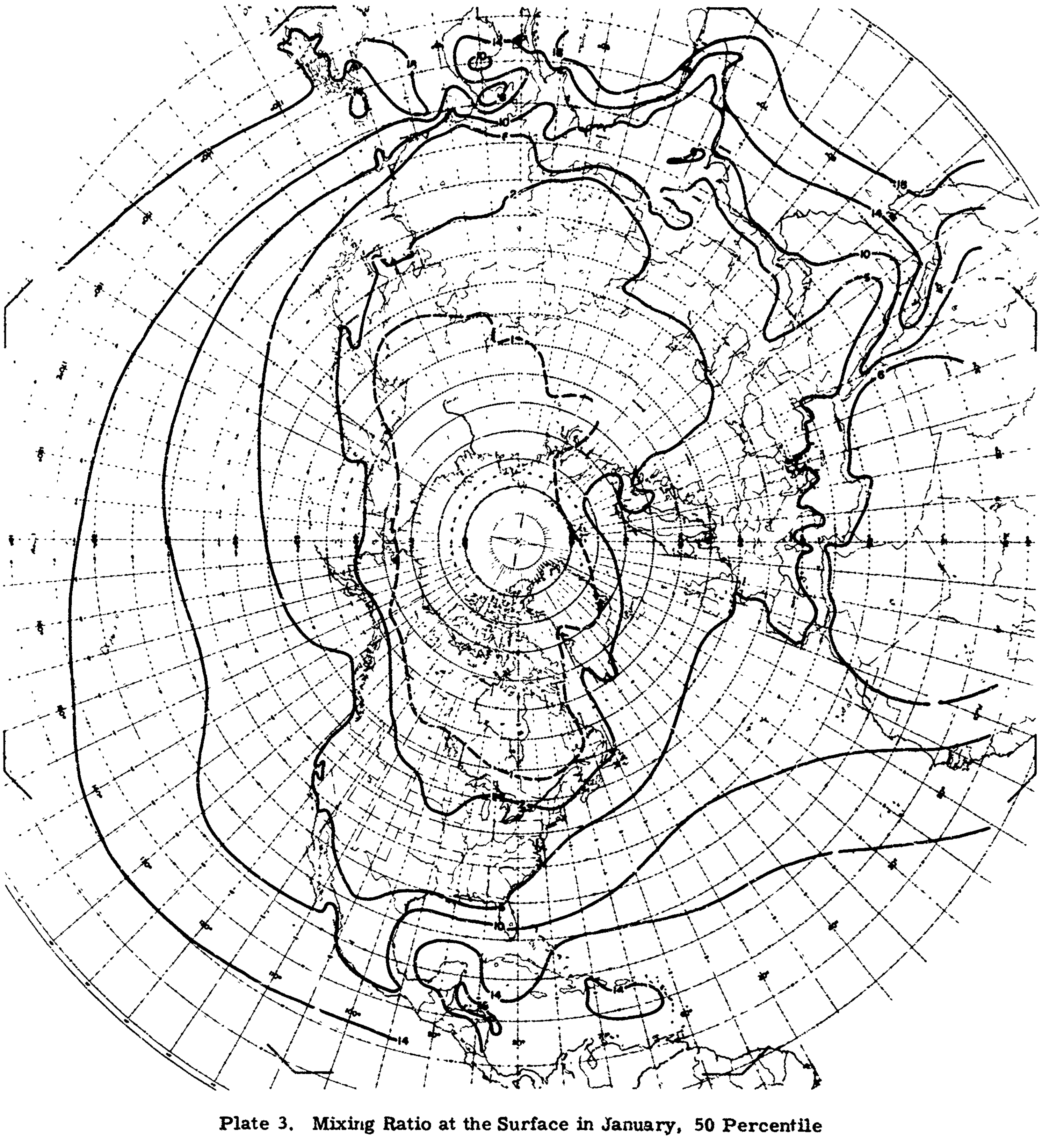

Plate 3. Mixing Ratio at the Surface in January, 50 Percentile

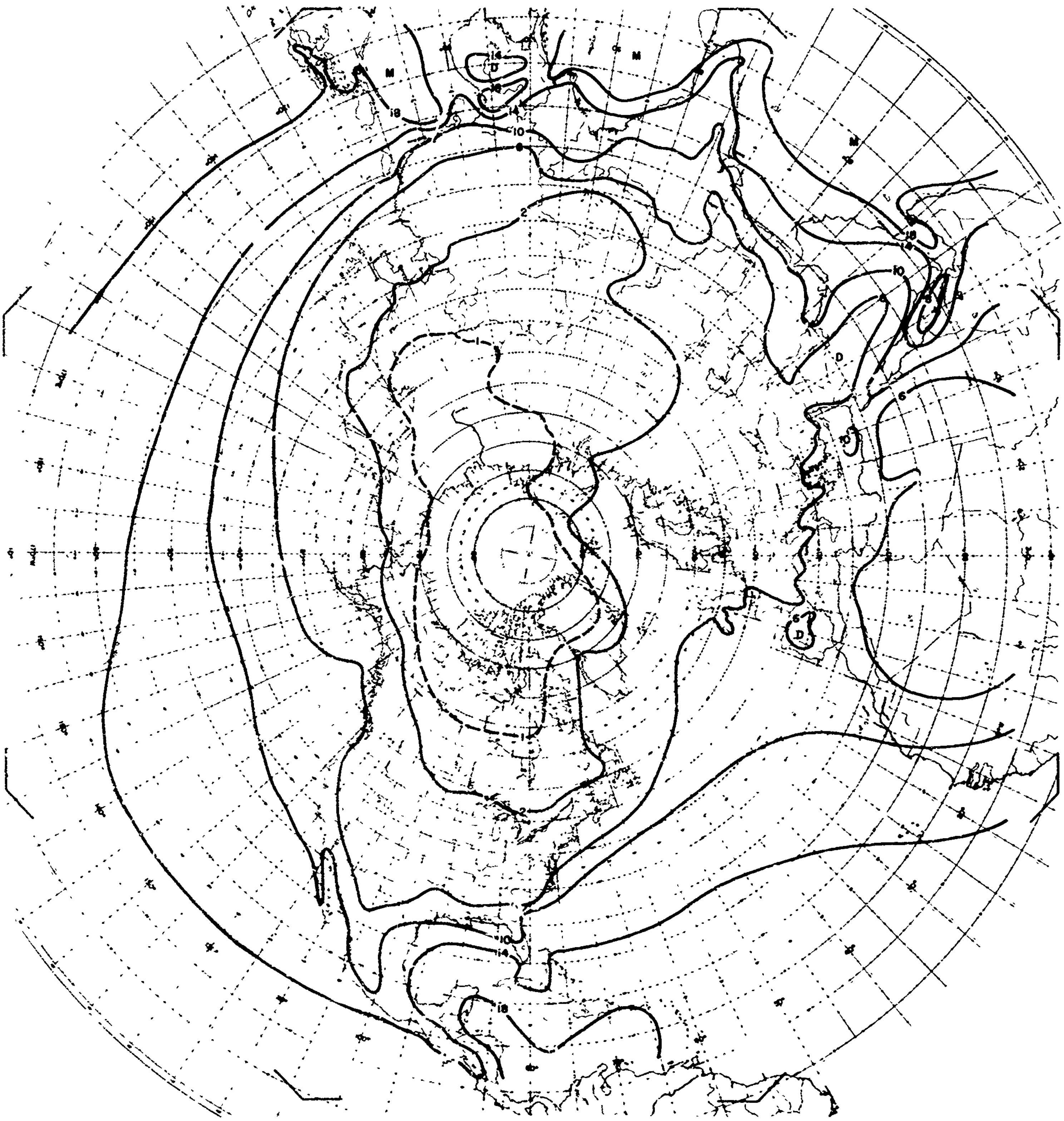

Plate 4. Mixing Ratio at the Surface in January, 75 Percentile

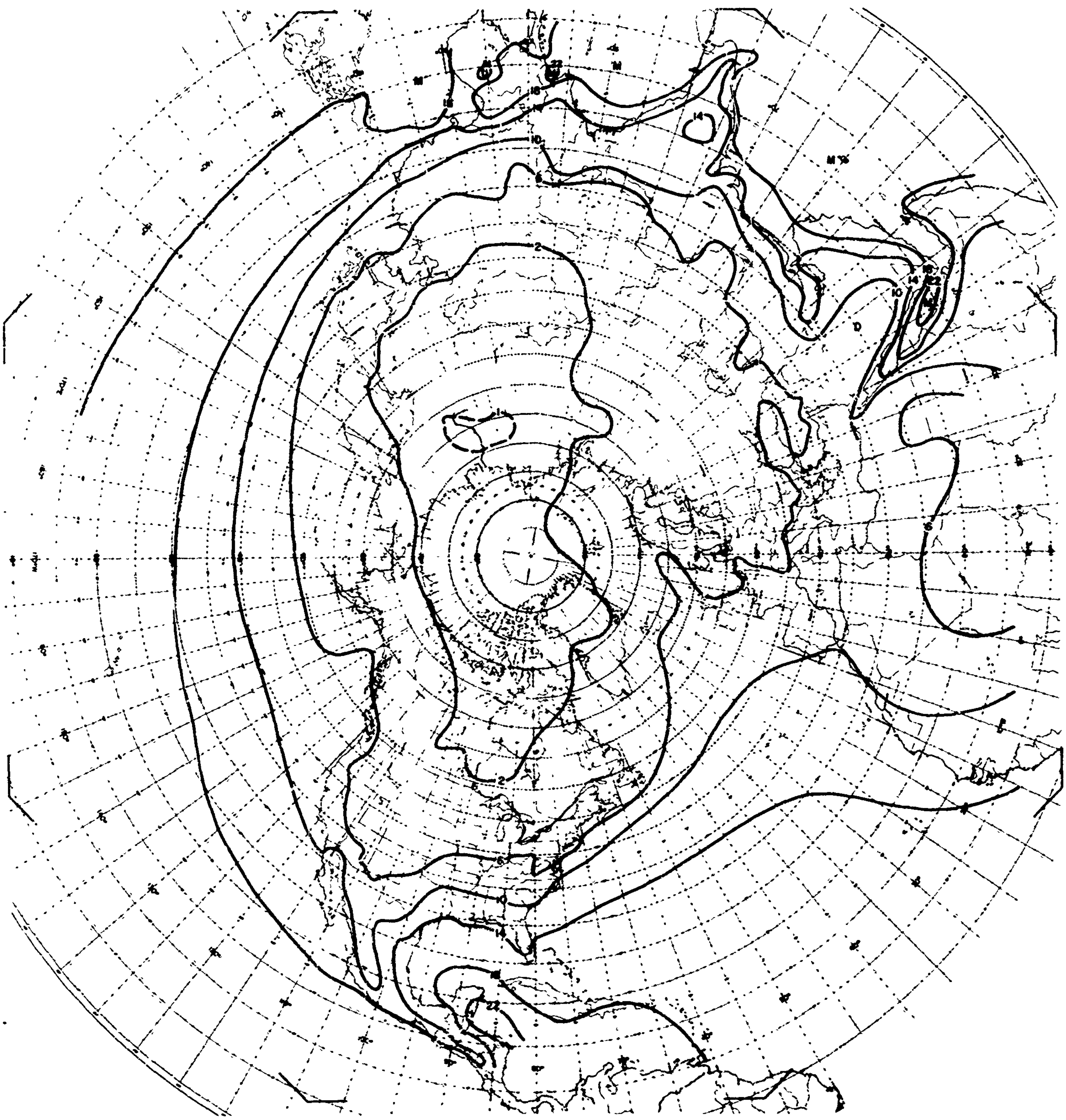

Plate 5. Mixing Rati.› at the Surface in January, 95 Percentile

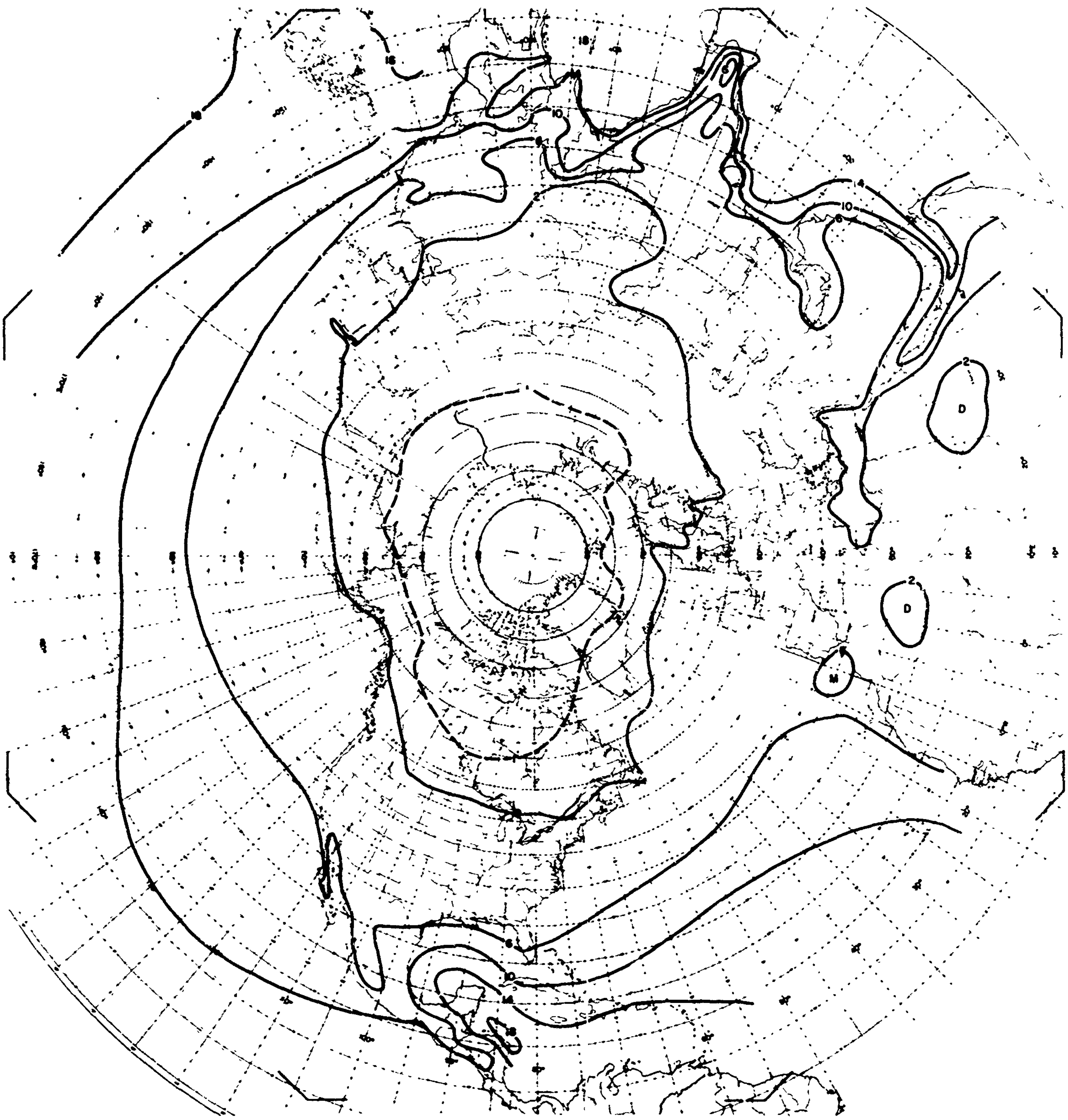

Plate 6. Mixing Ratio at the Surface in April, 5 Percentile

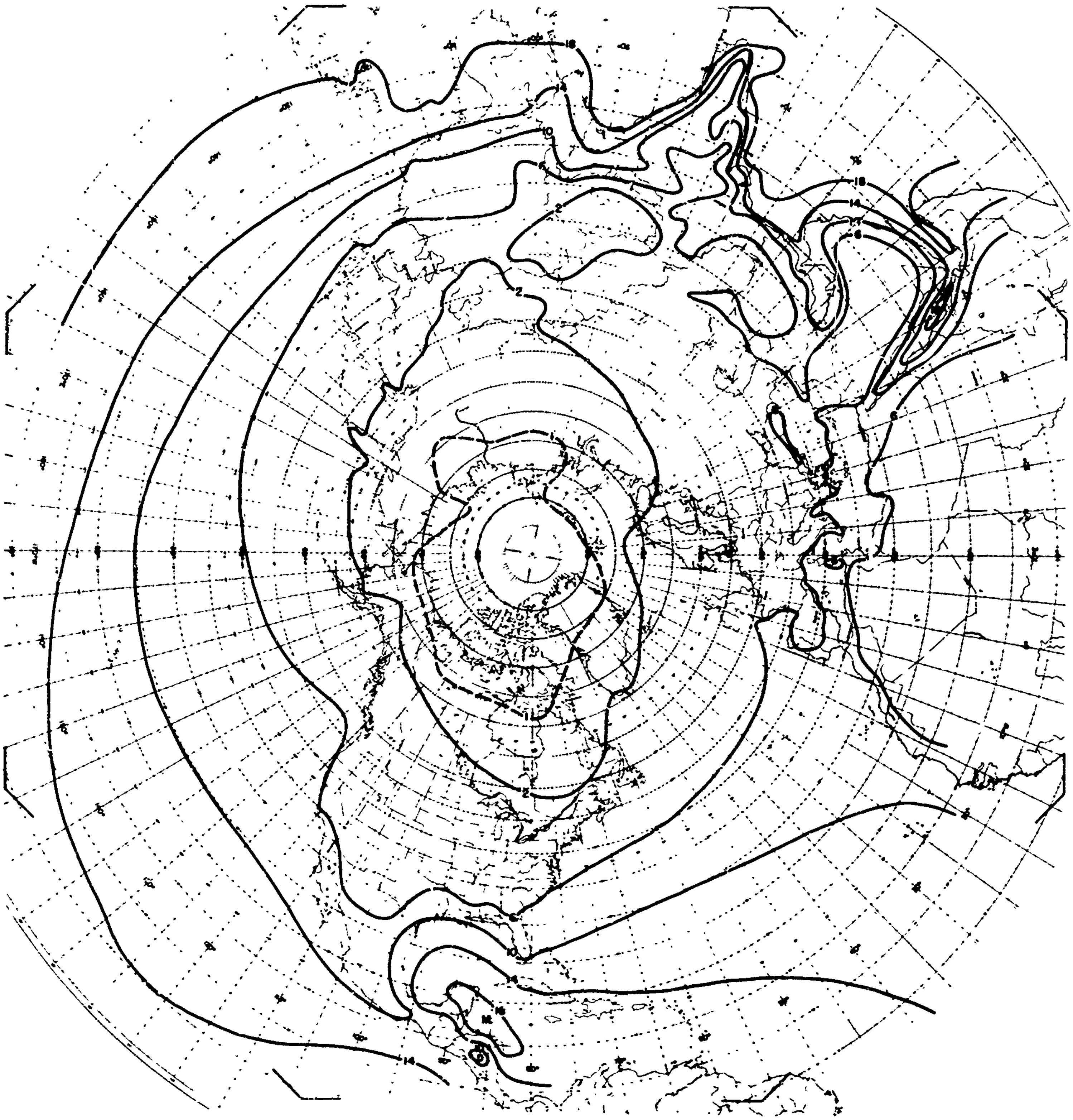

Plate 7. Mixing Ratio at the Surface in April, 25 Percentile

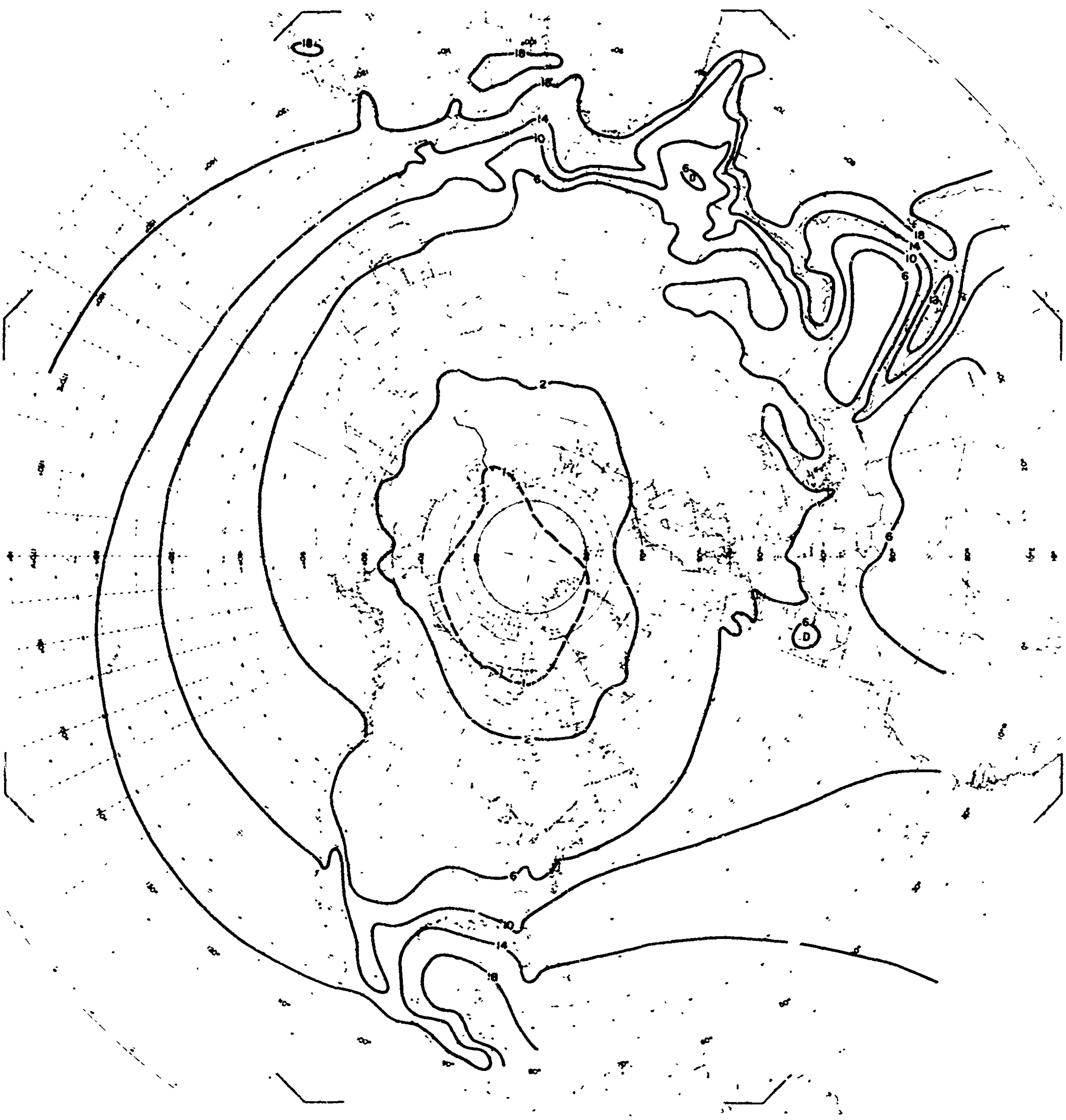

Plate 8. Mixing Ratio at the Surface in April, 50 Percentile

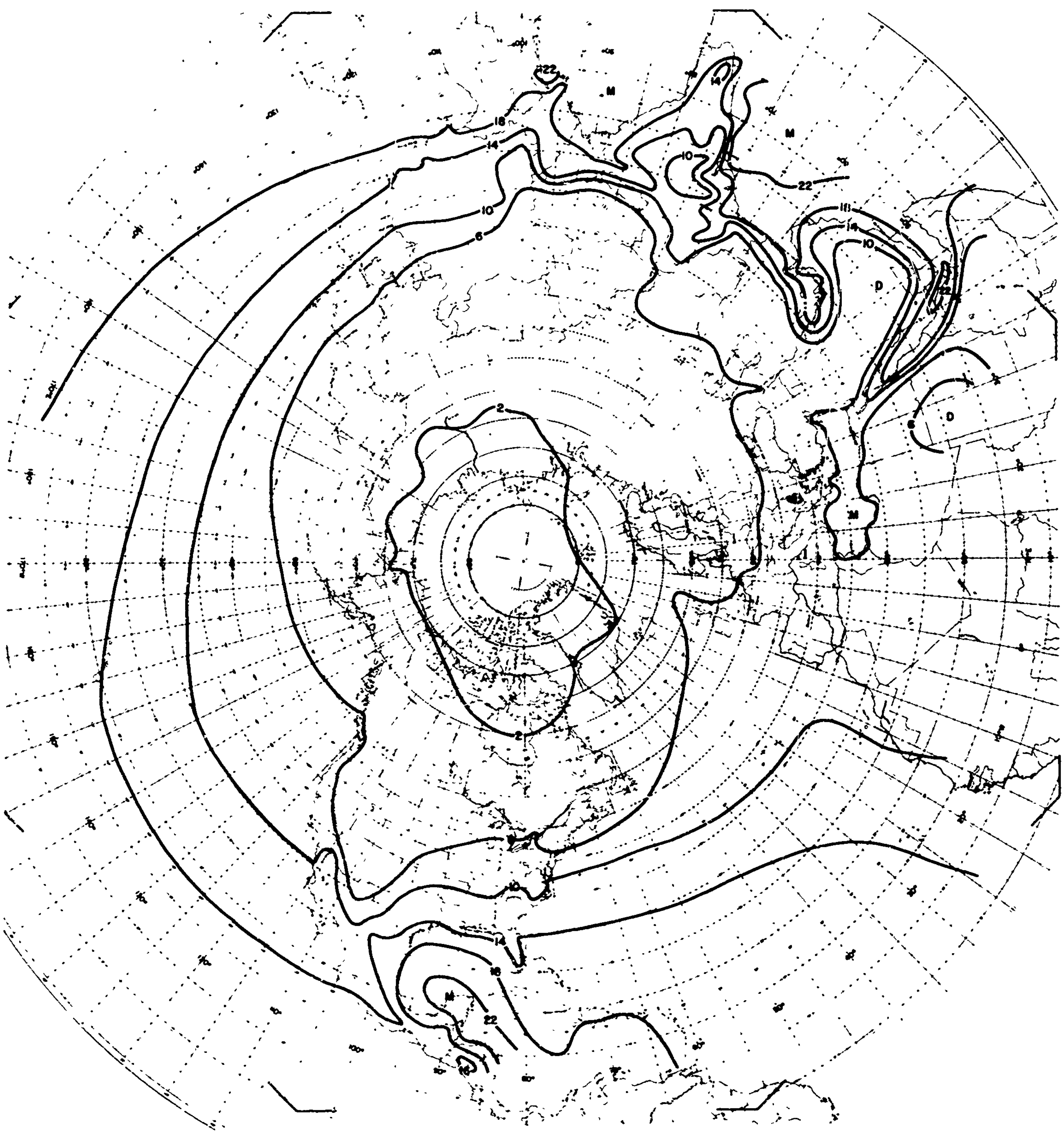

Plate 9. Mixing Ratio at the Surface in April, 75 Percentile

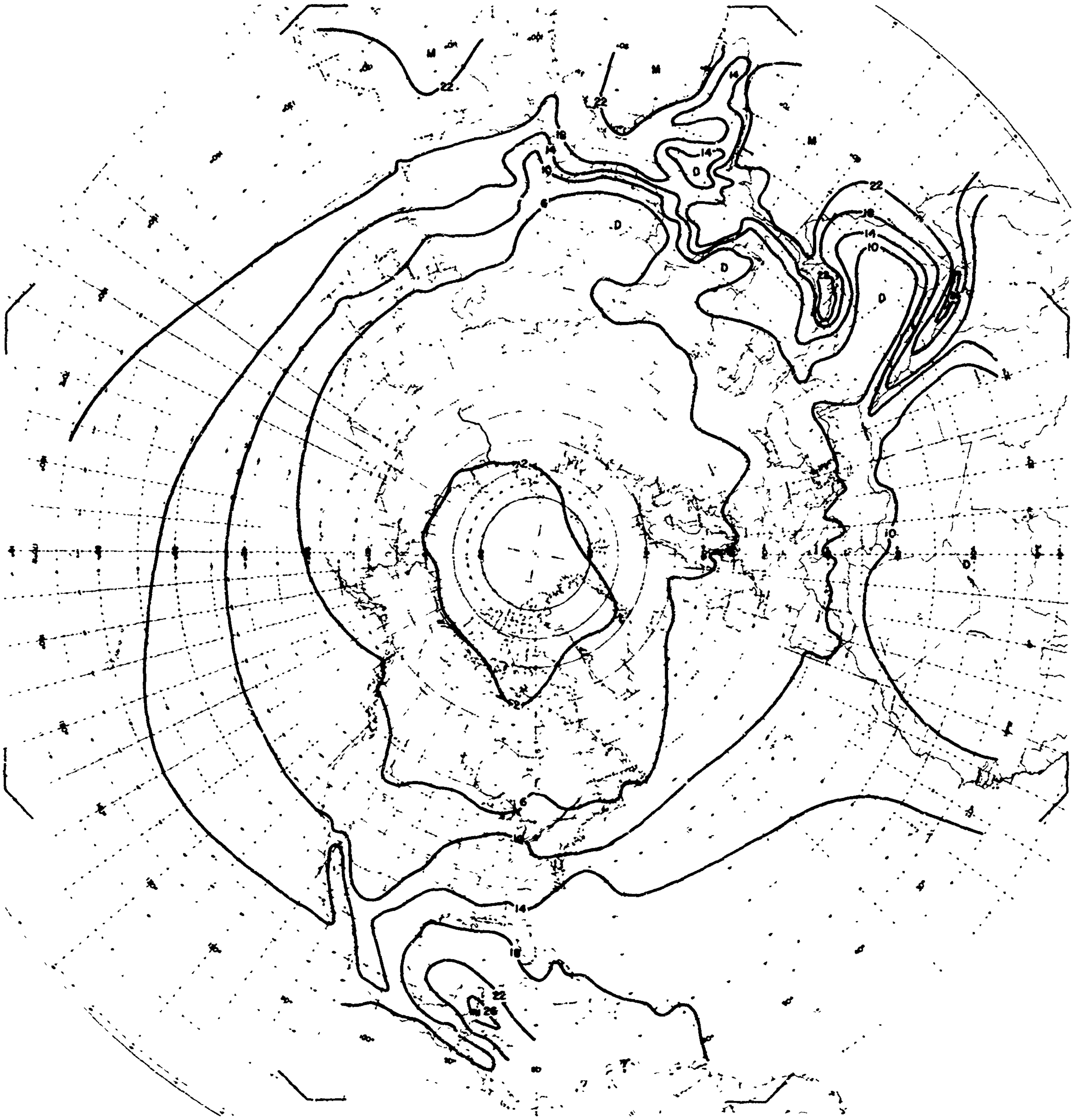

Plate 10. Mixing Ratio at the Surface in April, 95 Percentile

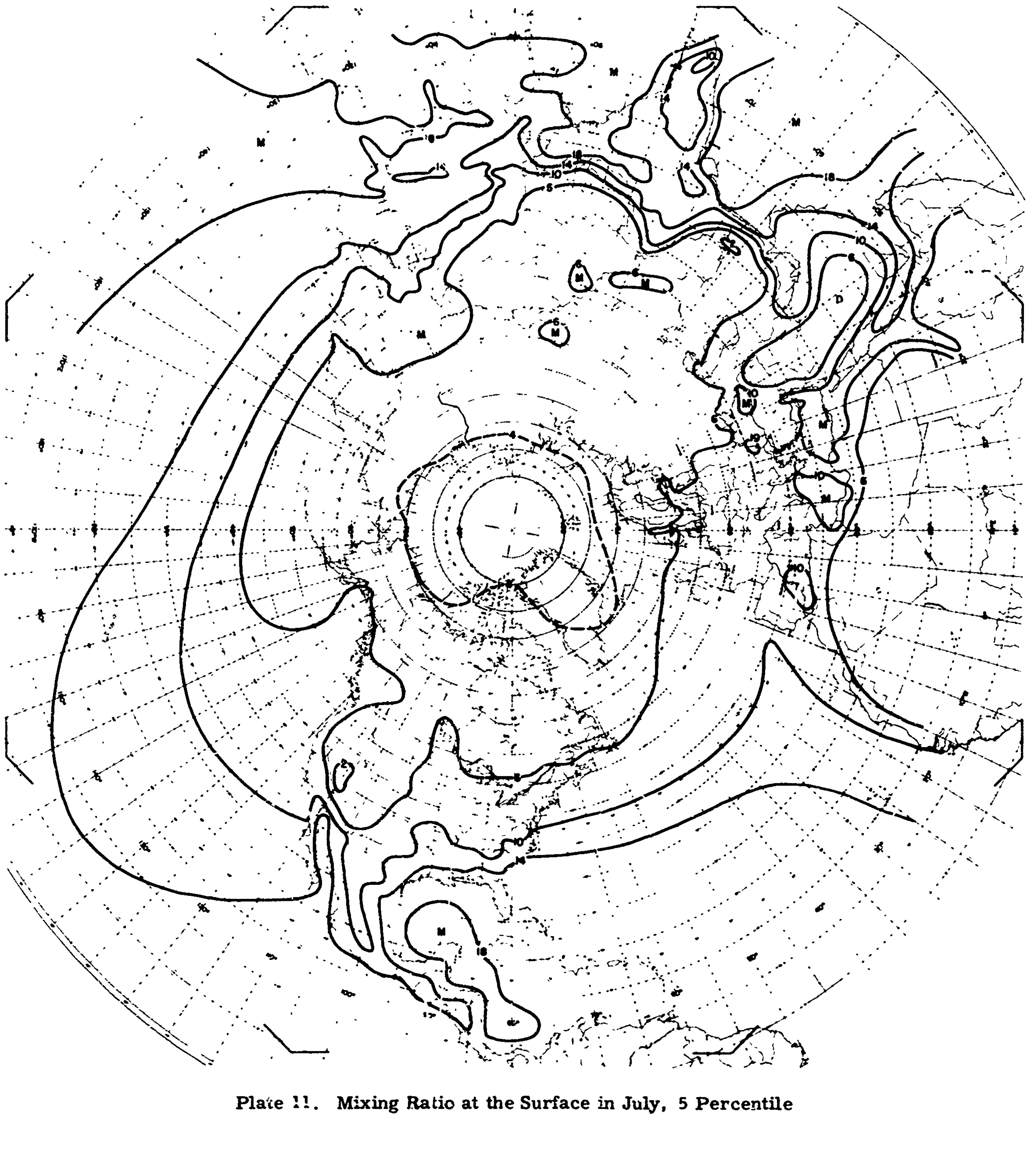

Plate 11. Mixing Ratio at the Surface in July, 5 Percentile

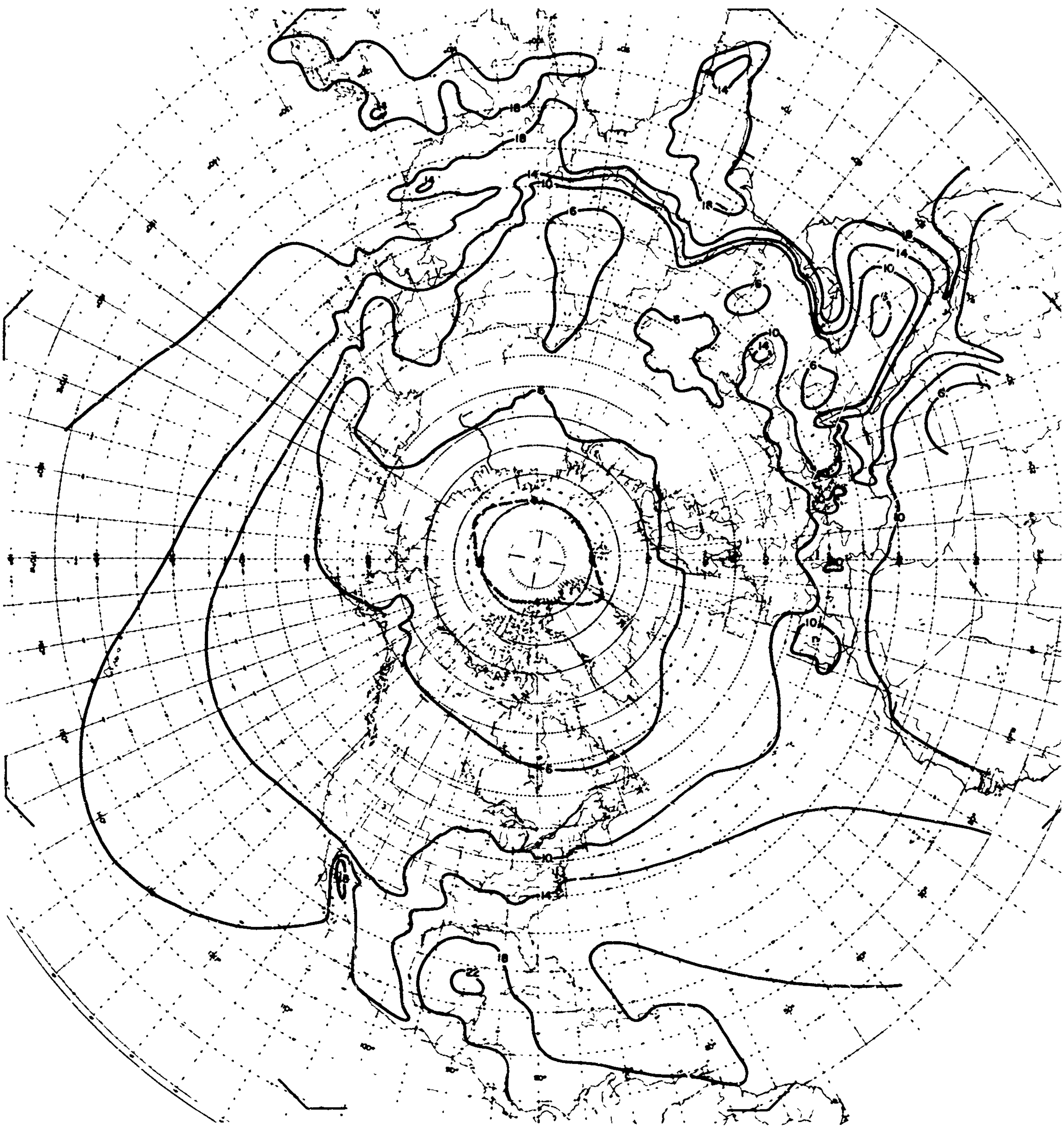

Plate 12. Mixing Ratio at the Surface in July, 25 Percentile

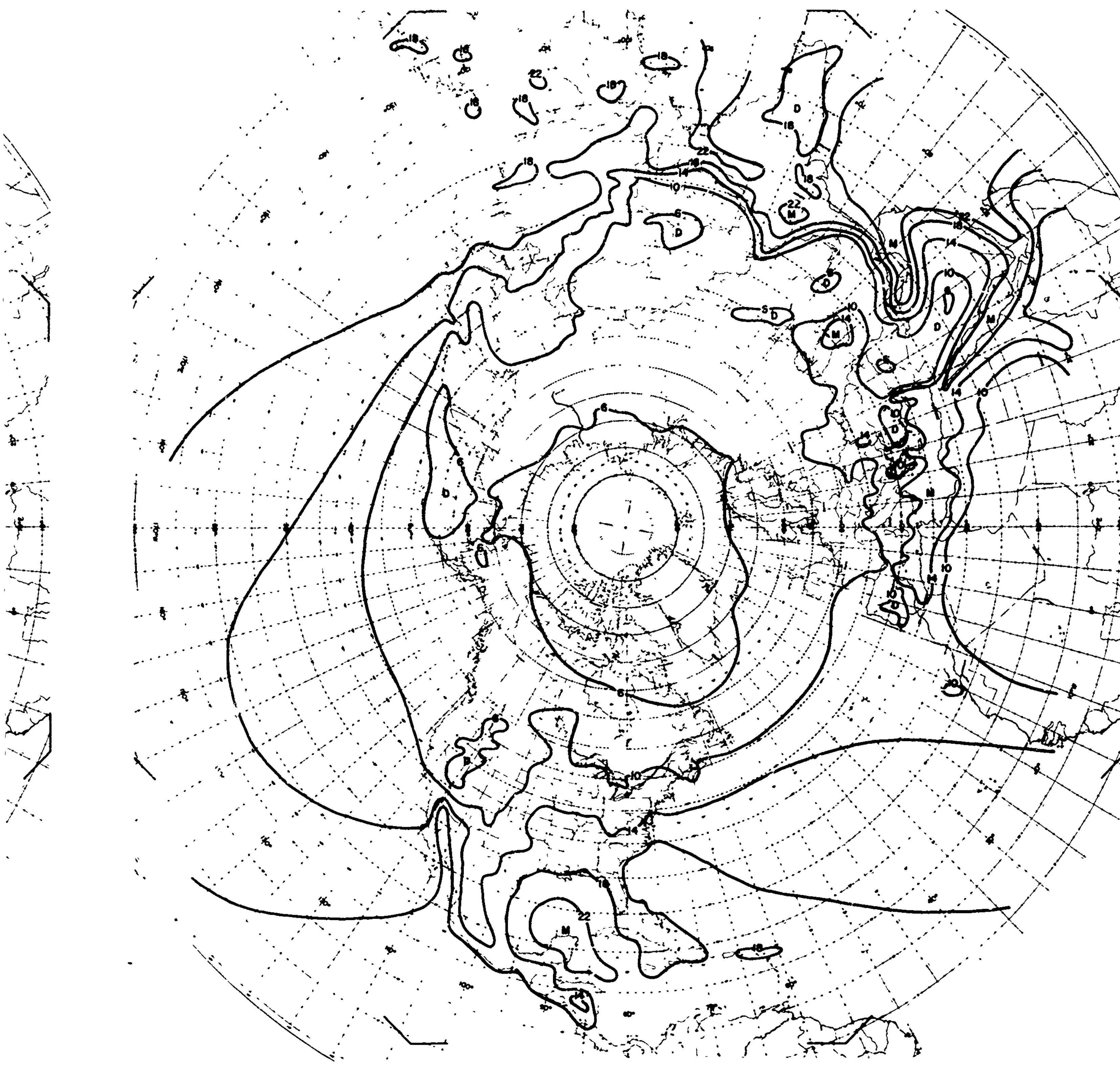

Plate 13. Mixing Ratio at the Surface in July, 50 Percentile

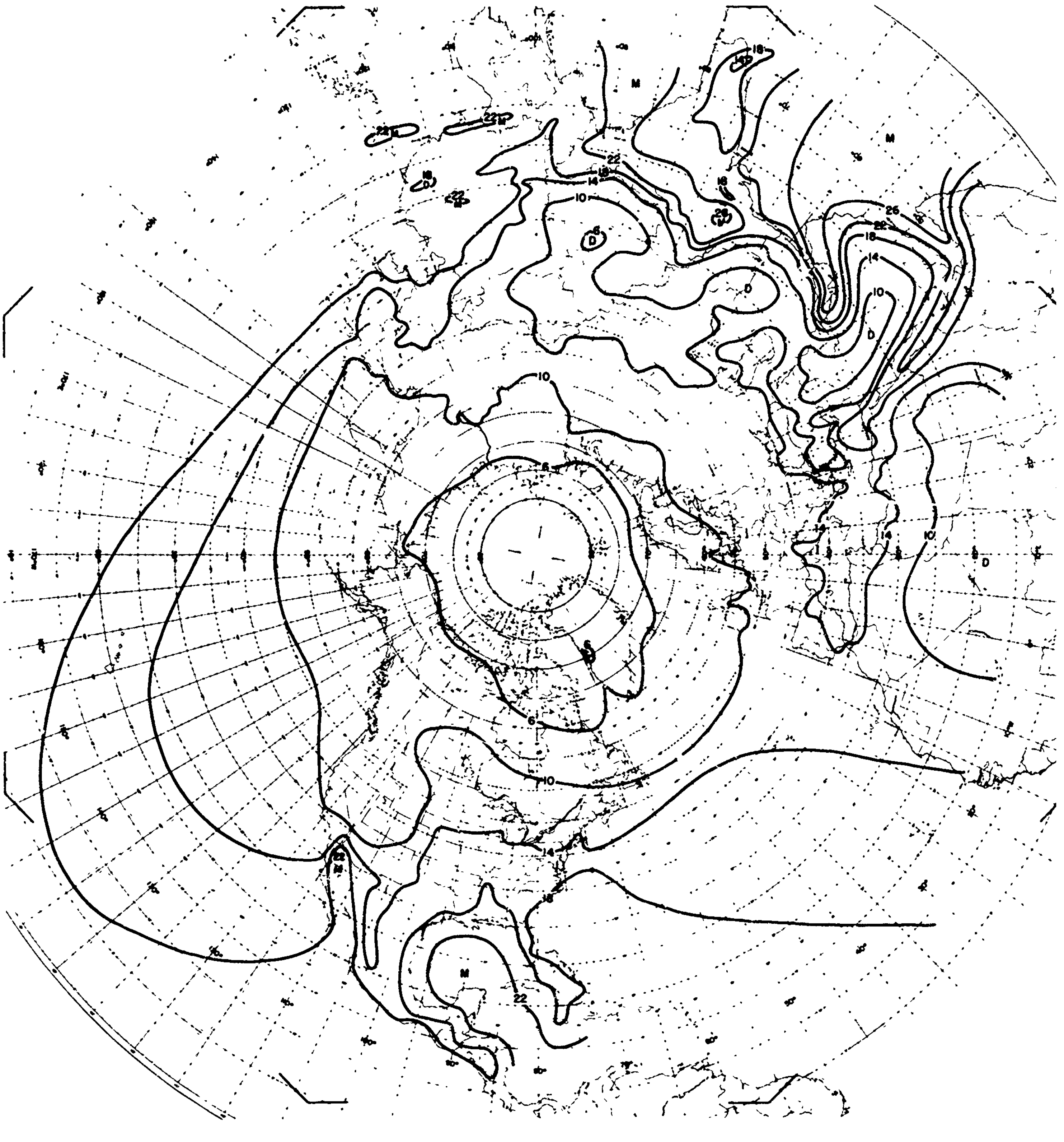

Plate 14. Mixing Ratio at the Surface in July, 75 Percentile

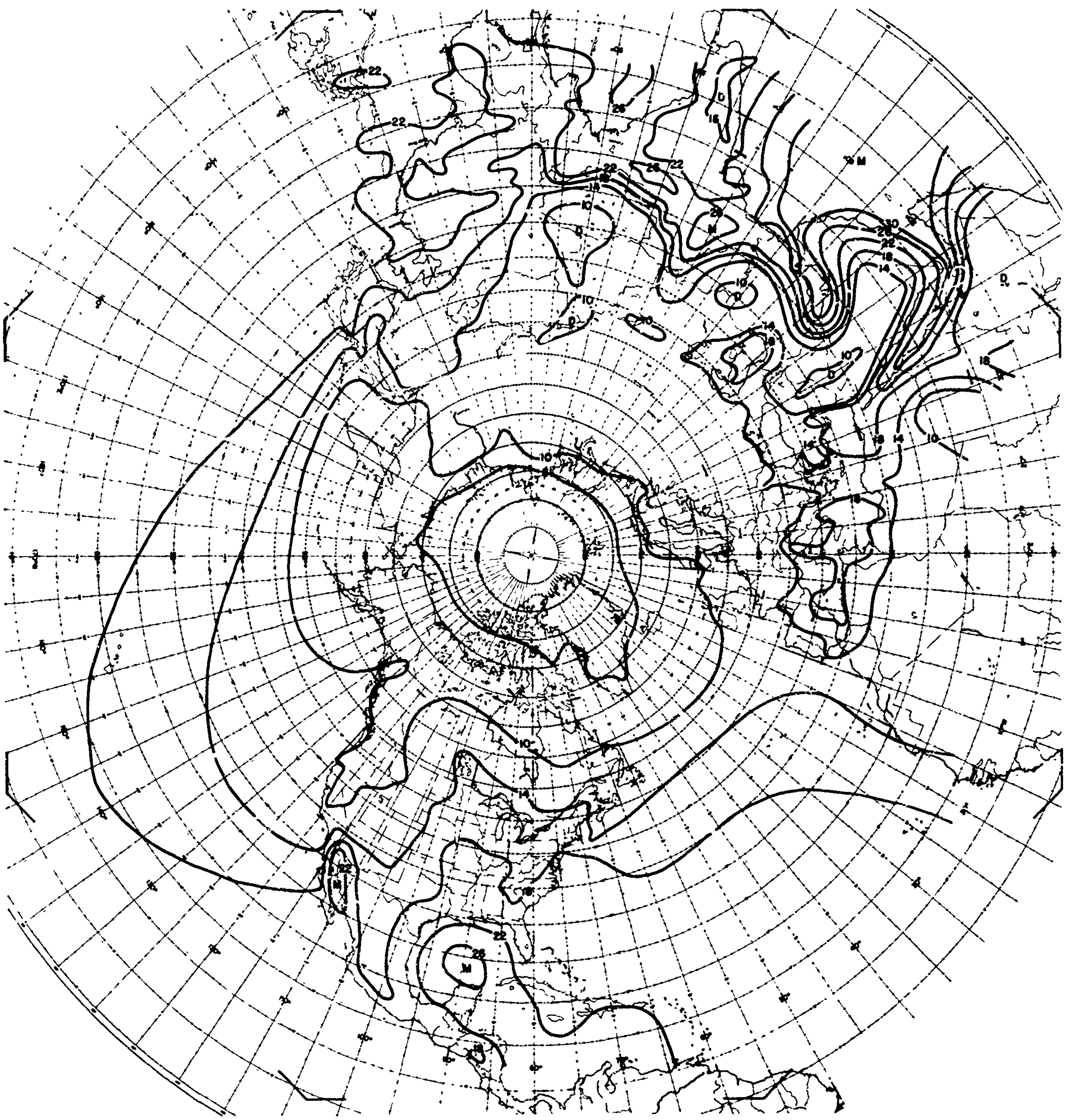

Plate 15. Mixing Ratio at the Surface in July, 95 Percentile

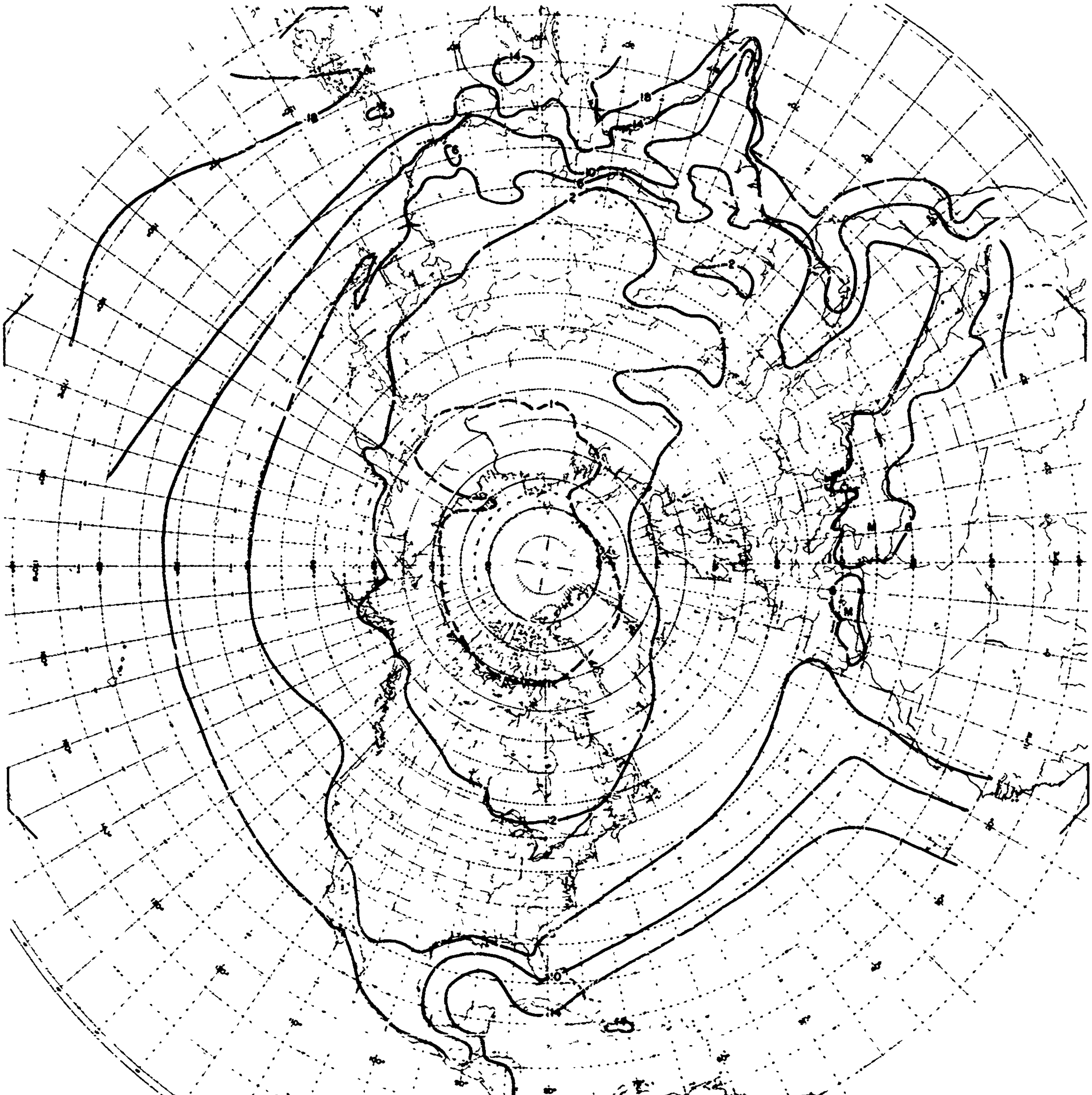

Plate 16. Mixing Ratio at the Surface in October, 5 Percentile

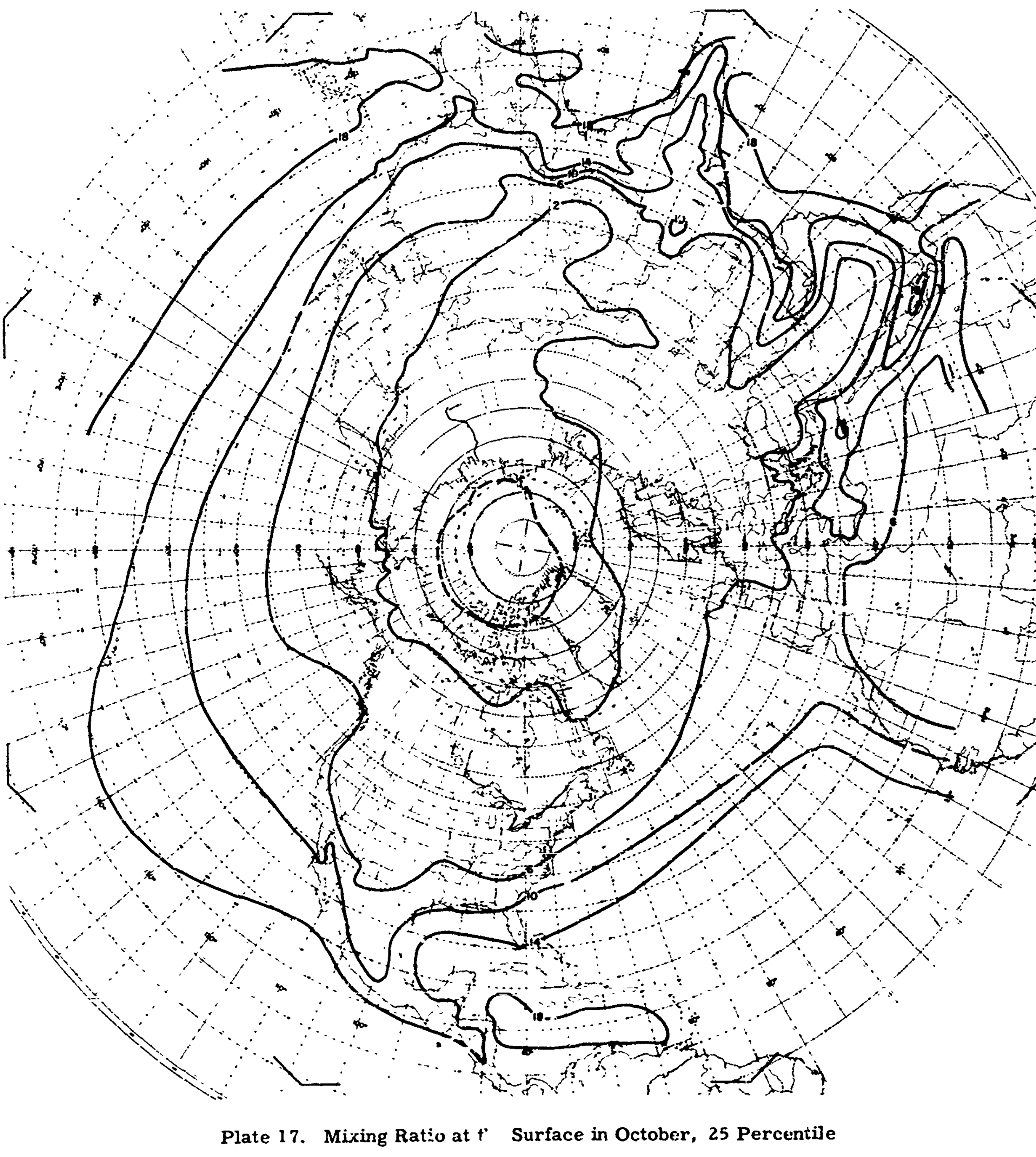

Plate 17. Mixing Ratio at t' Surface in October, 25 Percentile

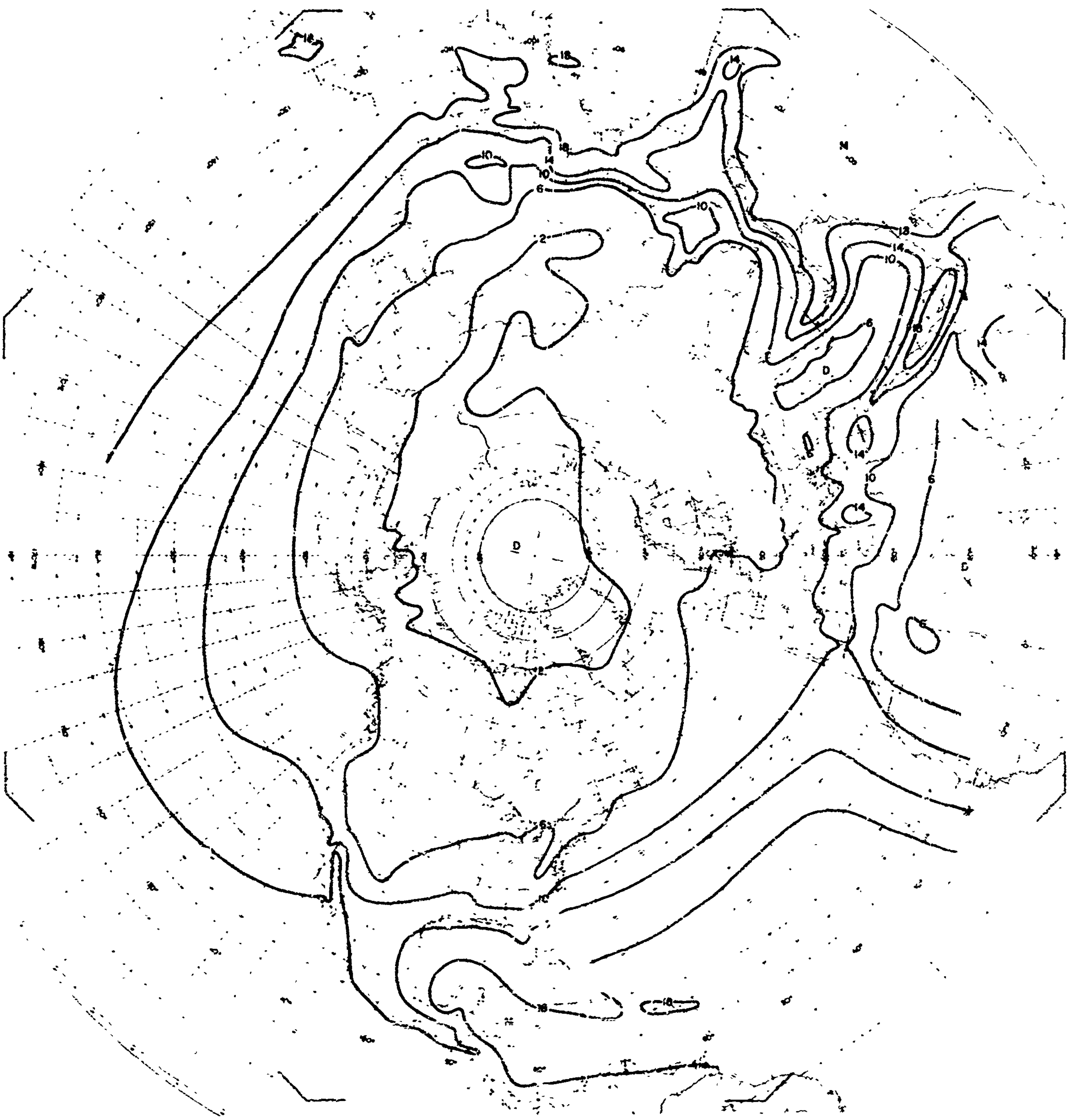

Plate 18. Mixing Ratio at the Surface in October. 50 Percentile

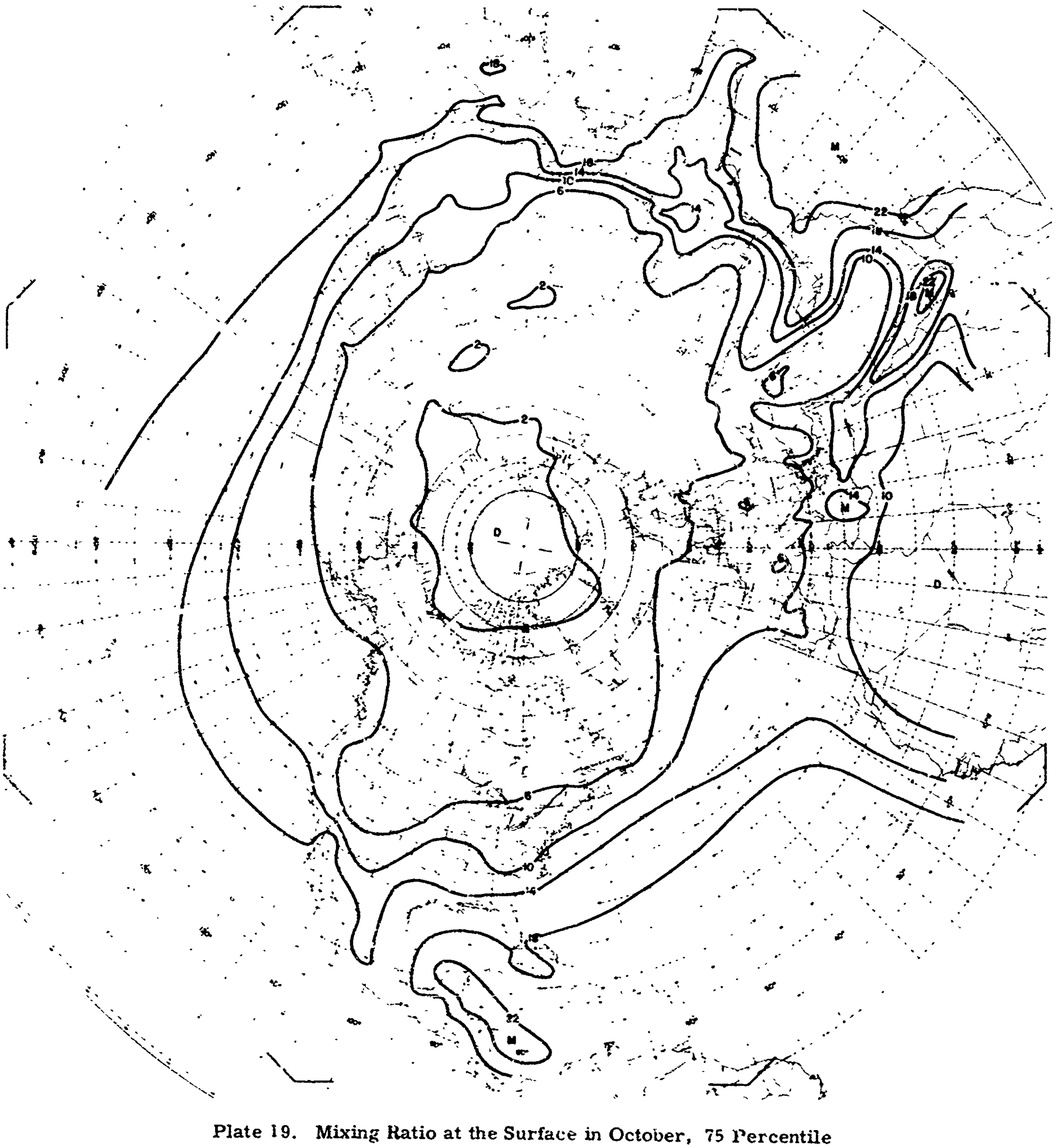

Plate 19. Mixing Ratio at the Surface in October, 75 Percentile

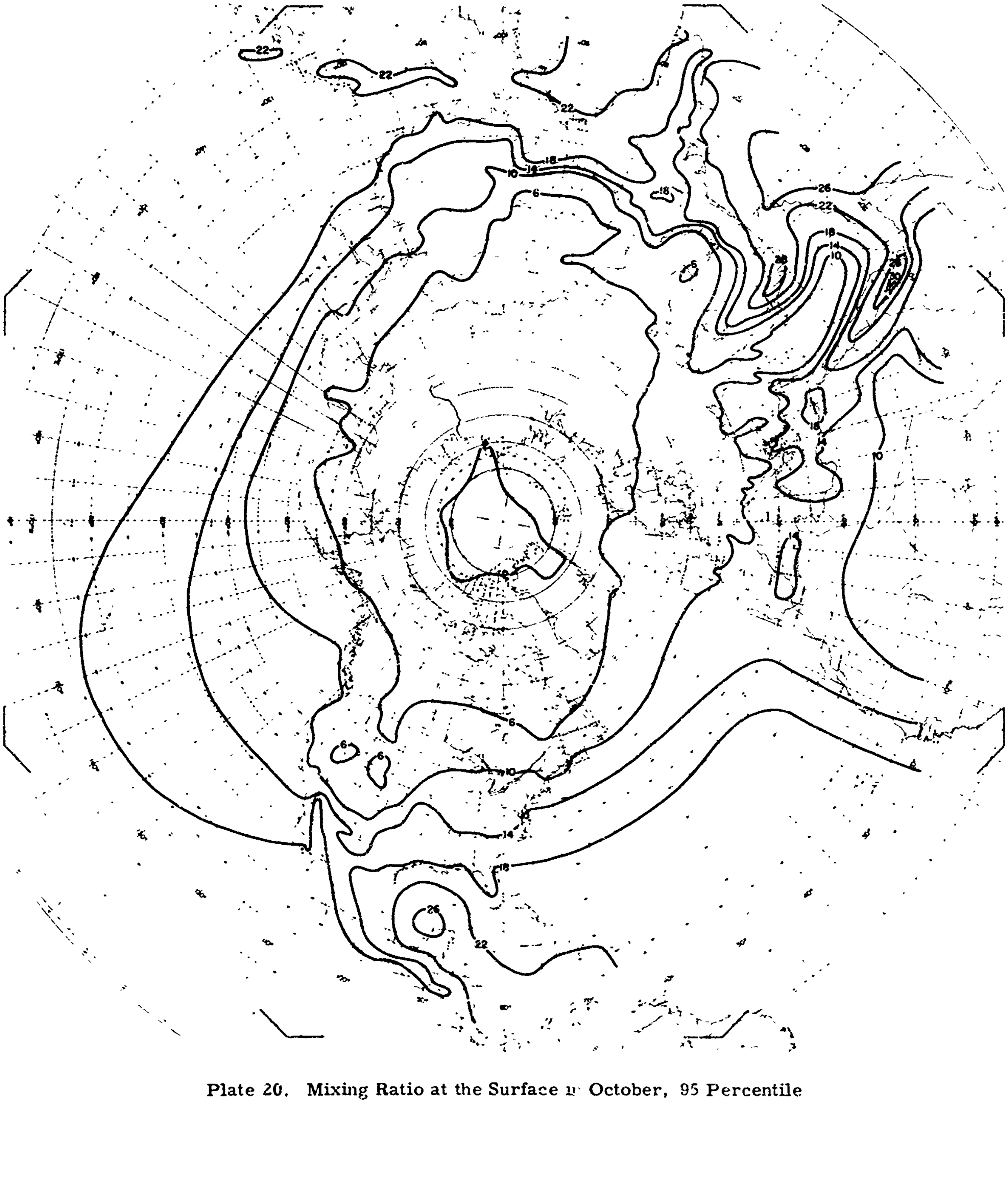

Plate 20. Mixing Ratio at the Surface in October, 95 Percentile

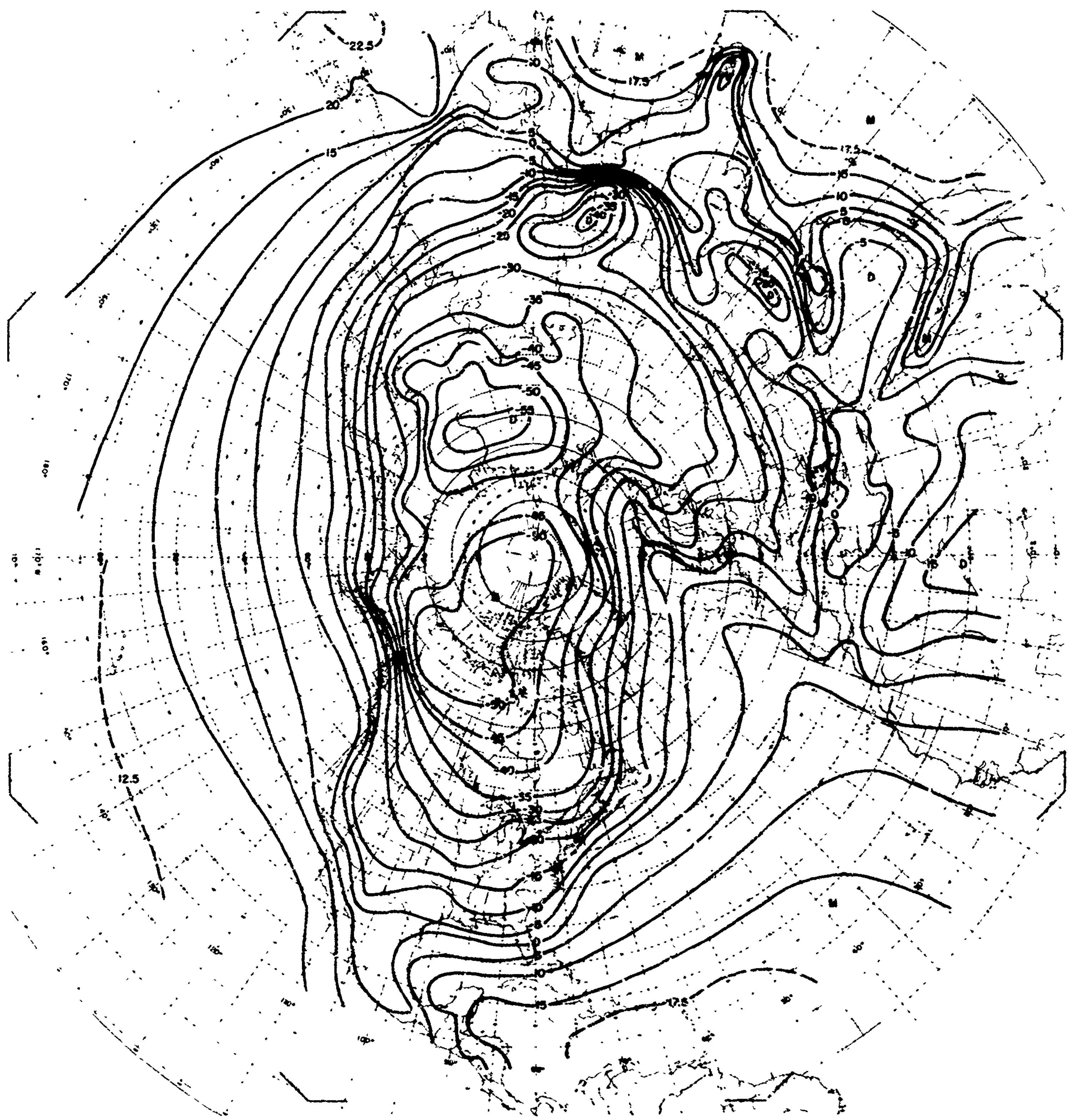

Plate 21. Dew Point at the Surface in January, 5 Percentile

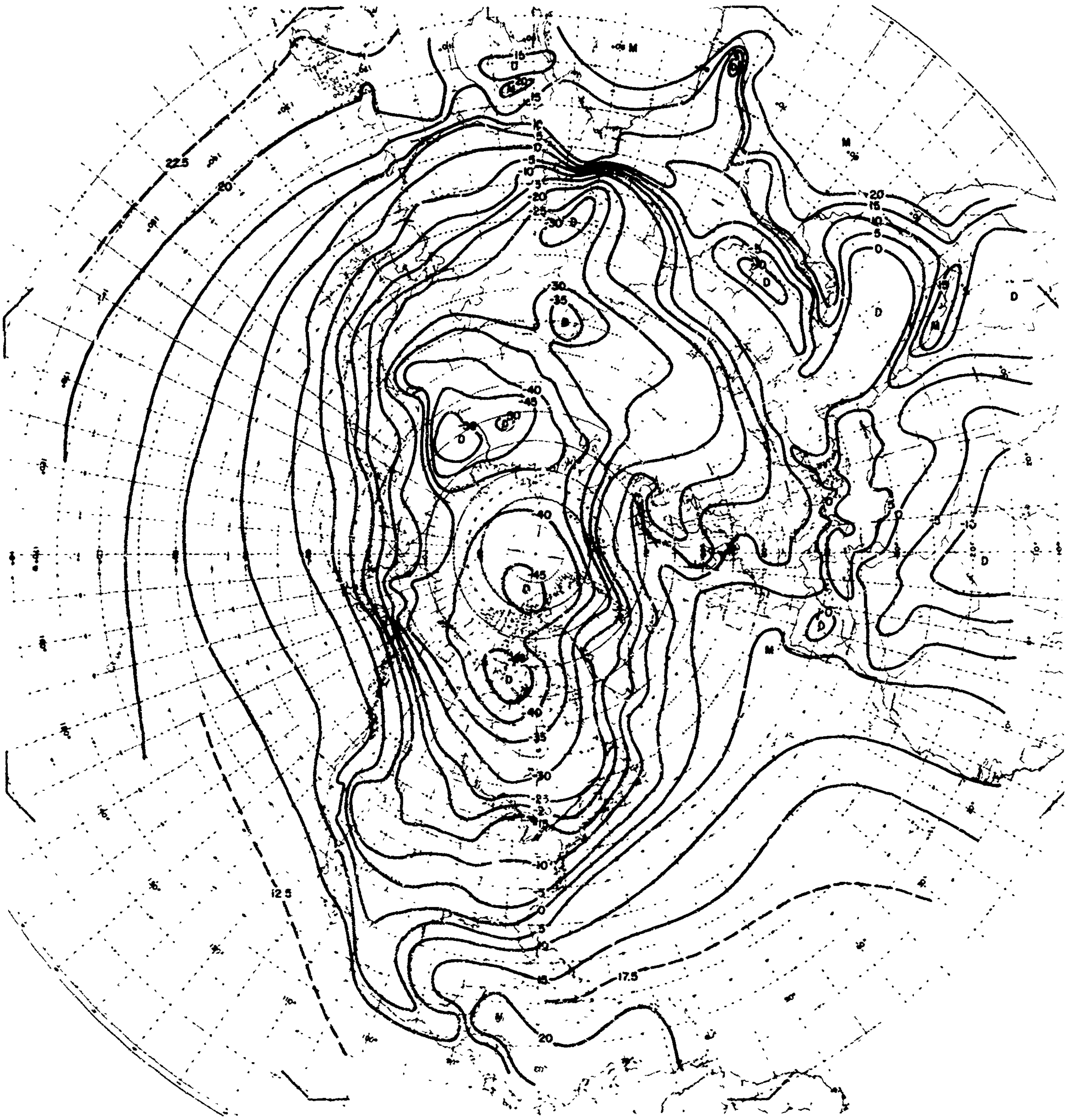

Plate 22. Dew Point at the Surface in January, 25 Percentile

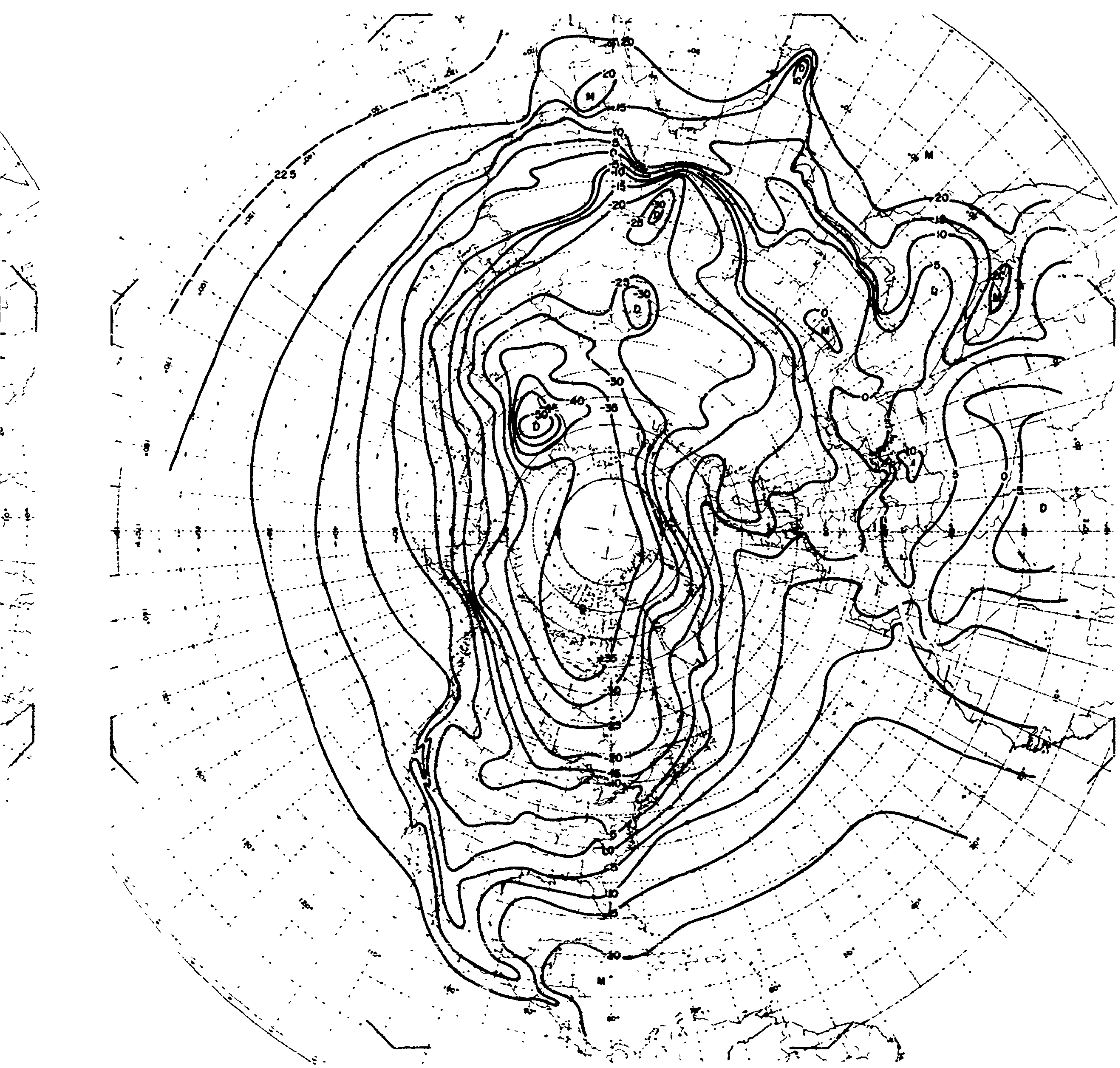

Plate 23. Dew Point at the Surface in January, 50 Percentile

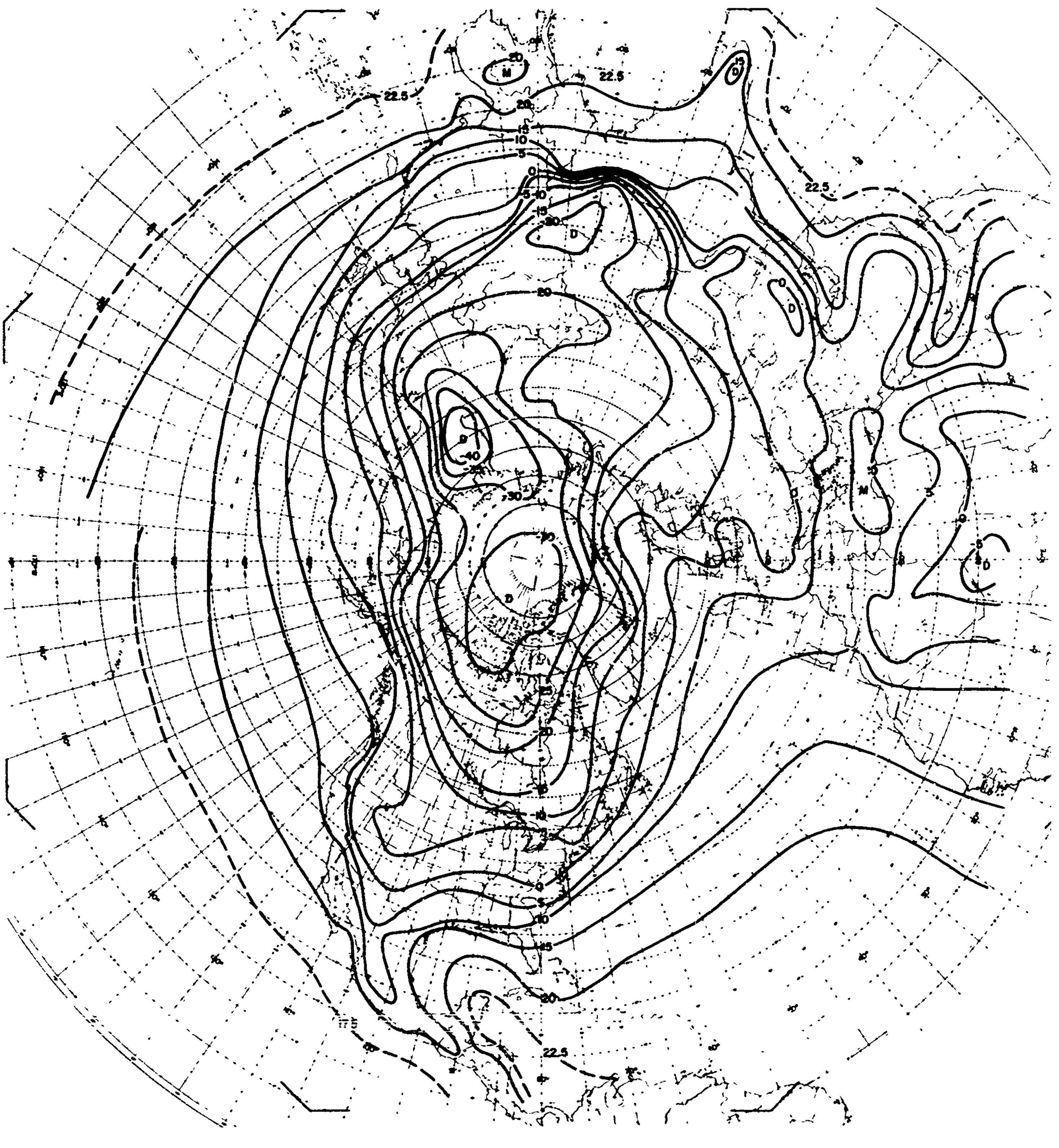

Plate 24. Dew Point at the Surface in January, 75 Percentile

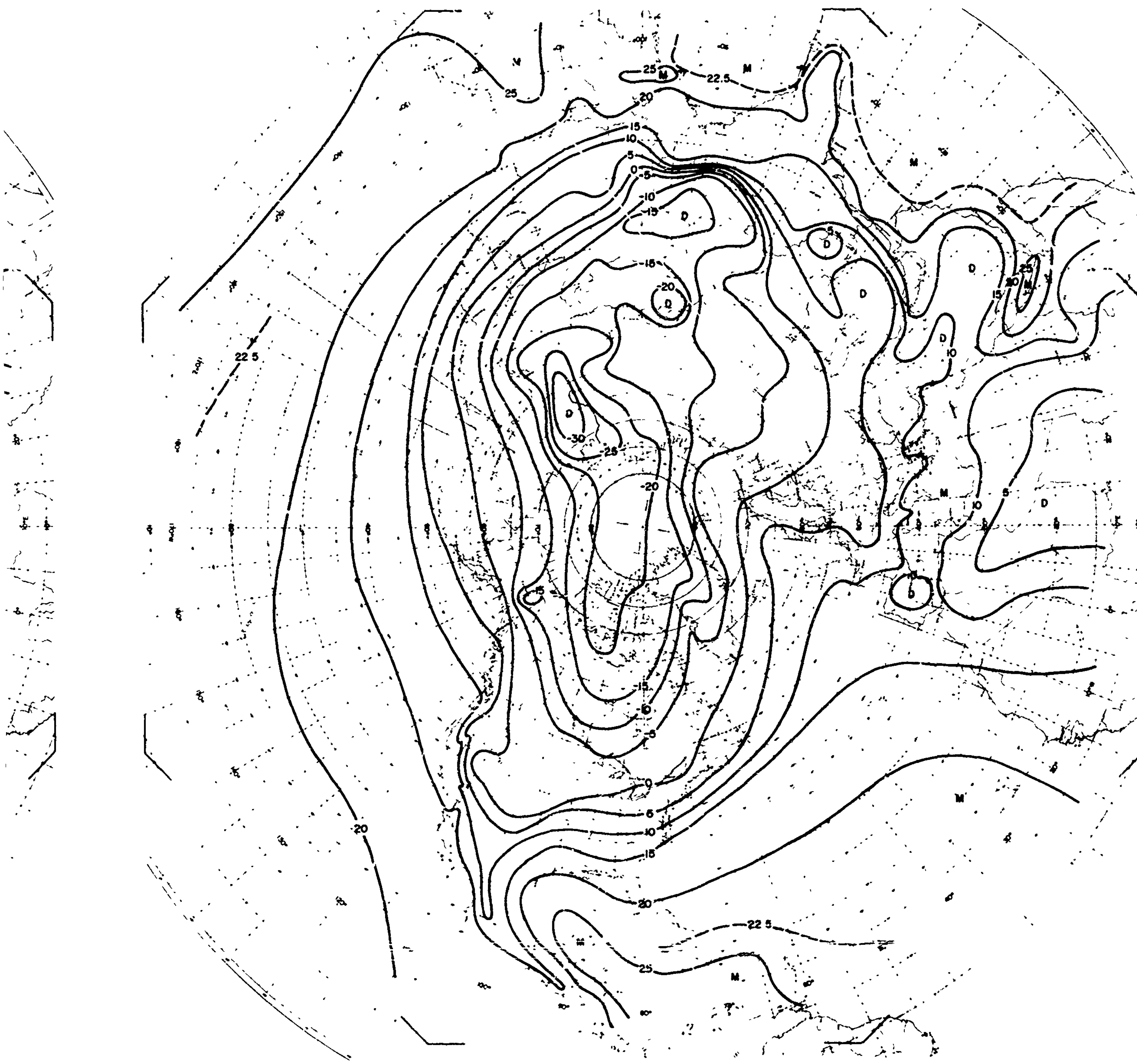

Plate 25. Dew Point at the Surface in January, 95 Percentile

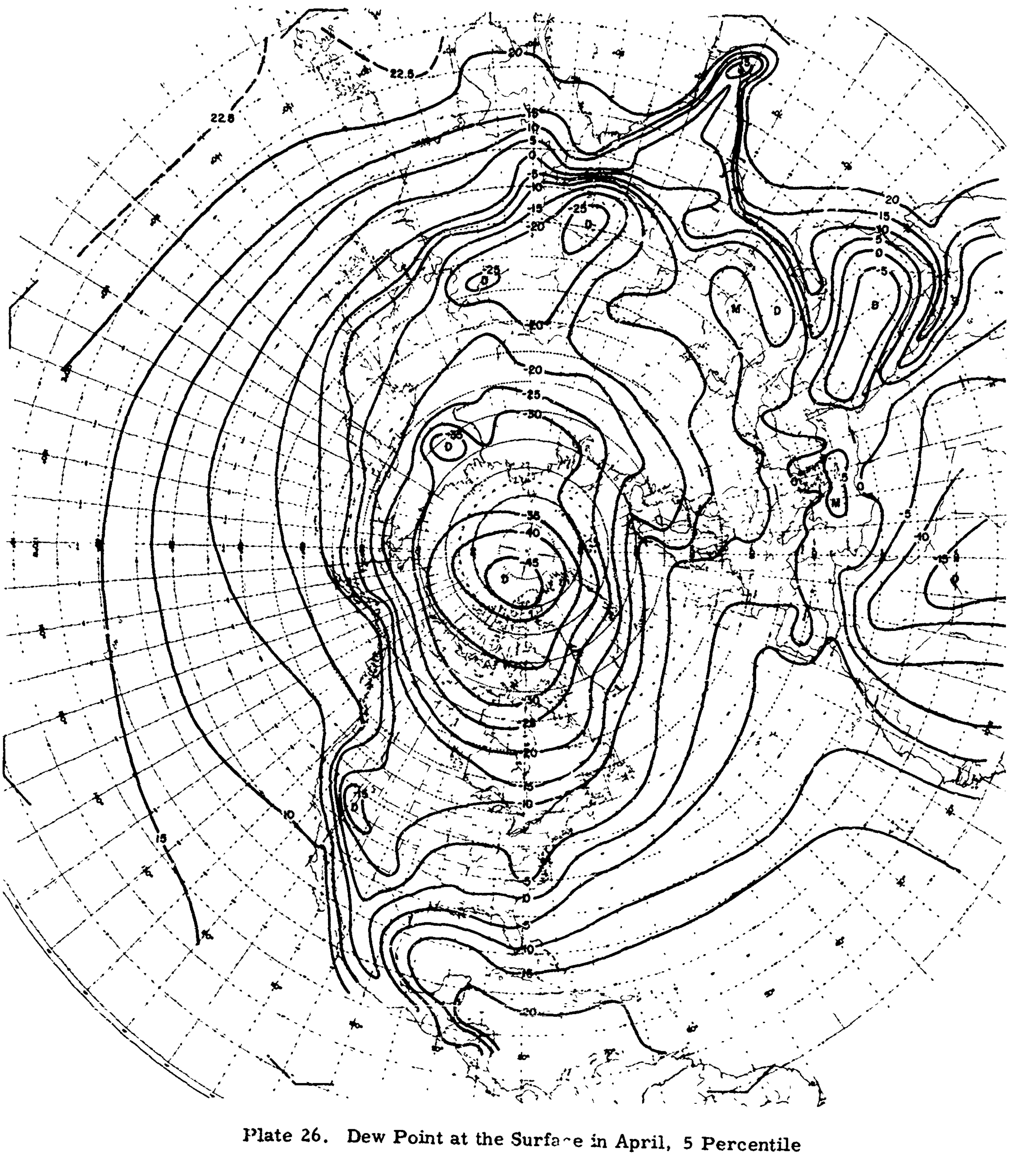

Plate 26. Dew Point at the Surface in April, 5 Percentile

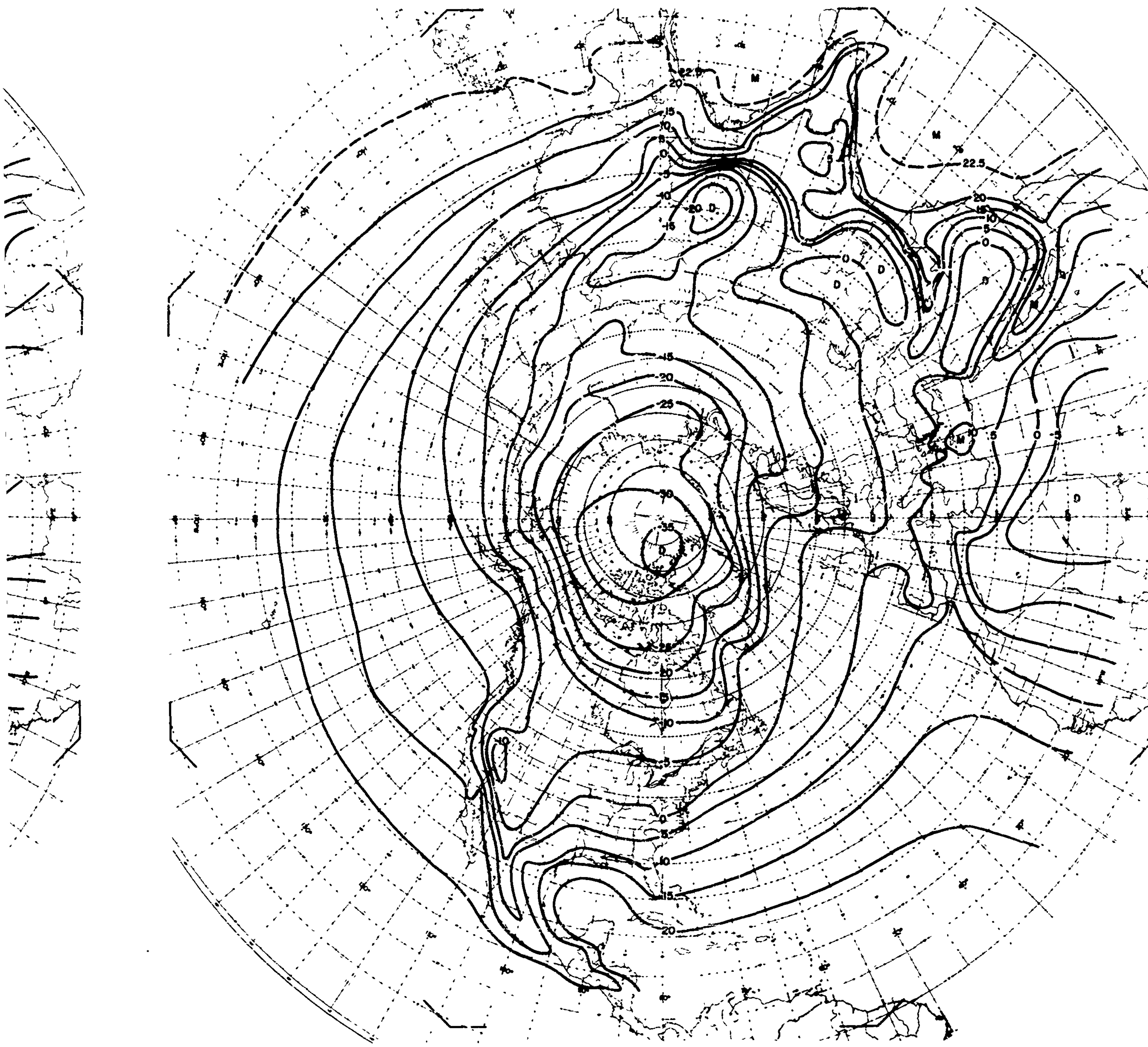

Plate 27. Dew Point at the Surface in April, 25 Percentile

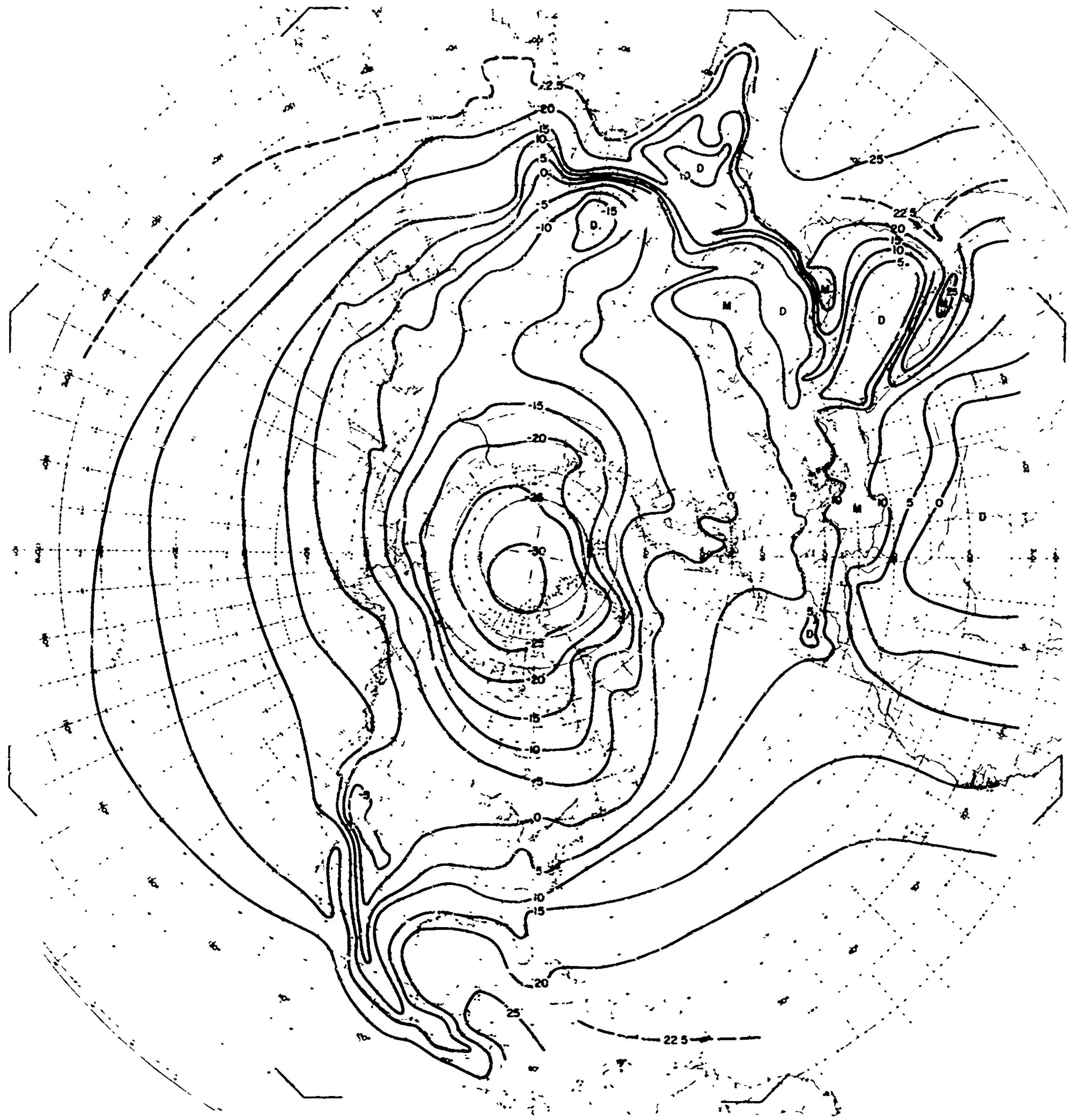

Plate 28. Dew Point at the Surface in April 50 Percentile

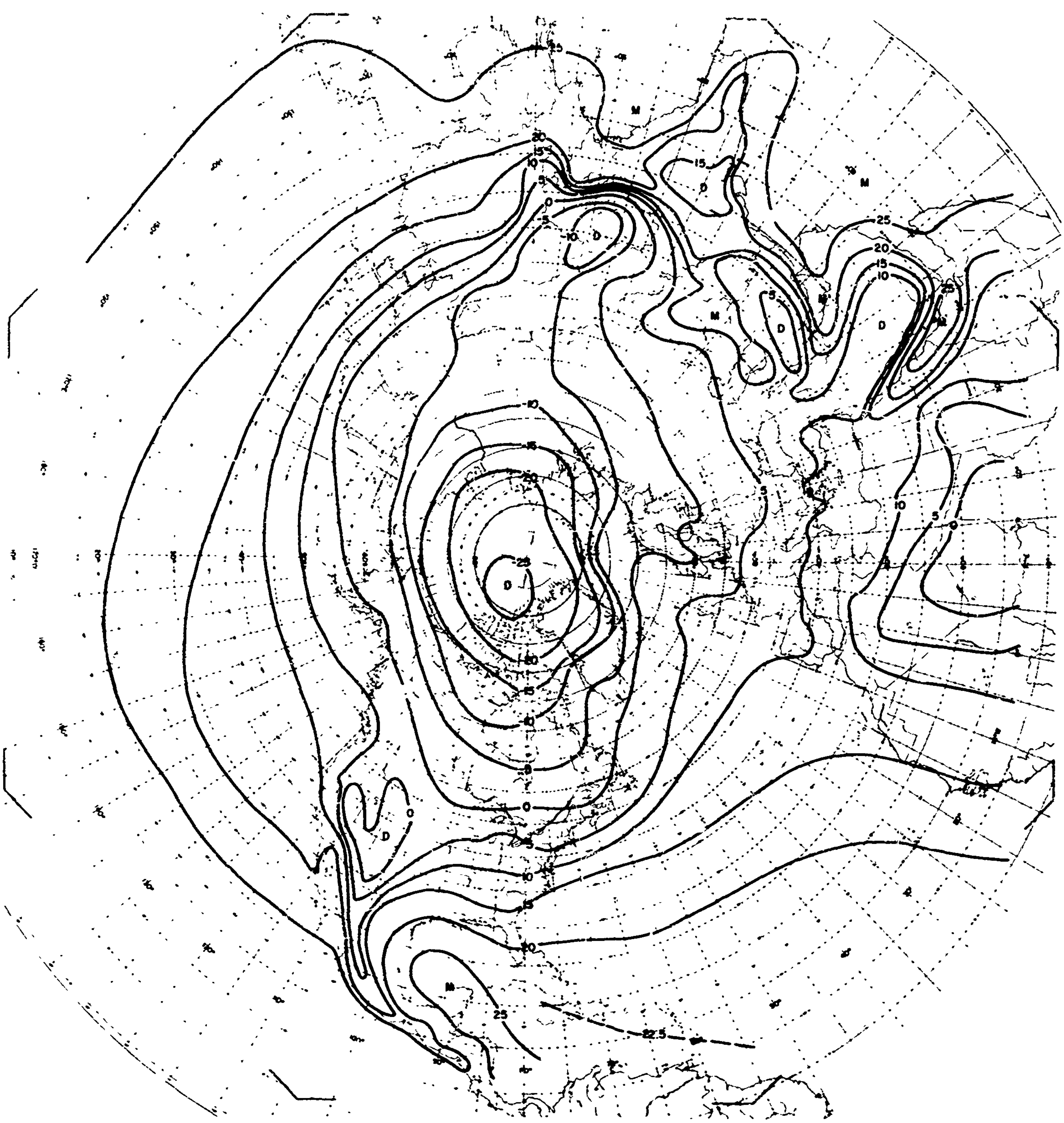

Plate 29. Dew Point at the Surface in April, 75 Percentile

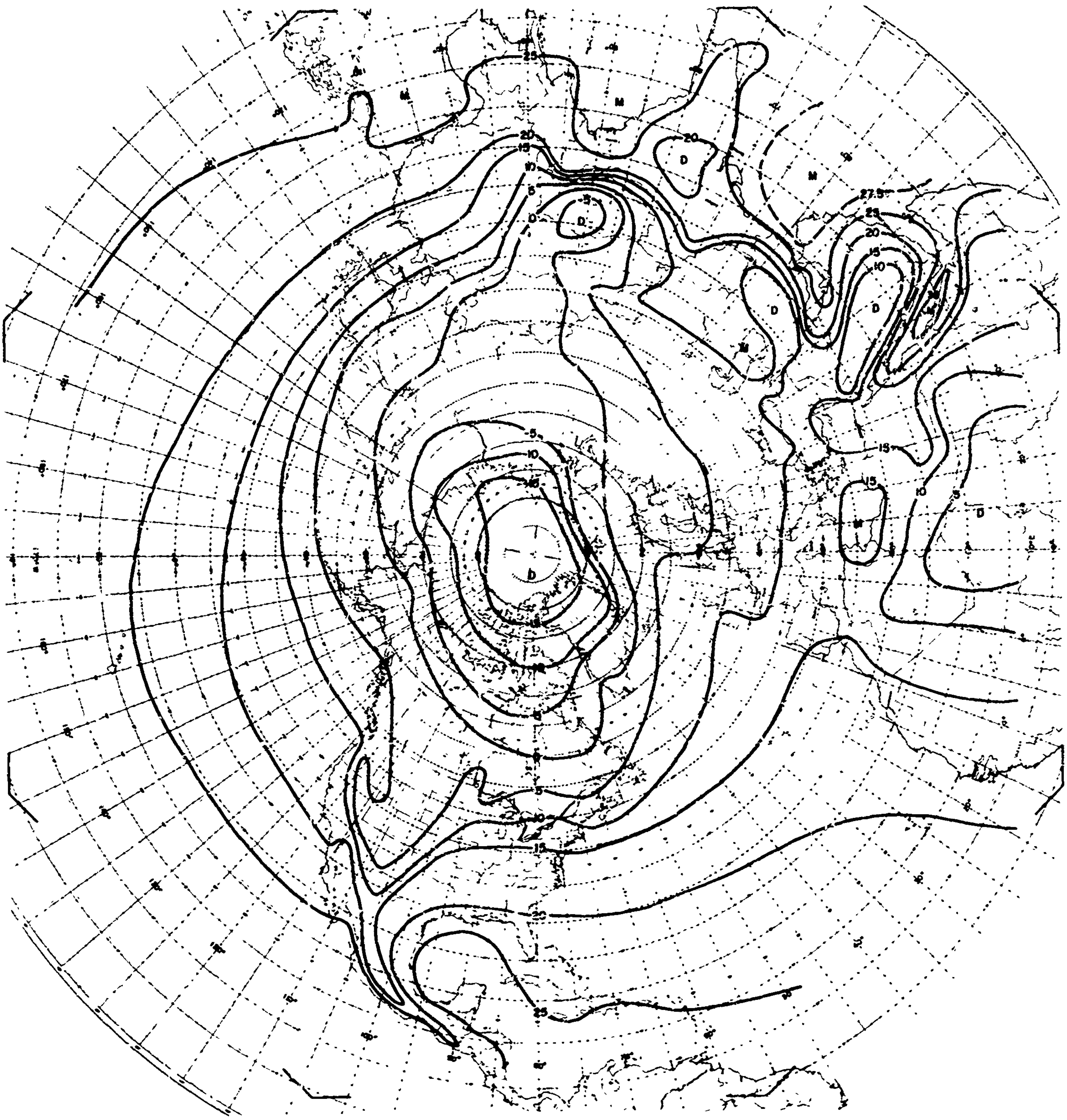

Plate 30. Dew Point at the Surface in April, 95 Percentile

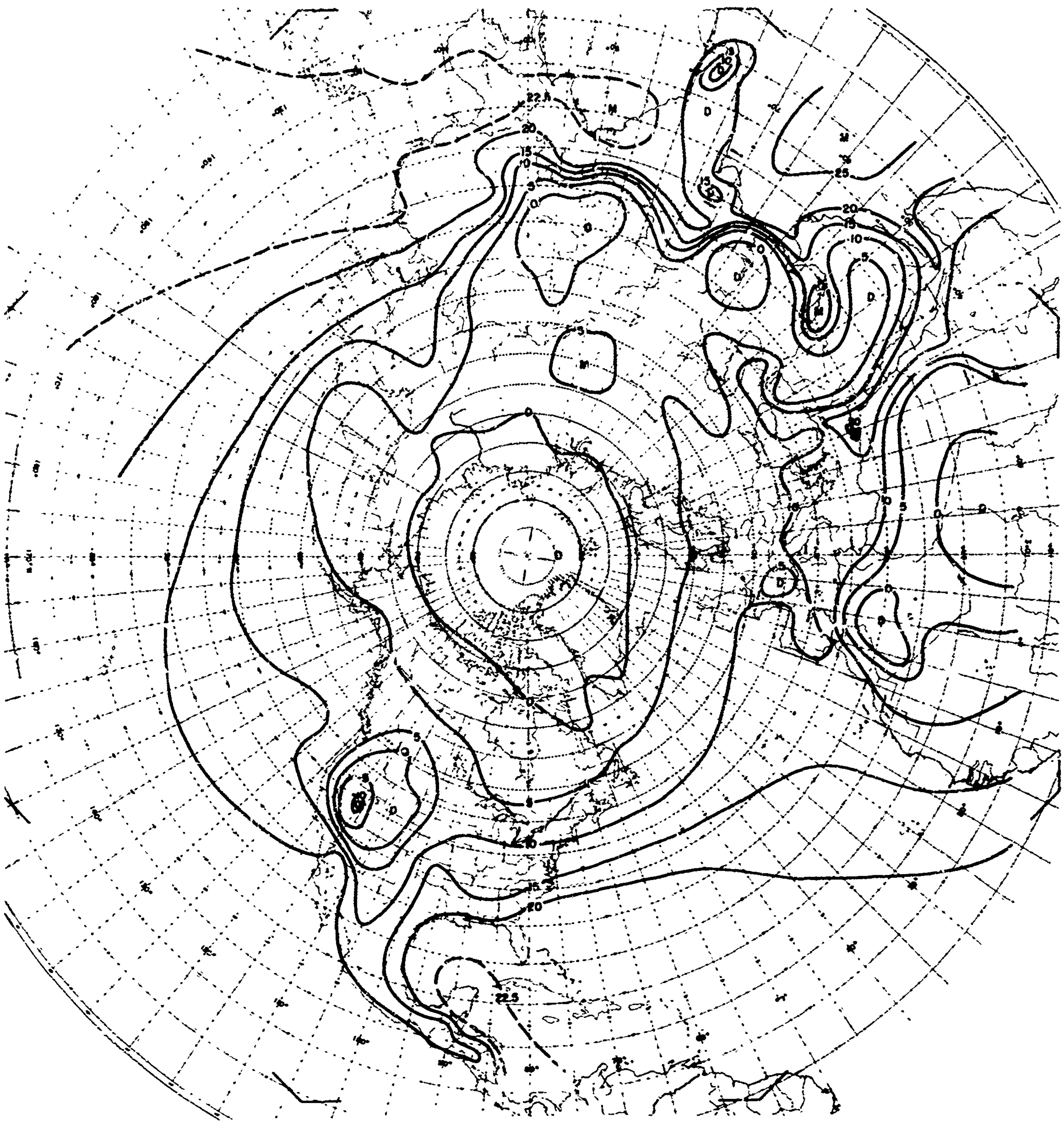

Plate 31. Dew Point at the Surface in July, 5 Percentile

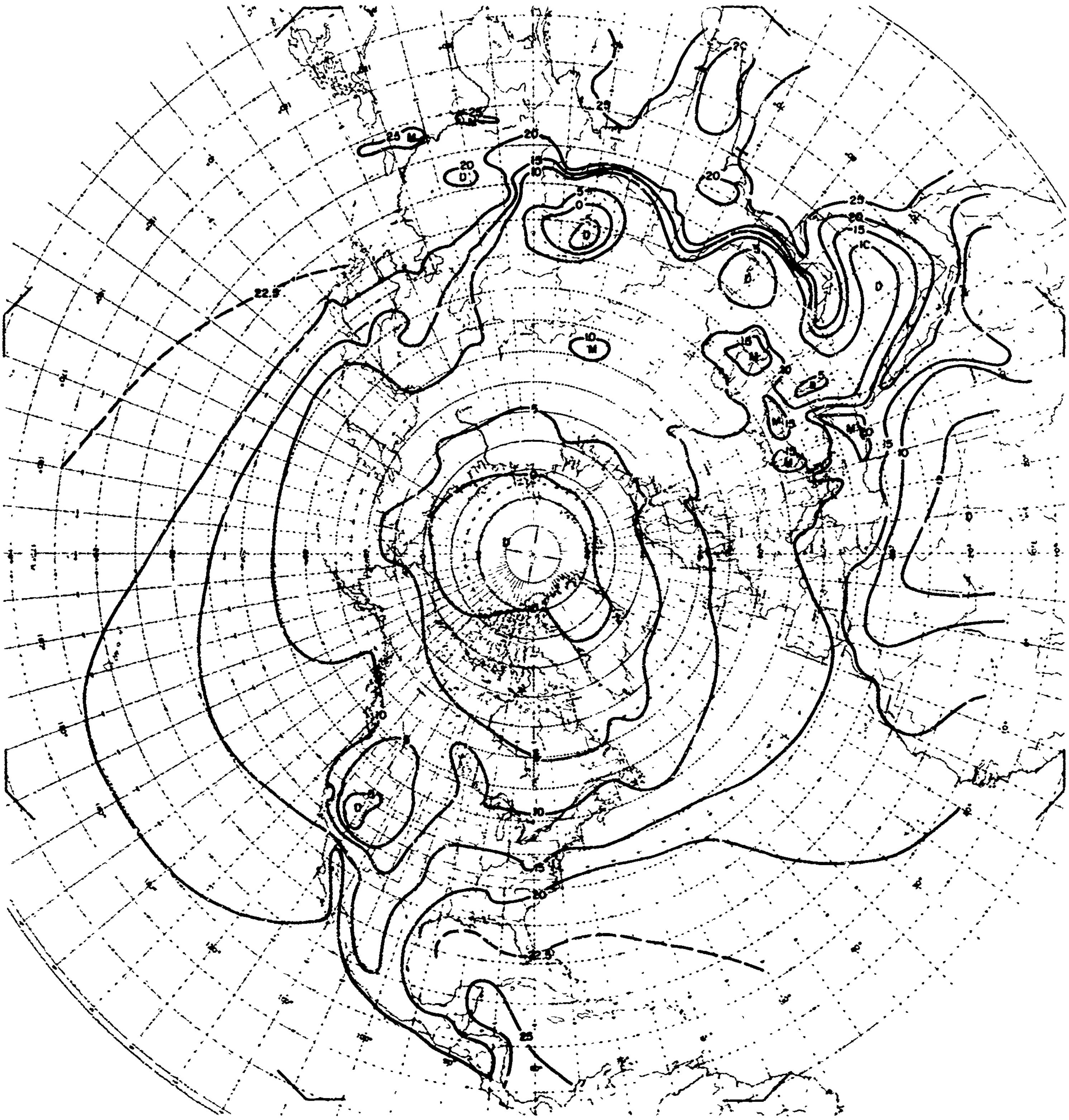

Plate 32. Dew Point at the Surface in July, 25 Percentile

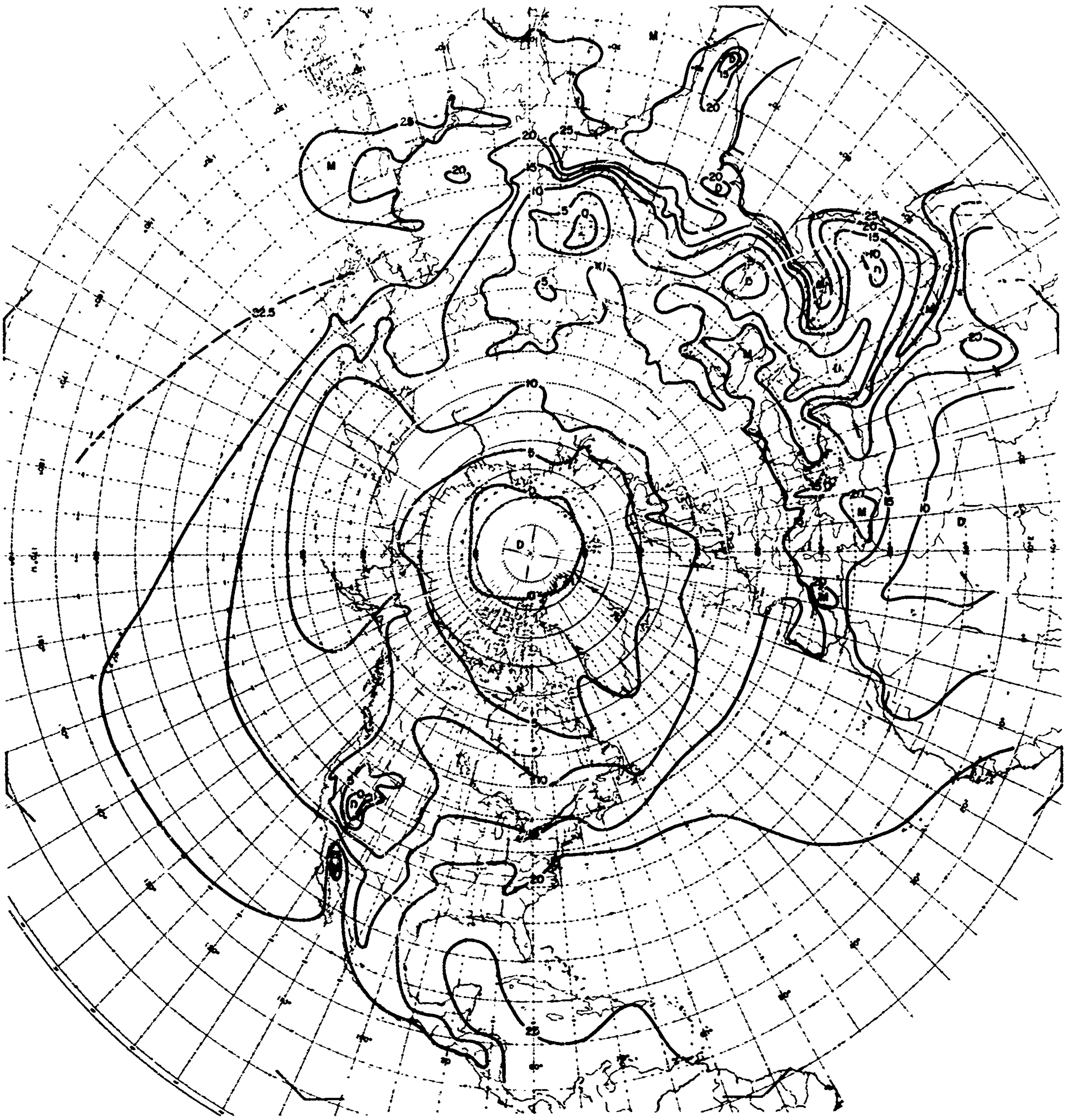

Plate 33. Dew Point at the Surface in July, 50 Percentile

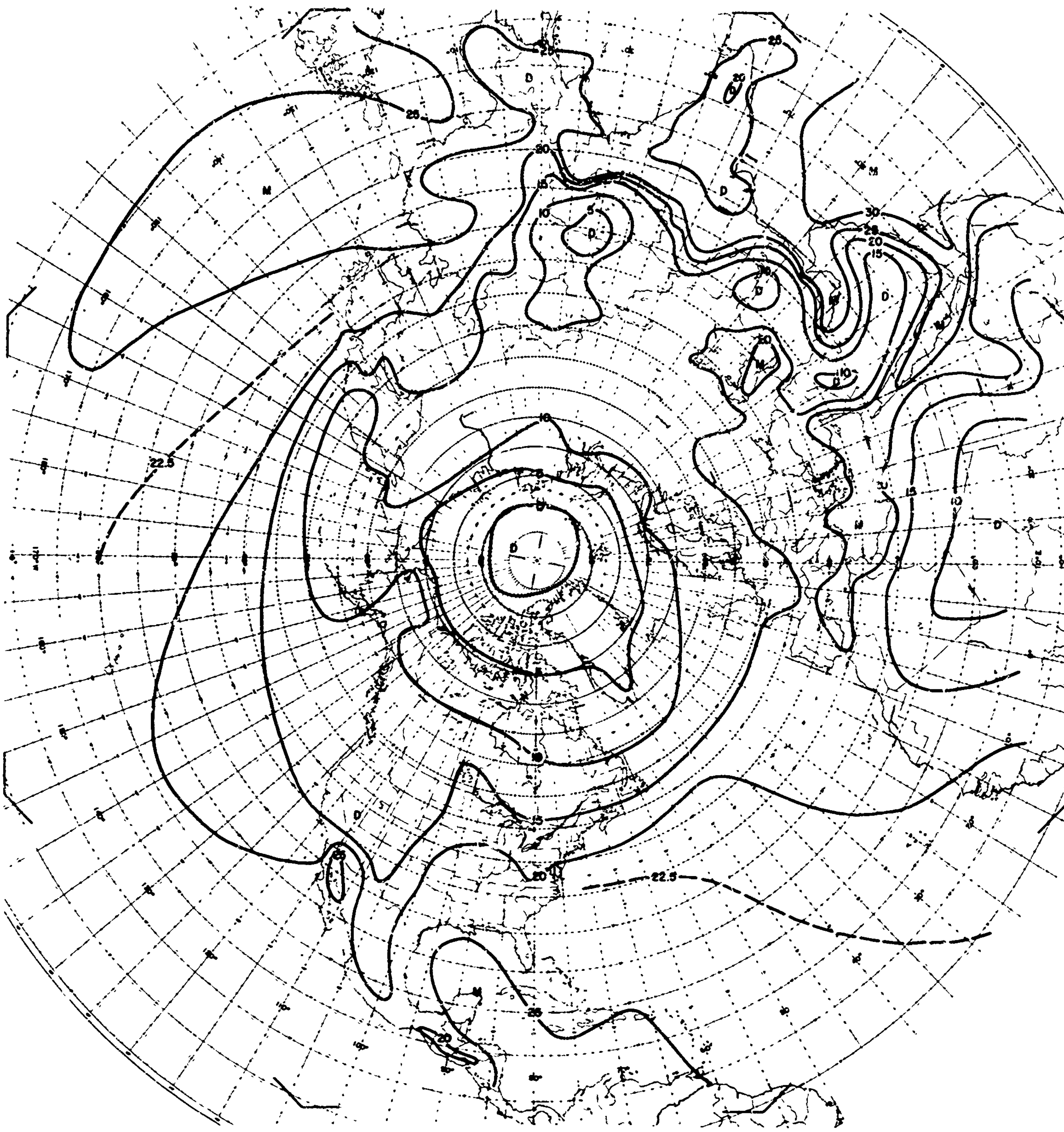

Plate 34. Dew Point at the Surface in July, 75 Percentile

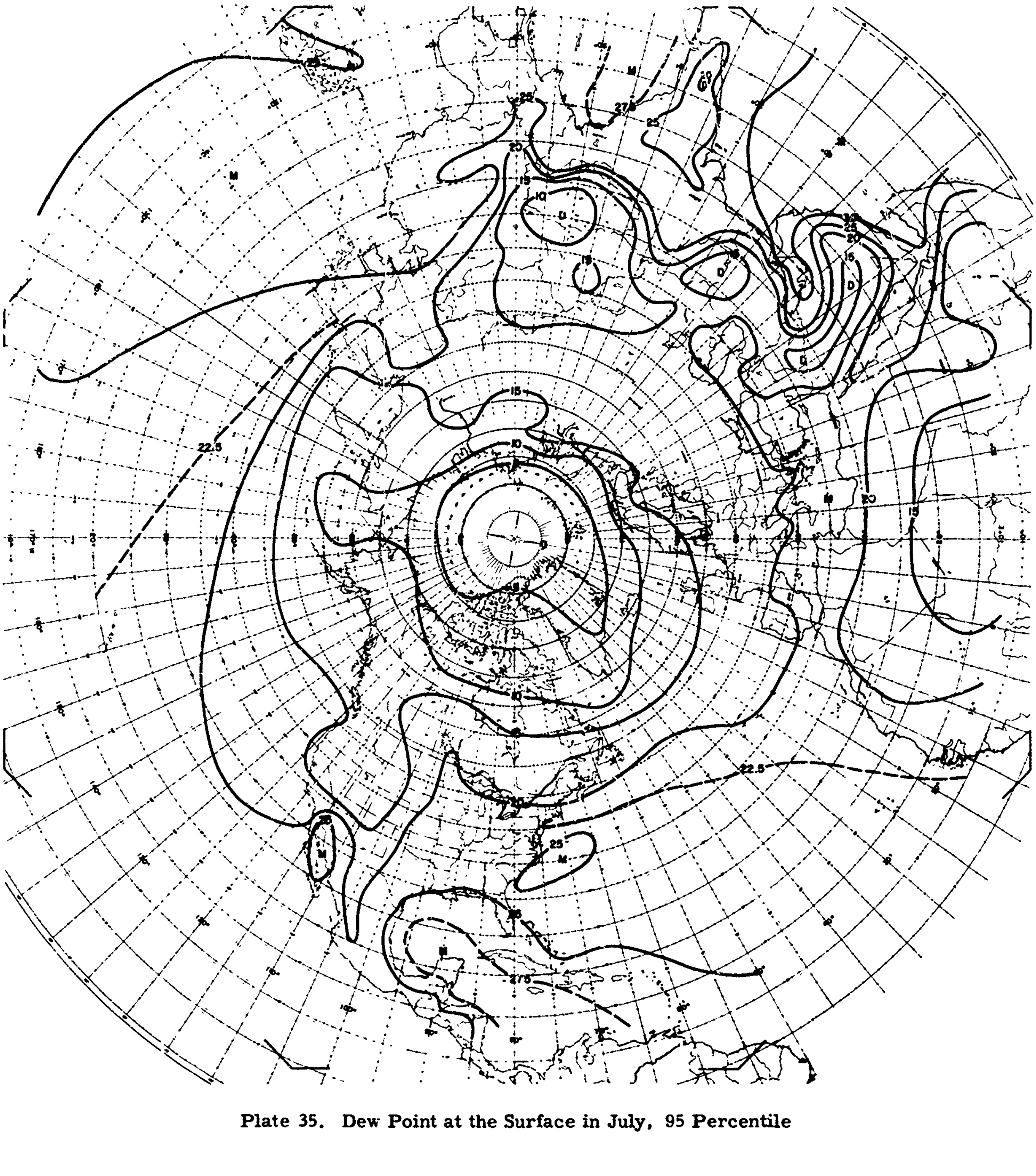

Plate 35. Dew Point at the Surface in July, 95 Percentile

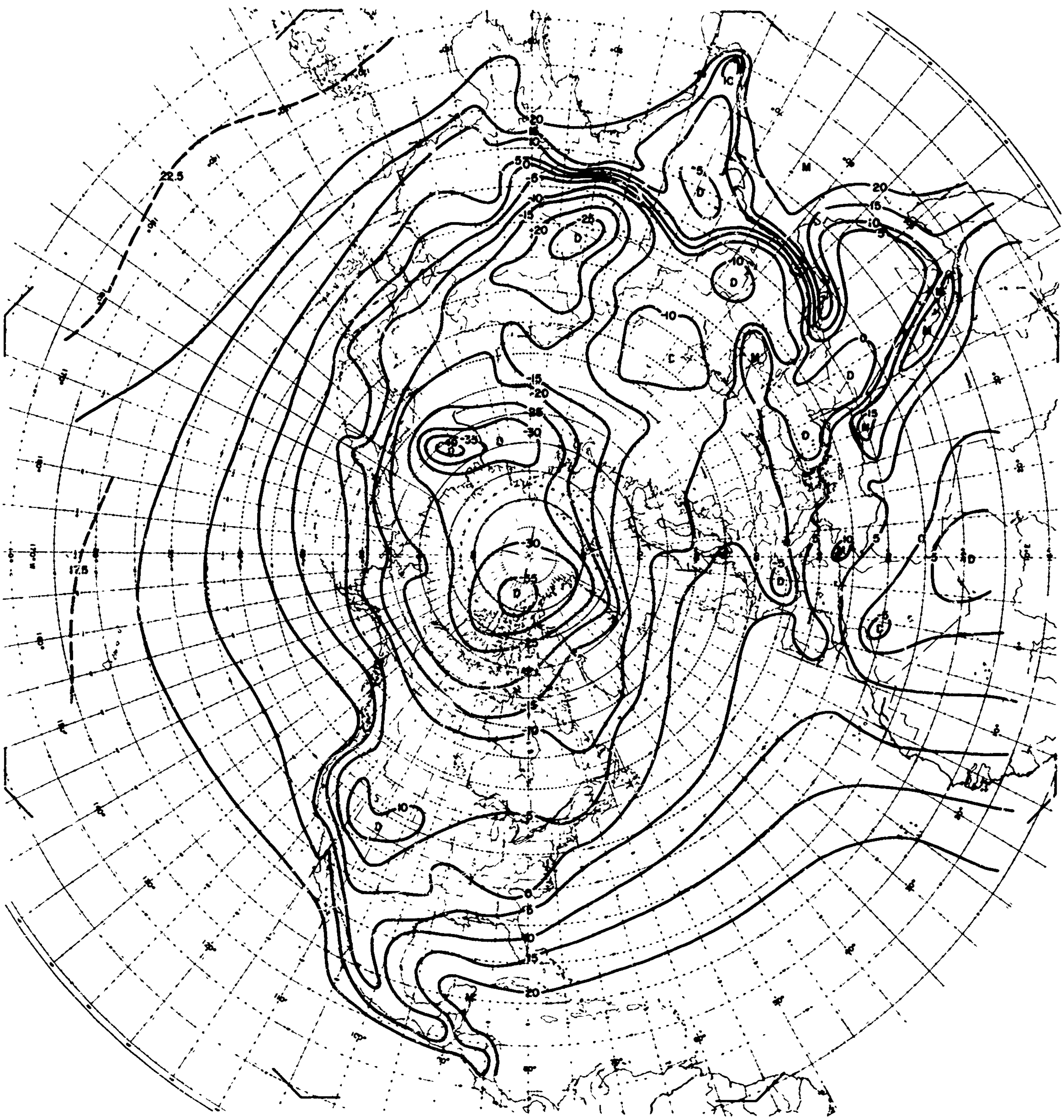

Plate 36. Dew Point at the Surface in October, 5 Percentile

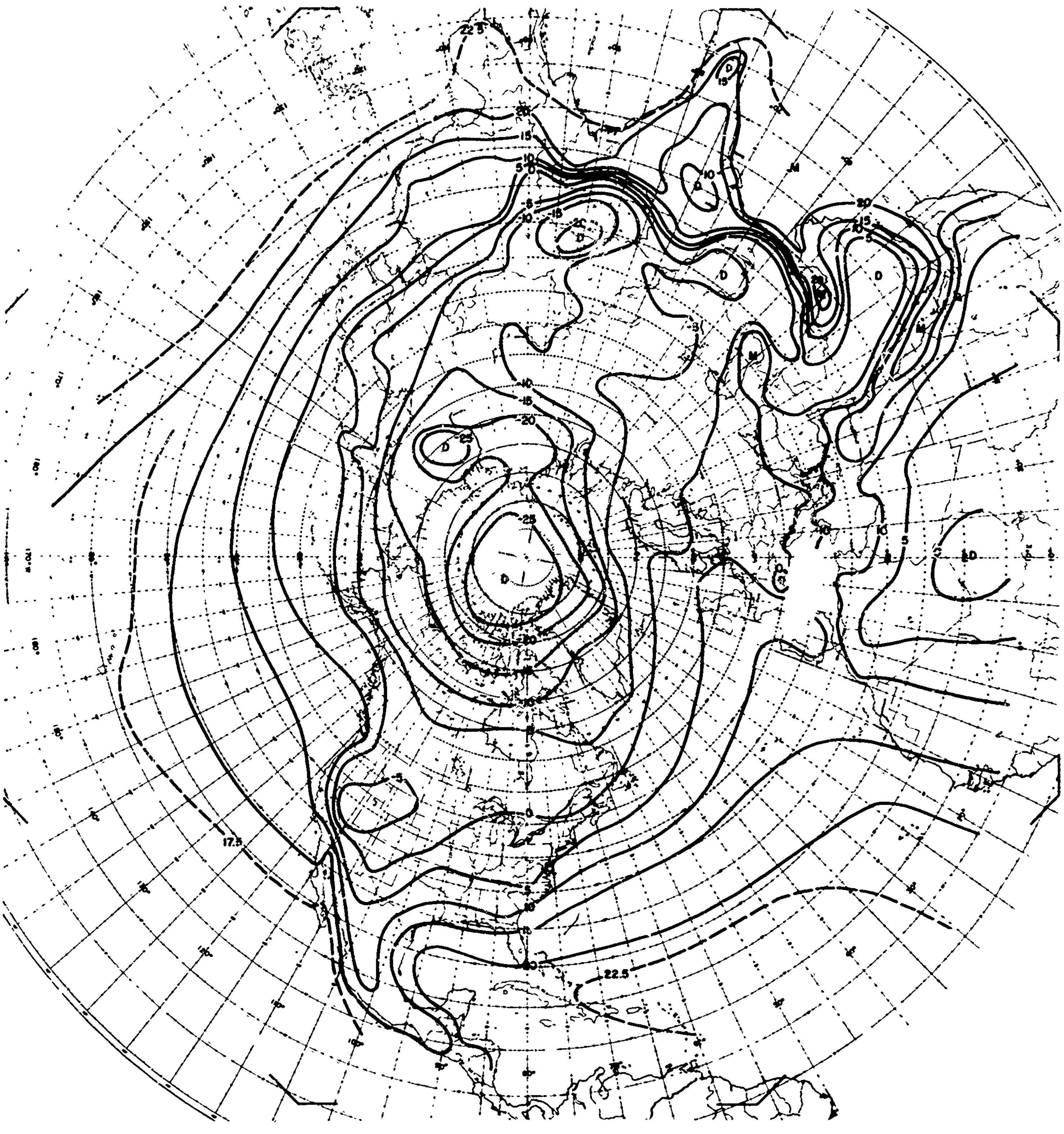

Plate 37. Dew Point at the Surface in October, 25 Percentile

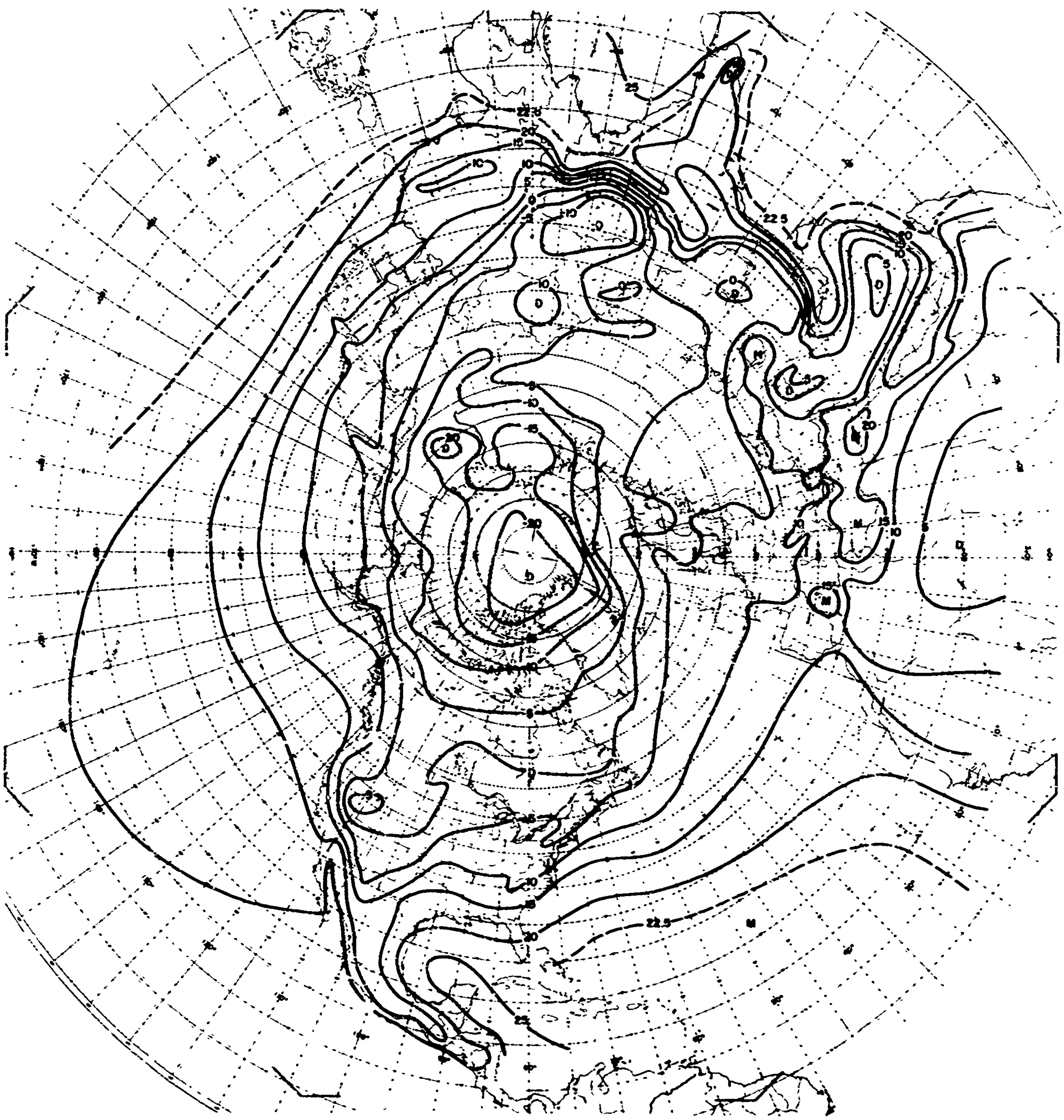

Plate 38. Dew Point at the Surface in October, 50 Percentile

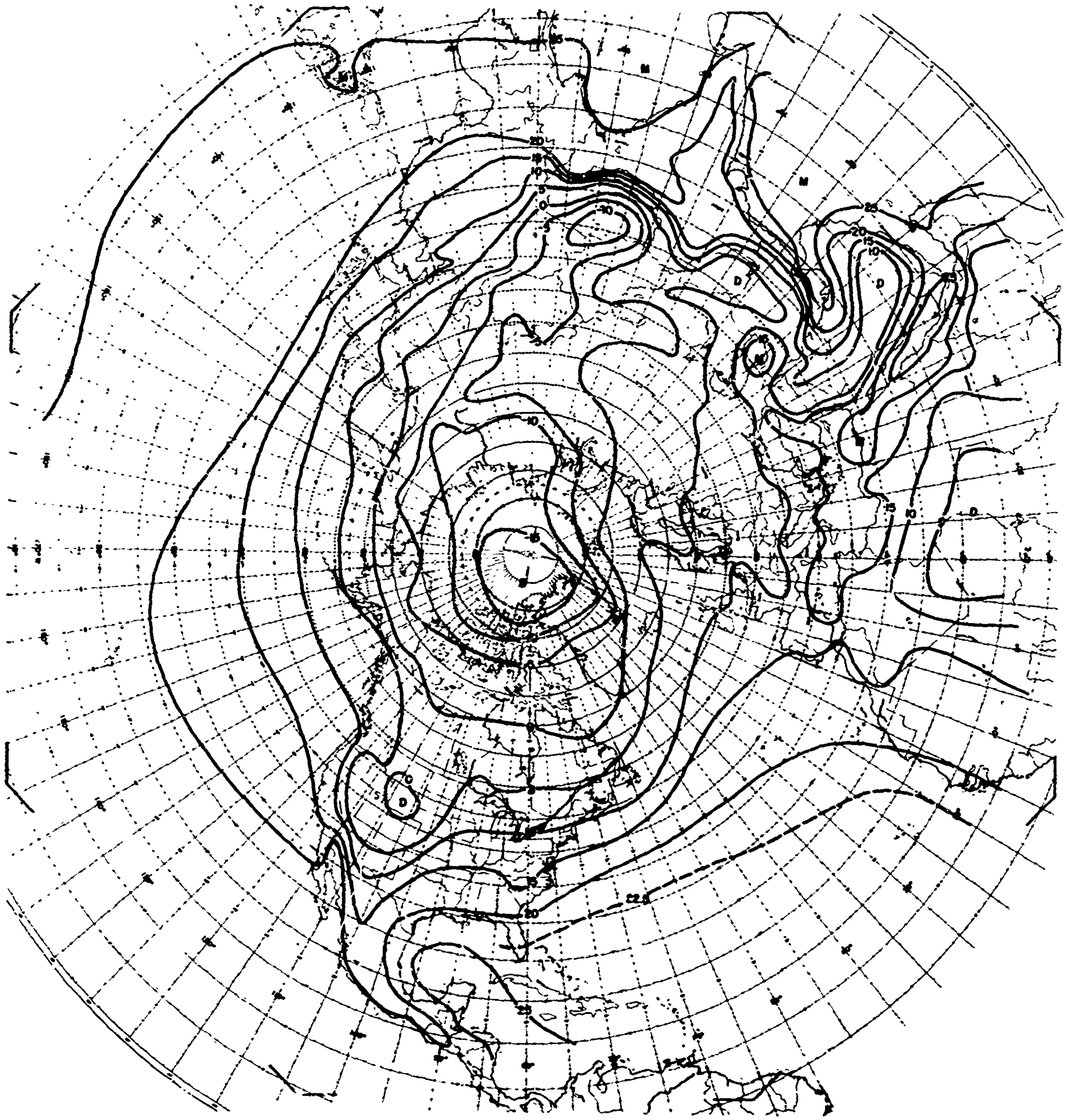

Plate 39. Dew Point at the Surface in October, 75 Percentile

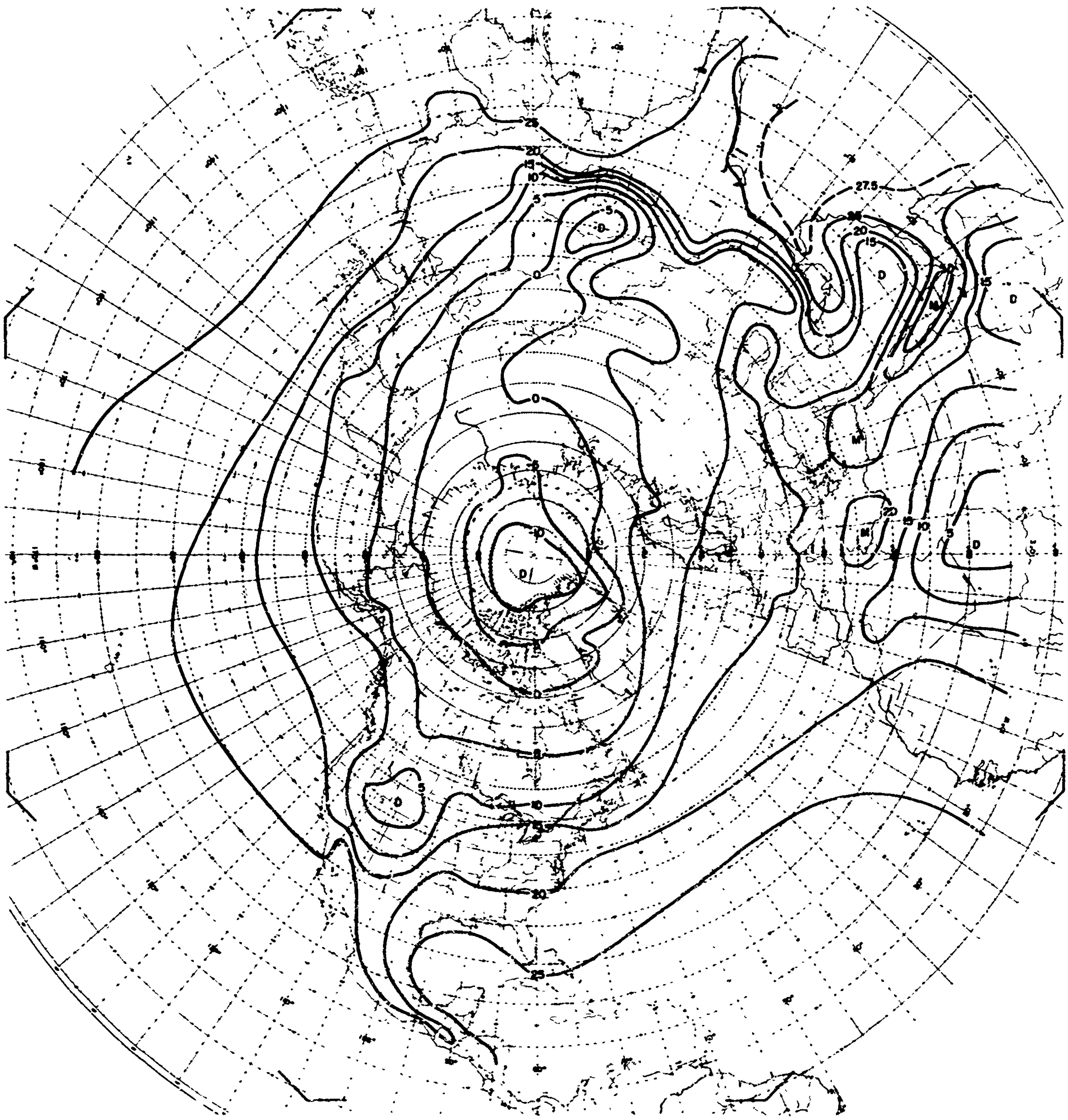

Plate 40. Dew Point at the Surface in October, 95 Percentile

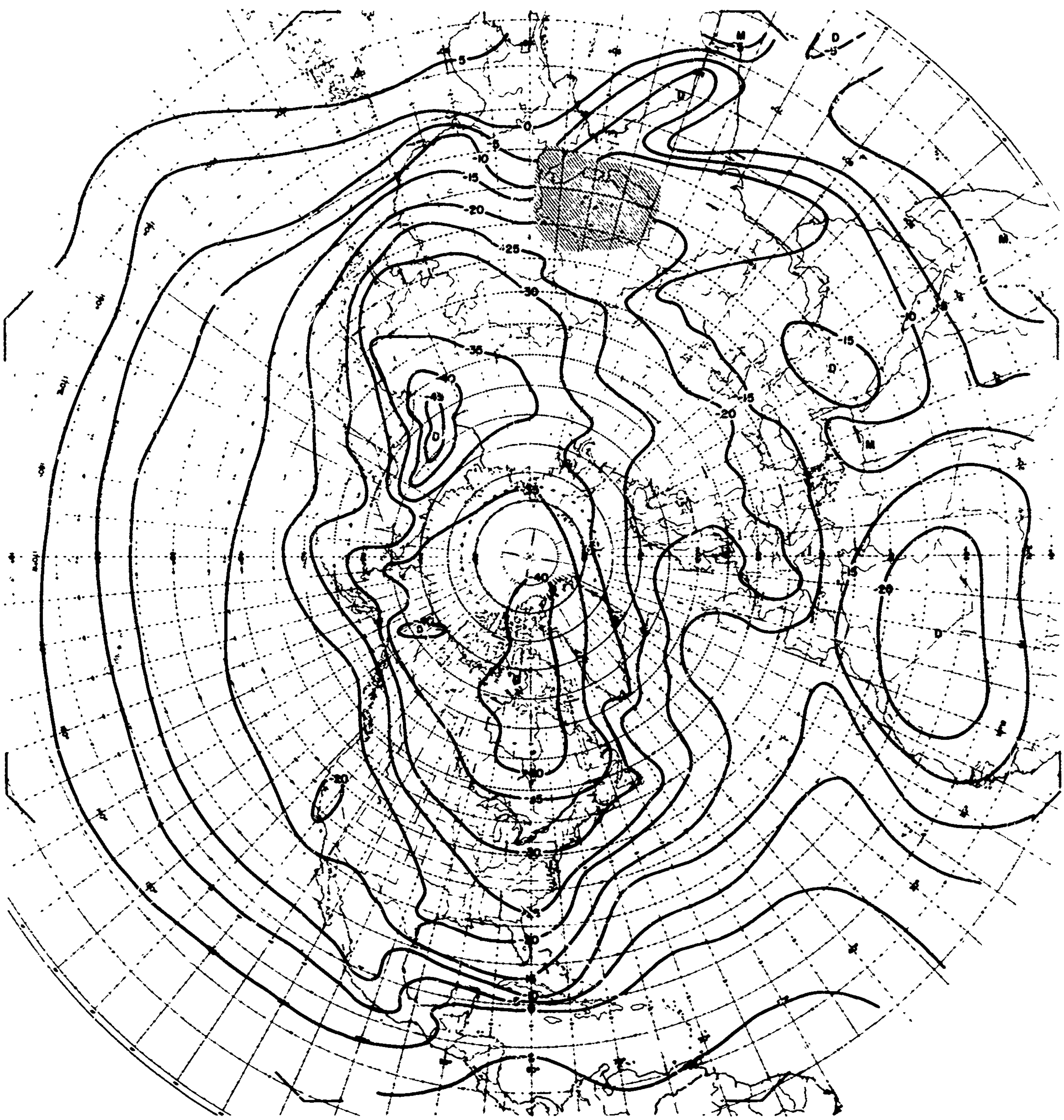

Plate 41. Dew Point at 850 mb in January, 5 Percentile

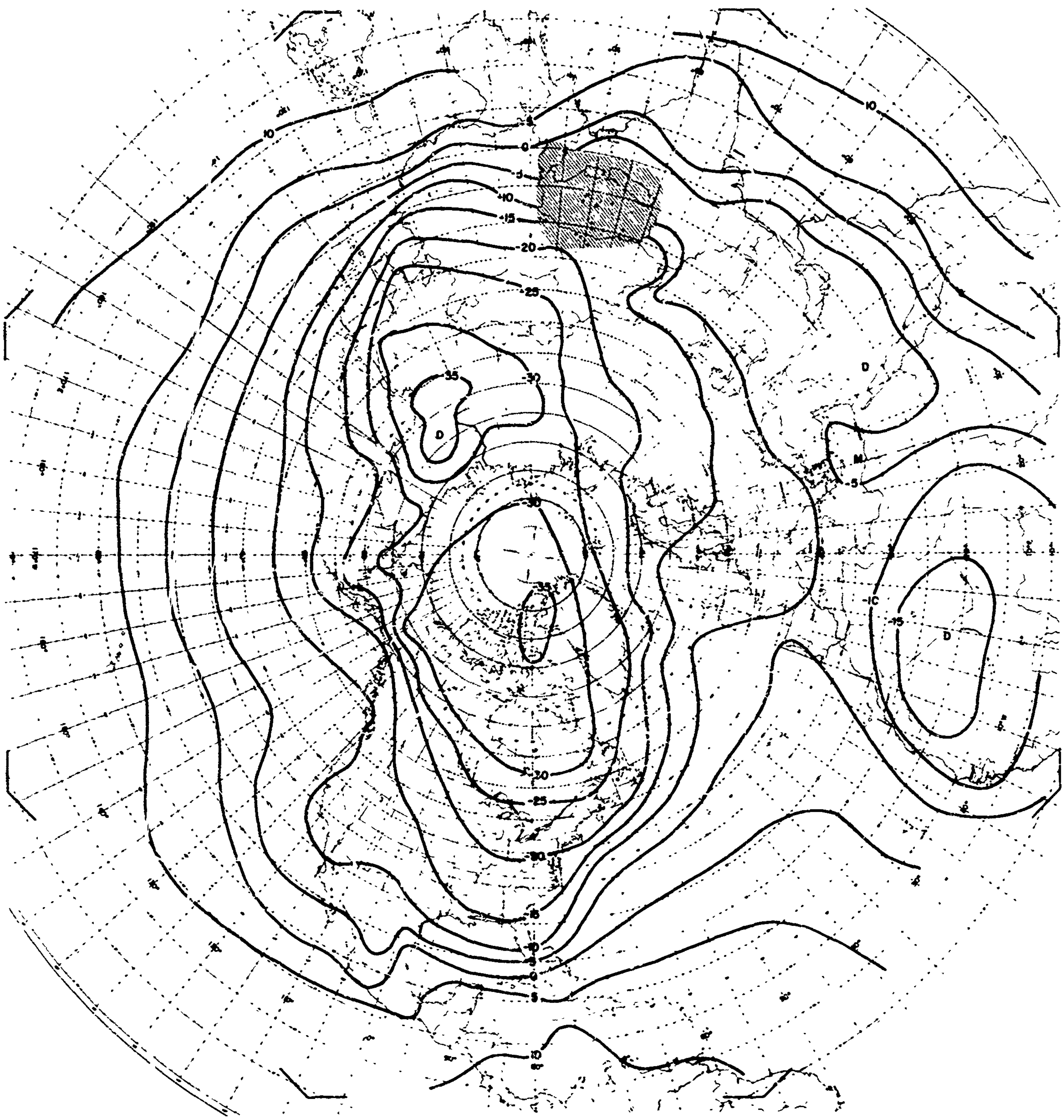

Plate 42. Dew Point at 850 mb in January, 25 Percentile

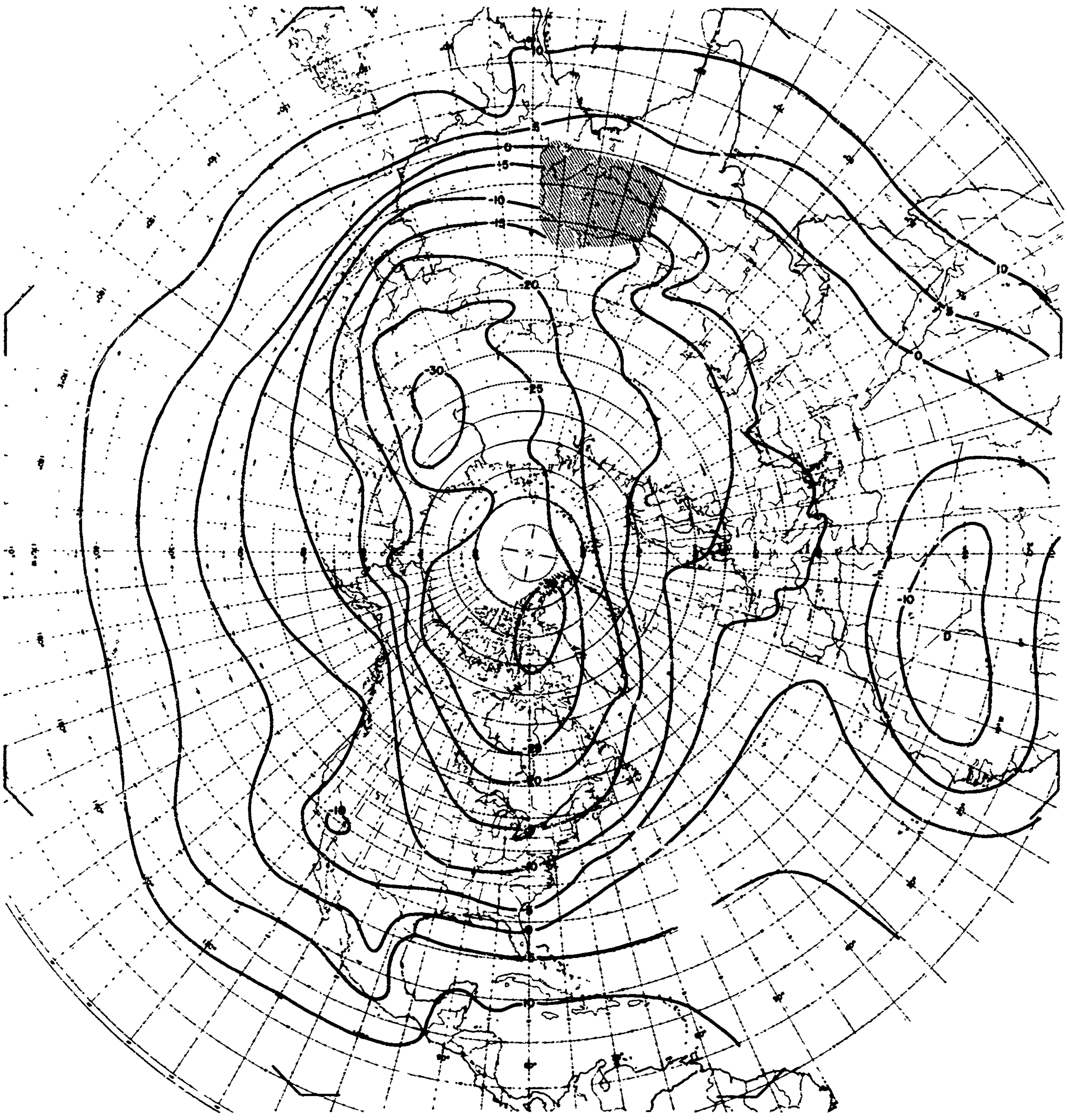

Plate 43. Dew Point at 850 mb in January, 50 Percentile

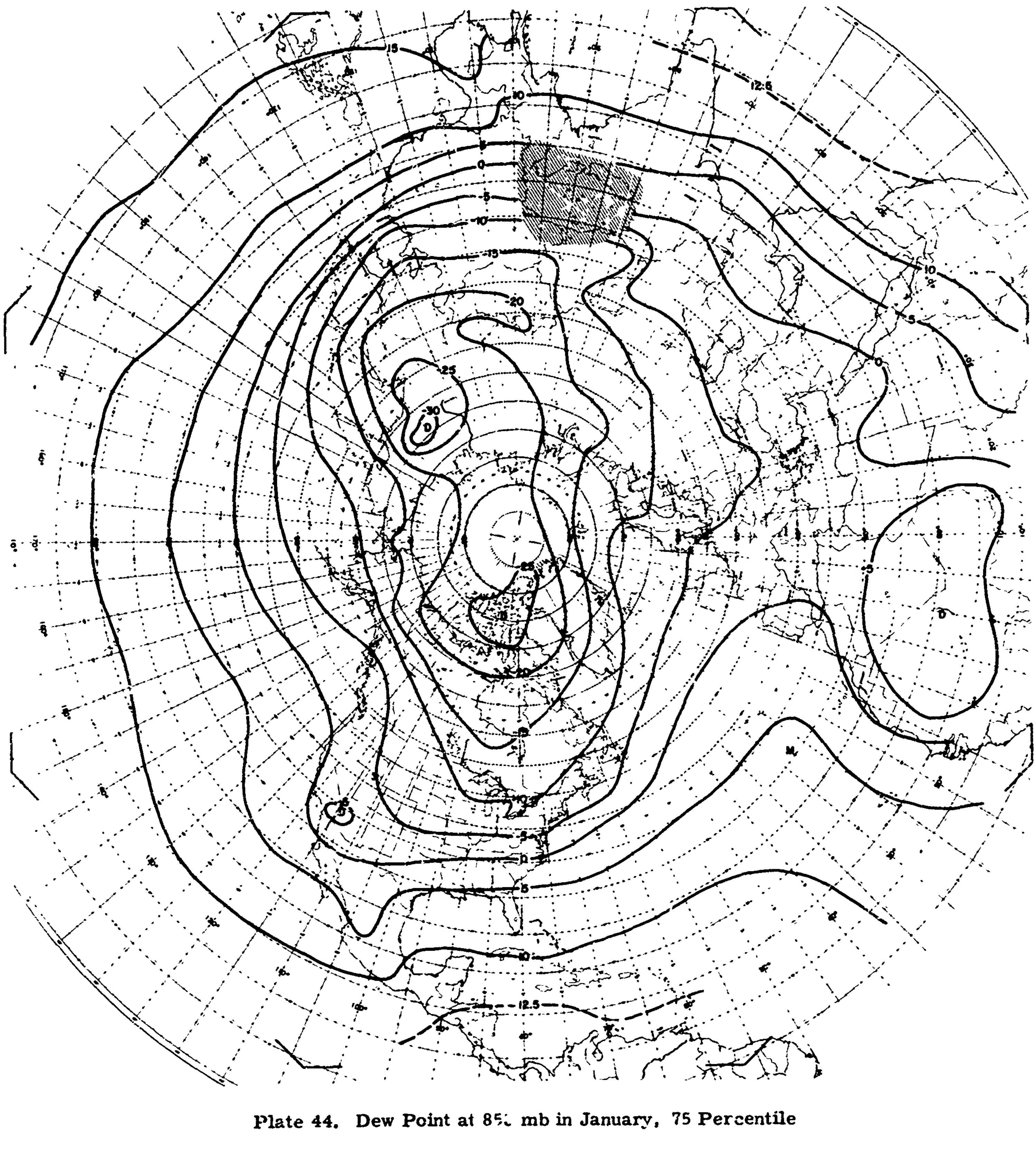

Plate 44. Dew Point at 85ℓ mb in January, 75 Percentile

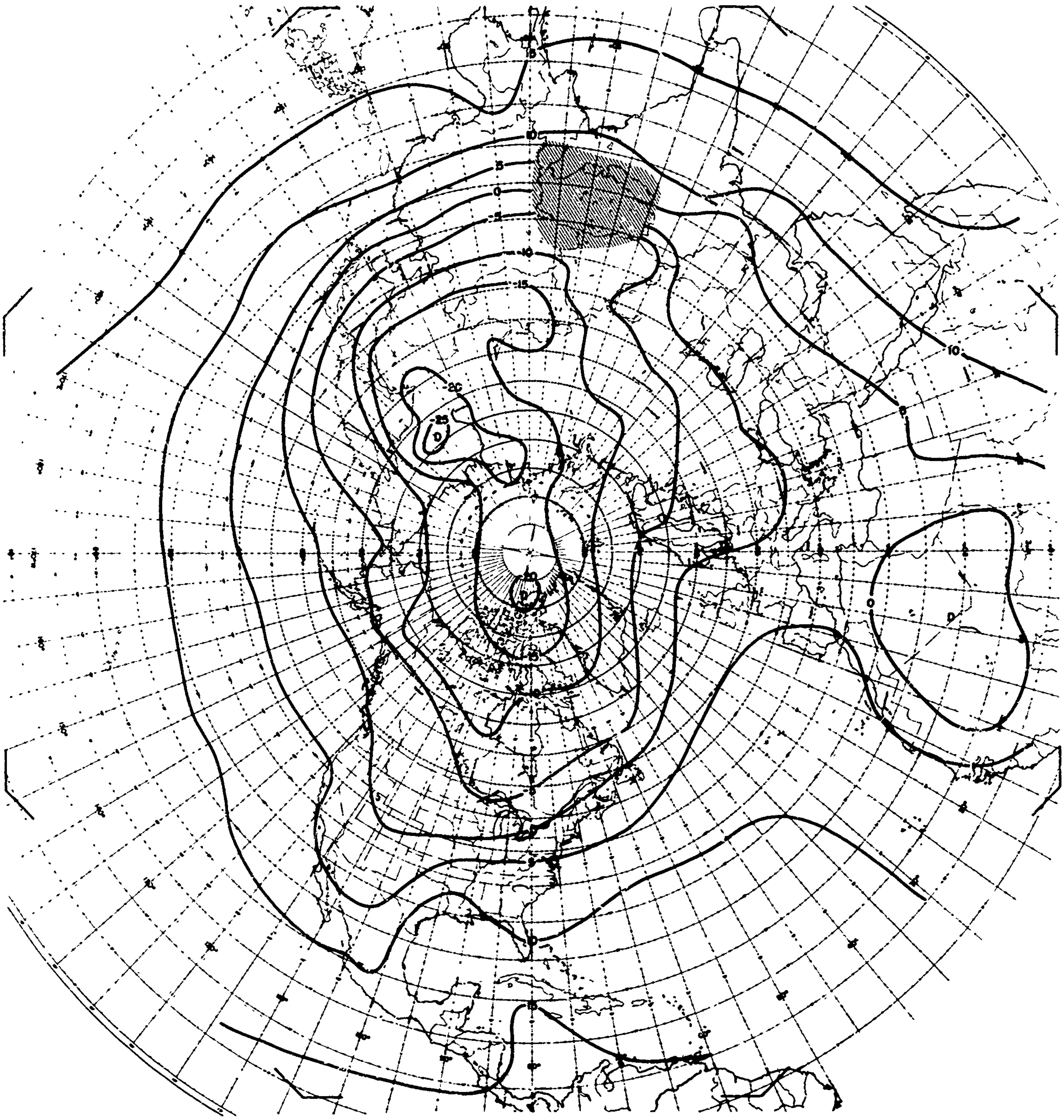

Plate 45. Dew Point at 850 mb in January, 95 Percentile

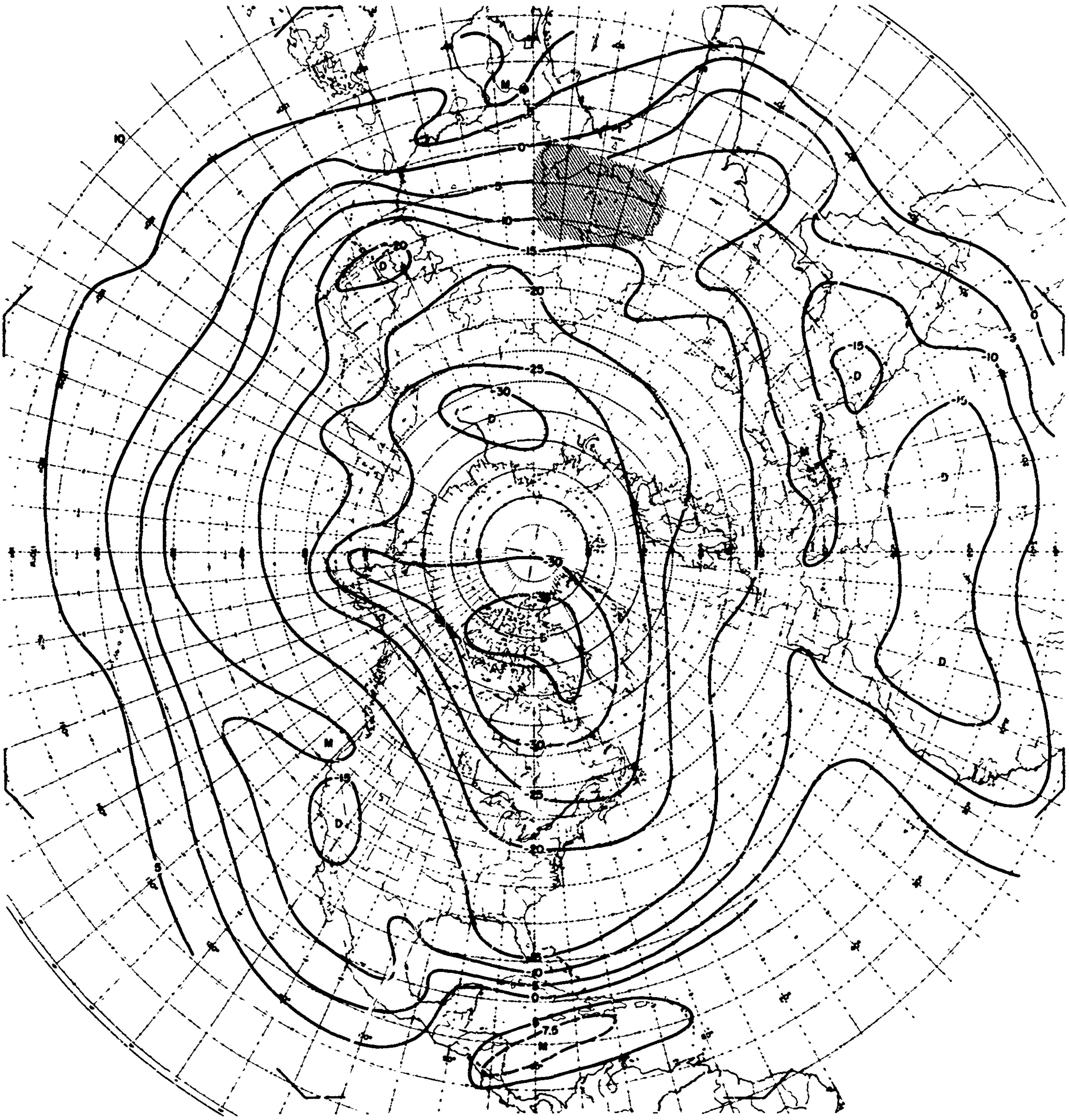

Plate 46. Dew Point at 850 mb in April, 5 Percentile

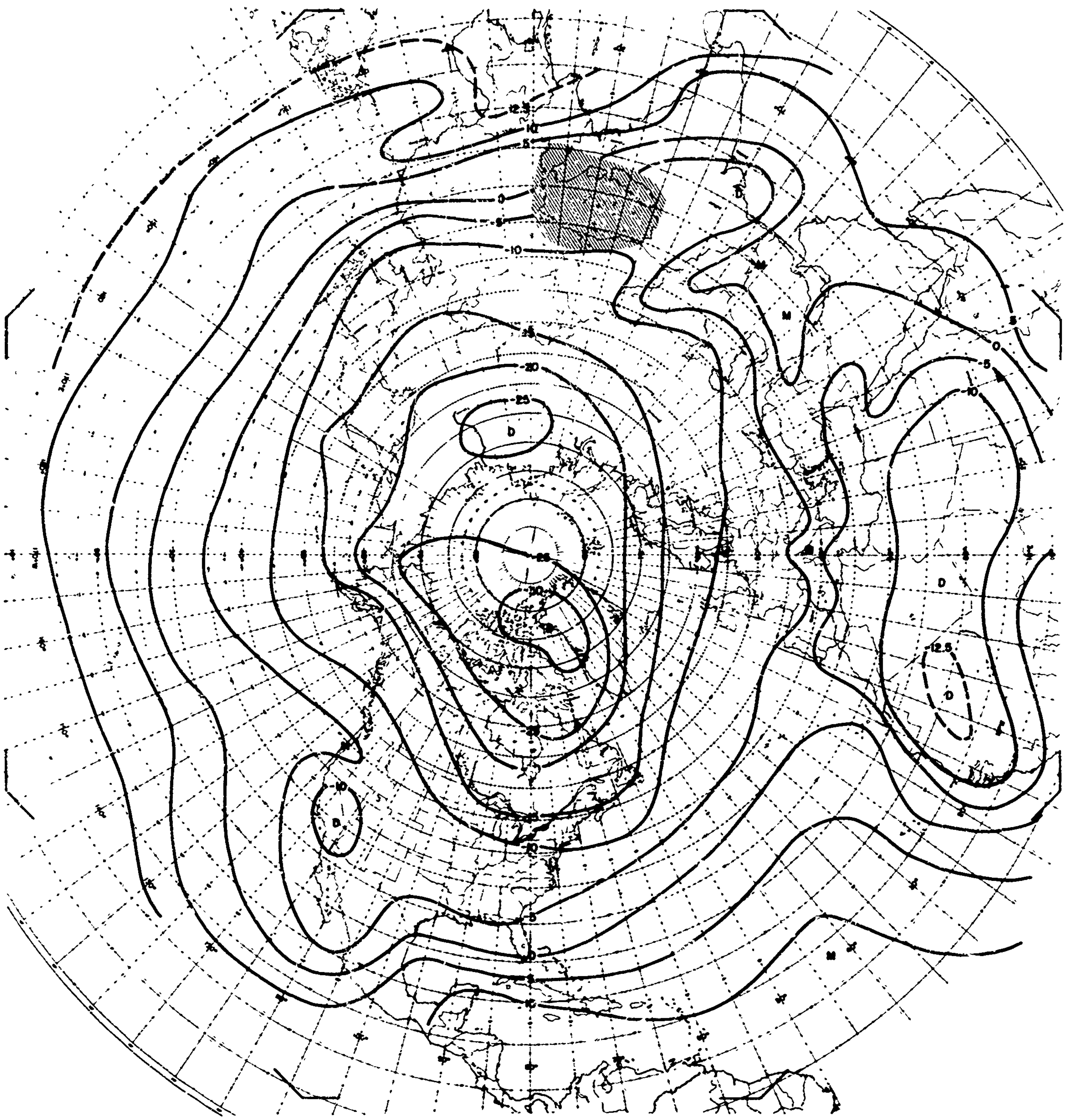

Plate 47. Dew Point at 850 mb in April, 25 Percentile

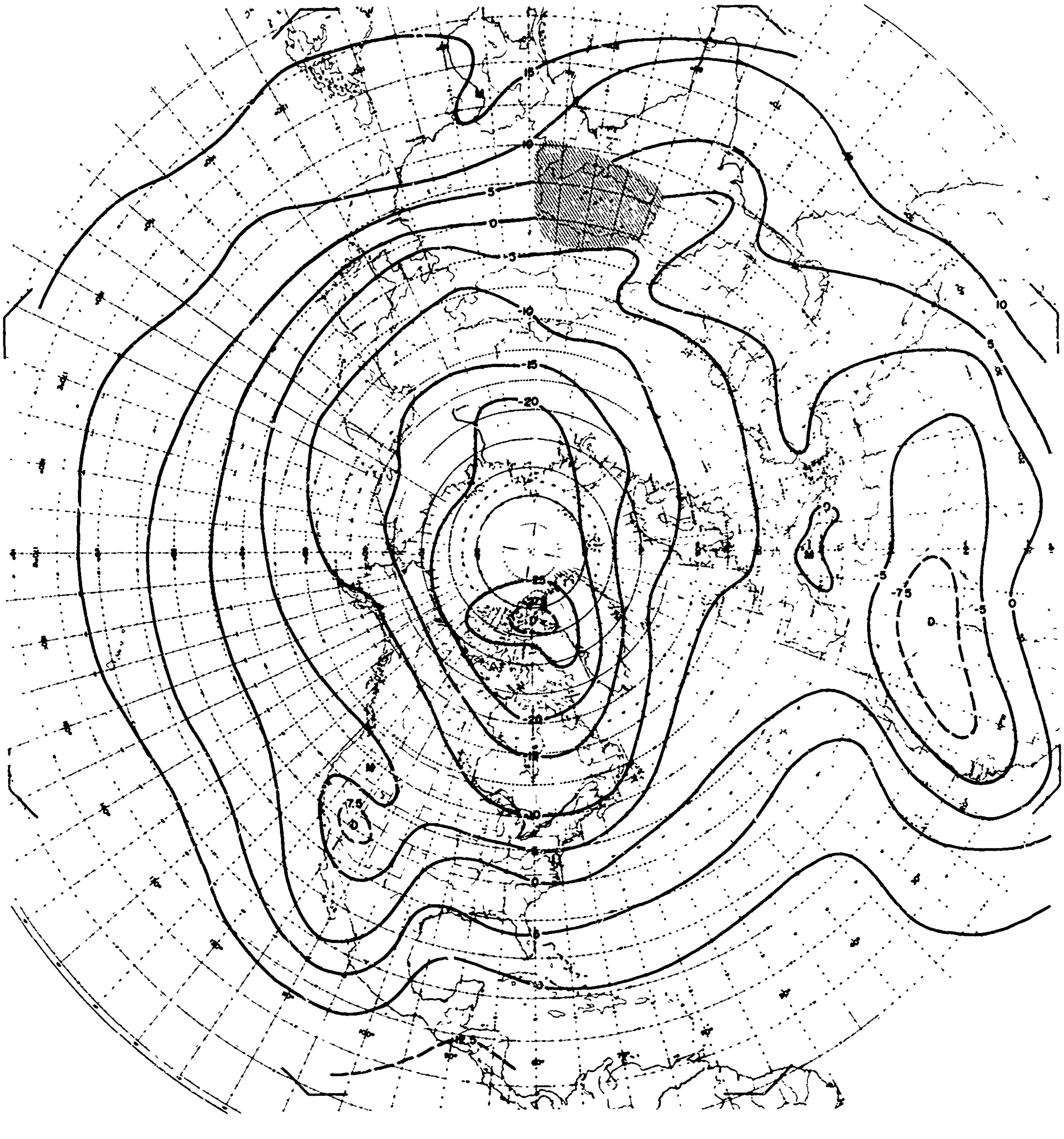

Plate 48. Dew Point at 850 mb in April, 50 Percentile

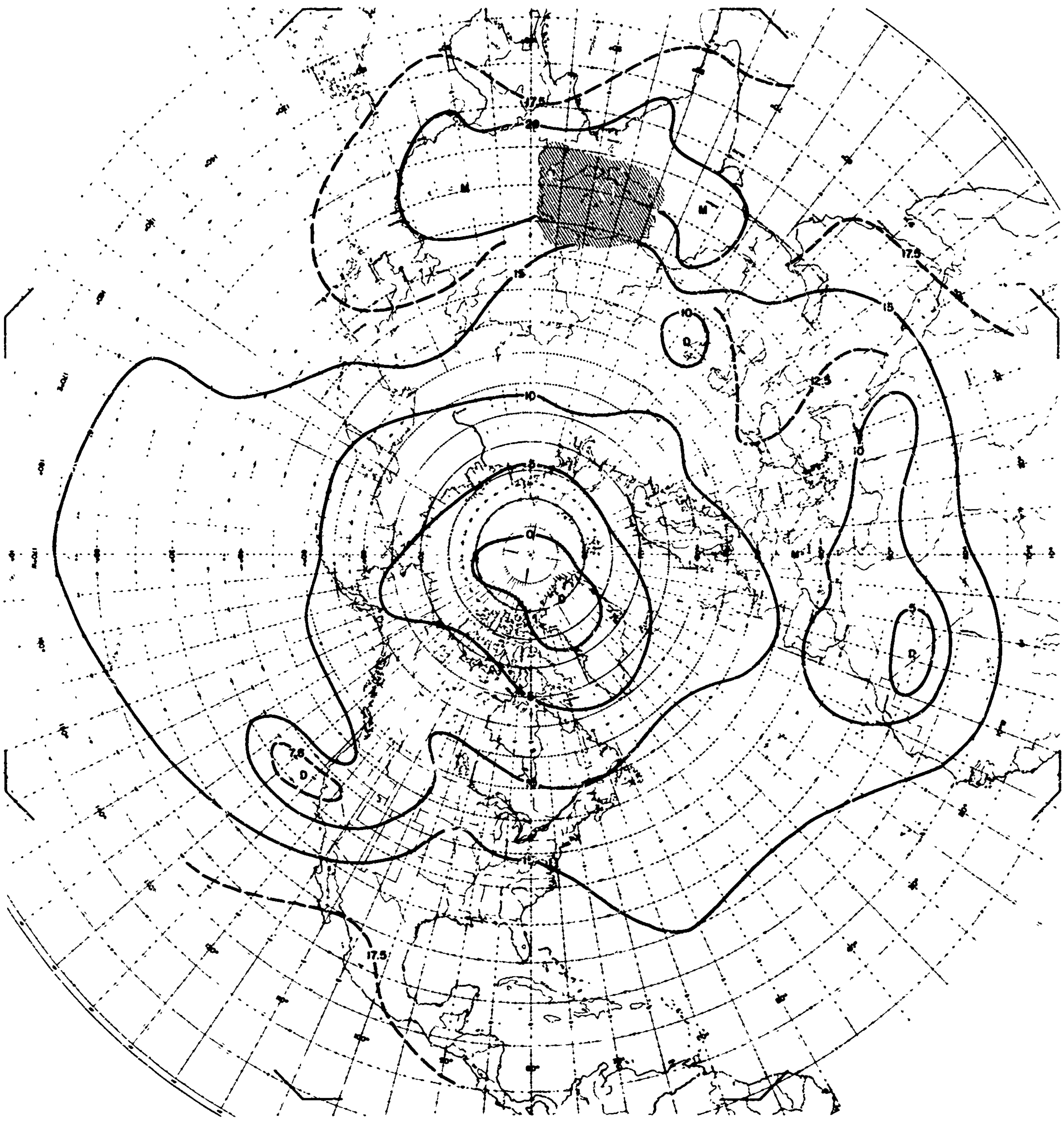

Plate 49. Dew Point at 850 mb in April, 75 Percentile

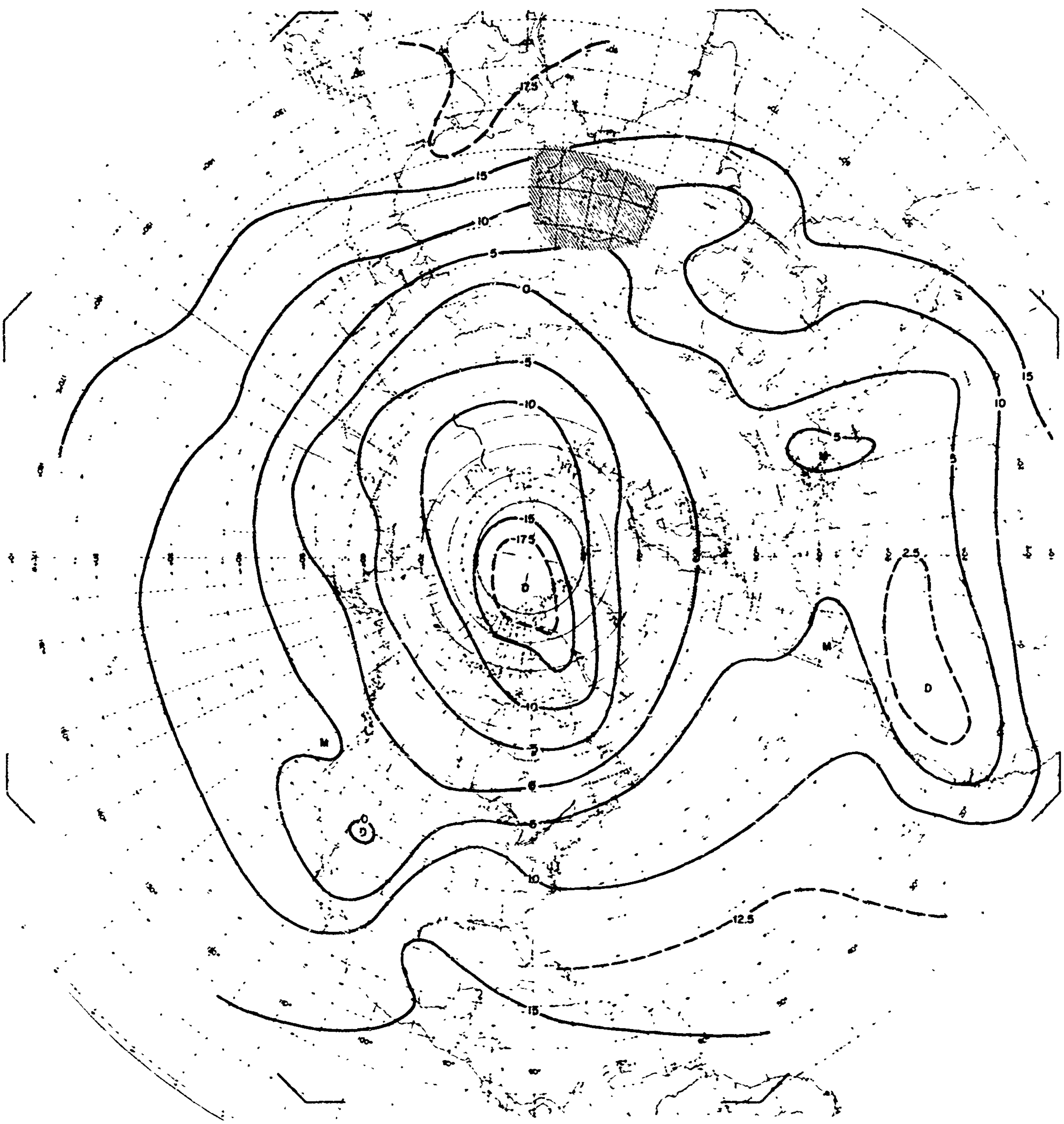

Plate 50. Dew Point at 850 mb in April, 95 Percentile

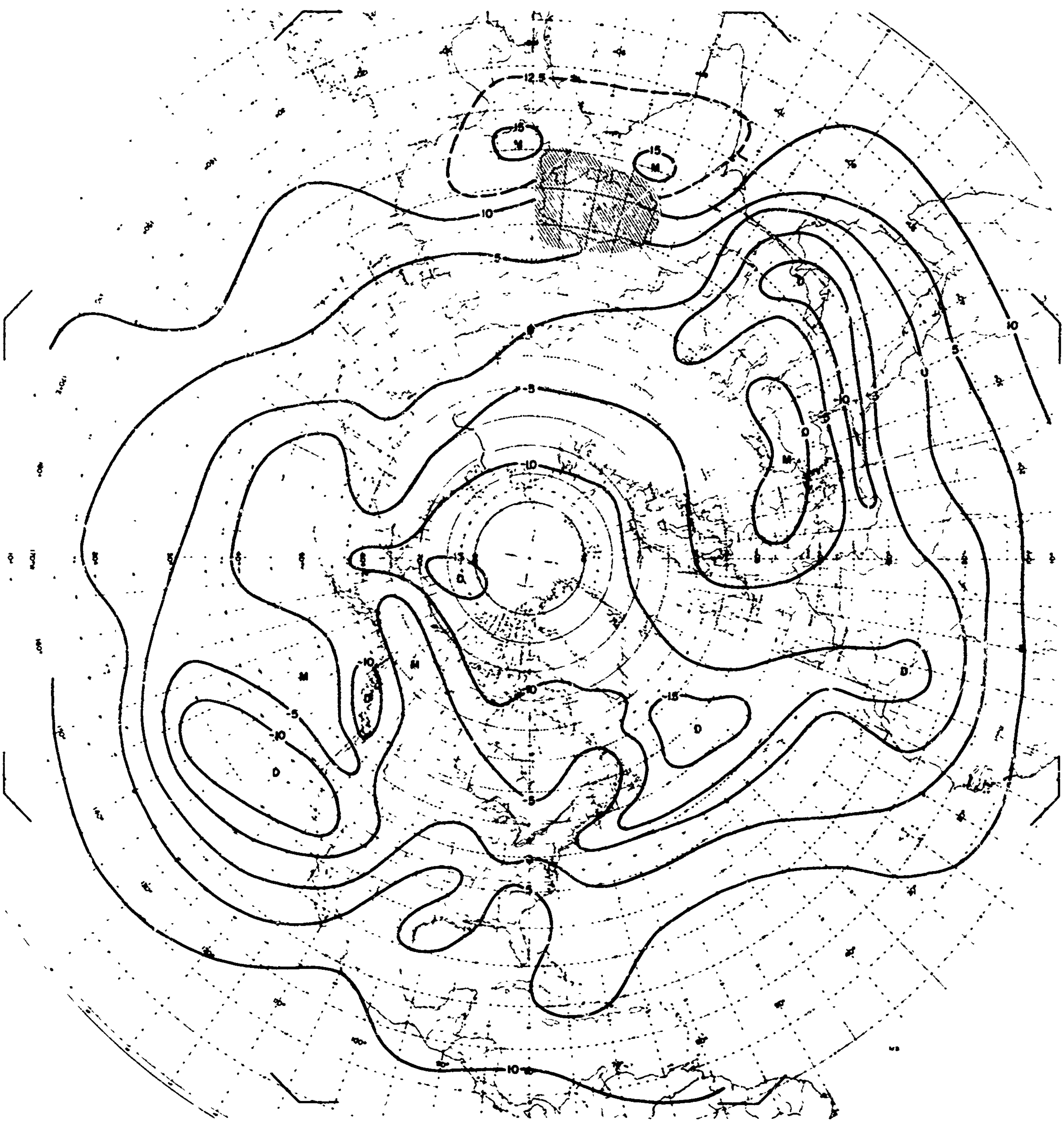

Plate 51. Dew Point at 850 mb in July, 5 Percentile

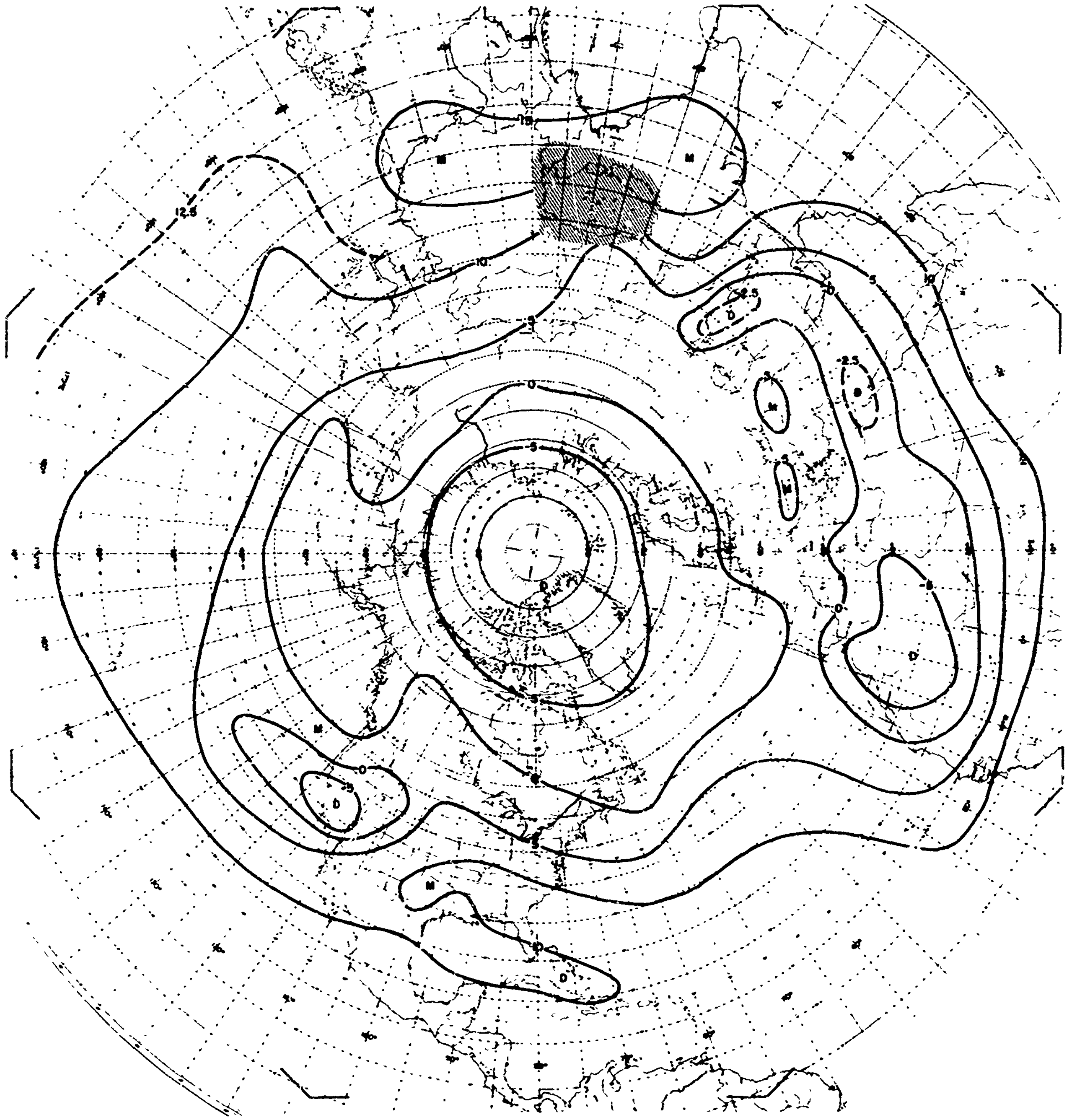

Plate 52. Dew Point at 850 mb in July, 25 Percentile

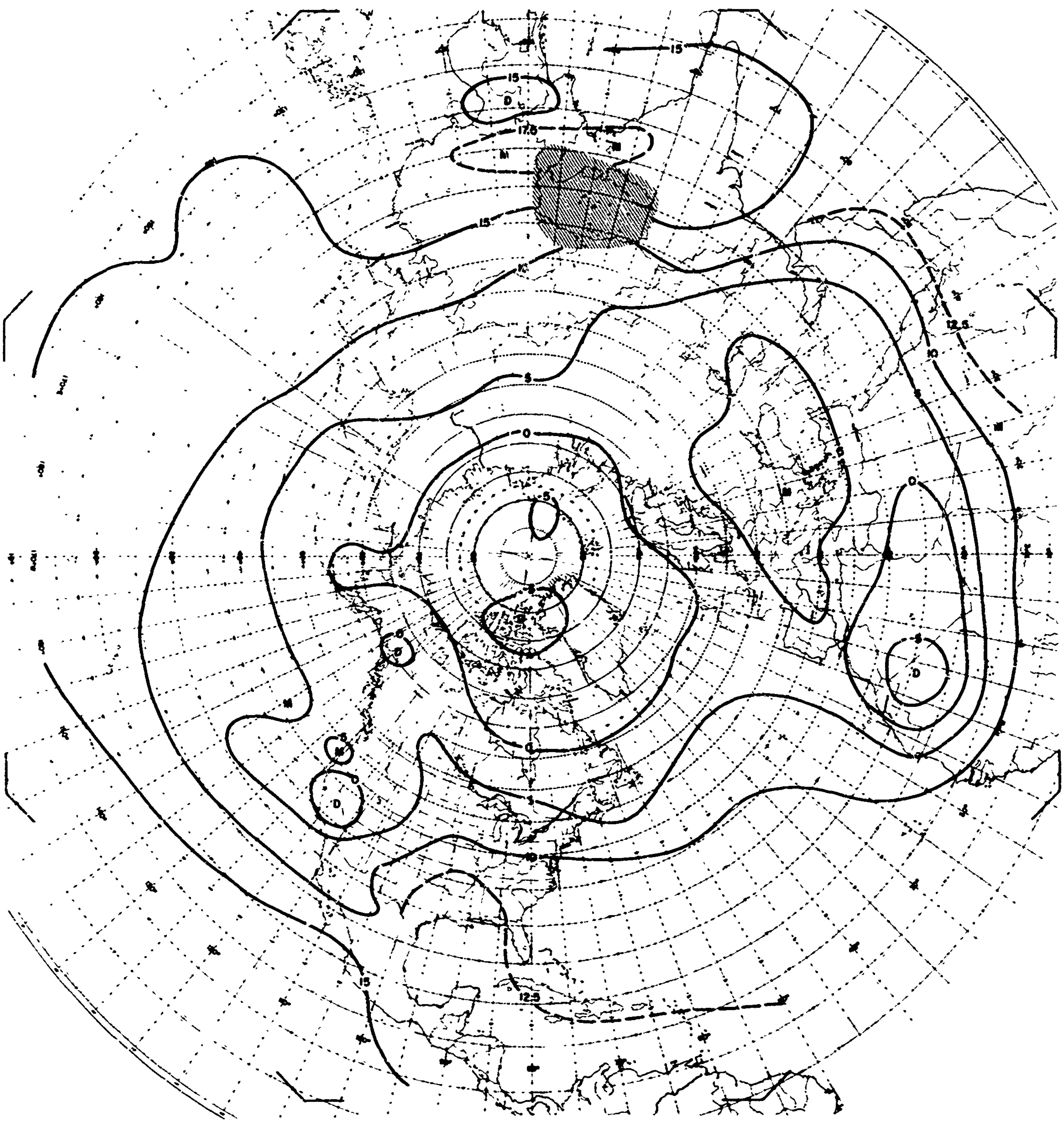

Plate 53. Dew Point at 850 mb in July, 50 Percentile

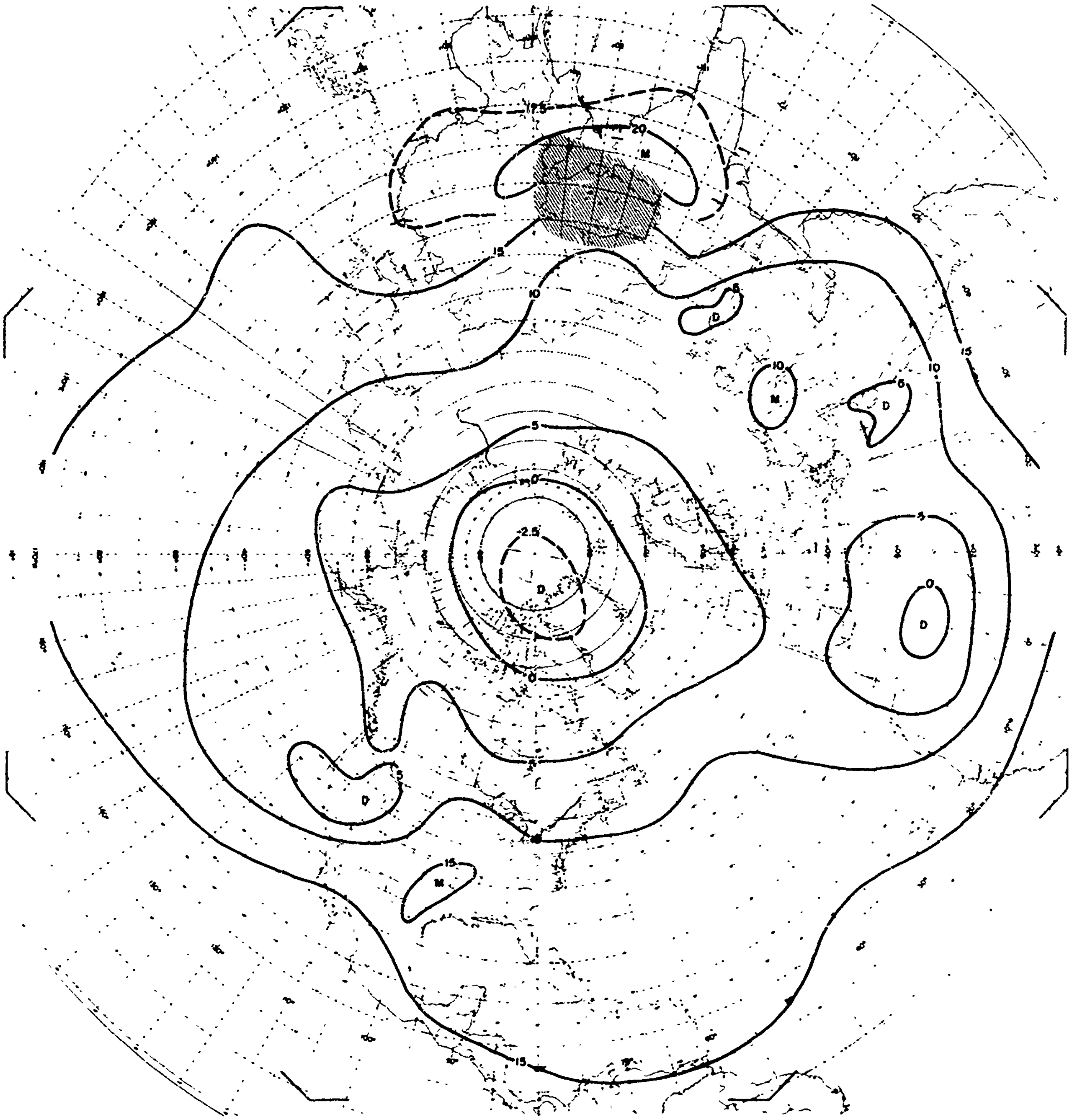

Plate 54. Dew Point at 850 mb in July, 75 Percentile

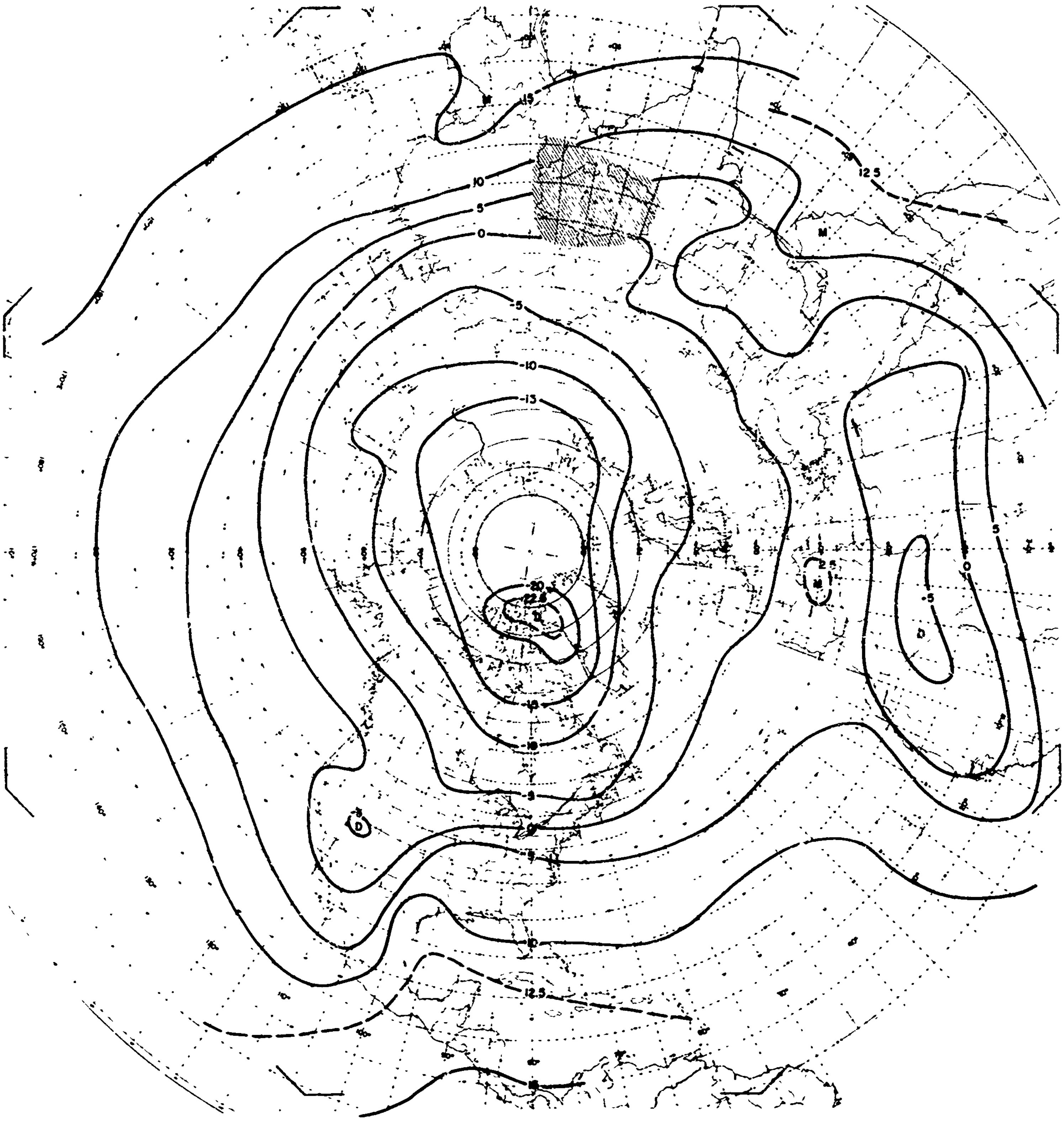

Plate 55. Dew Point at 850 mb in July, 95 Percentile

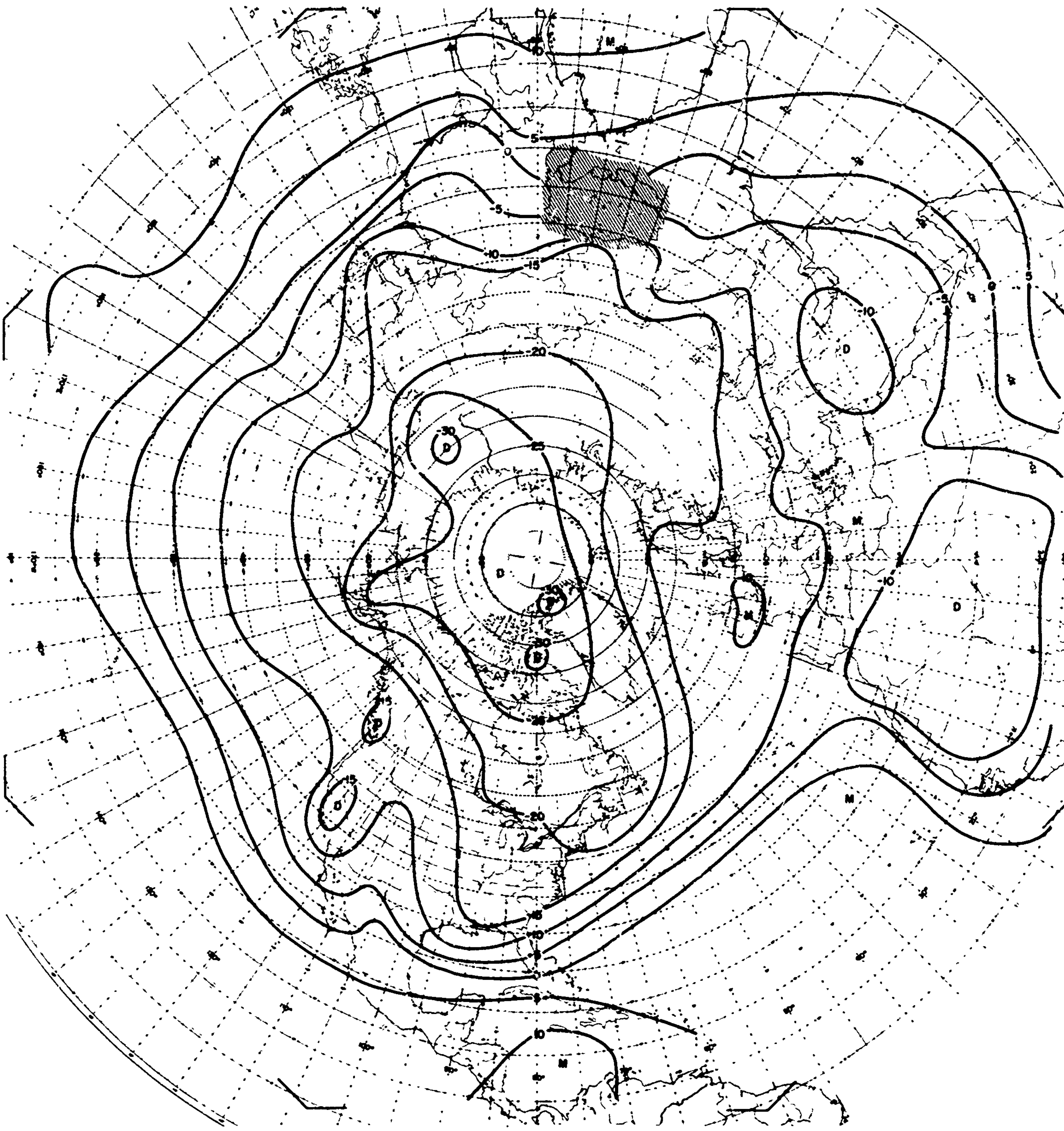

Plate 56. Dew Point at 850 mb in October, 5 Percentile

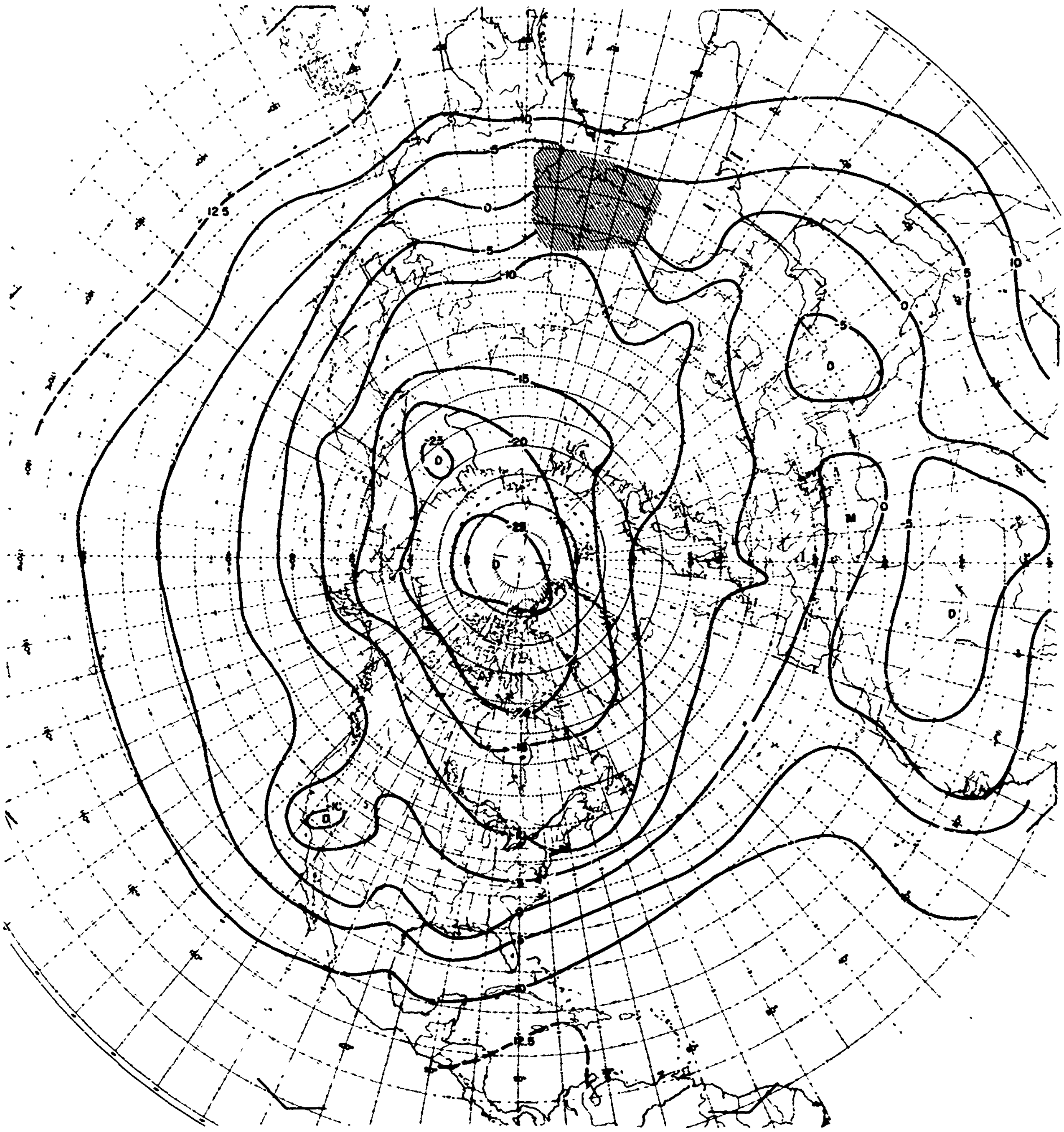

Plate 57. Dew Point at 850 mb in October, 25 Percentile

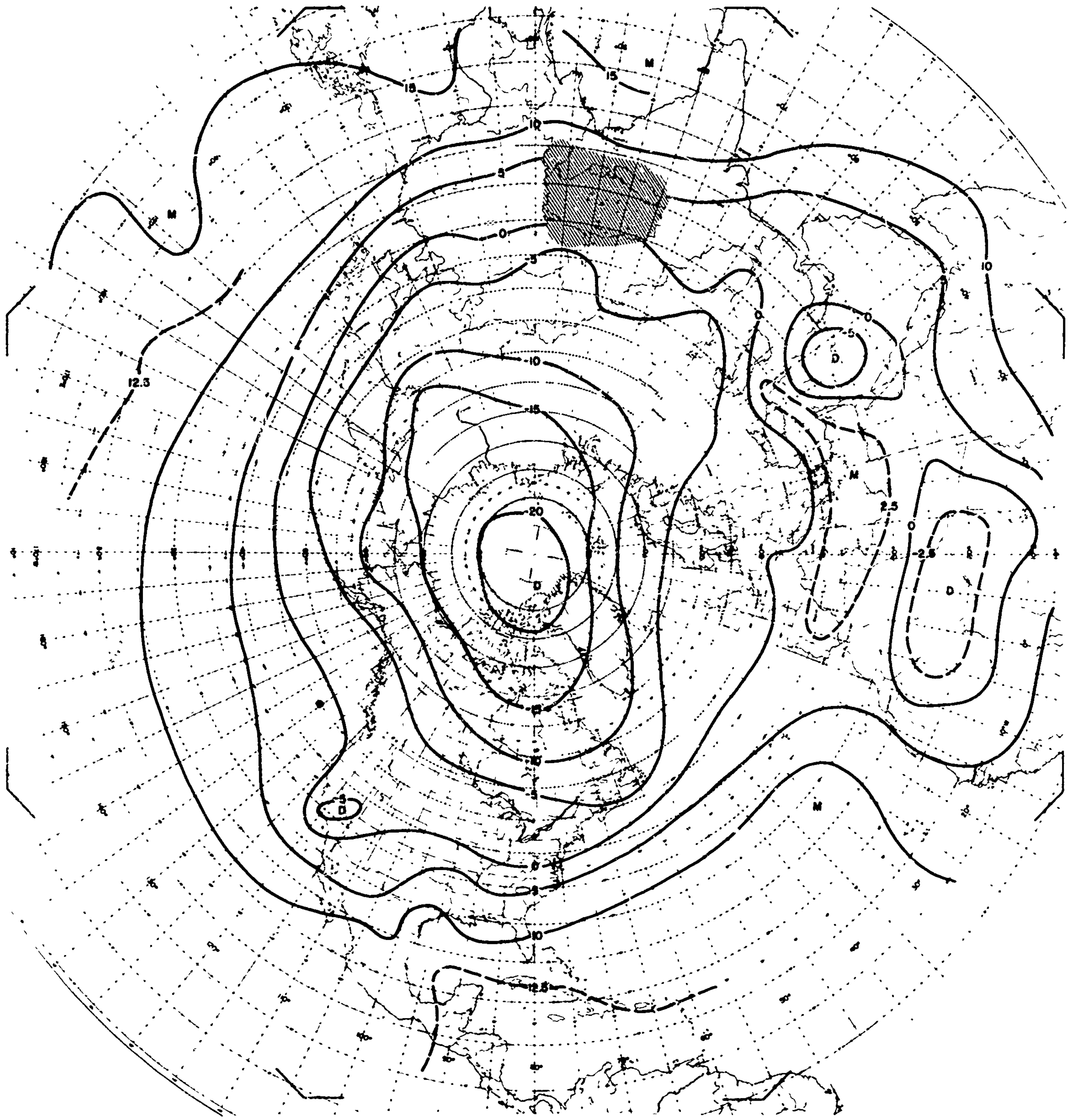

Plate 58. Dew Point at 850 mb in October, 50 Percentile

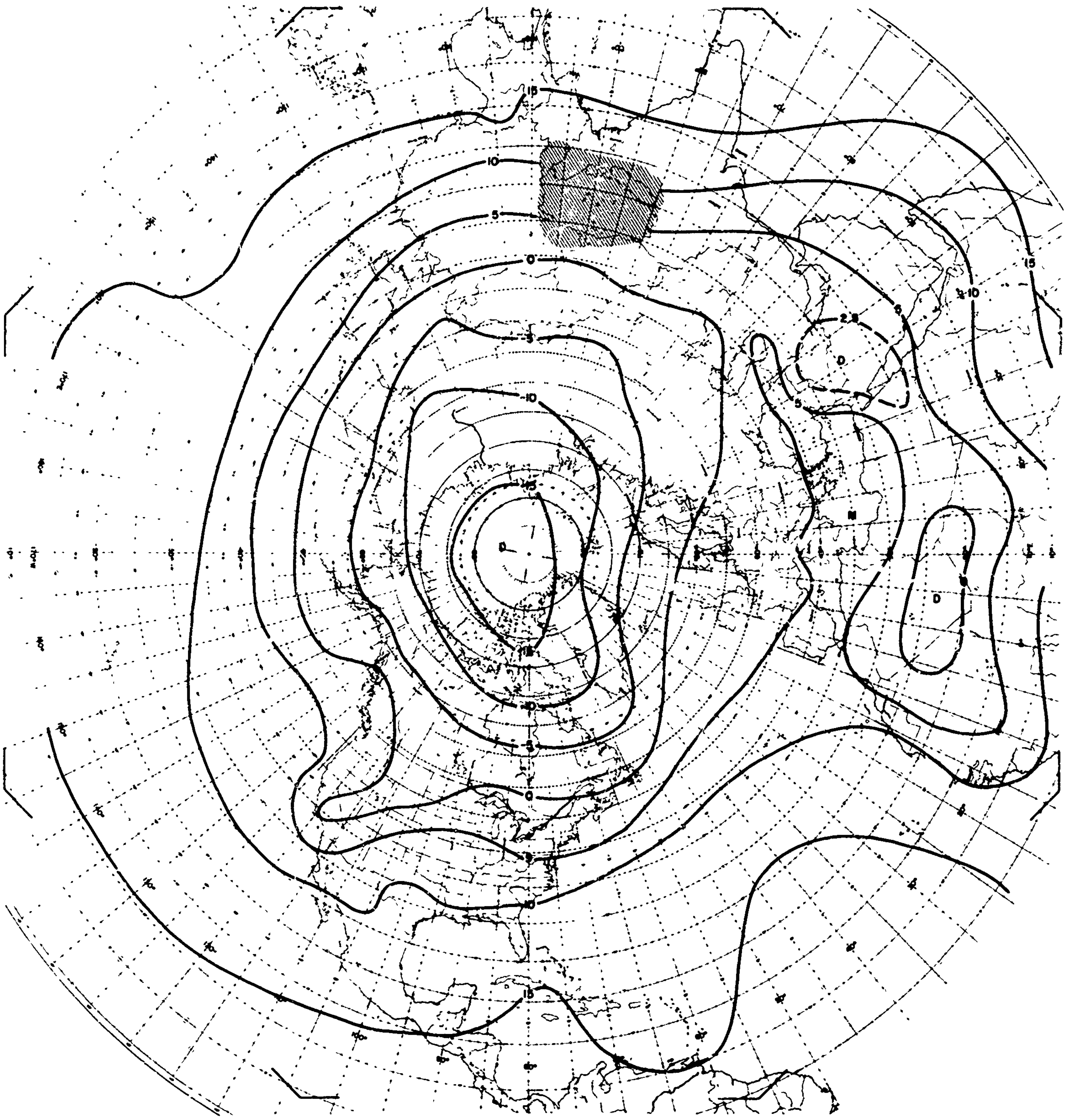

Plate 59. Dew Point at 850 mb in October, 75 Percentile

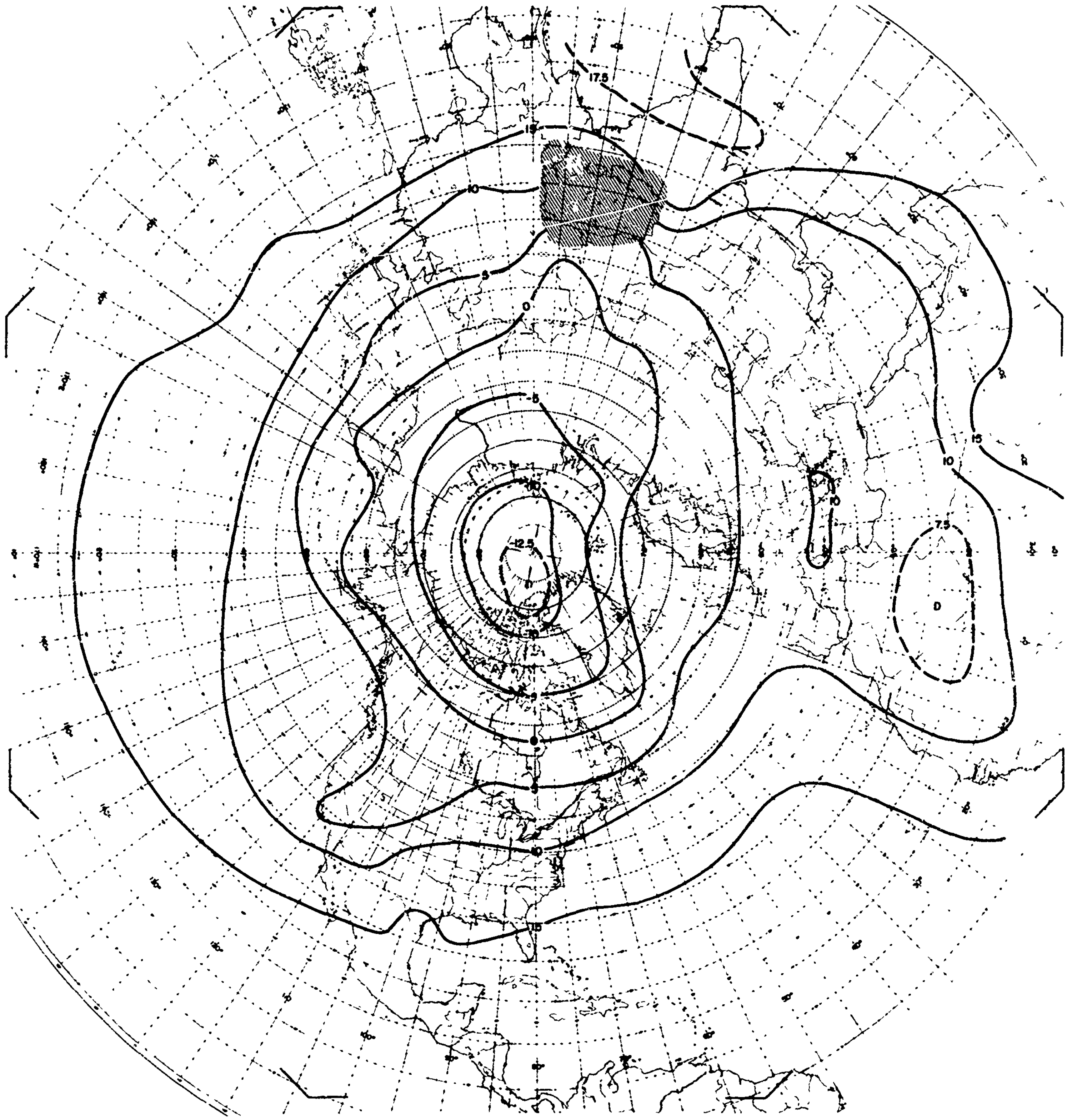

Plate 60. Dew Point at 850 mb in October, 95 Percentile

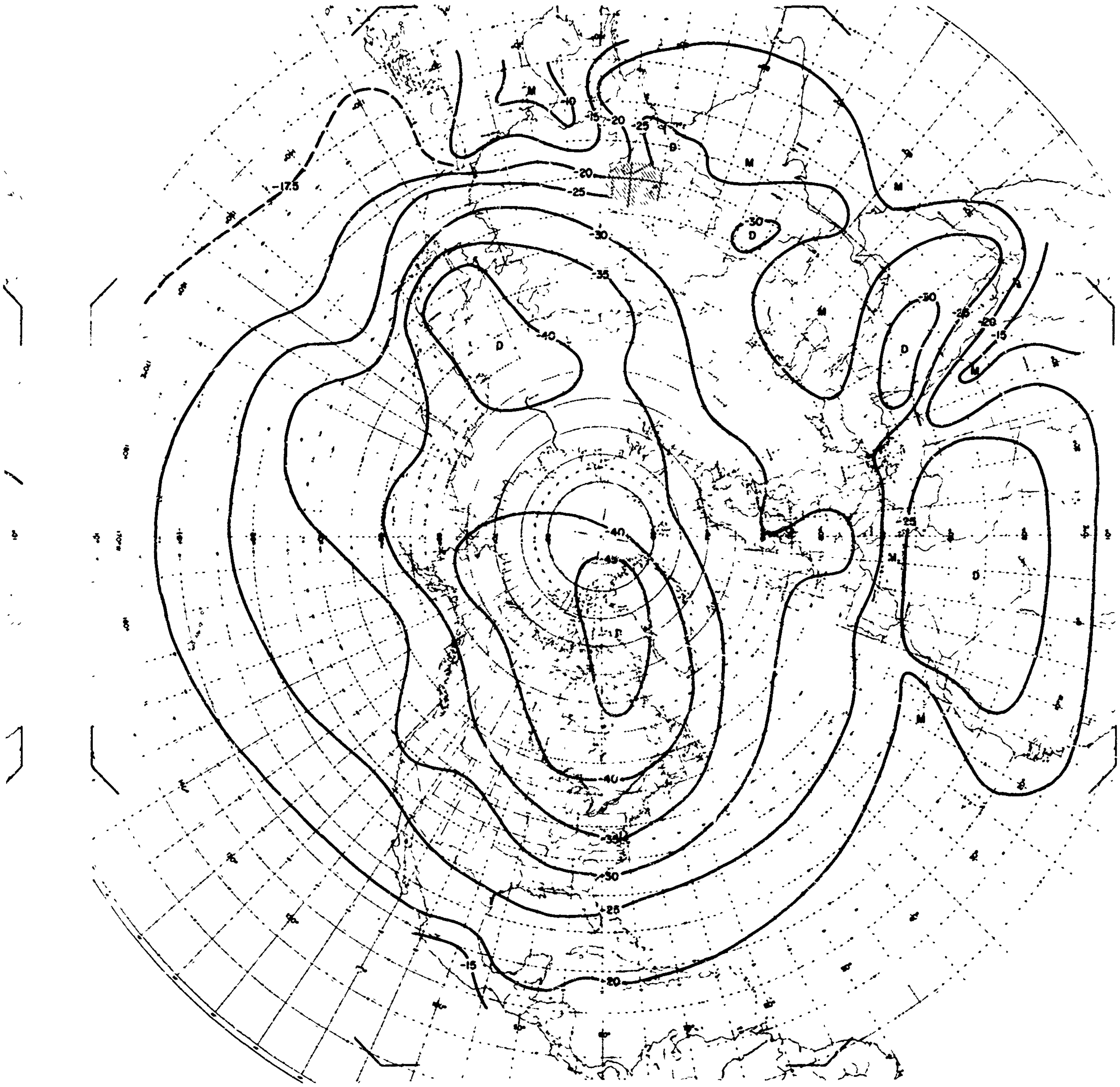

Plate 61. Dew Point at 700 mb in January, 5 Percentile

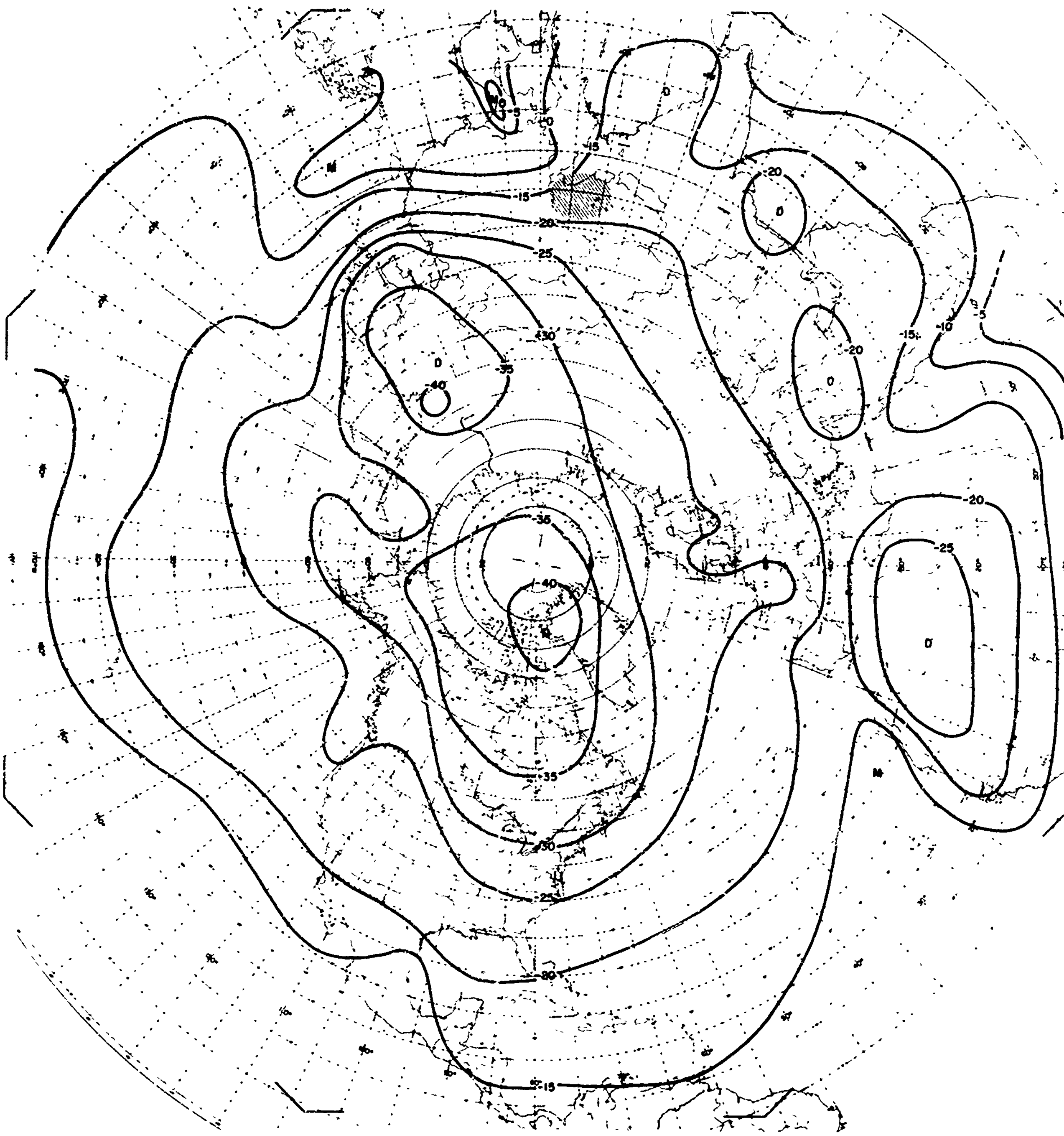

Plate 62. Dew Point at 700 mb in January, 25 Percentile

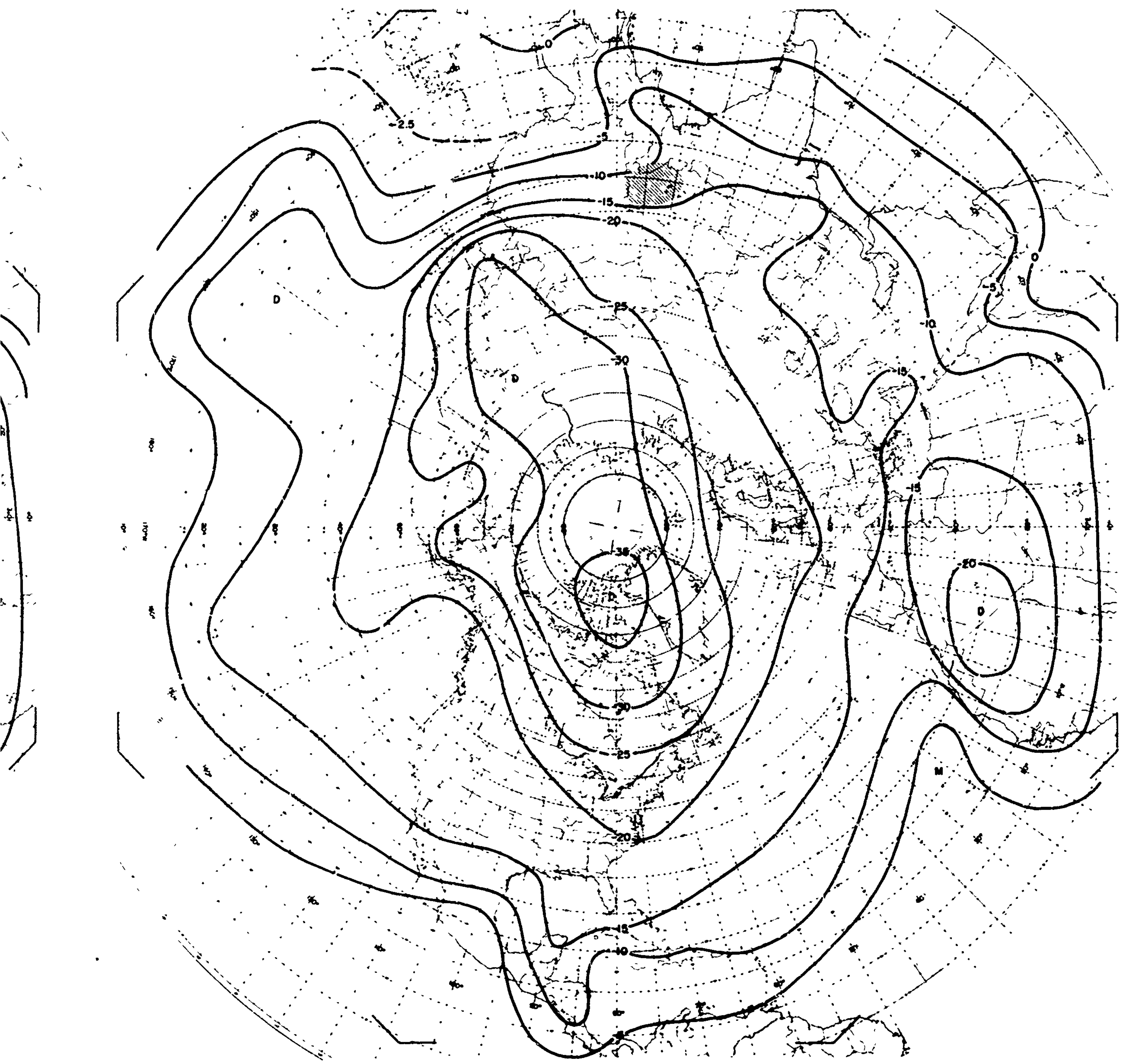

Plate 63. Dew Point at 700 mb in January, 50 Percentile

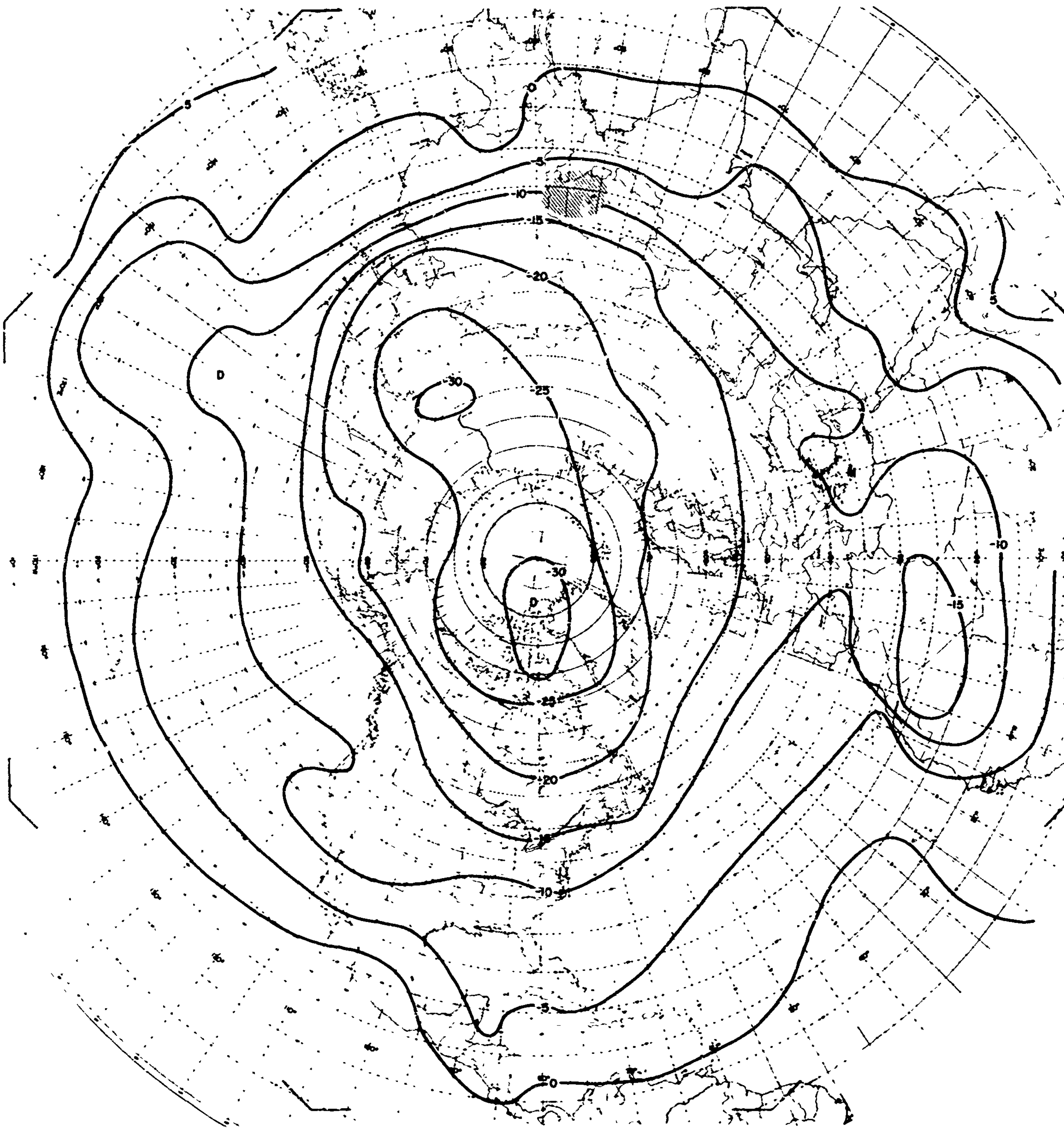

Plate 64. Dew Point at 700 mb in January, 75 Percentile

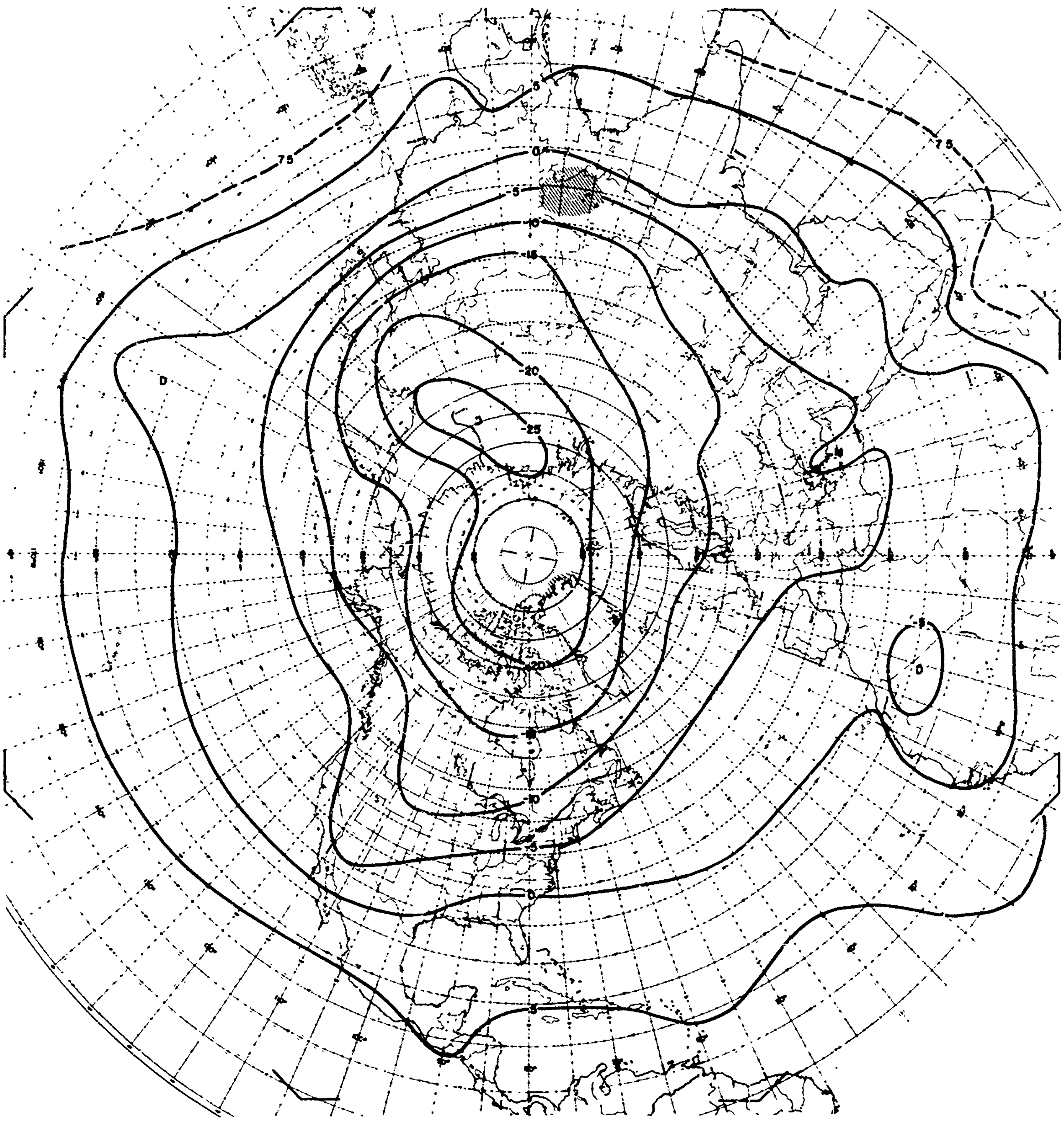

Plate 65. Dew Point at 700 mb in January, 95 Percentile

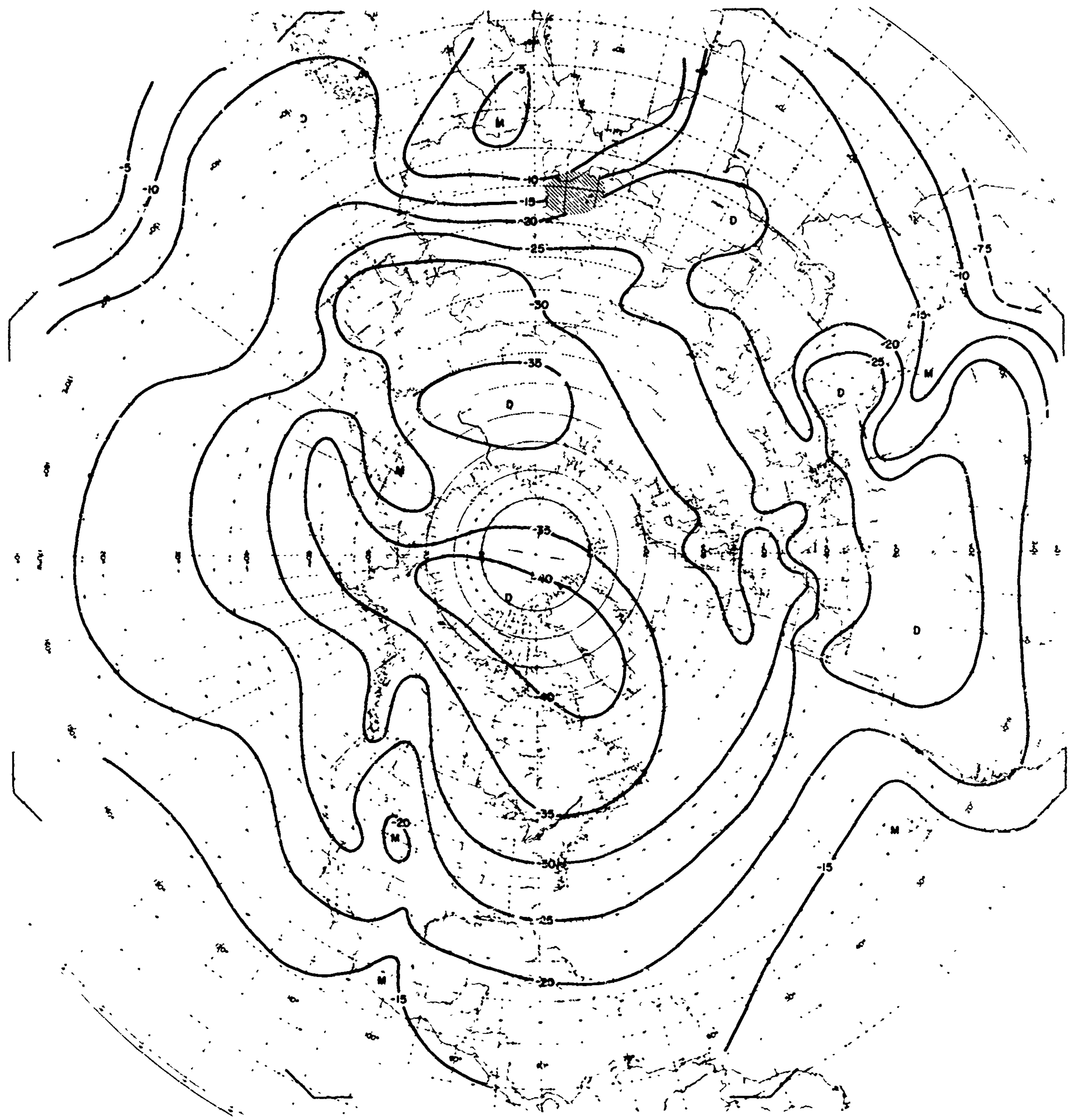

Plate 66. Dew Point at 700 mb in April, 5 Percentile

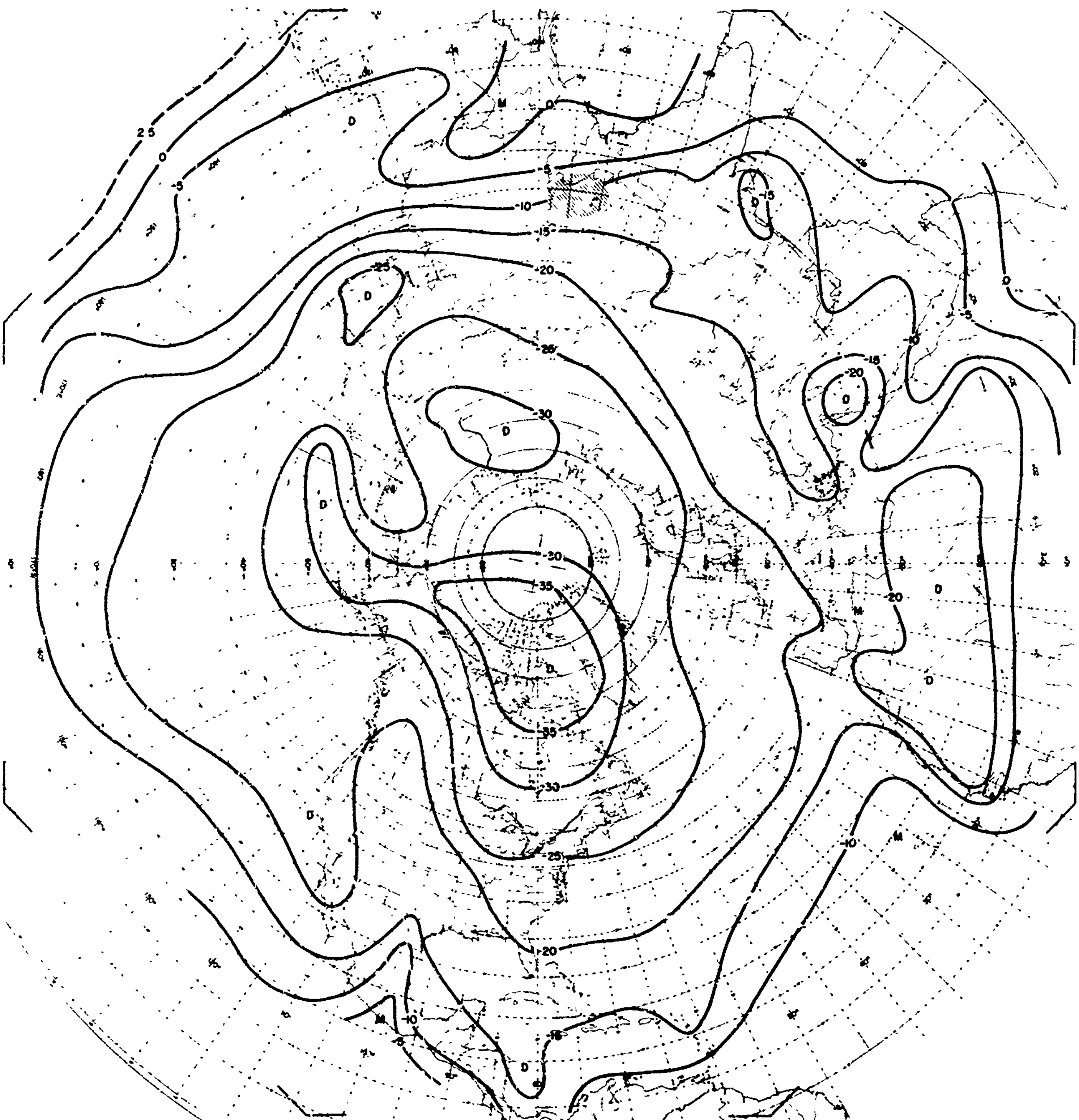

Plate 67. Dew Point at 700 mb in April, 25 Percentile

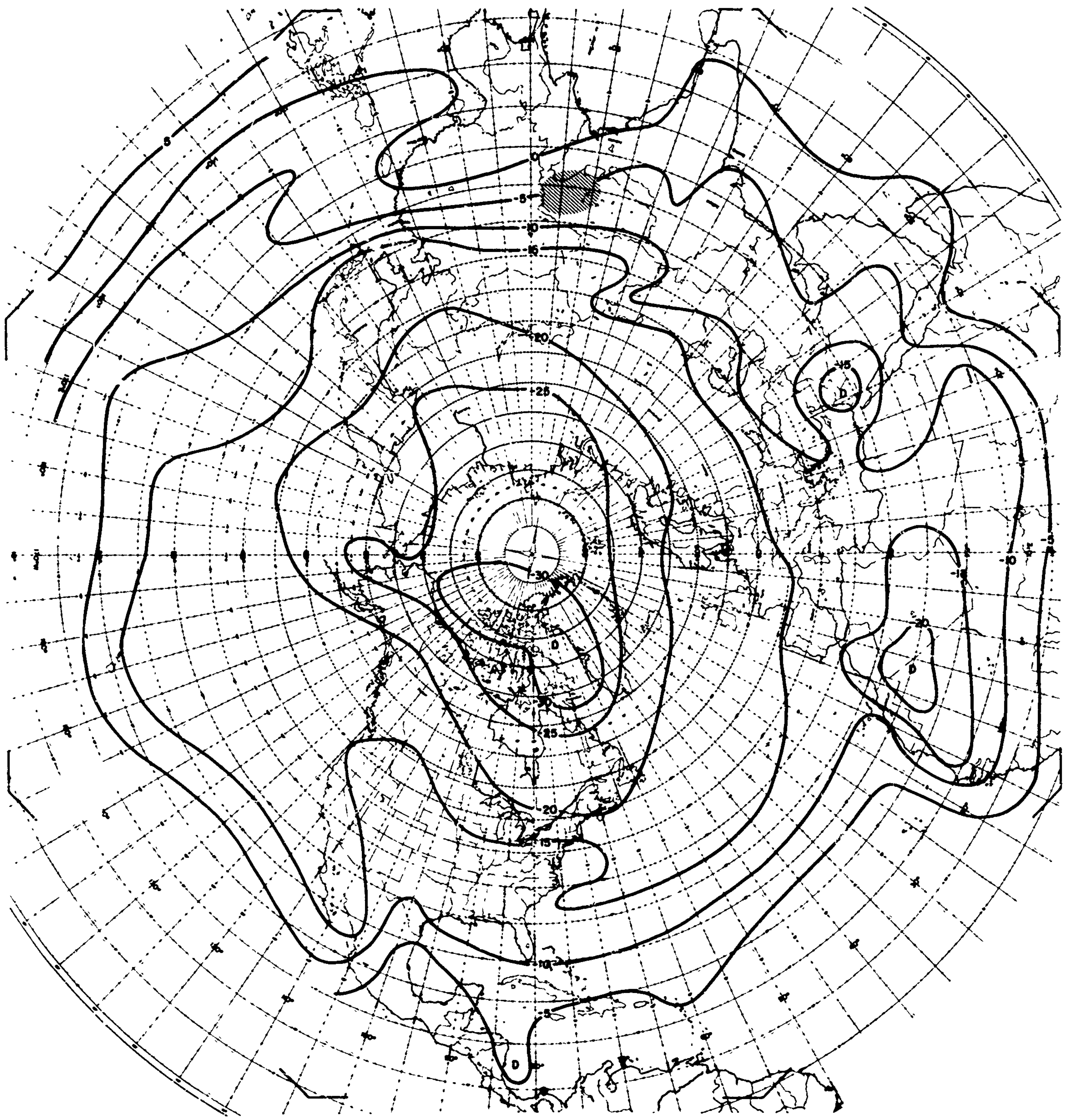

Plate 68. Dew Point at 700 mb in April, 50 Percentile

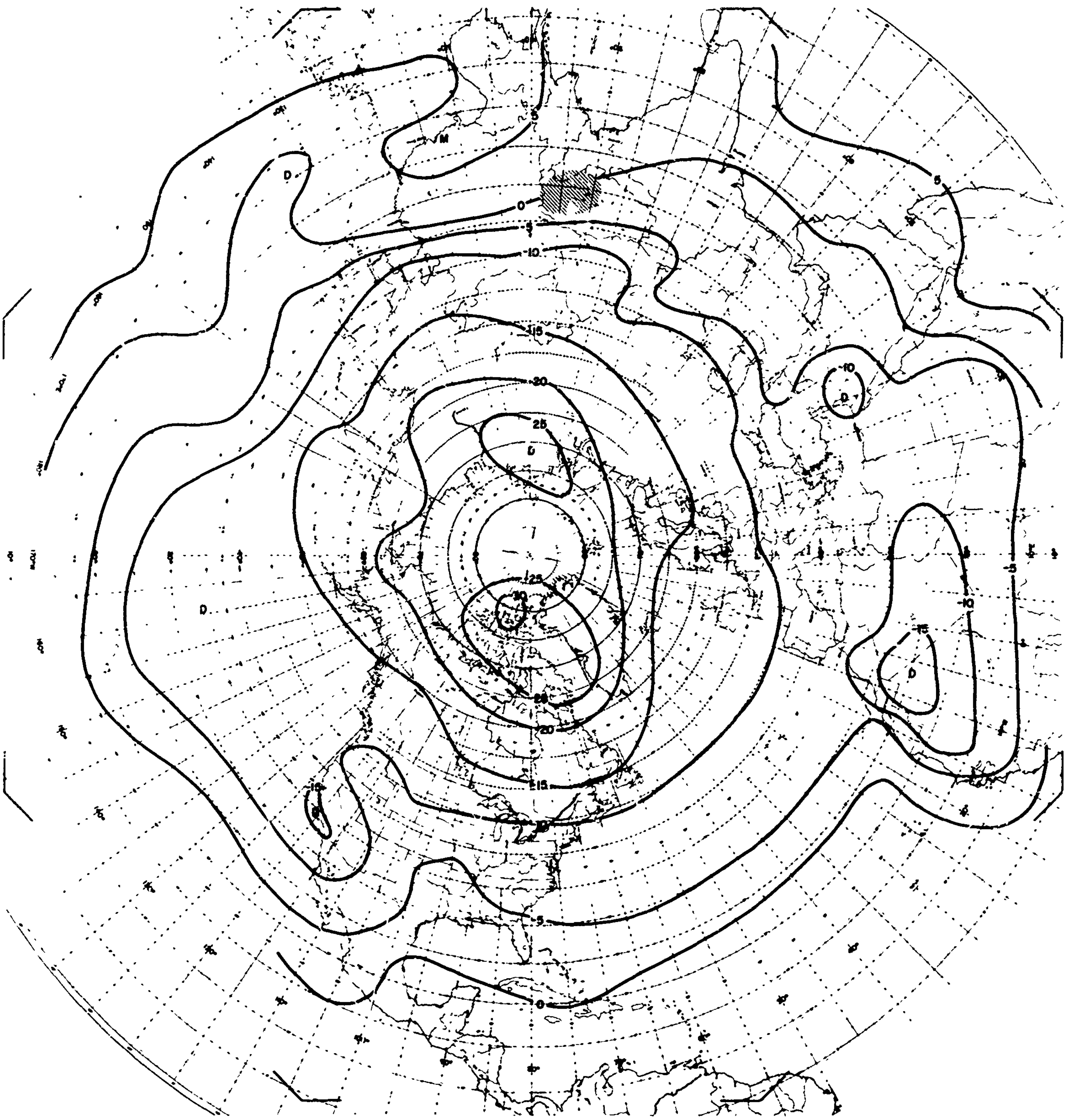

Plate 69. Dew Point at 700 mb in April, 75 Percentile

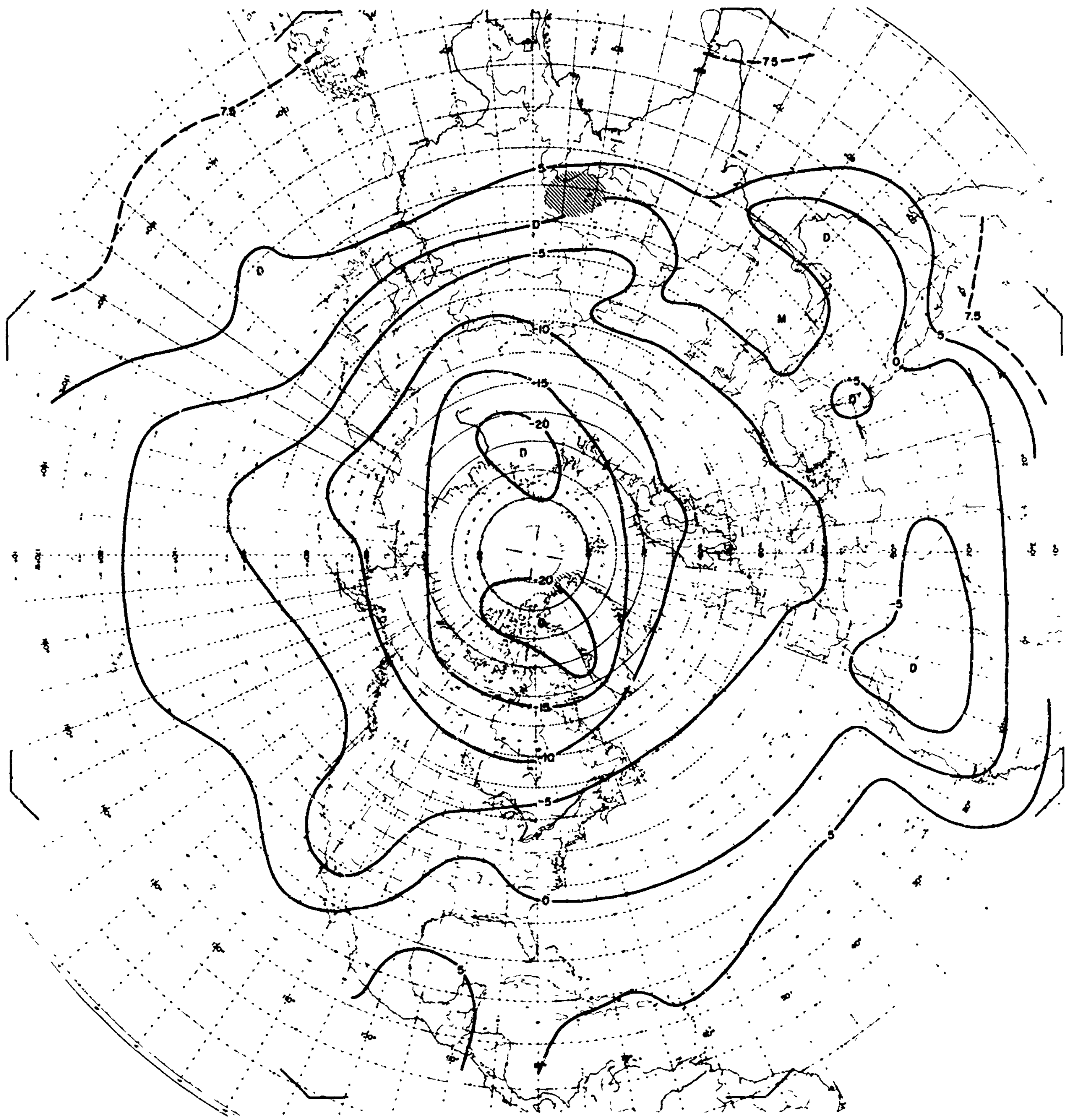

Plate 70. Dew Point at 700 mb in April, 95 Percentile

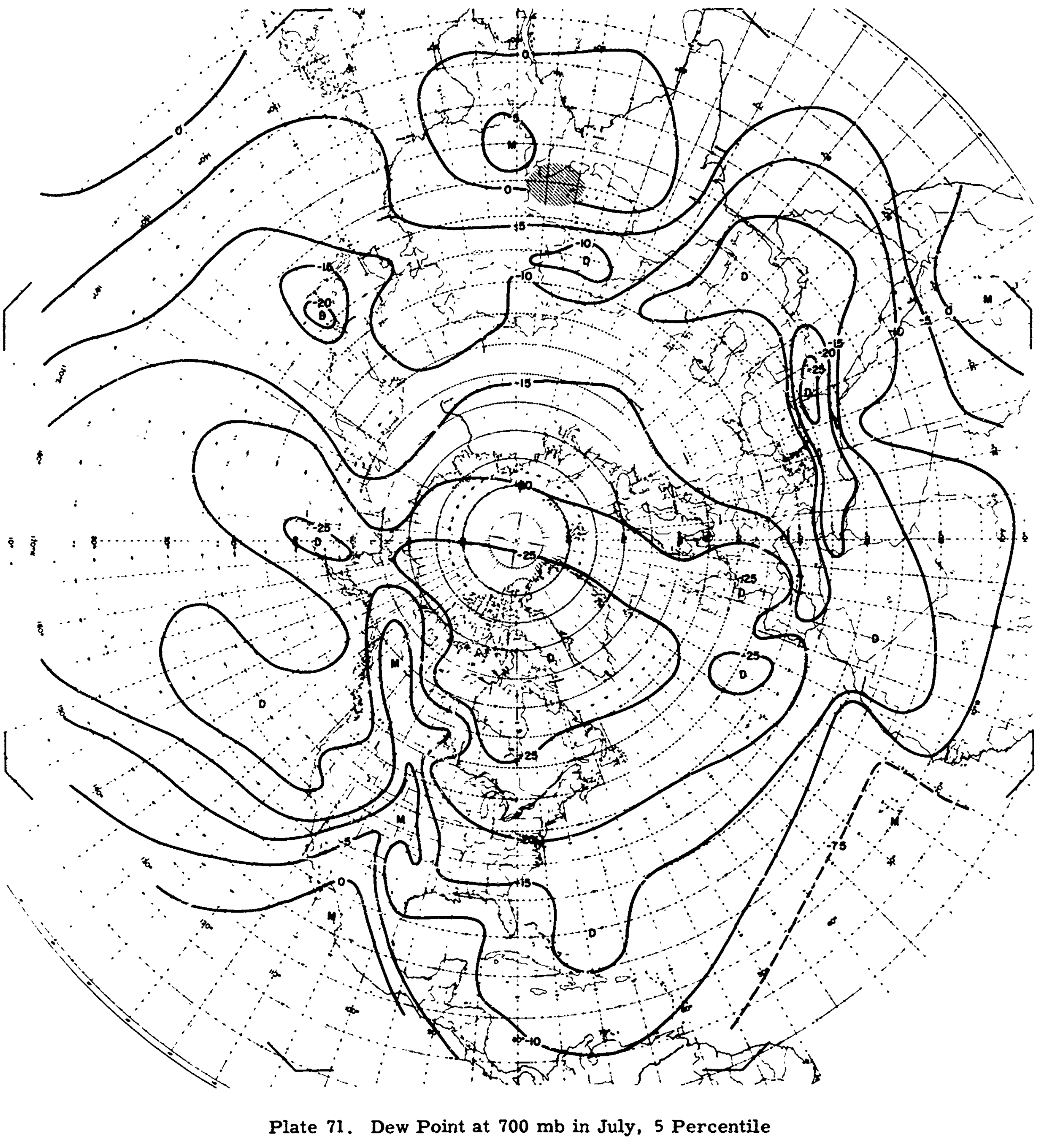

Plate 71. Dew Point at 700 mb in July, 5 Percentile

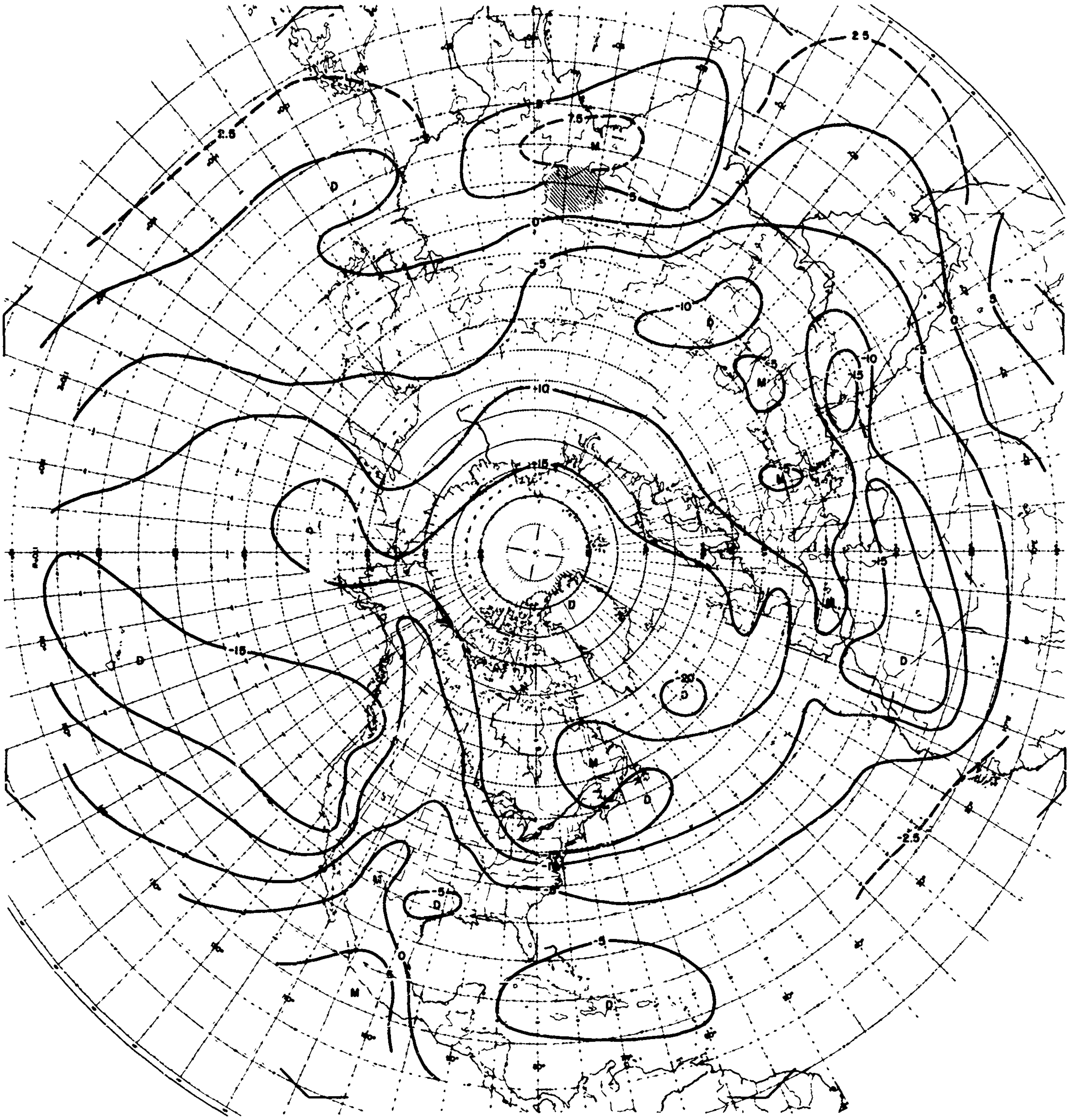

Plate 72. Dew Point at 700 mb in July, 25 Percentile

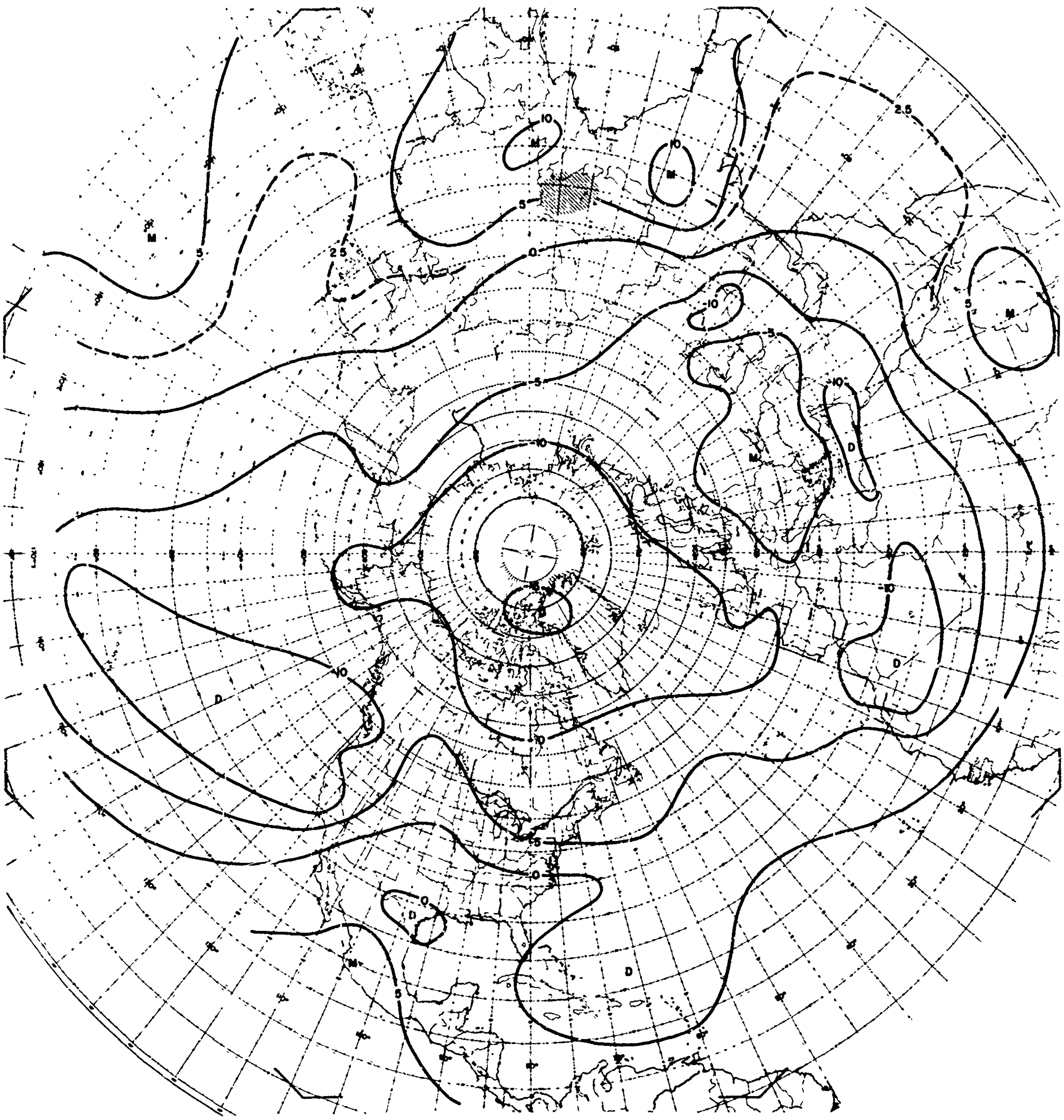

Plate 73. Dew Point at 700 mb in July, 50 Percentile

Plate 74. Dew Point at 700 mb in July, 75 Percentile

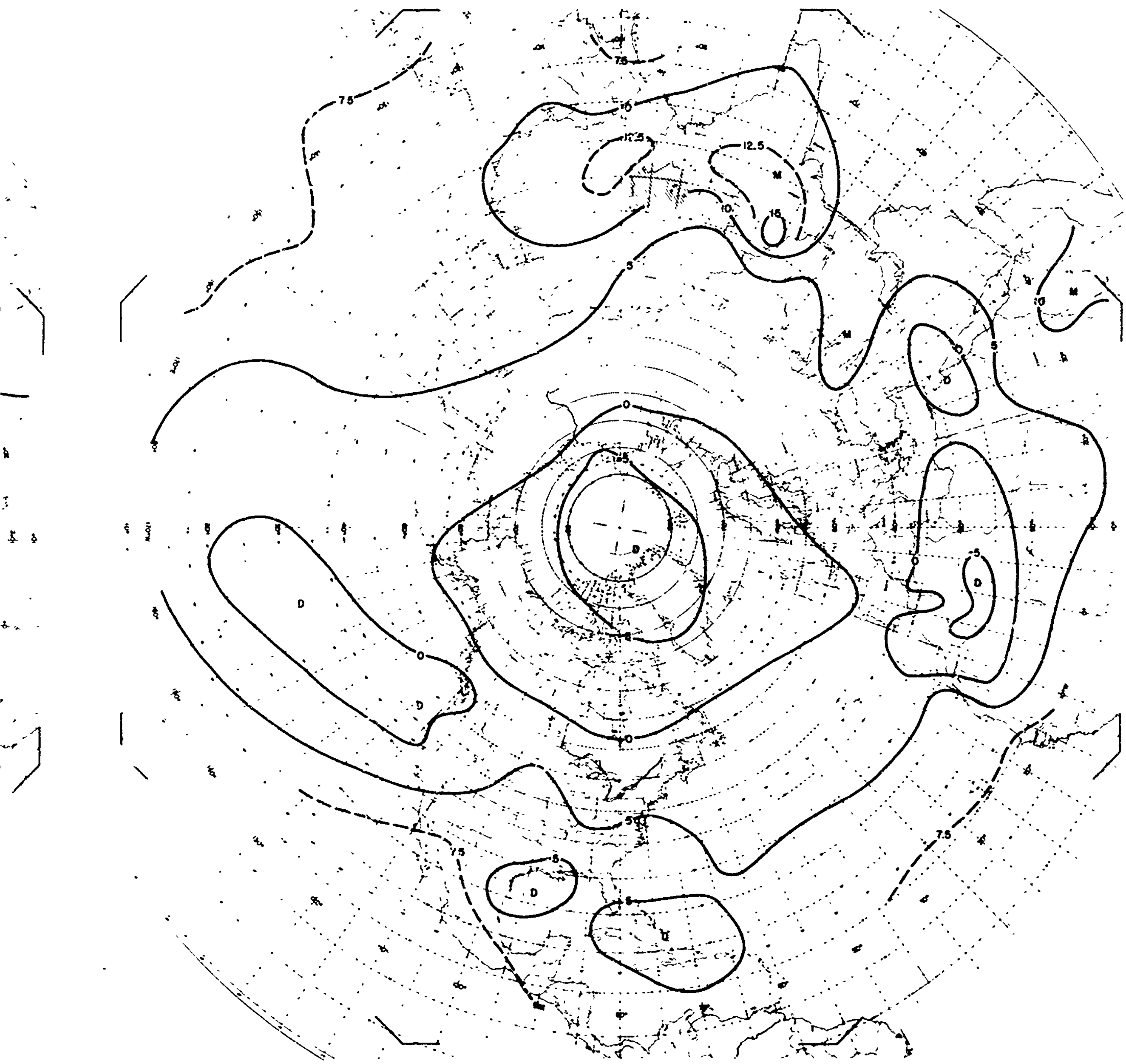

Plate 75. Dew Point at 700 mb in July, 95 Percentile

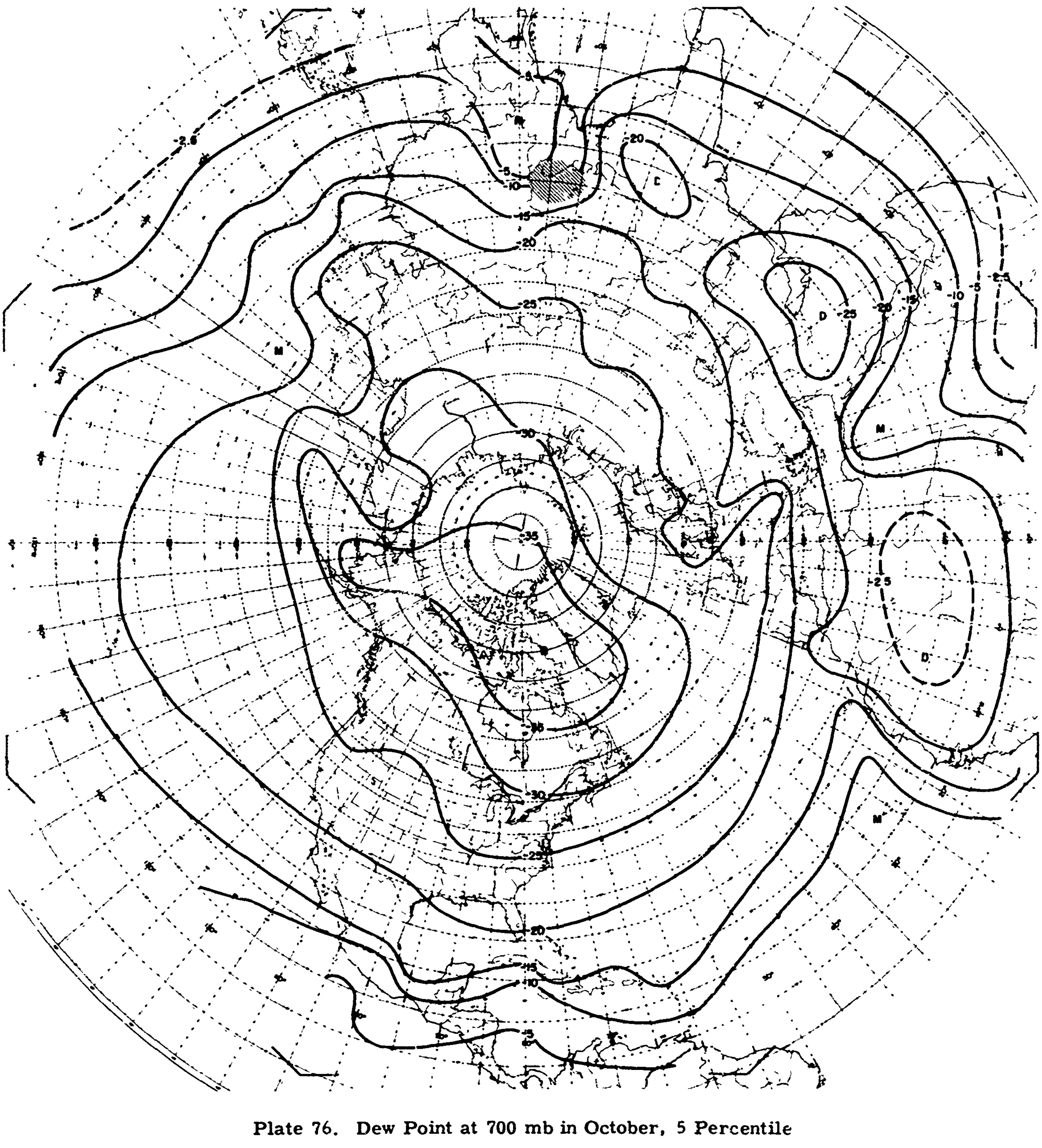

Plate 76. Dew Point at 700 mb in October, 5 Percentile

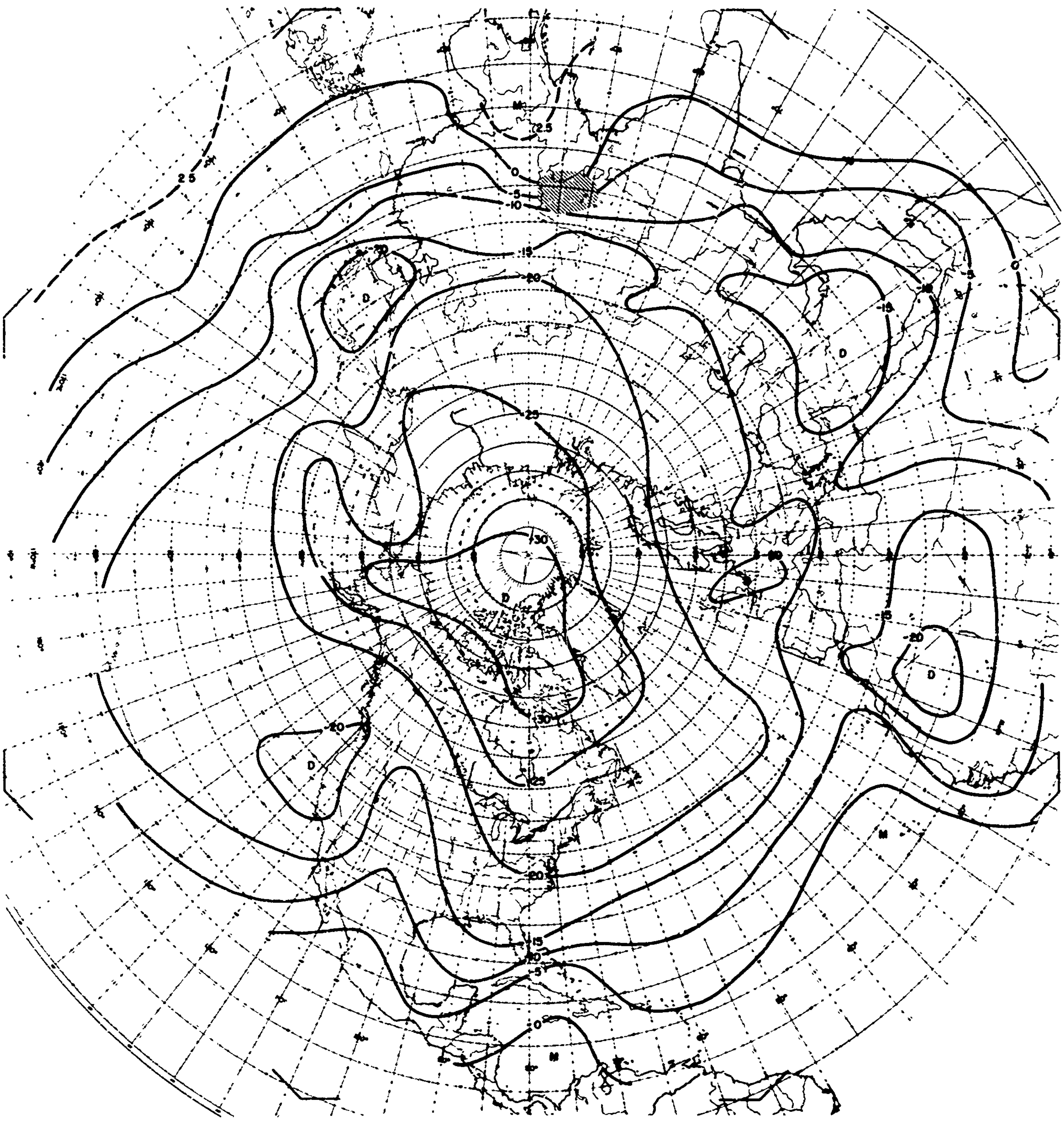

Plate 77. Dew Point at 700 mb in October, 25 Percentile

Plate 78. Dew Point at 700 mb in October, 50 Percentile

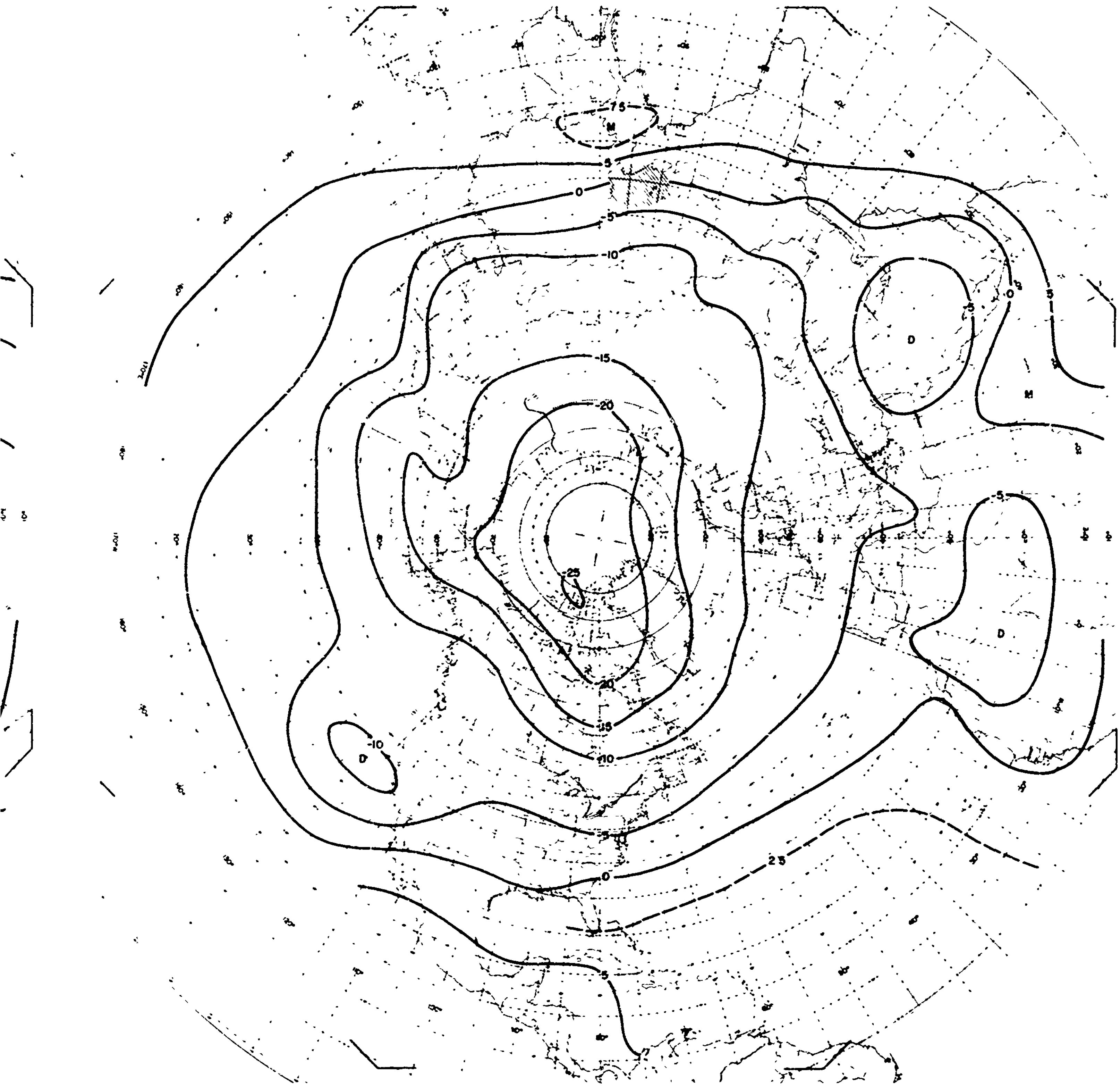

Plate 79. Dew Point at 700 mb in October, 75 Percentile

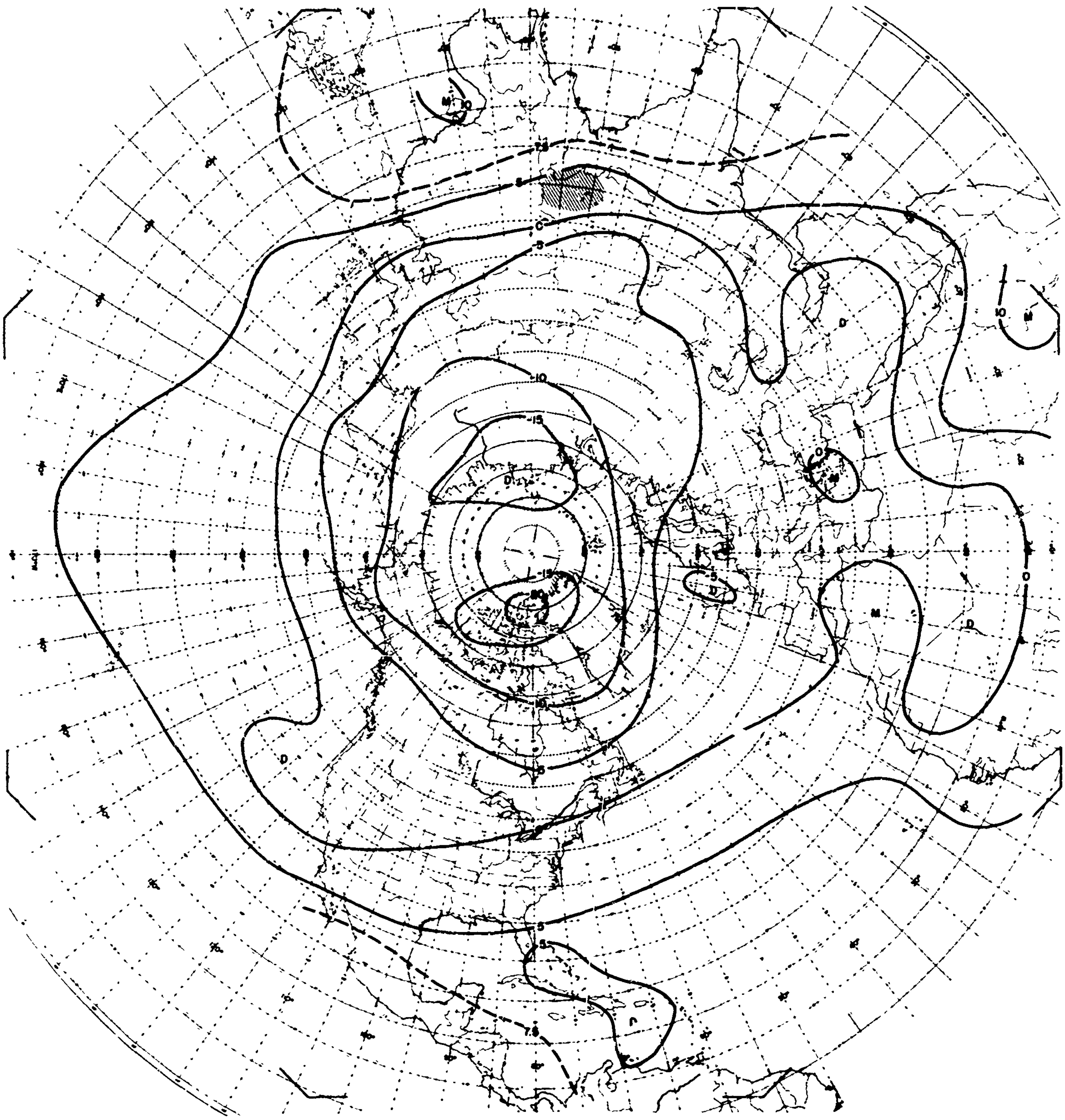

Plate 80. Dew Point at 700 mb in October, 95 Percentile

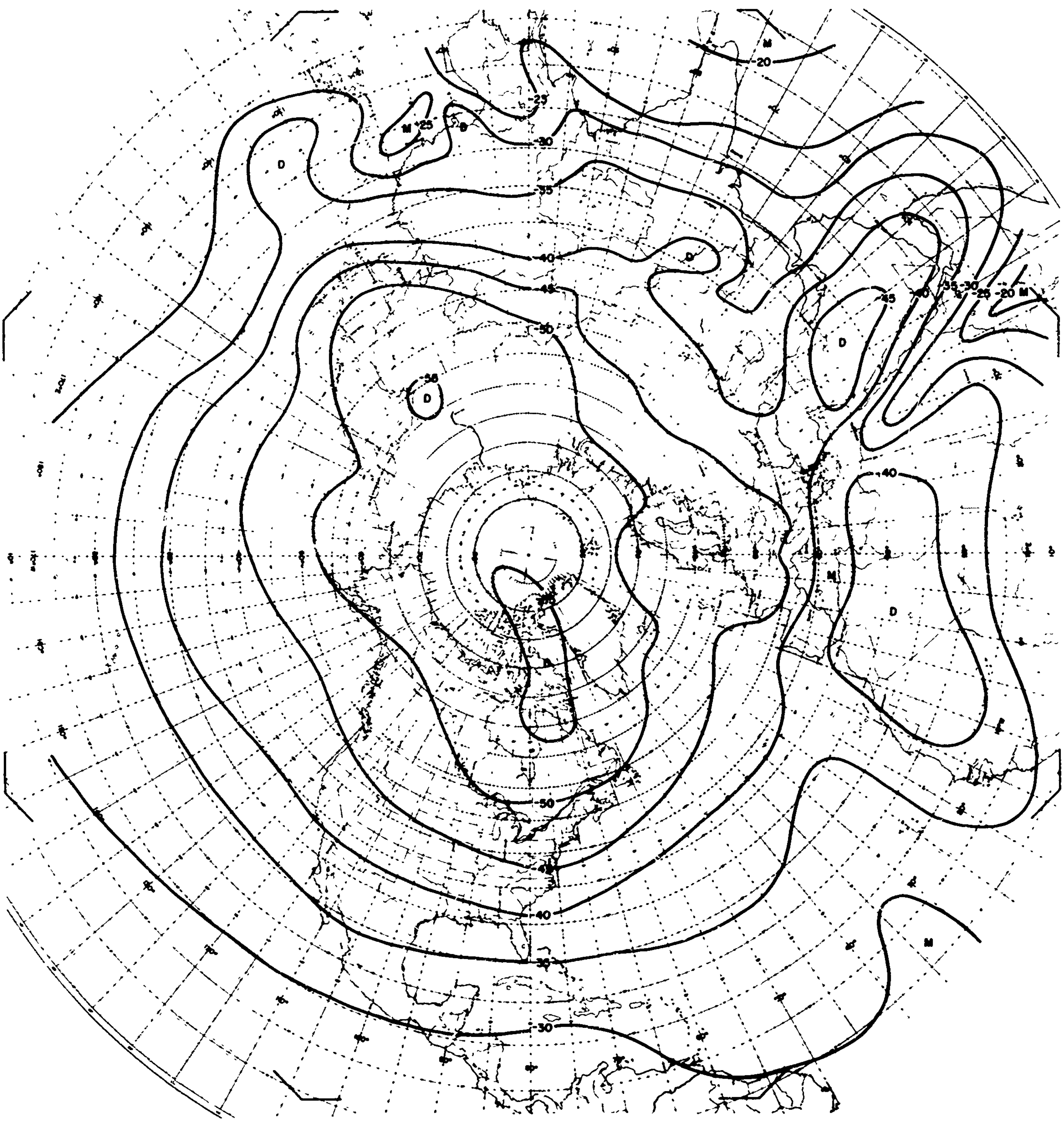

Plate 81. Dew Point at 500 mb in January, 5 Percentile

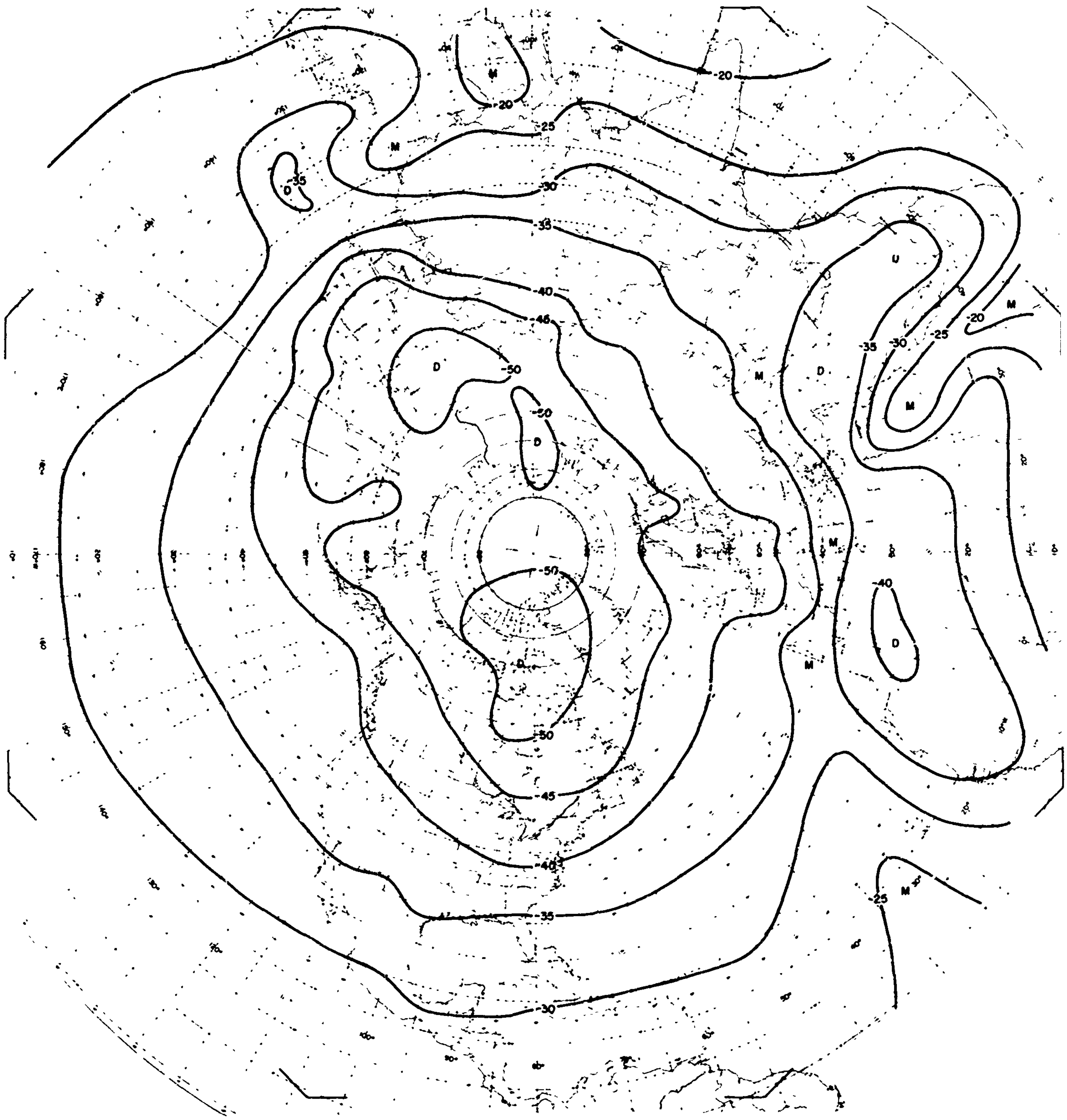

Plate 82. Dew Point at 500 mb in January, 25 Percentile

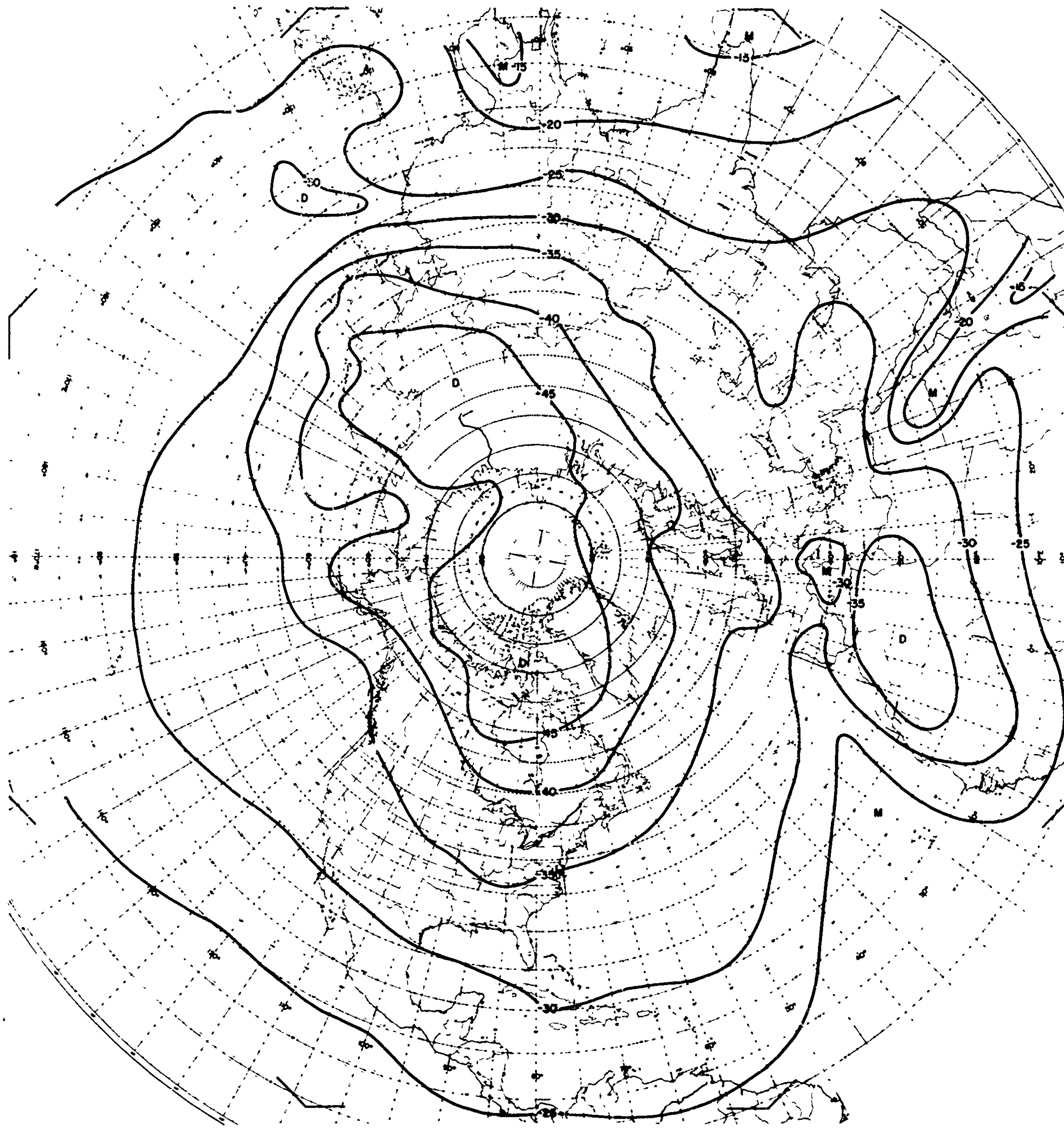

Plate 83. Dew Point at 500 mb in January, 50 Percentile

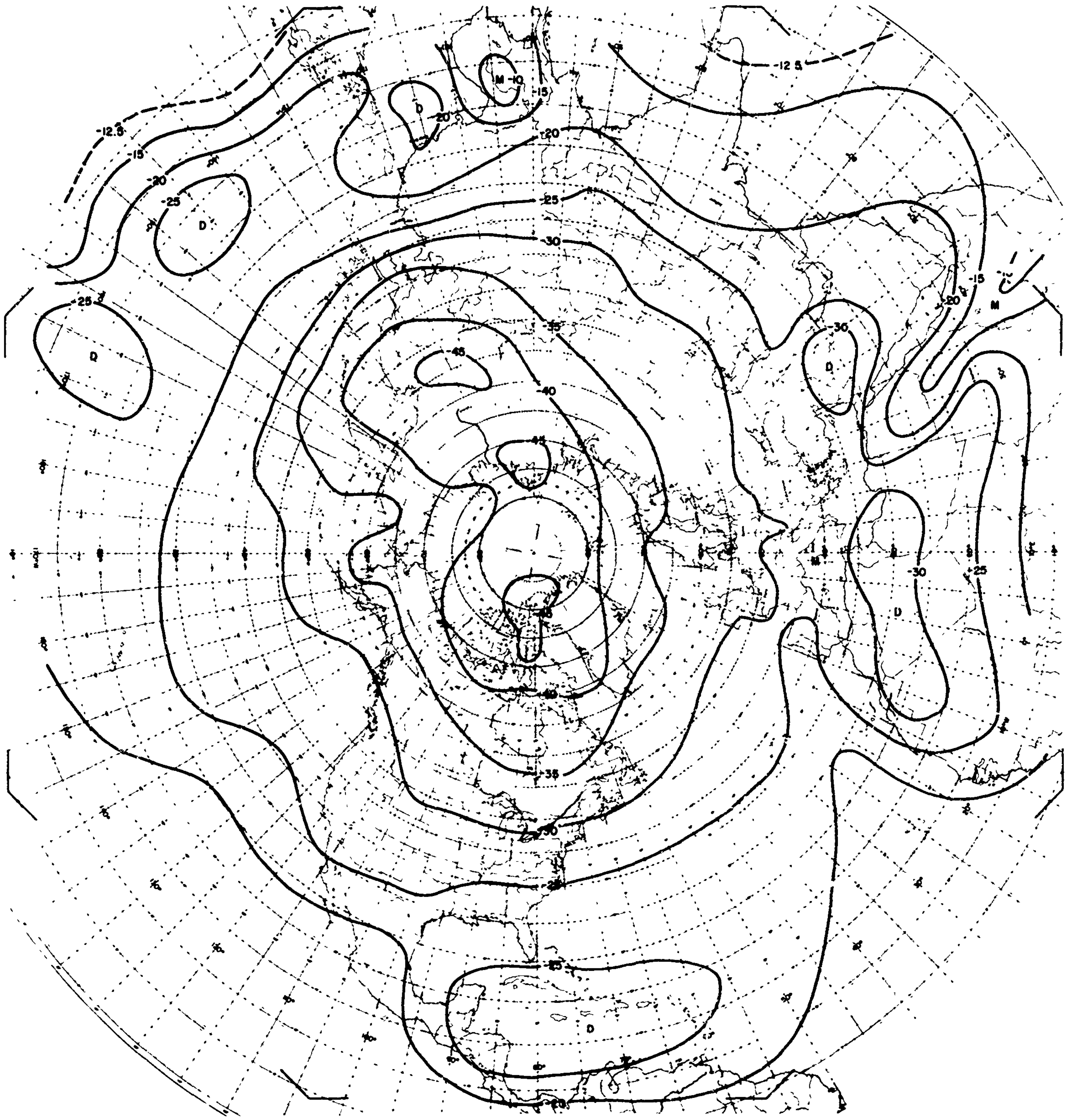

Plate 84. Dew Point at 500 mb in January, 75 Percen'

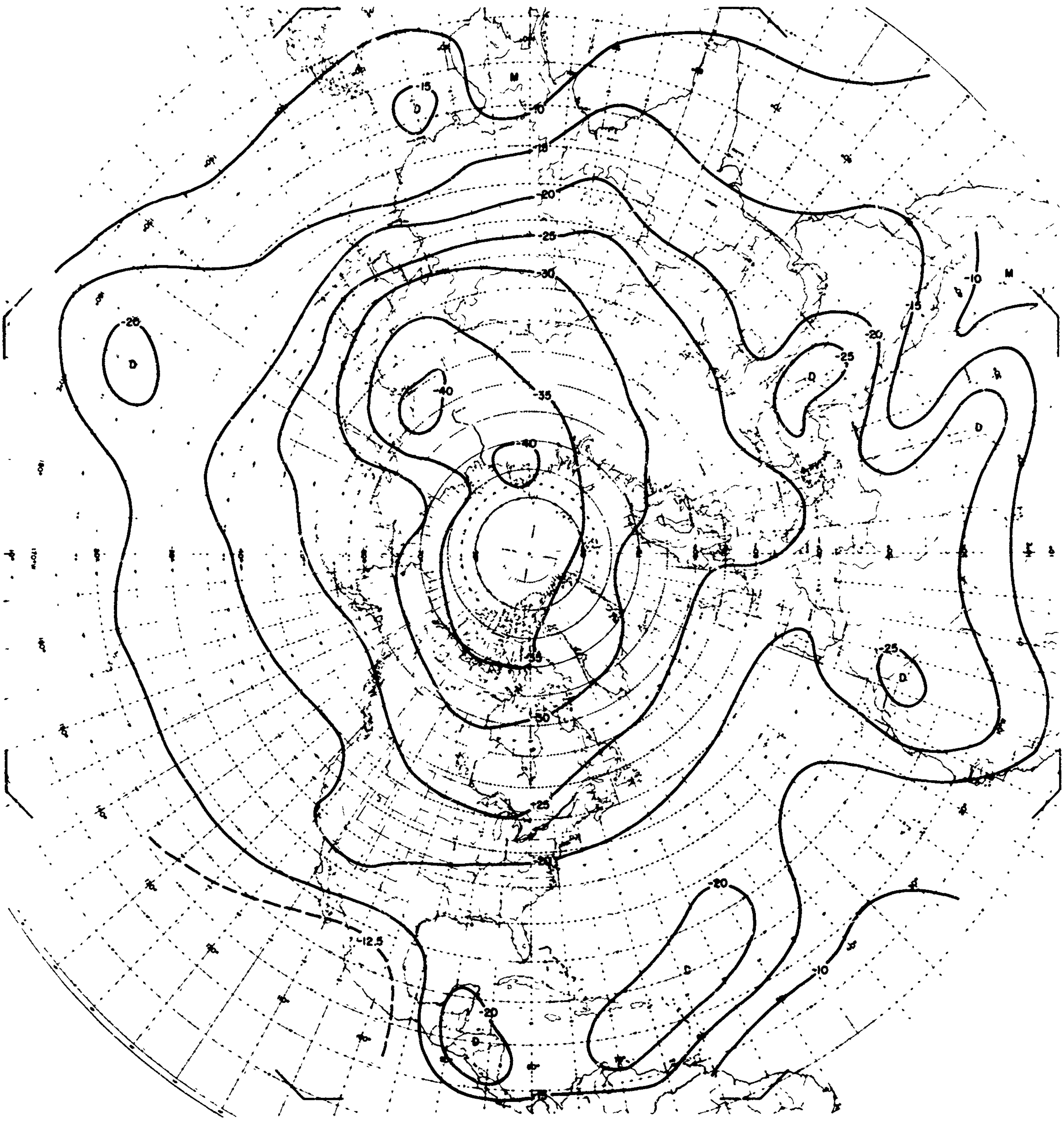

Plate 85. Dew Point at 500 mb in January, 95 Percentile

Plate 86. Dew Point at 500 mb in April, 5 Percentile

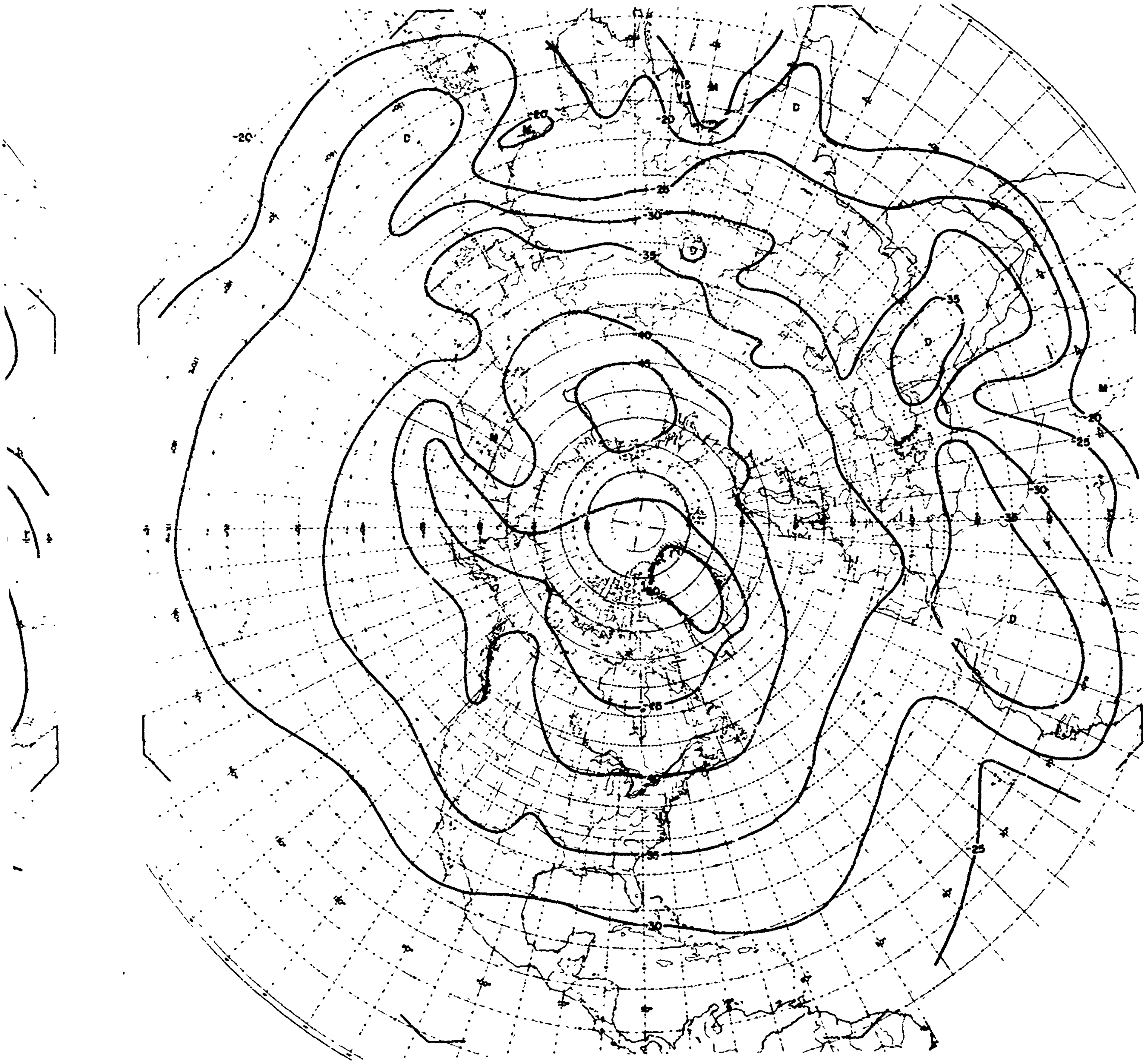

Plate 87. Dew Point at 50C . in April, 25 Percentile

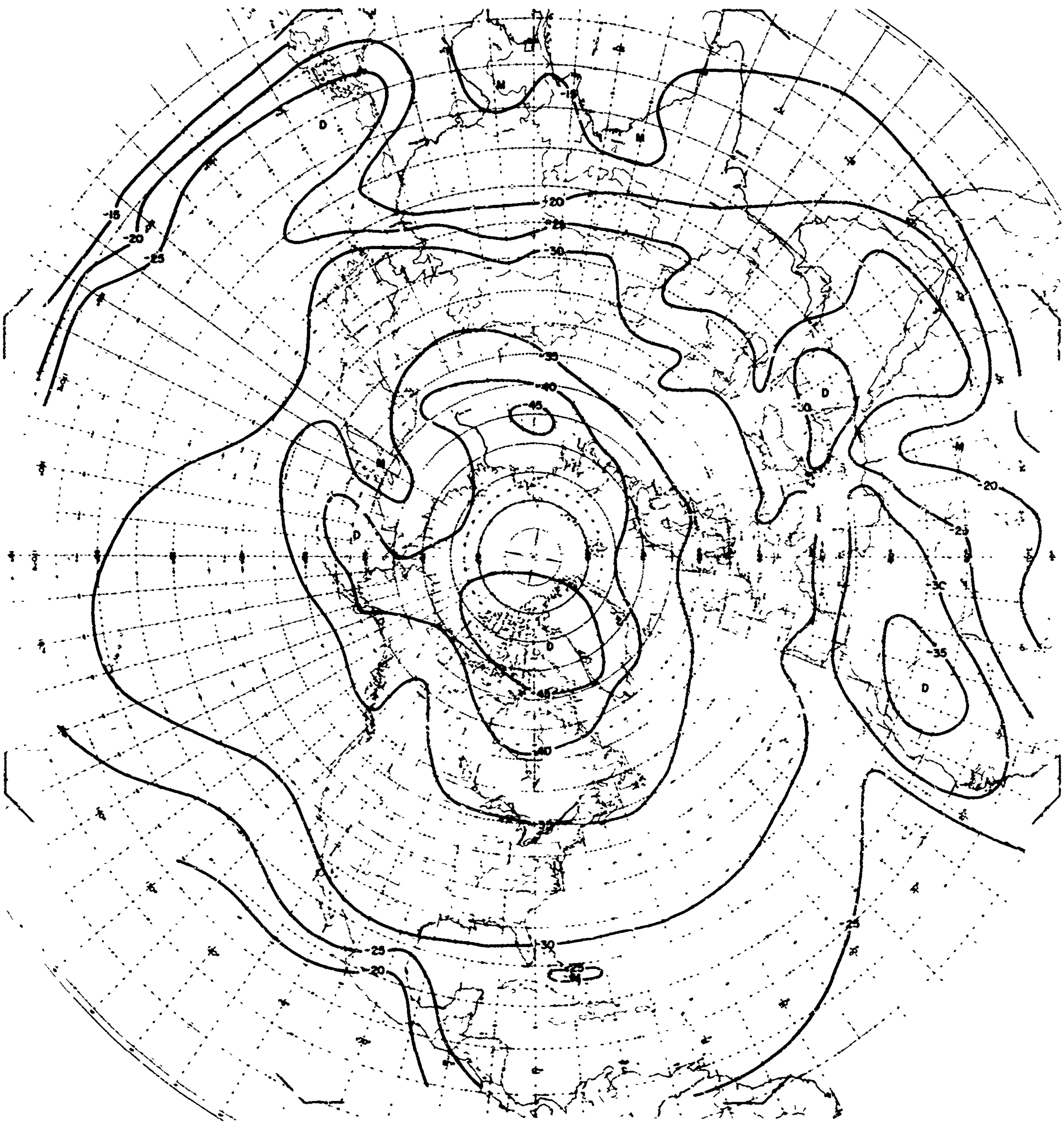

Plate 88. Dew Point at . . mb in April, 50 Percentile

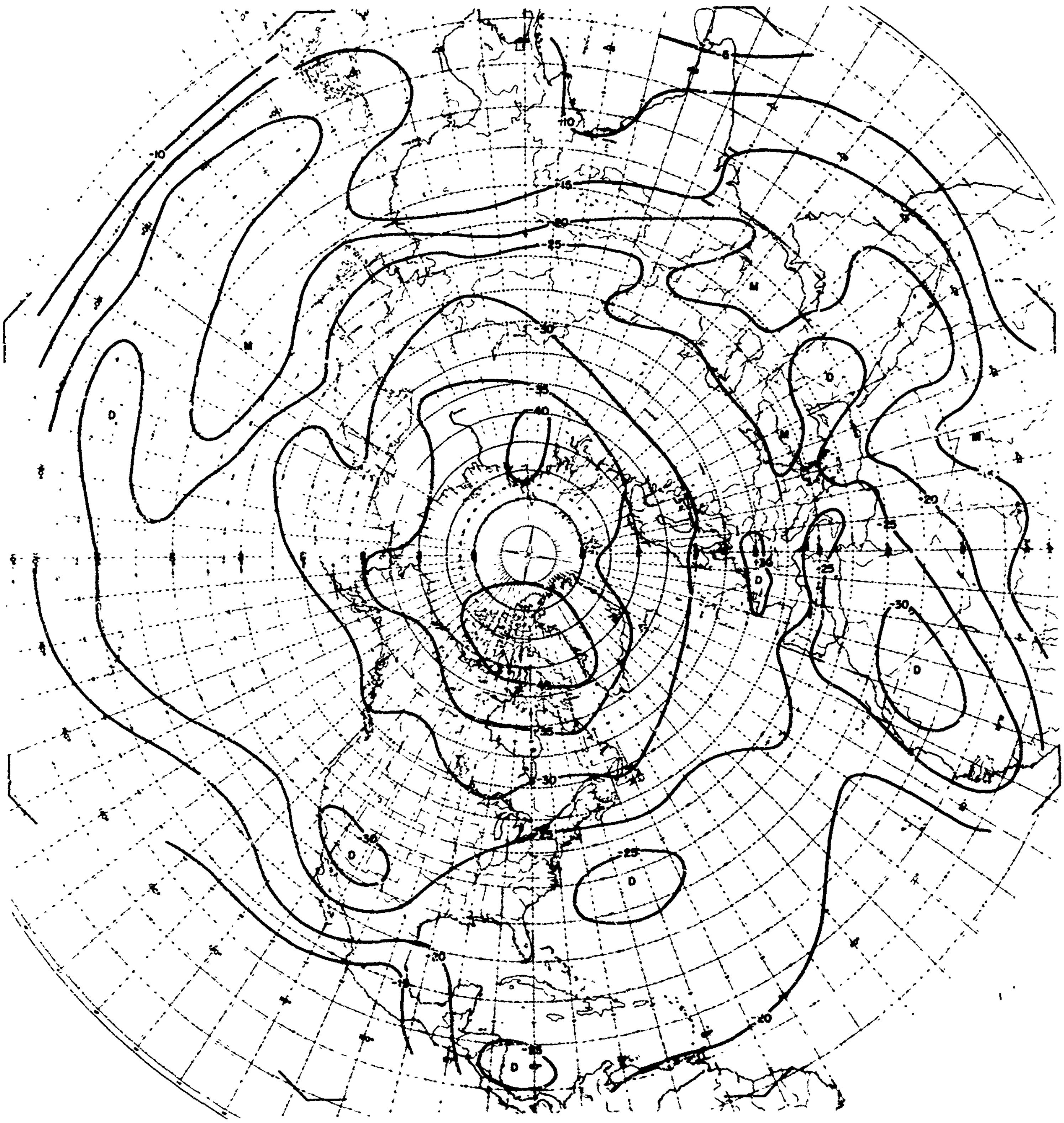

Plate 89. Dew Point at 500 mb in April, 75 Percentile

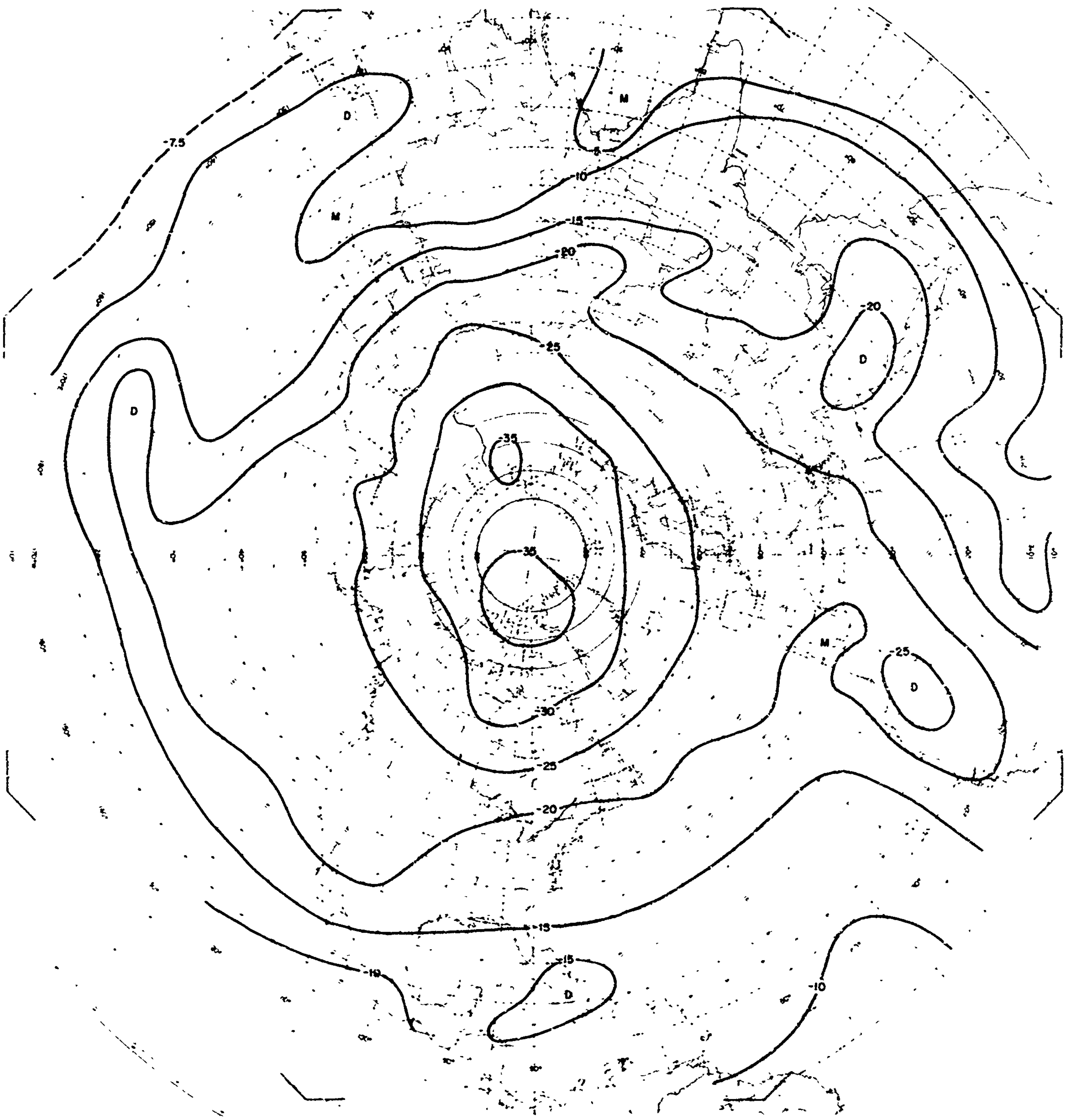

Plate 90. Dew Point at 500 mb in April, 95 Percentile

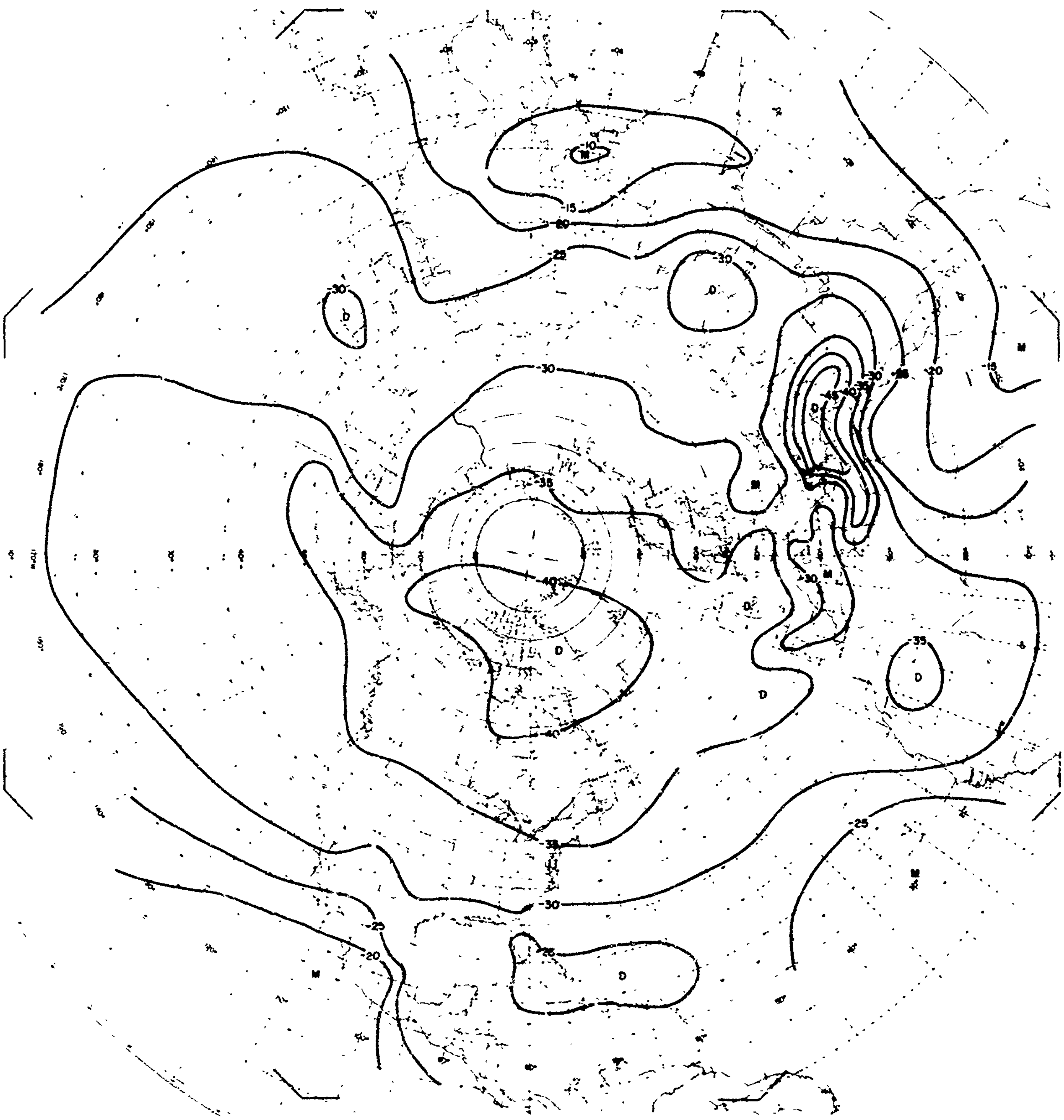

Plate 91. Dew Point at 500 mb in July, 5 Percentile

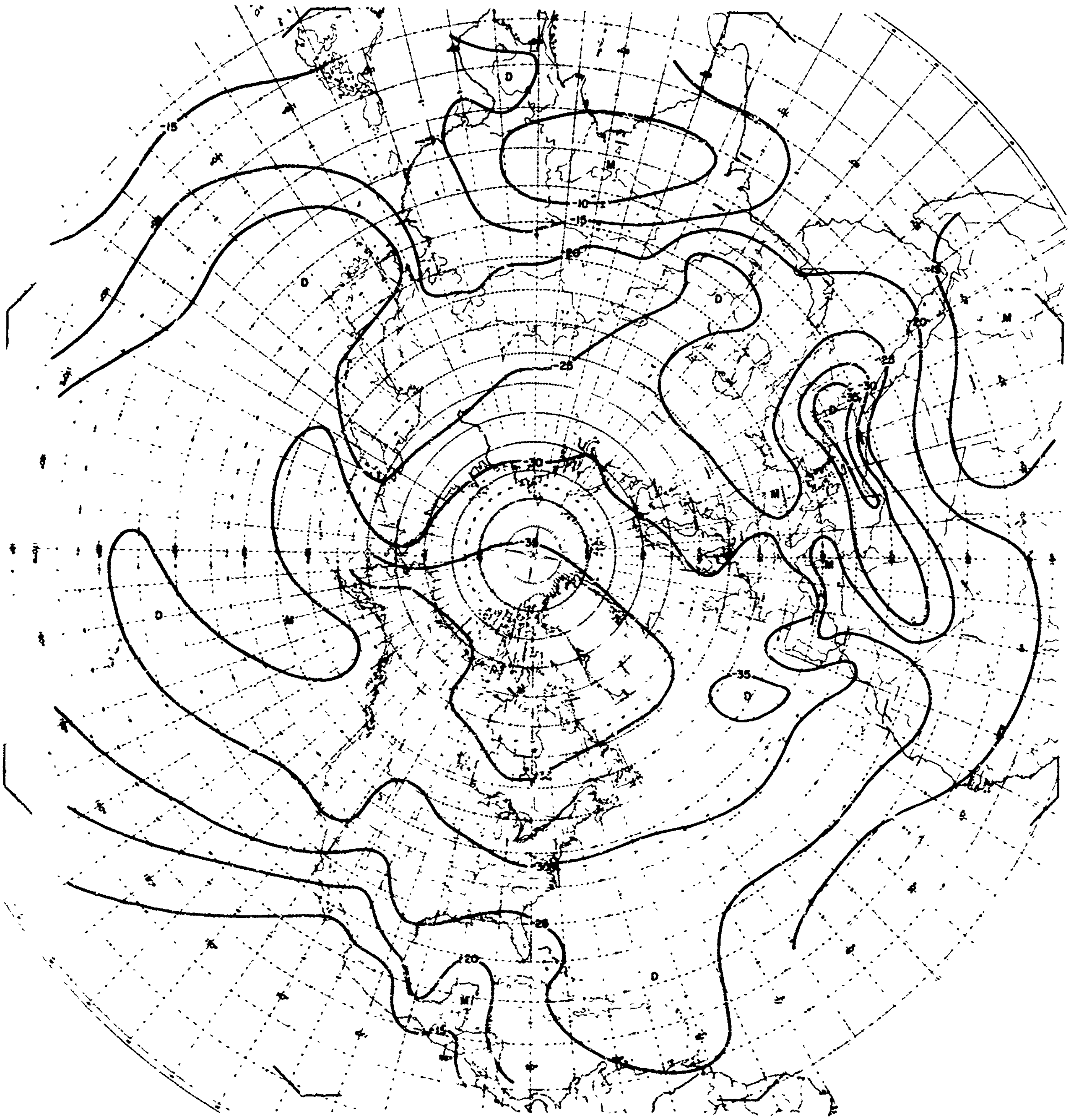

Plate 92. Dew Point at 500 mb in July, 25 Percent

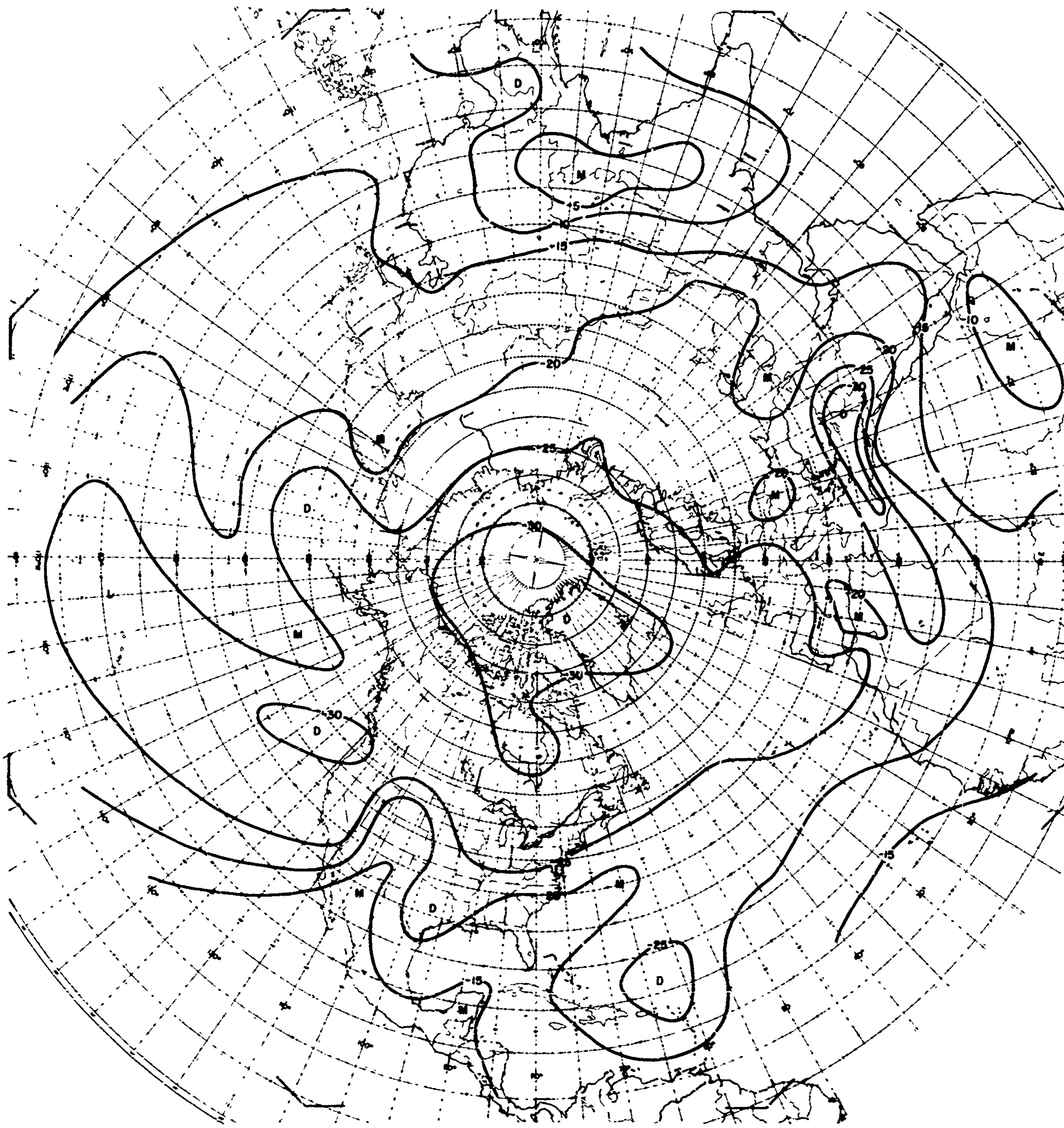

Plate 93. Dew Point at 500 mb in July, 50 Percentile

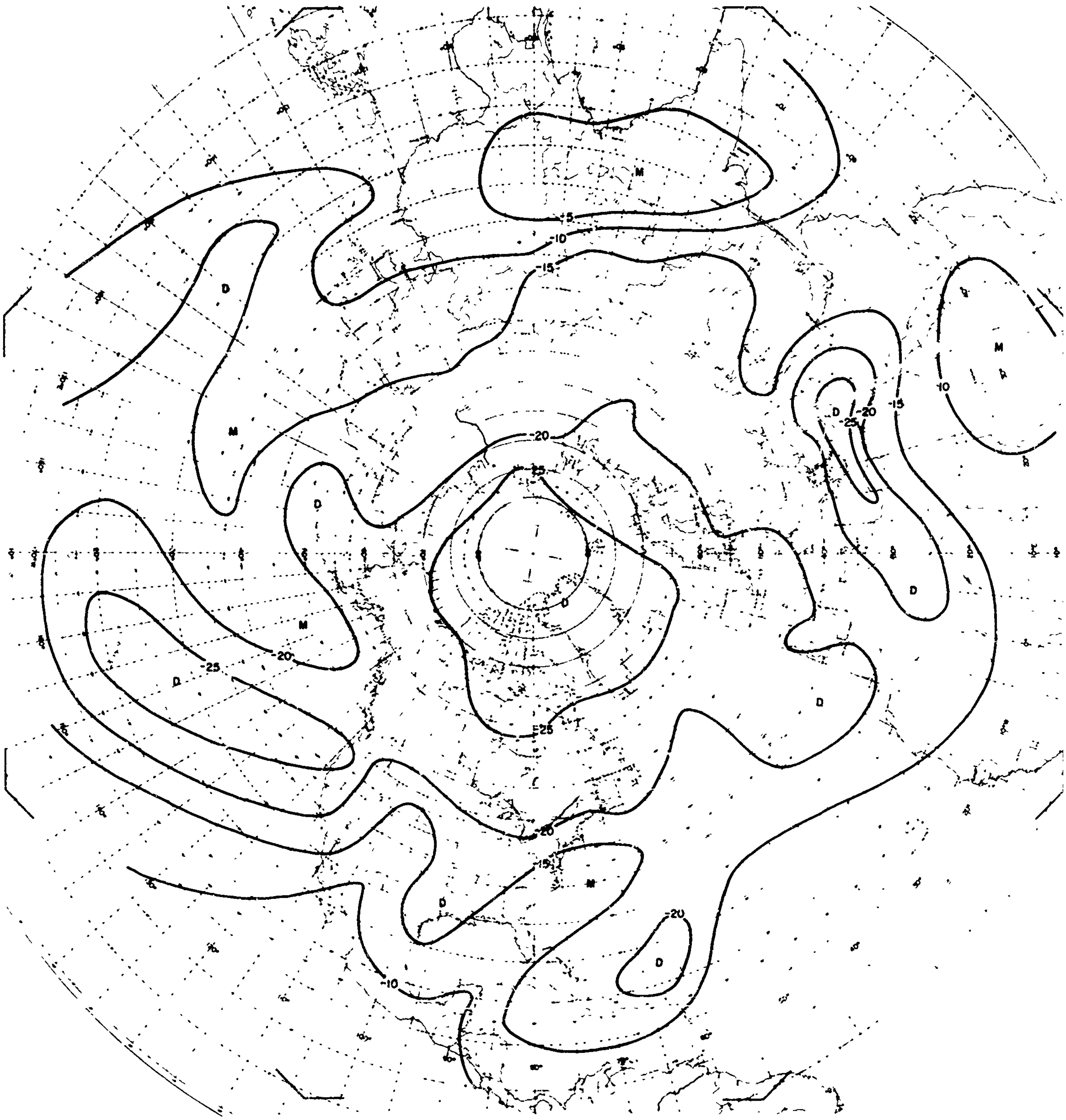

Plate 94. Dew Point at 500 mb in July, 75 Percentile

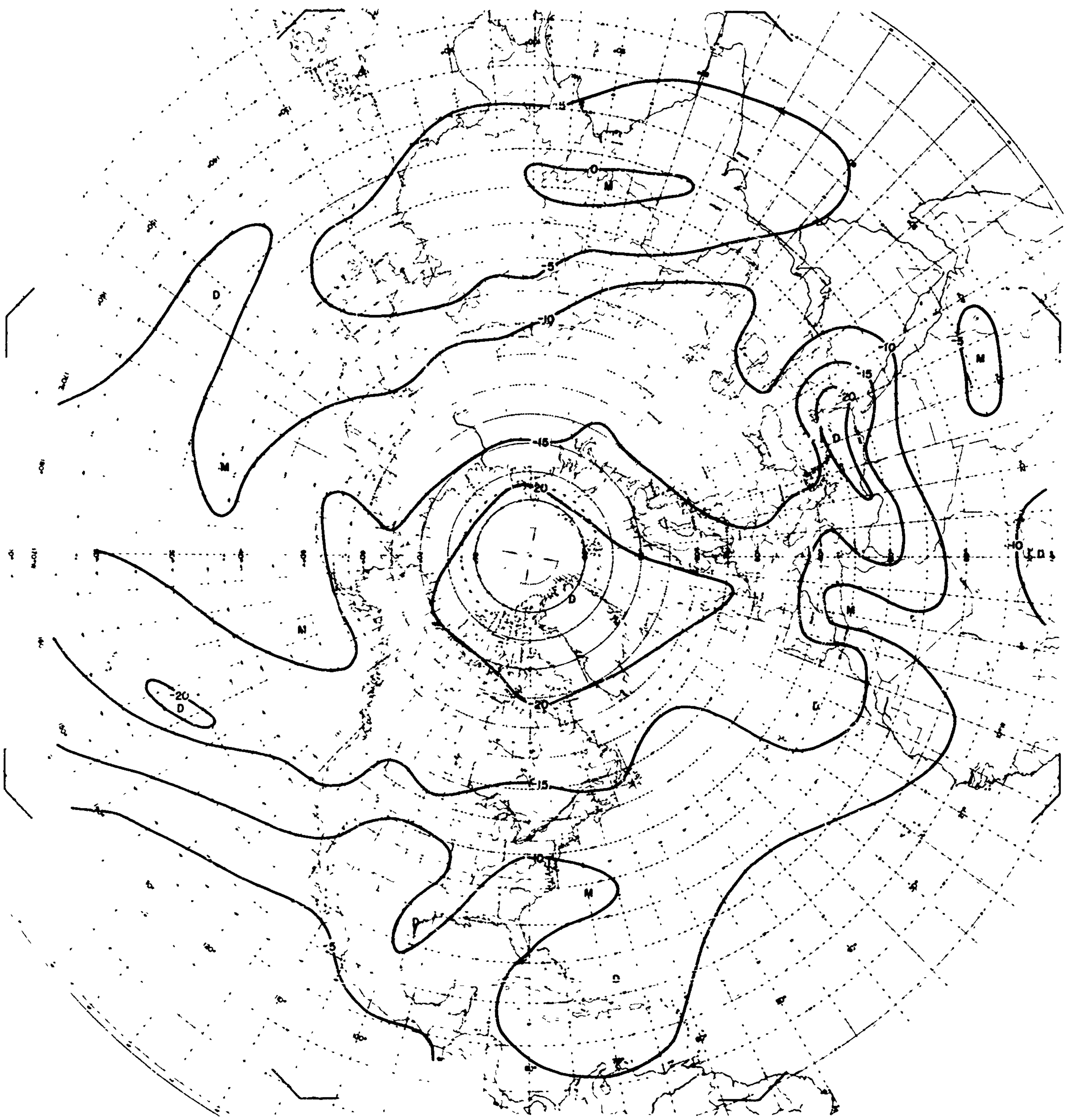

Plate 95. Dew Poi · a 00 mb in July, 95 Percentile

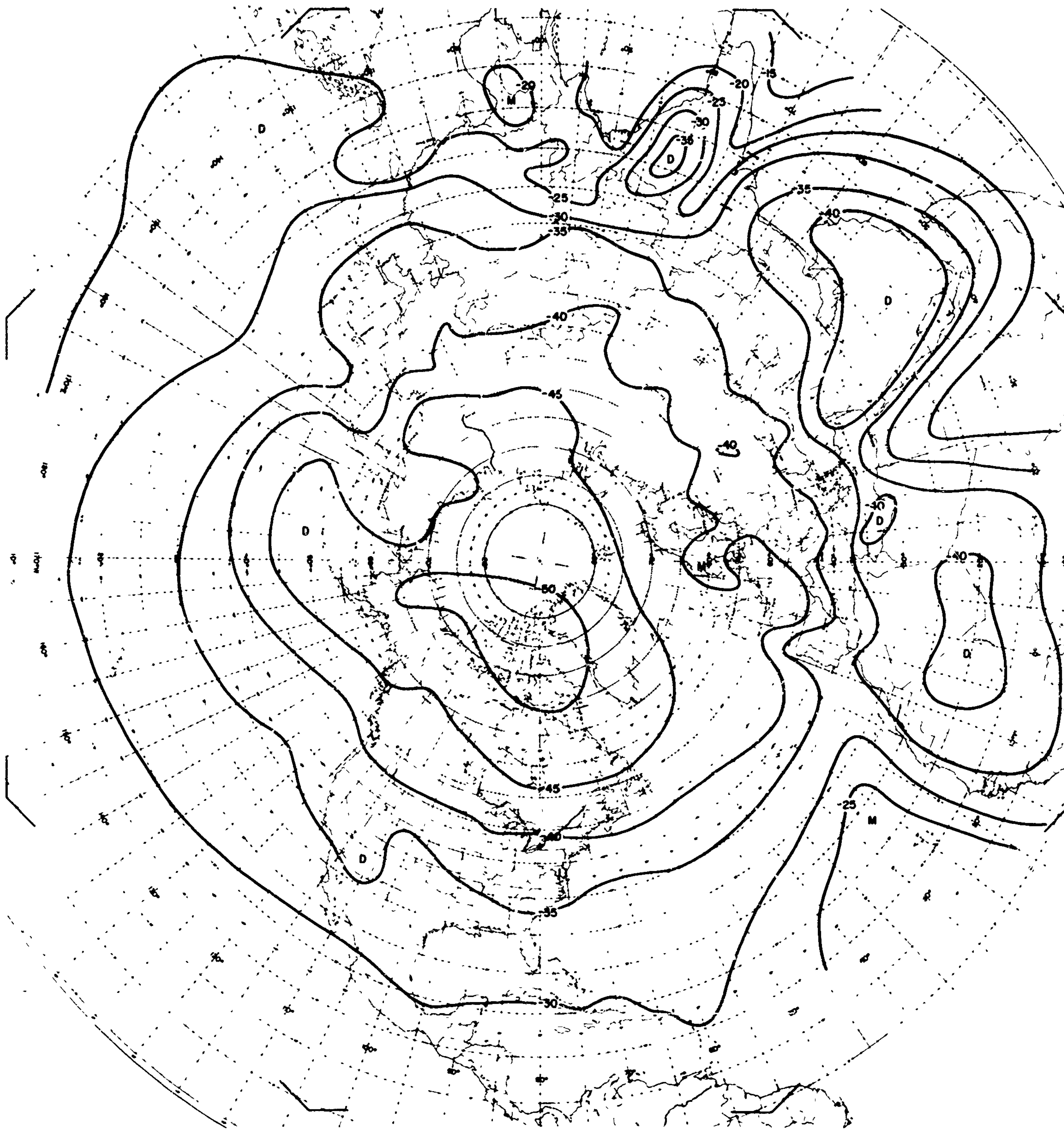

Plate 96. Dew Point at 500 mb in October, 5 Percentile

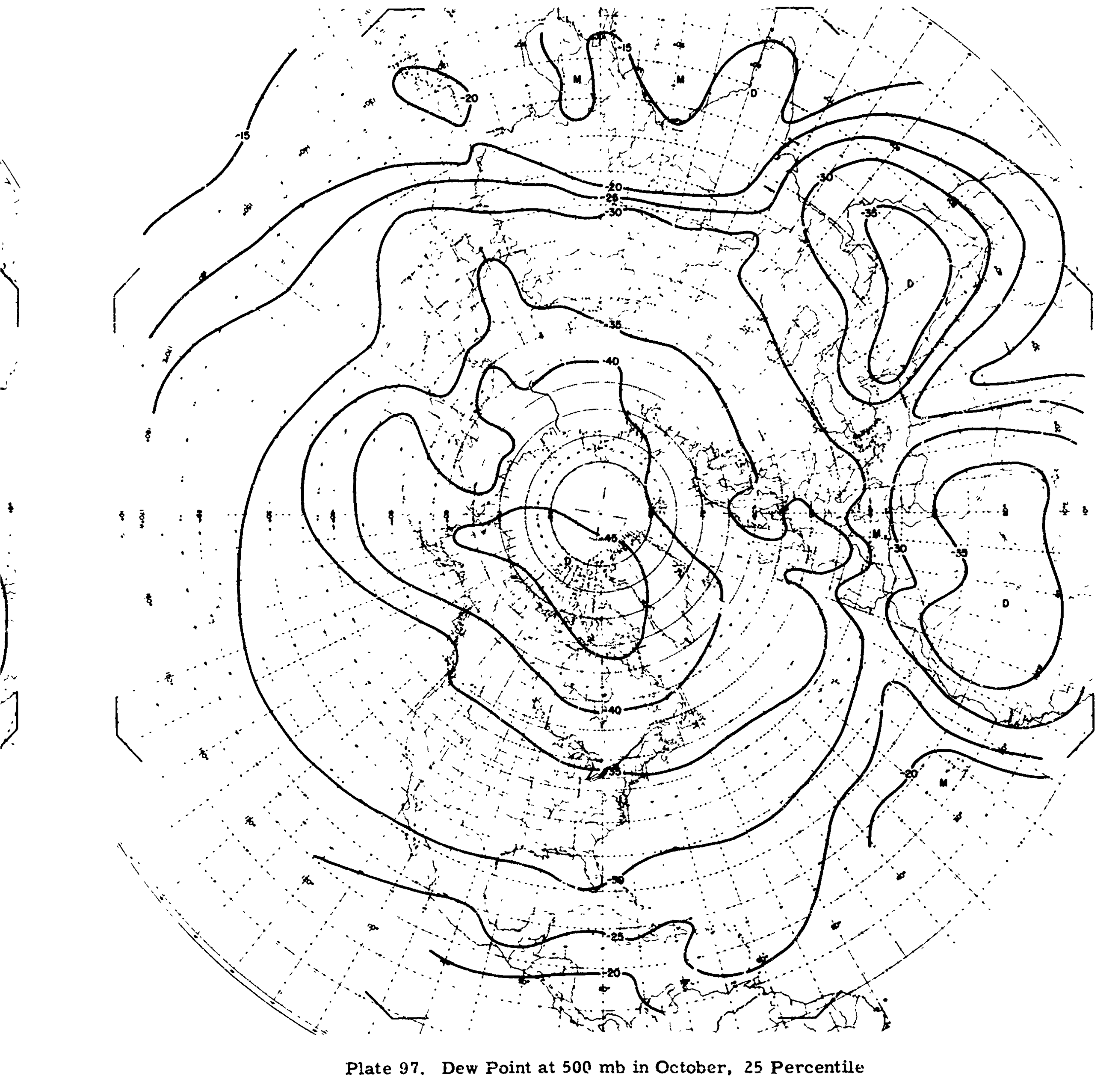

Plate 97. Dew Point at 500 mb in October, 25 Percentile

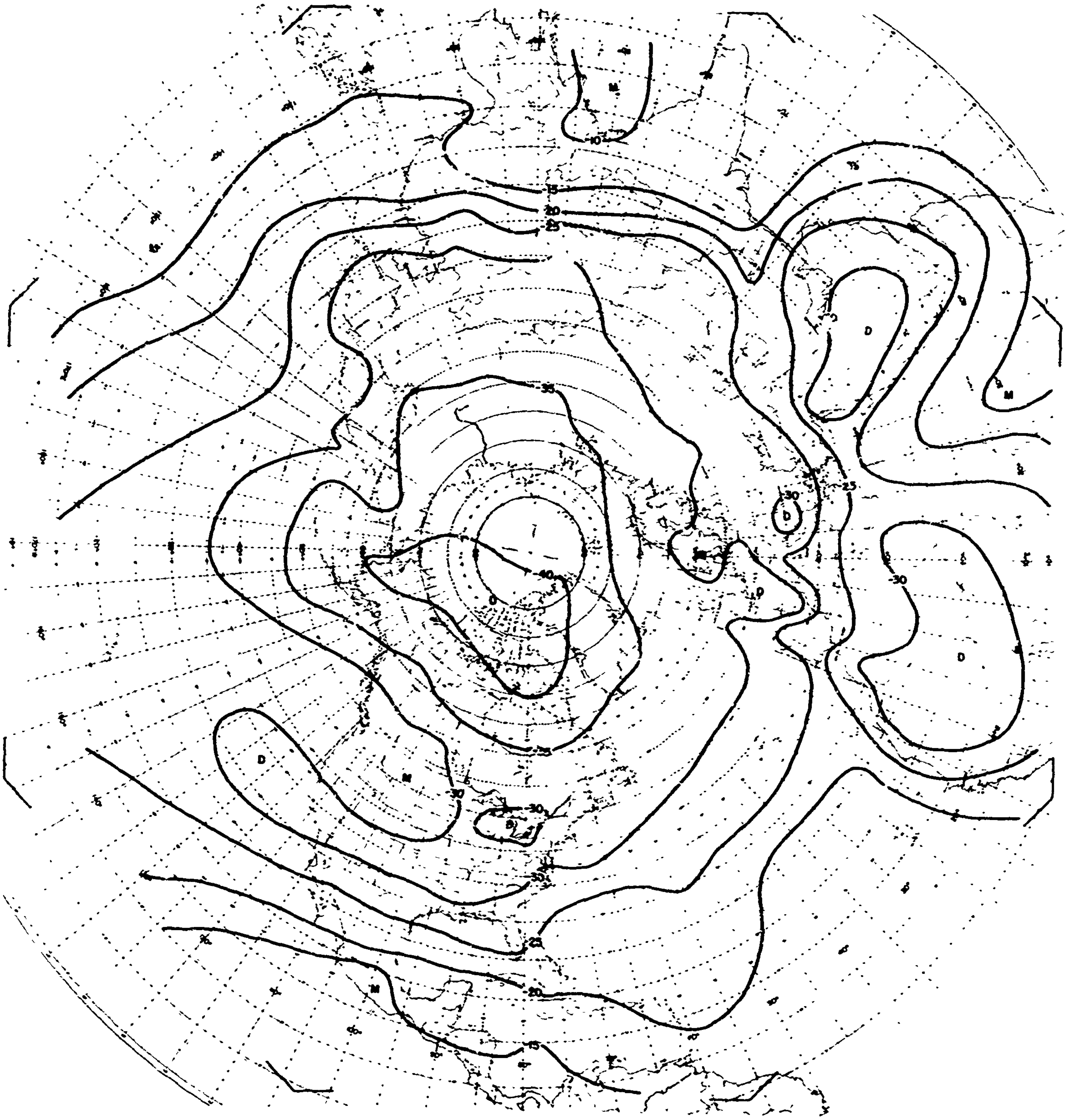

Plate 98. Dew Point at 500 mb in October, 50 Percentile

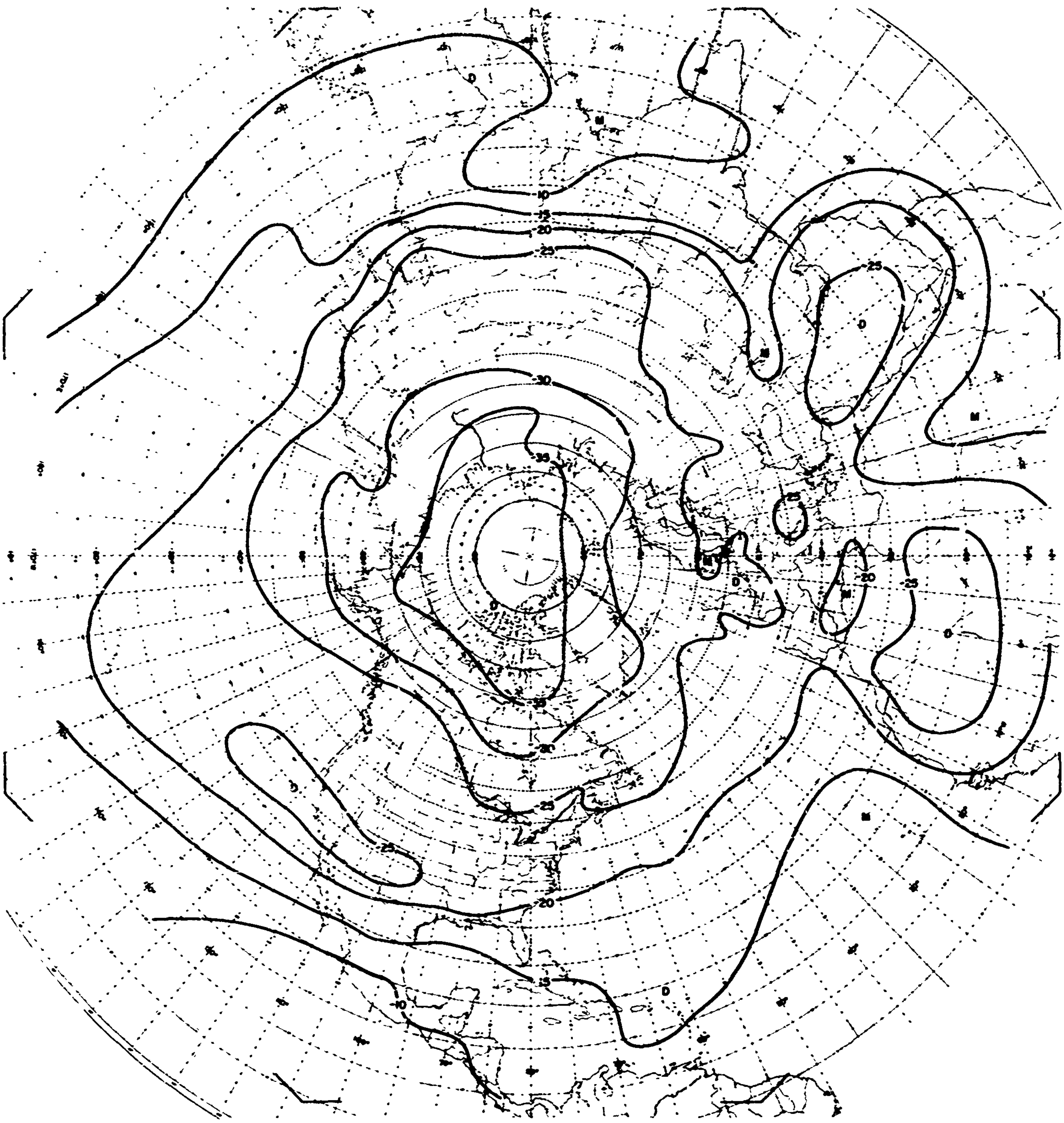

Plate 99. Dew Point at 500 mb in October, 75 Percentile

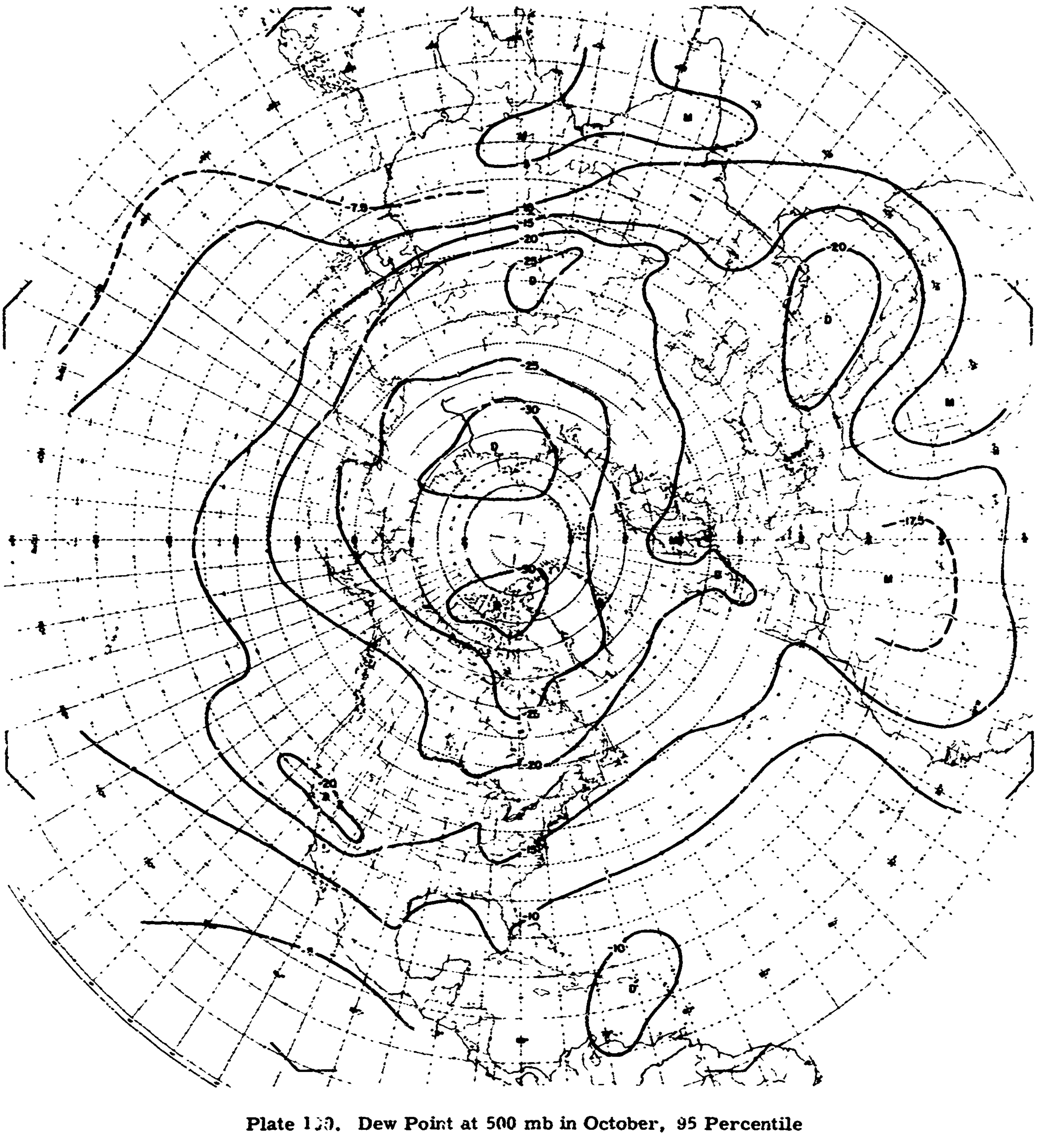

Plate 120. Dew Point at 500 mb in October, 95 Percentile

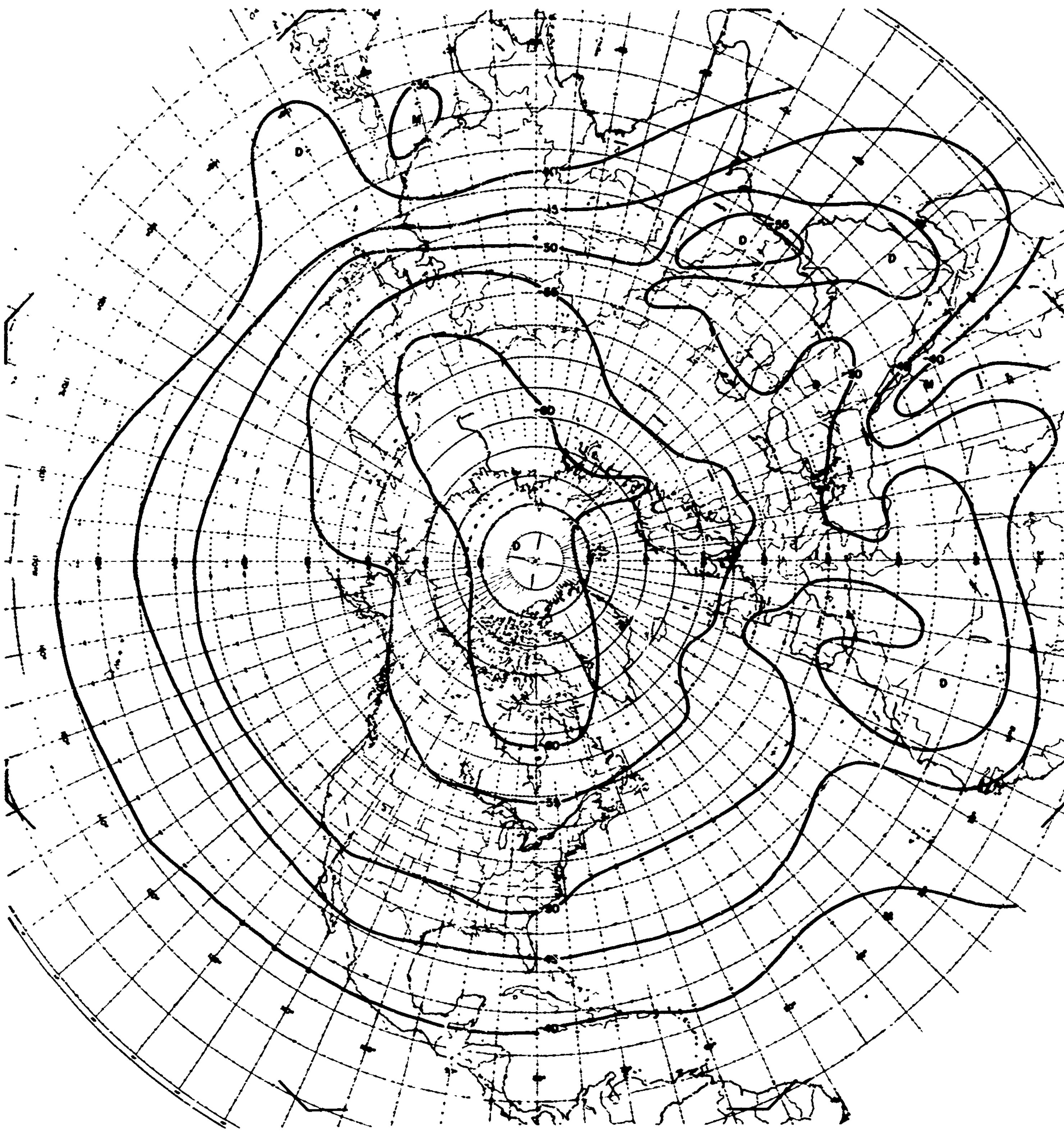

Plate 101. Dew Point at 400 mb in January, 5 Percentile

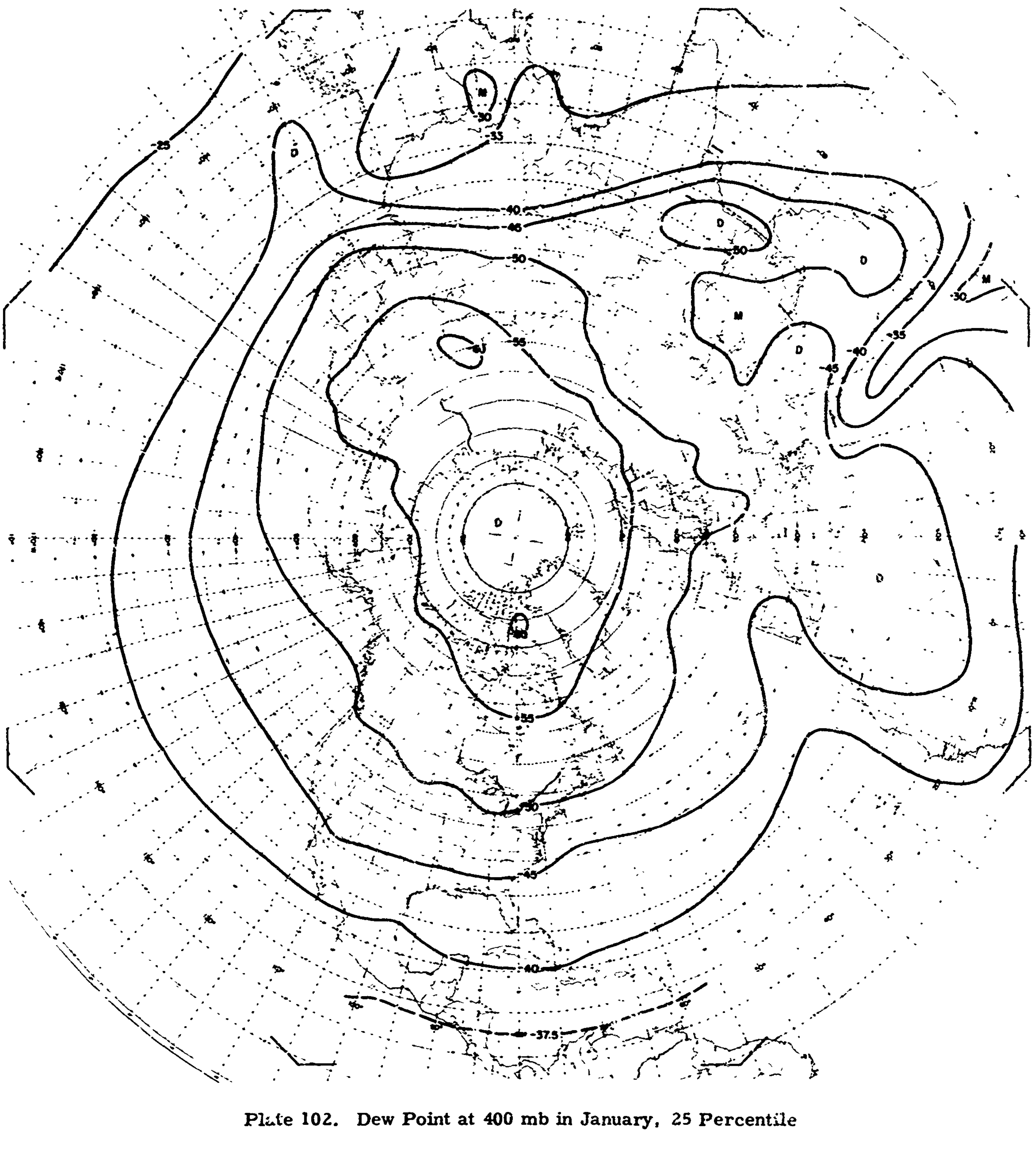

Plate 102. Dew Point at 400 mb in January, 25 Percentile

Plate 103. Dew Point at 400 mb in January, 50 Percentile

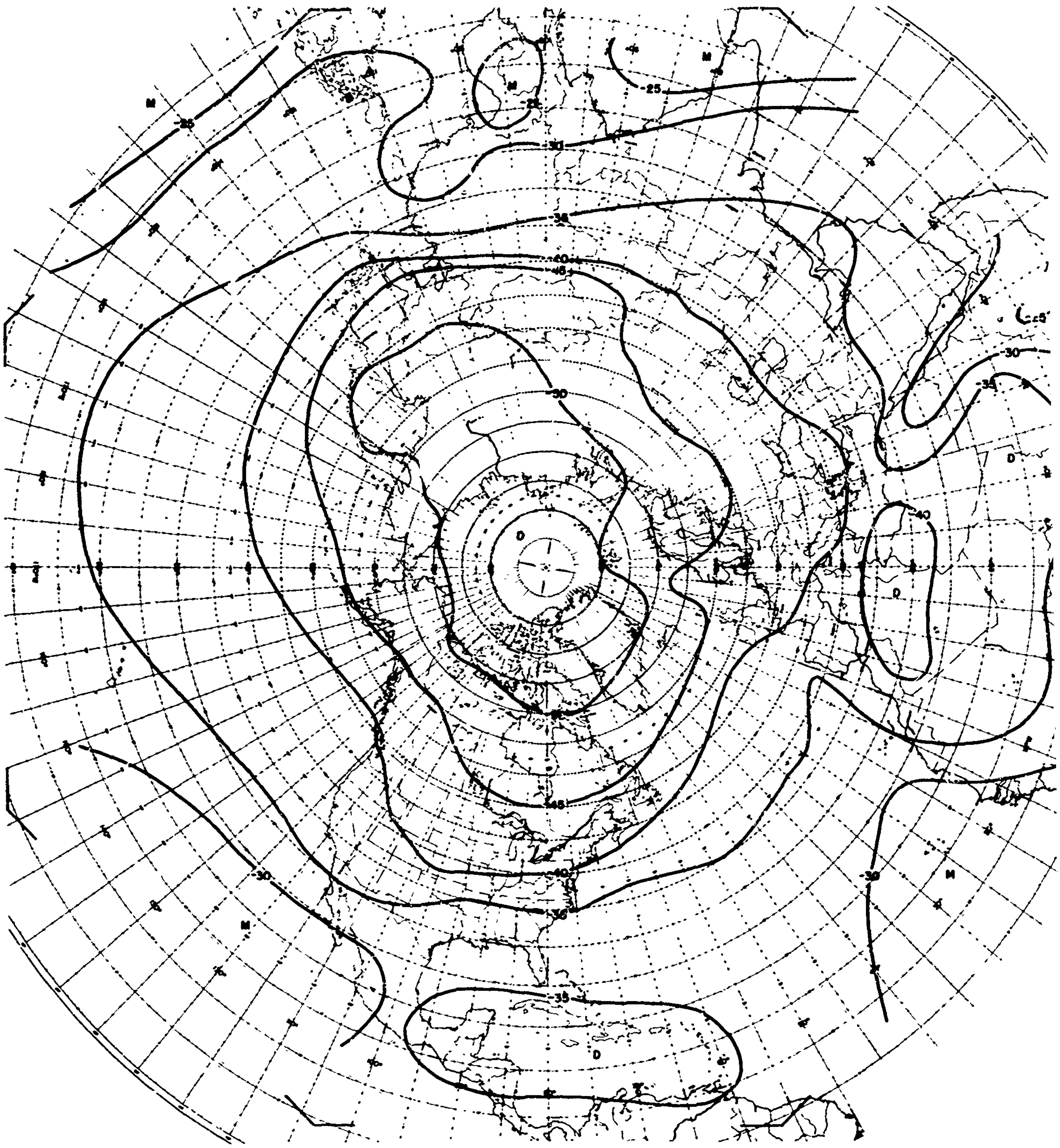

Plate 104. Dew Point at 400 mb in January, 75 Percentile

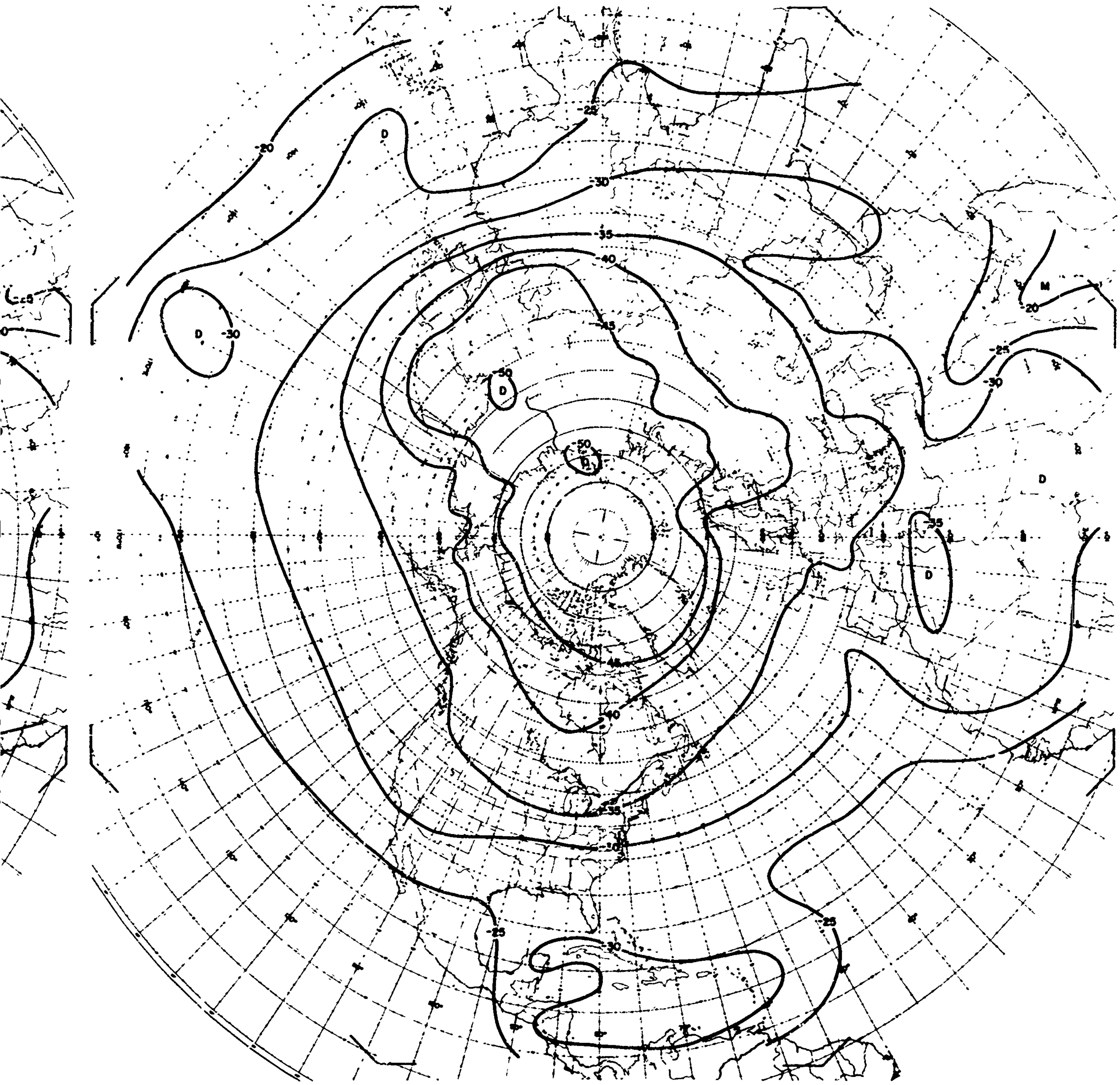

Plate 105. Dew Point at 400 mb in January, 95 Percentile

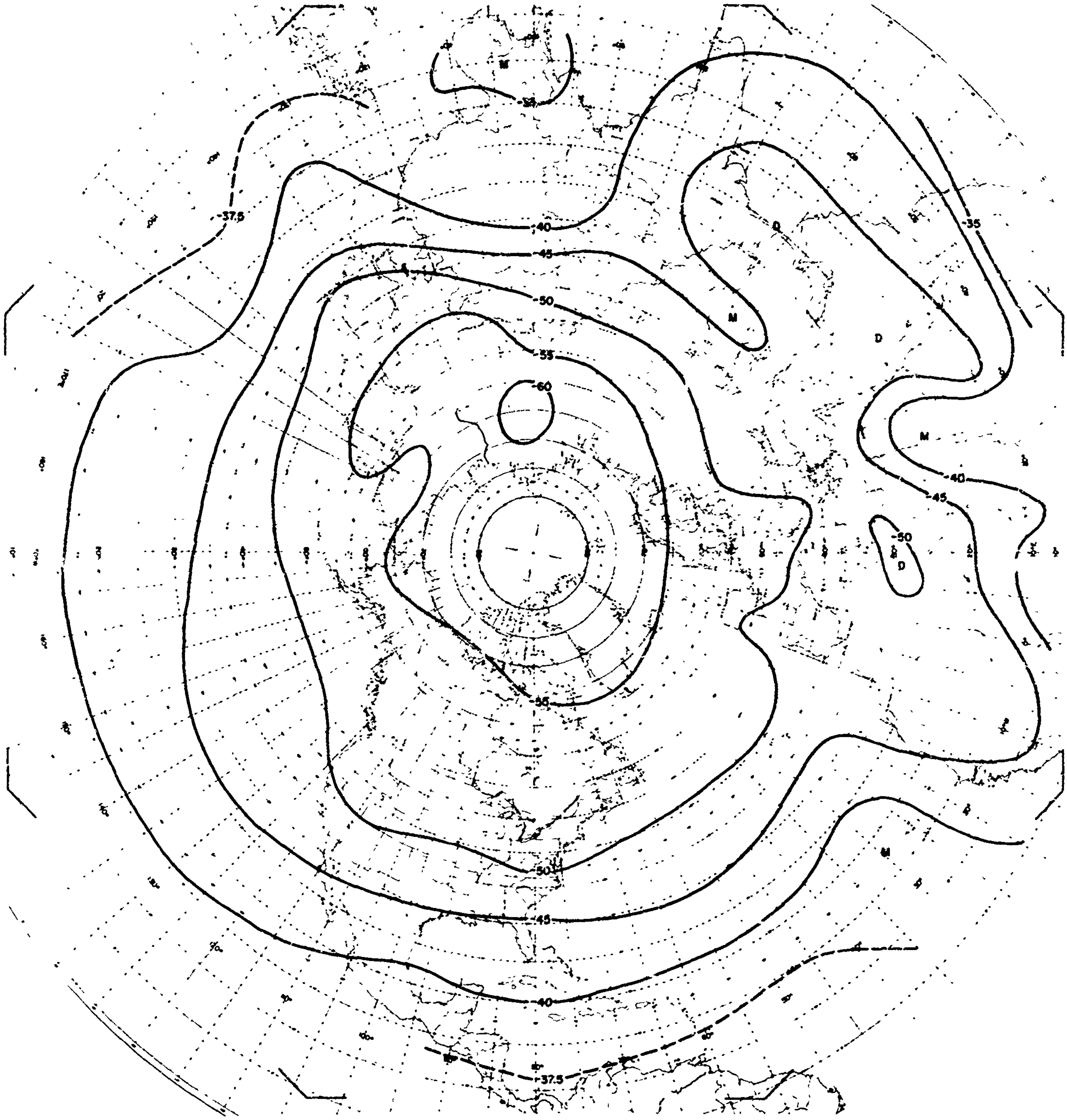

Plate 106. Dew Point at 400 mb in April, 5 Percentile

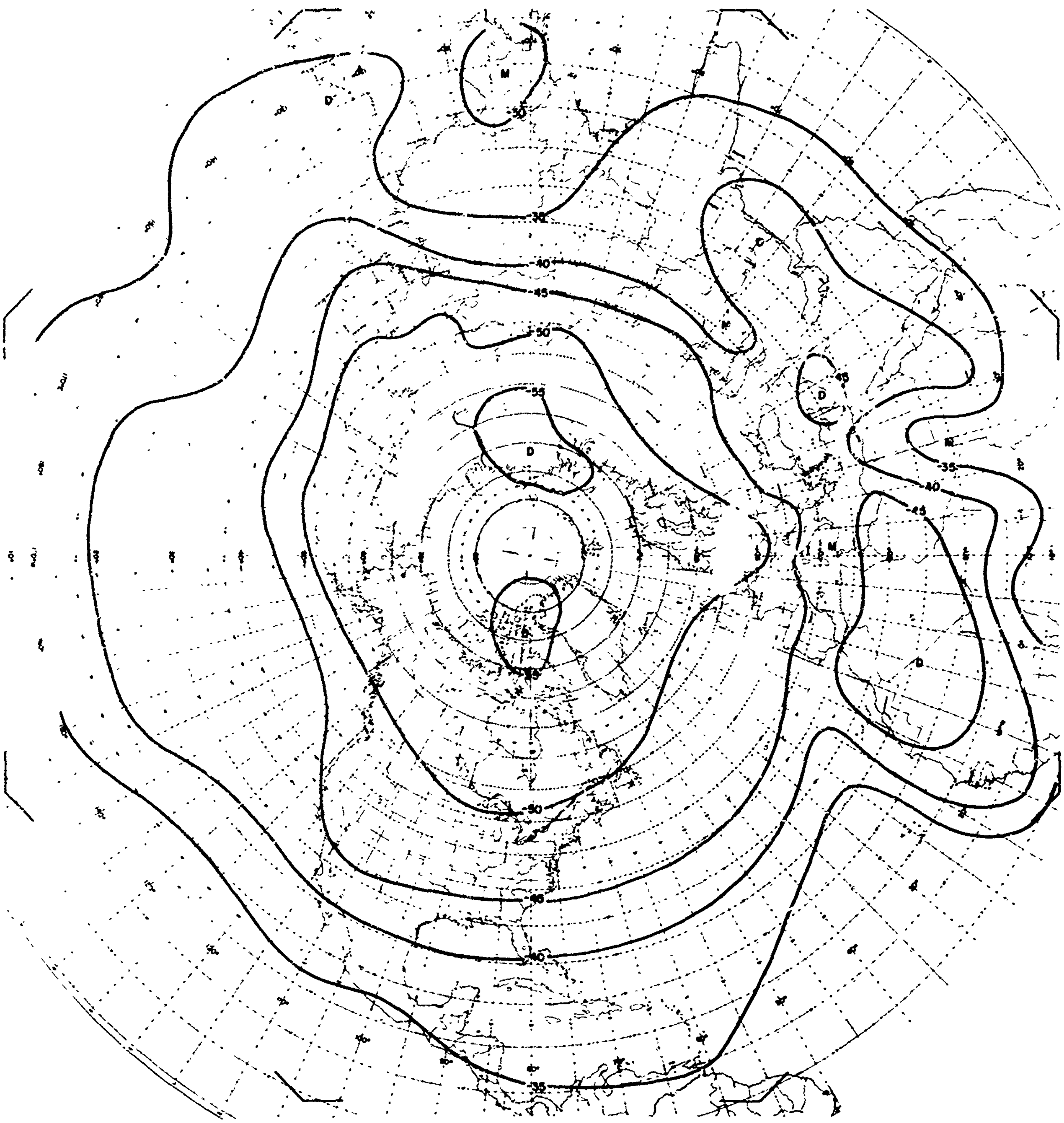

Plate 107. Dew Point at 400 mb in April, 25 Percentile

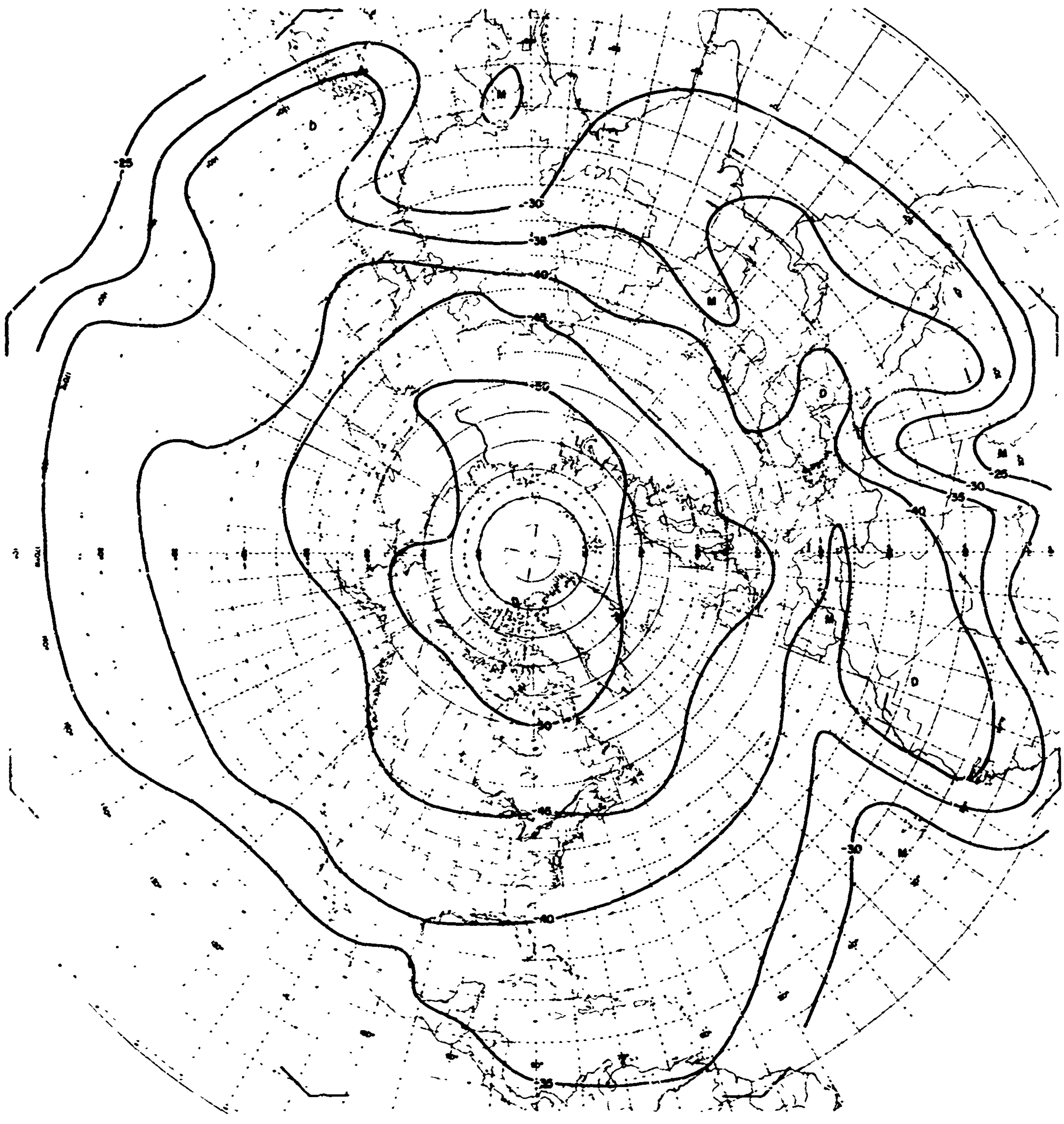

Plate 108. Dew Point at 400 mb in April, 50 Percentile

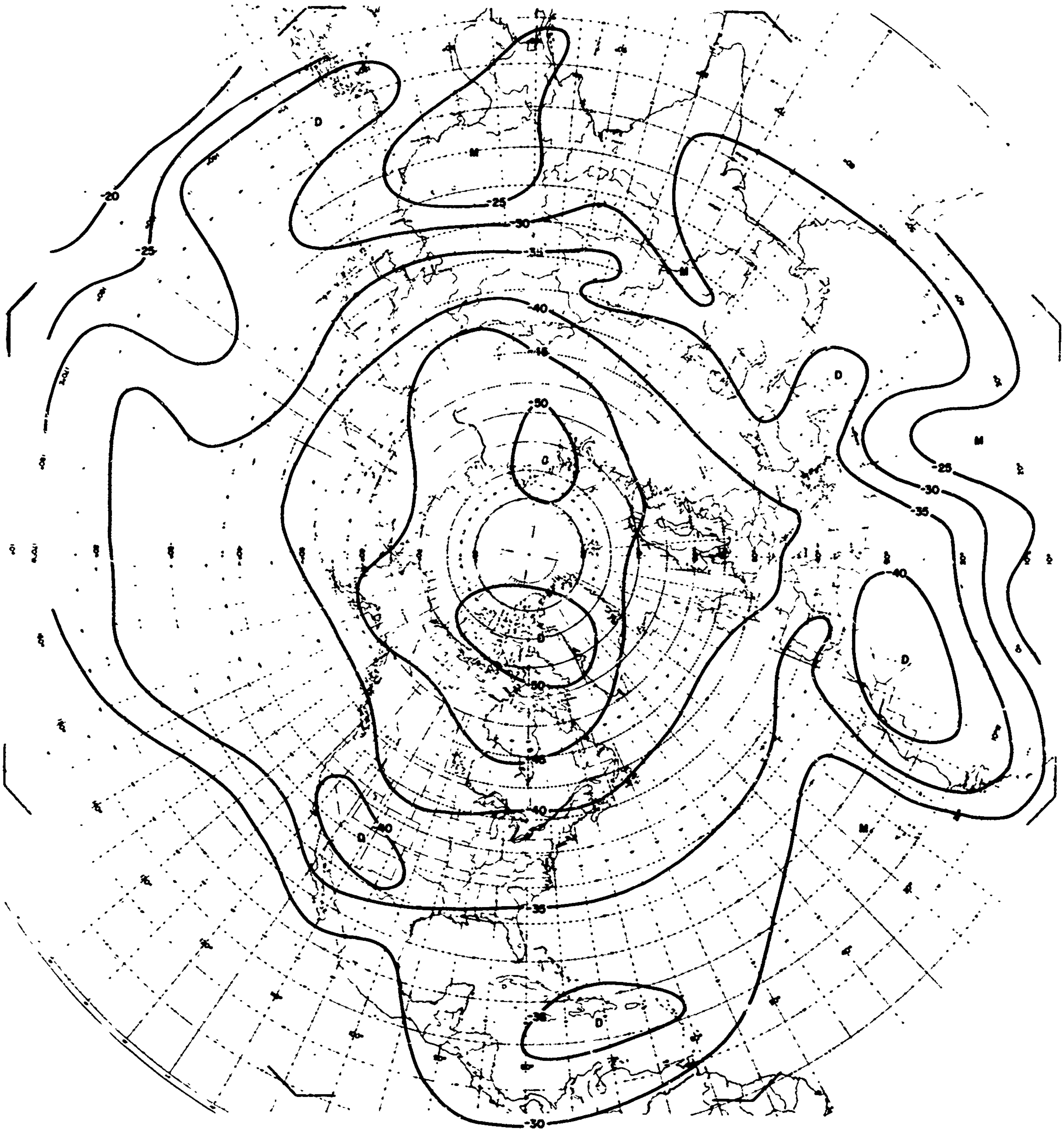

Plate 109. Dew Point at 400 mb in April, 75 Percentile

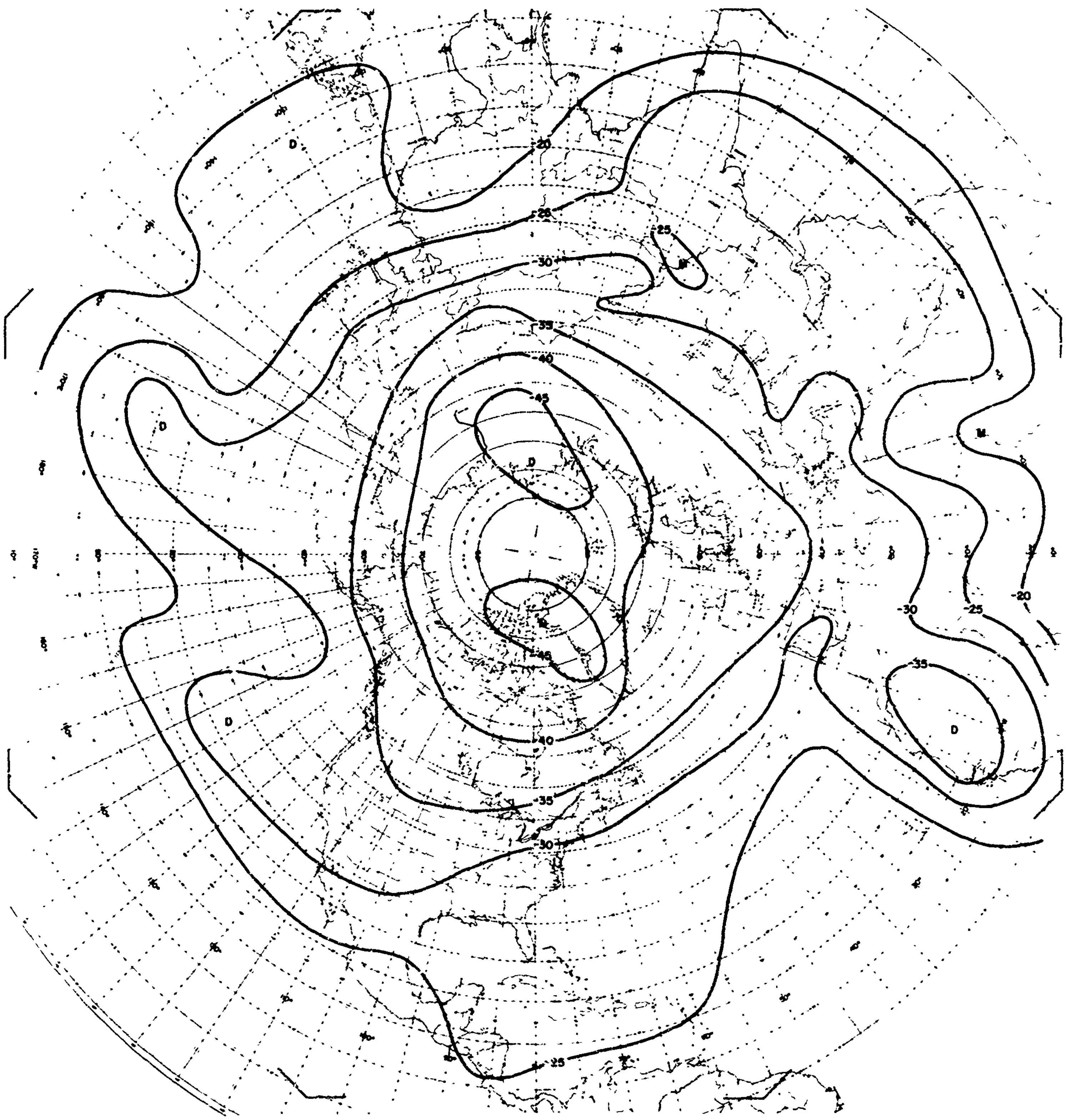

Plate 110. Dew Point at 400 mb in April, 95 Percentile

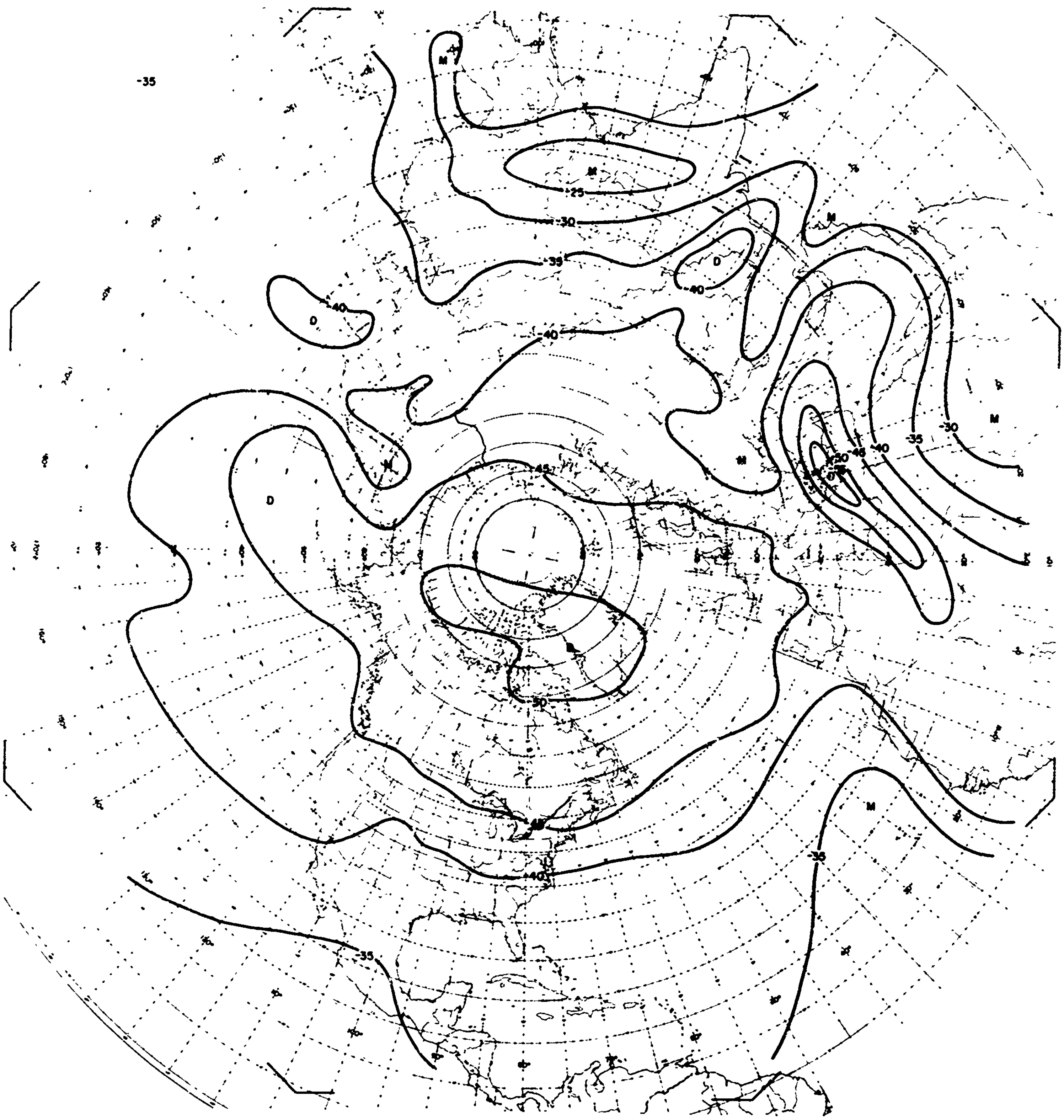

Plate 111. Dew Point at 400 mb in July, 5 Percentile

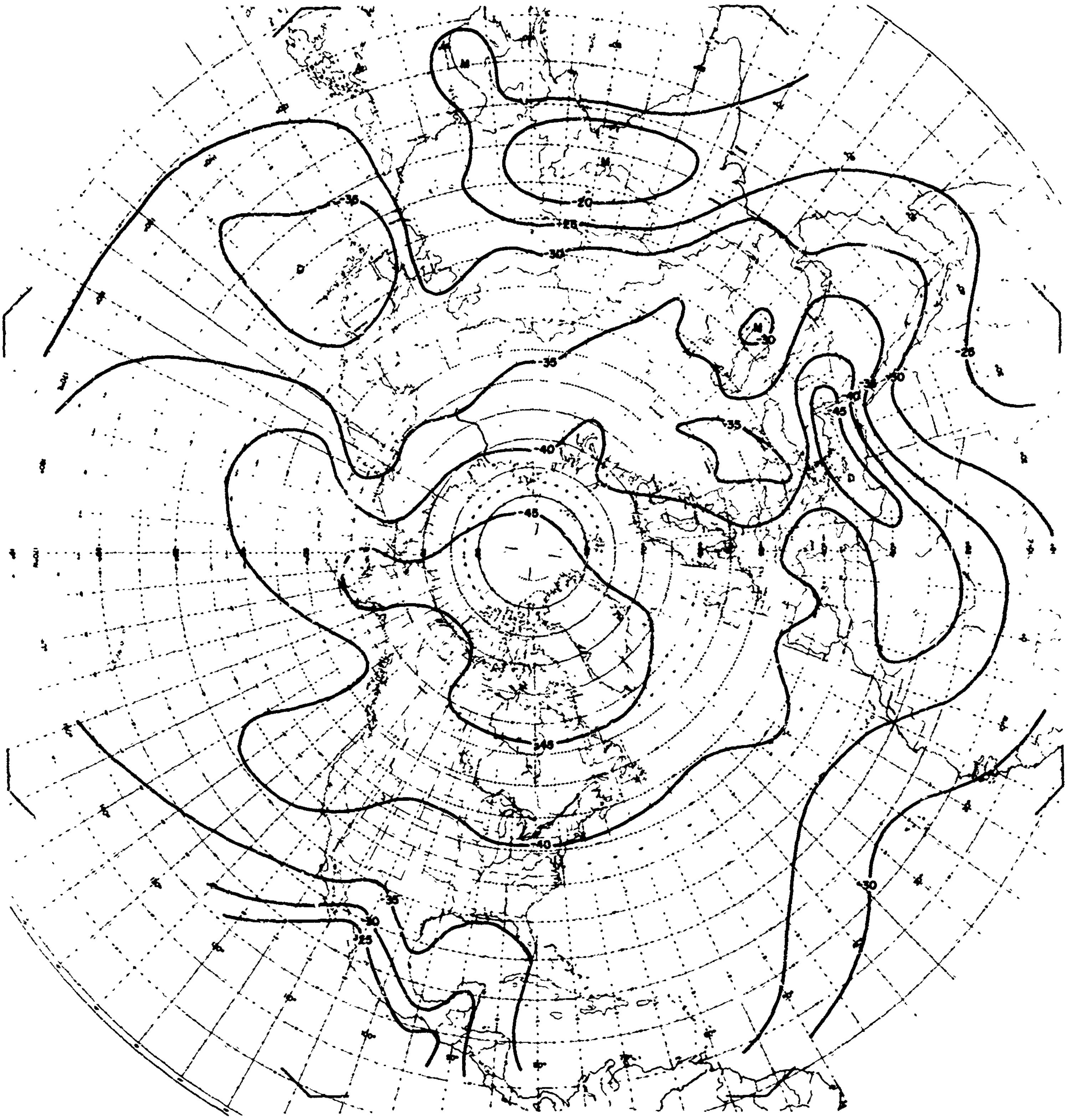

Plate 112 Dew Point at 400 mb in July, 25 Percentile

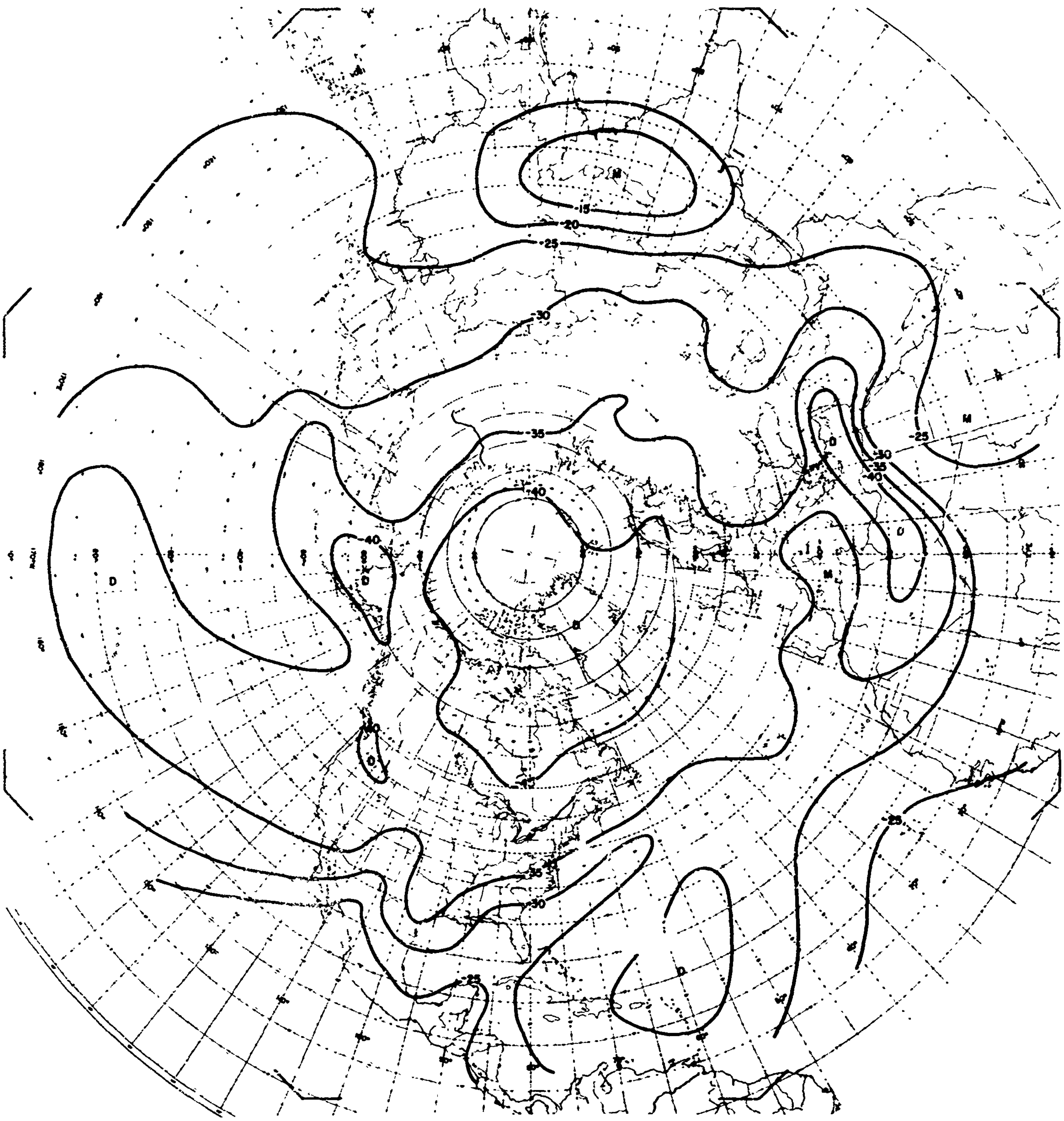

Plate 113. Dew Point at 400 mb in July, 50 Percentile

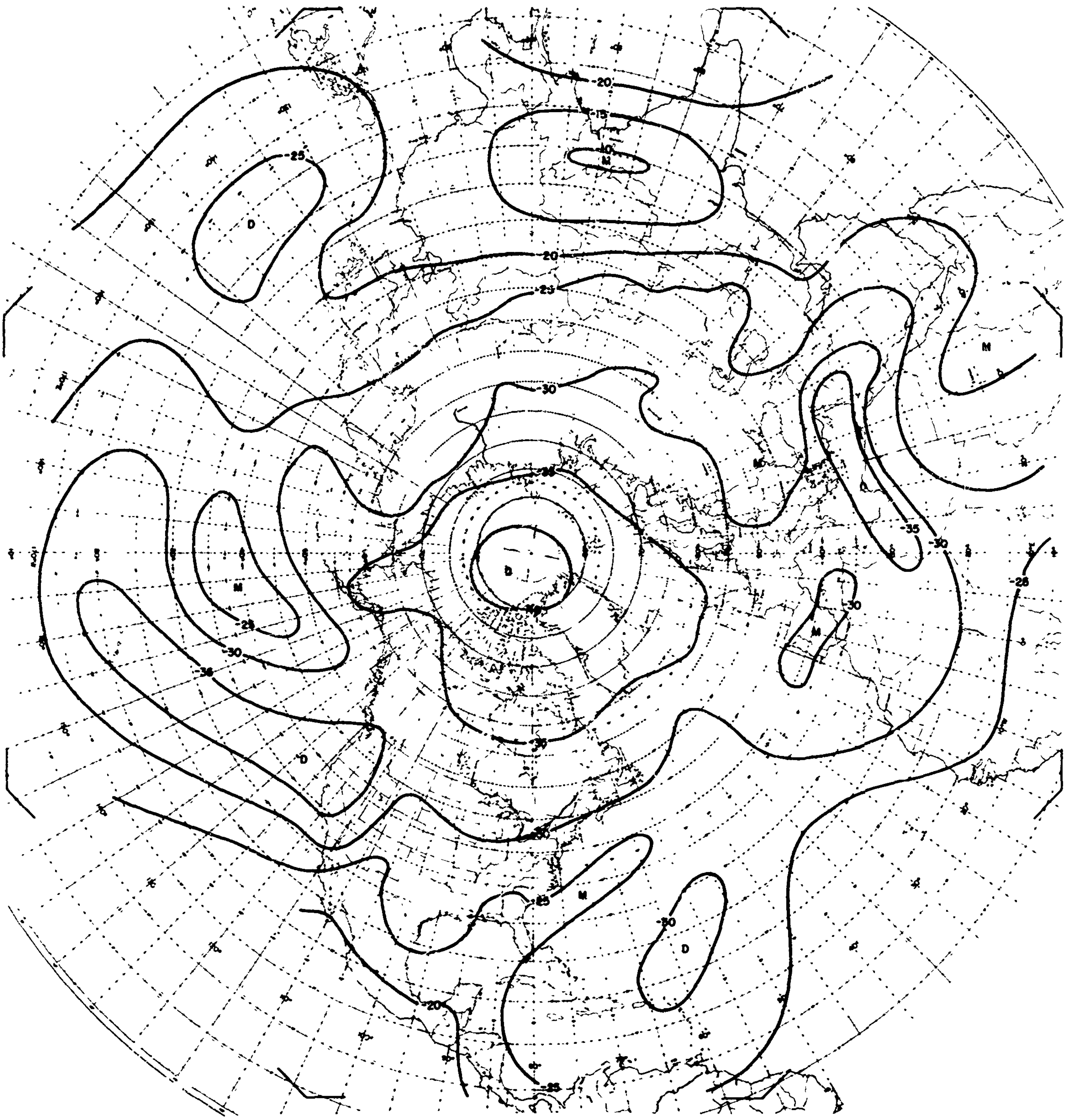

Plate 114. Dew Point at 400 mb in July, 75 Percentile

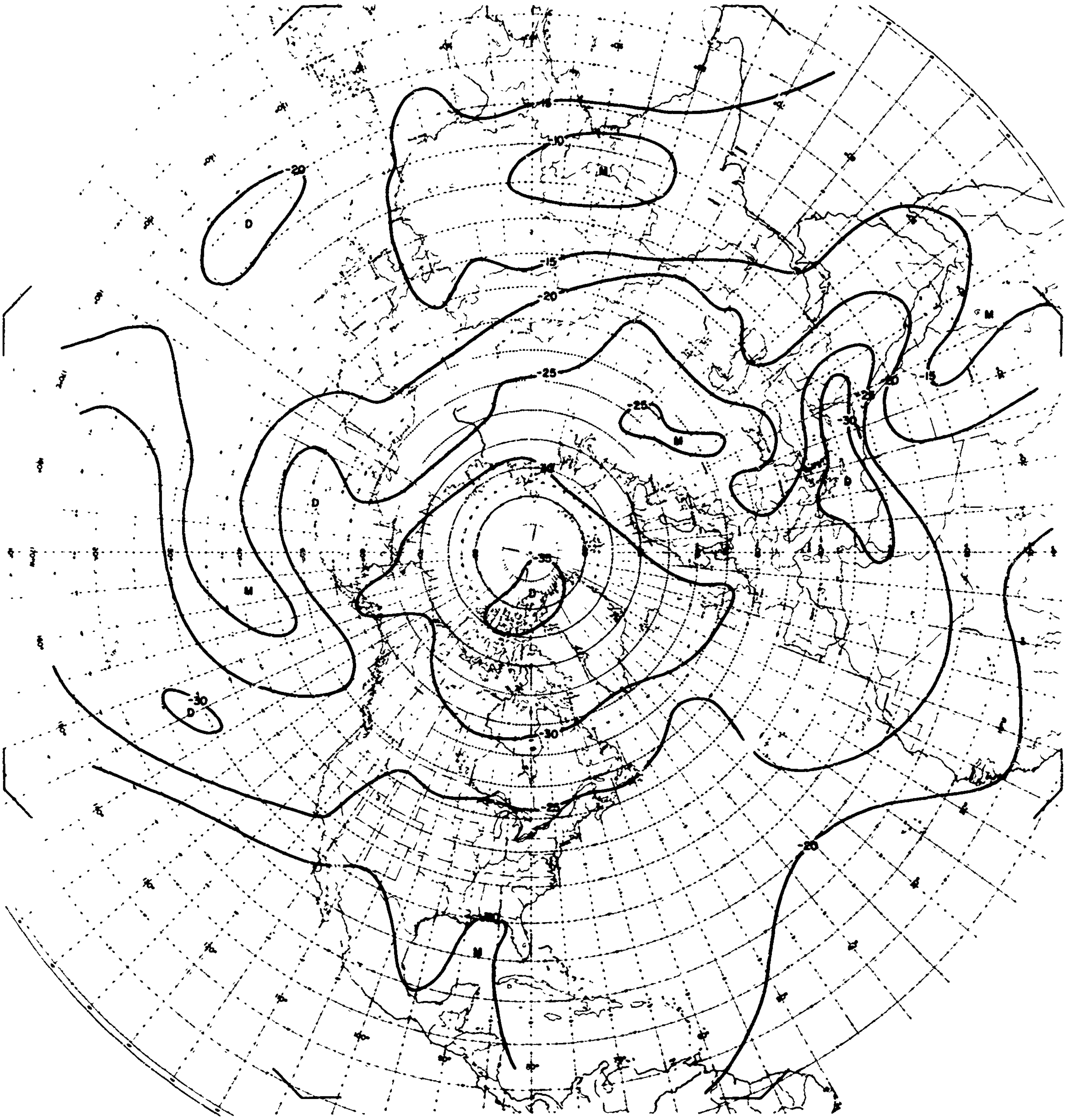

Plate 115. Dew Point at 400 mb in July, 95 Percentile

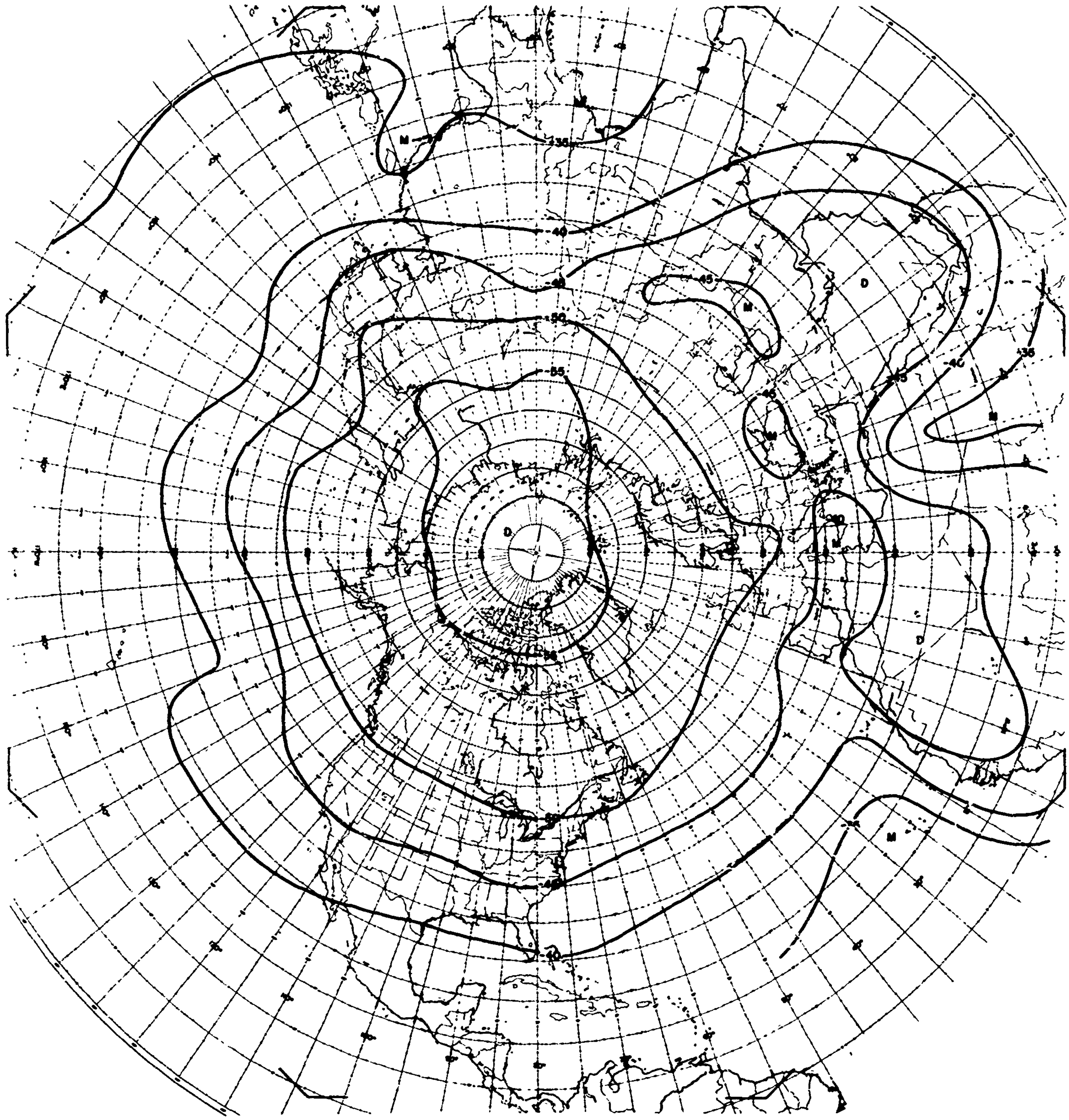

Plate 116. Dew Point at 400 mb in October, 5 Percentile

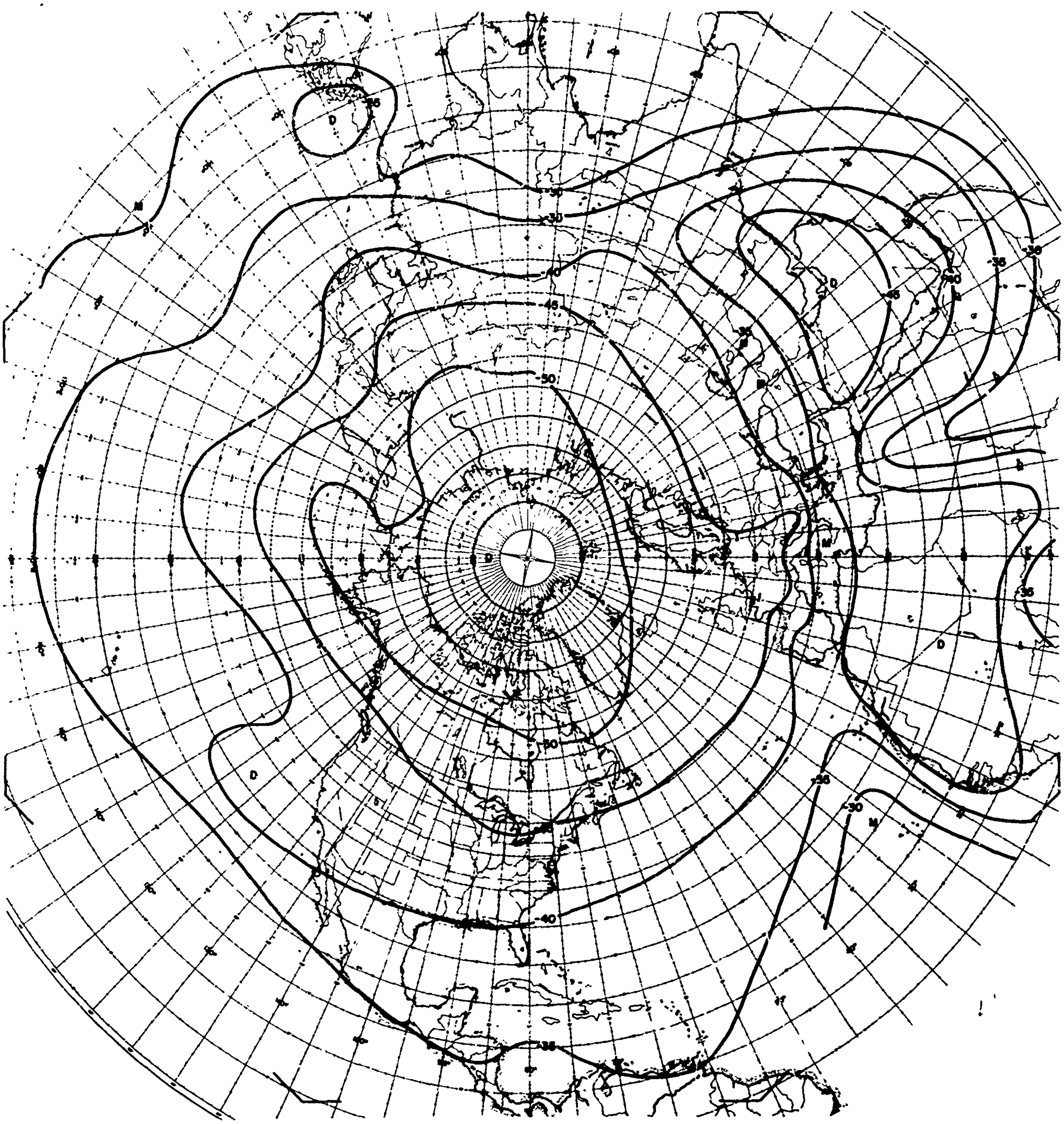

Plate 117. Dew Point at 400 mb in October, 25 Percentile

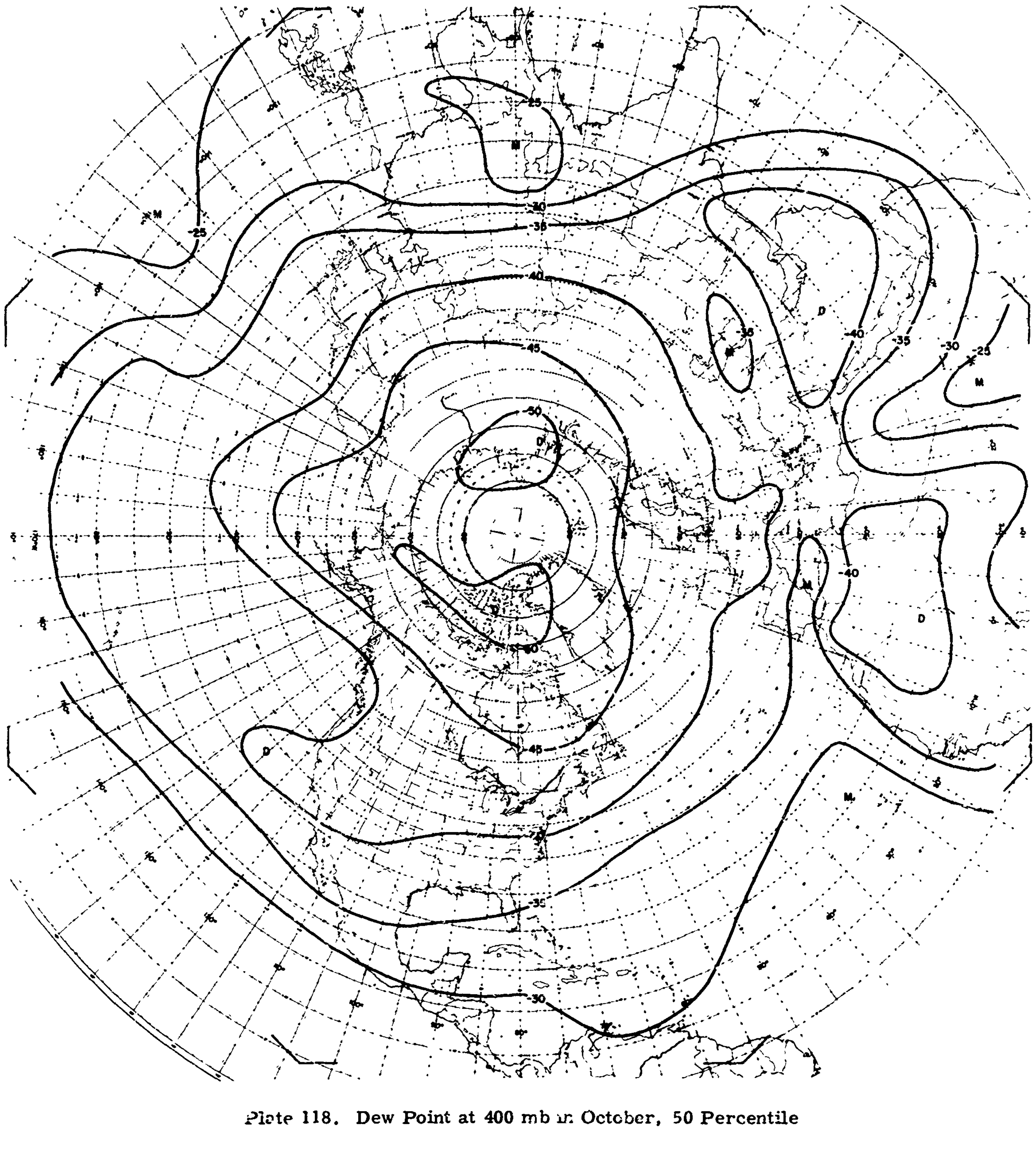

Plate 118. Dew Point at 400 mb in October, 50 Percentile

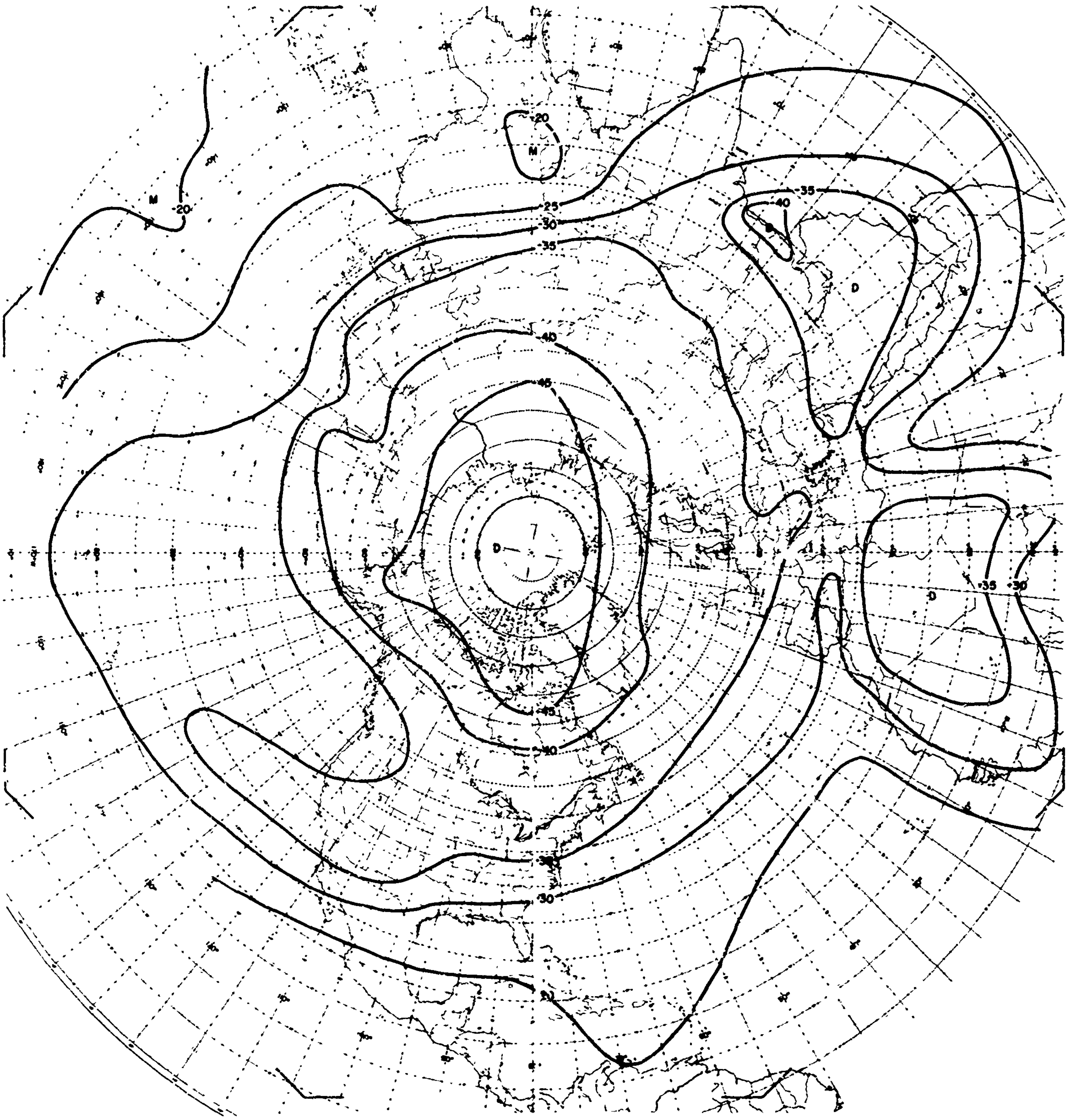

Plate 119. Dew Point at 400 mb in October, 75 Percentile

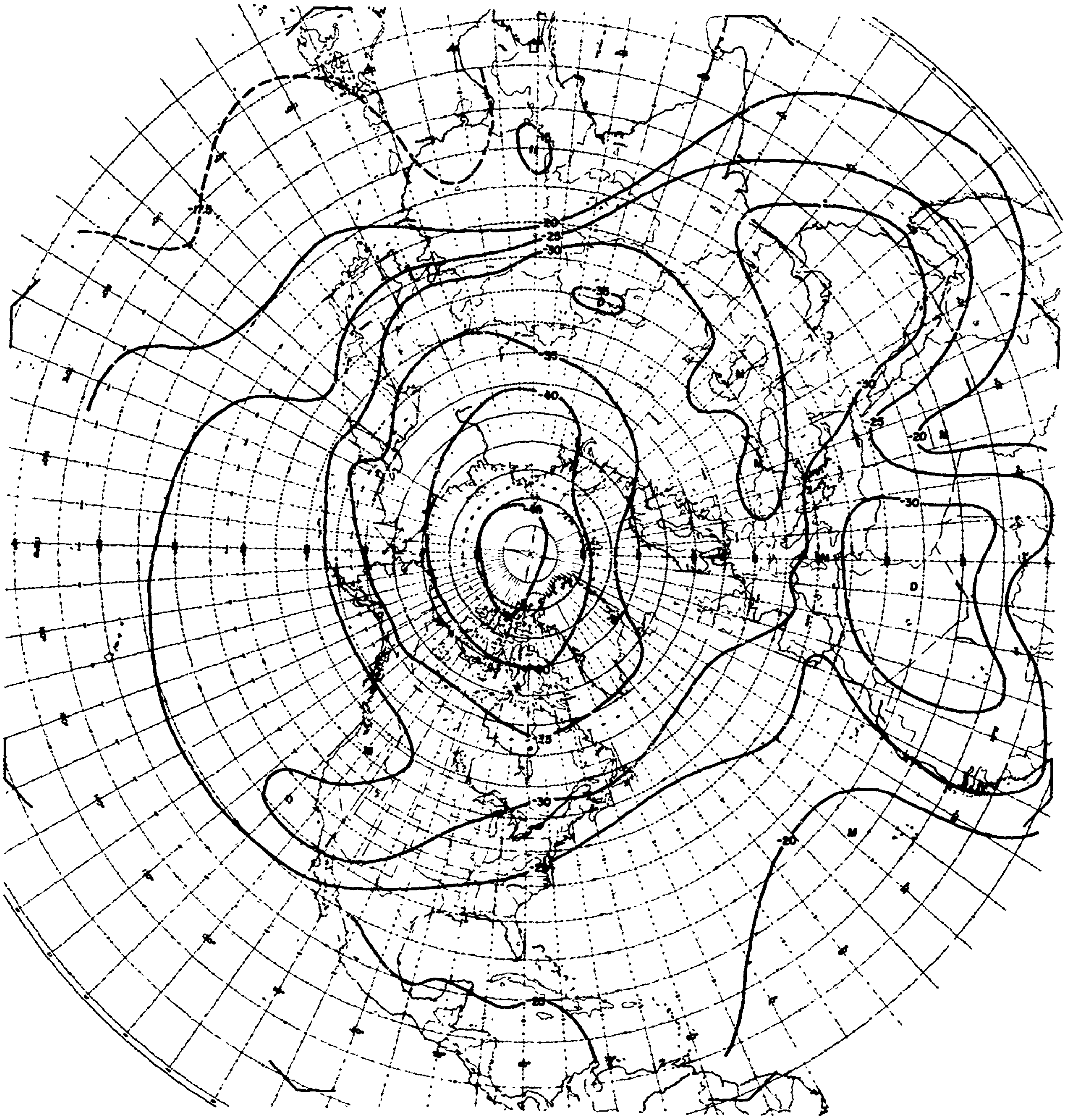

Plate 120. Dew Point at 400 mb in October, 95 Percentile

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13. ABSTRACT

This atlas presents 120 plates showing the distribution of water vapor in the atmosphere of the Northern Hemisphere. There are 20 plates in terms of mixing ratio at the surface and 100 plates in terms of dew point at the surface and at the 850-, 700-, 500-, and 400-mb levels. The distributions of other measures of moisture, including vapor pressure, frost point, water-vapor density, and mixing ratio aloft, are readily obtainable from the distribution of the dew points. The plates will be useful to designers faced with the problem of estimating the effects of atmospheric water vapor on aerospace hardware and for those concerned with the operation and storage of equipment. The plates of frequency distributions, from 5 to 95 percent, are especially useful for estimating the duration or persistence of moist conditions, as illustrated by several examples.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
atlas						
humidity						
water vapor						
Northern Hemisphere						
climatology						
atmosphere						
statistics						
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Technical Report 191

ATMOSPHERIC HUMIDITY ATLAS— NORTHERN HEMISPHERE

By
I. I. GRINGORTEN
H. A. SALMELA
I. SOLOMON
and
MAJ. J. SHARP

Published By
AIR WEATHER SERVICE (MAC)
UNITED STATES AIR FORCE

AUGUST 1966

PREFACE

This report is a joint effort of the Air Force Cambridge Research Laboratories and the Air Weather Service (see AFCRL's Preface, Page ix) and is being issued simultaneously by both agencies under their respective covers.

Atmospheric humidity is a constituent continuously and everywhere present in the troposphere but very variable with time and space both as to absolute amount and relative to saturation. It has manifold influences, often essential or troublesome, in the design and operation of devices, on materials, and for most forms of life. This report presents humidity data in a form and coverage more adequate than previously available, especially for application to global military problems. Air Weather Service and other defense activities will find the date herein readily applicable in answering questions where the probability, or frequency and duration, of given humidity levels is more significant than averages.

The Air Weather Service is pleased to acknowledge the long collaboration of AFCRL and AWS to bring to a conclusion this project so useful to the missions of both organizations in solving problems of environmental support.

RUSSELL K. PIERCE, JR., BRIGADIER GENERAL, USAF
Commander
Air Weather Service

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AUGUST 1966
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ATMOSPHERIC HUMIDITY ATLAS – NORTHERN HEMISPHERE

I.I. Gringorten
H.A. Salmela
I. Solomon
J. Sharp, Major, USAF

ERRATA

Page 3, line one of text.

Change to read:

"... Fortunately, however, the ..."

Page 4, line 2.

Change to read:

"... Given the frequency distribution of dew point at a station, ..."

Page 22, first reference.

Add:

"pp 606-624"

Page 71

Cross out the title

"Plate 49. Dew Point at 850 mb in April. 75 Percentile"

and insert

"Plate 55. Dew Point at 850 mb in July, 95 Percentile
(For Plate 49 see page 77)"

Page 77

Cross out the title

"Plate 55. Dew Point at 850 mb in July, 95 Percentile"

and insert

"Plate 49. Dew Point at 850 mb in April, 75 Percentile
(For Plate 55 see page 71)"

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