Weather in the MEDITERRANEAN
Vol. I

METEOROLOGICAL OFFICE

THE ORIGINAL EDITION OF THIS handbook was issued in 12 parts and dealt with each region climatically. In this revision, the climatic material is largely assembled in reference tables in Volume II. The text, in Volume I, now treats the subject synoptically, and is liberally illustrated by synoptic charts both surface and upper air. Emphasis is placed on the association of air masses, fronts, and pressure systems, with the cool and warm seasons, and on features of special significance for forecasting in the subtropics.

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WEATHER IN THE MEDITERRANEAN

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PREFACE

This is a revised edition of the handbook of *Weather in the Mediterranean* first published in 1937. As in the first edition it is written primarily for the use of the Naval Weather Service but it is hoped that it will prove of value to other meteorologists and especially those connected with aviation.

In carrying out this revision the opportunity has been taken to make some rearrangements of the layout.

Volume I now contains all descriptive material while Volume II consists entirely of climatic tables for the region. These are divided into three parts corresponding to the three main basins of the Mediterranean: the western, central and eastern. Important features of local weather which are not evident from the tables of Volume II are incorporated in the text of Volume I. There are also a number of smaller and more specialized tables included in Volume I as well as a large number of figures. The figures are in two series prefixed by 1 and 2 respectively. The first series is included with the text while the charts and tephigrams of actual synoptic situations in the second series are included in Part II of Volume I.

In Volume I emphasis is placed on the association of air masses, fronts, depressions and anticyclones with types of weather during the cool and warm seasons of the year; and important features of air-mass and frontal analysis which might be overlooked by someone unused to forecasting in the subtropics are stressed.

Part II of Volume I consists of a number of charts, many of which have been prepared with the use of the *Täglicher Wetterbericht des Deutschen Wetterdienstes* and it is due to this that there is a preponderance of charts for 0000 G.M.T. Surface charts dated before 1 January 1949 show slightly different plotting symbols, since the codes of observing and plotting were altered on that date by international agreement. In the same way plots of surface wind prior to 1 January 1955 show wind in Beaufort force, each fleche on the arrow representing two points on the Beaufort scale while those after this date are in knots, each flèche representing ten knots. No cloud is plotted at any stations on the charts, although present weather is occasionally included.

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CHAPTER I

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The Mediterranean Sea (see Frontispiece) lies between 30° and 46°N., and between 5°30'W. and 36°E. Its east-west extent is approximately 2,500 miles while its average north-south extent is only about 500 miles. The western outlet to the Atlantic through the Strait of Gibraltar is only eight miles wide at its narrowest point. Except along the North African coast east of Tunisia, the sea is enclosed by mountains lying close to the coast, and the coastline is much indented.

The Mediterranean may be regarded as being divided geographically into a western and an eastern basin by the peninsula of Italy and the island of Sicily, with the Adriatic and Aegean Seas as northward extensions of the eastern basin. For many purposes it is convenient to distinguish also an area known as the central Mediterranean roughly between the longitude of Corsica-Sardinia-Tunisia in the west, and Greece-Cyrenaica in the east.

The western basin is surrounded by mountains over 3,000 feet high with many higher peaks. In Spain the Iberian plateau which covers the greater part of the country has a general level between 1,500 and 3,000 feet and there are several mountain ranges over 6,000 feet with one top over 11,000 feet in the Sierra Nevada and another over 11,000 feet in the Pyrenees. North and east of the Pyrenees is the Garonne-Carcassonne gap which separates the Pyrenees from the Massif Central of France, including the Cevennes. To the east of this is the narrower Rhône-Saône gap which separates the Massif Central from the Alps. The Alps rise to more than 10,000 feet over wide areas (Mont Blanc is 15,782 feet) and connect with the Apennines which rise to peaks of 9,500 feet in central Italy. In Sicily the mountains are mainly about 3,000 feet high, with the volcano of Etna reaching over 10,700 feet above sea level. The Strait of Gibraltar and the Alboran Channel separate the mountains of Spain from the Atlas range in North Africa. This range lies parallel to the coast between 50 and 200 miles inland. Between 0° and 10°W. the high Atlas ridges are over 10,000 feet and have two peaks of over 13,000 feet above sea level in 6° and 9°W. near Marrakesh. Between 0° and 10°E. they rise generally to heights between 3,000 and 6,000 feet, with one peak over 7,600 feet in the department of Constantine (6°E.).

All round the western basin the coastal plain is narrow except where the Rhône enters the Gulf of Lions.

The largest islands in the western Mediterranean are Corsica and Sardinia. Both are mountainous. Only a small area of Sardinia is over 3,000 feet, but one peak exceeds 6,000 feet above sea level, whereas the peaks of Corsica rise to over 8,800 feet. One hundred miles off the east coast of Spain are the Balearic Islands, of which the largest, Majorca, has a range of mountains in the north-west over 3,000 feet high.

The eastern basin of the Mediterranean is bordered on the north and east by ranges of mountains of over 3,000 feet. The Adriatic Sea is hemmed in on the west and north by the Apennines and the Alps. On the east the Dinaric Alps lie along the island-fringed coast of Yugoslavia. East of 18°E. the mountains reach 6,000 feet above sea level and continue south as the Pindus range of Albania and Greece. In Greece the highest peaks rise to over 9,000 feet and the mountain chains in many places come right down to the sea. North of the Aegean Sea the Rhodope mountains rise to over 7,000 feet.

Between the Rhodope range and the mountains of Turkish Anatolia there is a break, between 50 and 100 miles wide, where the land seldom exceeds 600 feet above sea level. Here the Dardanelles open into the Aegean and provide an outlet from the Black Sea.

The Anatolian plateau rises in places to over 7,000 feet, and the Taurus range which backs the southern coast of Turkey is more than 6,000 feet above sea level for most of its length. In longitude 34°30'E. it rises to 11,800 feet and there are several other peaks of 10,000 feet and over between 29° and 35°E. To the south it falls in a steep scarp, indented by coastal plains. To the east the Mediterranean is again bounded by mountains reaching 3,000 to 6,000 feet above sea level, and the tops reach 9,000 and 10,000 feet in the Lebanon and borders of Syria. The coastal plain south of Beirut is divided from the Jordan depression by hills mainly between 1,500 and 3,000 feet high.

The only large area of lowland on the north side of the eastern Mediterranean is the wide funnel-shaped Po valley basin at the northern end of the Adriatic Sea, enclosed between the Apennines and the Alps.

The north coast of Africa bordering the eastern Mediterranean is low-lying, being less than 600 feet above sea level except for the highlands of Cyrenaica, which lie to the east of the Gulf of Sidra and are more than 1,500 feet high. In the west of Tripolitania the land rises to over 1,500 feet at about 100 to 150 miles from the coast. South of the Gulf of Sidra there is a gradual rise to the Libyan desert, while the low plain continues east of Cyrenaica to beyond the Nile delta.

The largest islands of the eastern Mediterranean are Crete and Cyprus. Crete has a mountainous backbone of over 3,000 feet, with one peak (Mount Ida) over 8,000 feet high. In Cyprus there are two mountain ranges, one peak being over 6,000 feet high.

GENERAL EFFECTS OF TOPOGRAPHY ON THE WEATHER

The flow of air into the Mediterranean takes place mainly through gaps in the mountain ranges, except over the southern shores east of Tunisia. Strong winds "funnelled" through the gaps are the most important and best known winds of the Mediterranean: the north-westerly mistral through the Alps-Pyrenees gap; the north-easterly bora through the Trieste gap; the easterly levanter and the westerly vendaval through the Strait of Gibraltar. The warm south-easterly to south-westerly wind which blows from Africa is also well known as the scirocco, ghibli or khamsin. An account of these and other well known regional winds of the Mediterranean is given in Chapter 6.

Local ravine winds are also prominent when atmospheric pressure on one side of a mountain range is considerably greater than that on the other side. Ravine effects may also cause considerable local increases in wind speed, for example with the bora or mistral. Anabatic and katabatic winds are important, as are land- and sea-breezes. Eddies, particularly in the lee of steep mountains, hills or cliffs, are often dangerous to aircraft and small vessels. In the neighbourhood of headlands the wind is often greatly strengthened by horizontal confluence and is also rendered turbulent due to eddy motion.

Barrier effects. A flow of air directed towards a mountain range is partly deflected sideways by the range, while some flow takes place over the summit. The manner in which the air is diverted depends on the stability of the air mass. In a stable air mass most of the air below the level of the summit is turned aside, while in an unstable air mass the proportion deflected is very much smaller, the rest being lifted over the range. In such cases the effects of upward motion may extend to heights many times that of the crest of the range and be apparent both in excessively strong winds on and near the summits due to confluence in the vertical plane, and in turbulence and wave motion downstream, sometimes as high as cirrus levels.

There is a reduction of pressure on the lee side of a range, especially if the range is concave on the lee side, for example, south of the Alps with northerly winds. The majority of Mediterranean depressions have their origin as lee depressions, although their subsequent development and motion are decided more by usual air-mass and frontal considerations.

There is a corresponding ridge of high pressure on the windward side of a mountain, especially if the range is concave to windward. This happens with the Alps when there is a general southerly current. In spite of the rise in pressure, there is usually copious rainfall on the windward side and a general clearance on the lee side.

Effect of vertical motion of air. When air is lifted over a mountain range it is cooled adiabatically with a resulting tendency for the formation of cloud and development of precipitation. In maritime air masses moving over the Alps there is frequently nimbostratus with embedded cumulonimbus extending to 20,000 feet and with some tops to 30,000 or 40,000 feet. When air descends in the lee of mountains it is warmed adiabatically and as a result there is a tendency for cloud sheets to disperse and precipitation to cease, particularly if much of the moisture has fallen from the air mass over the mountains.

Fronts. Mountain ranges may affect the movement of fronts in a variety of ways. In some cases a front may be completely held up except for portions which pass through the main gaps. In others the front may pass over the range almost without hindrance. Specific situations involving such occurrences are dealt with more fully later in this volume.

GENERAL CHARACTER OF MEDITERRANEAN WEATHER

The outstanding features of weather in the Mediterranean are windy, mild, wet winters and relatively calm, hot, dry summers. The transitional season of spring is similar to that in the British Isles in that it is a period of "indecision", the change from the winter to the summer régime taking place in a number of false starts. On the other hand autumn is relatively short, the disturbed winter régime generally setting in fairly decisively. The connotation of autumn familiar in the British Isles - harvest and the fall of leaves - is not applicable in the Mediterranean where harvesting is generally completed by June and deciduous trees do not normally lose their leaves till around November.

The rainfall at all seasons decreases rapidly inland from the North African coast except on the windward slopes of the Atlas mountains and smaller ridges in Libya. On the coasts, except those of Egypt and Libya, and over the islands of the eastern Mediterranean the rainfall amounts in the winter months equal and in some places exceed those typical of eastern England.

The main features of summer and winter are so well marked in the Mediterranean from year to year, and have been so long recognized, that the term "Mediterranean" has come into general use for describing this type of climate wherever it is found. Owing to the danger of introducing ideas which are not valid in the Mediterranean, the terms "warm season" and "cool season", will be used in certain connexions. "Warm season" will be used to denote the months June to September and "cool season" the months October to May, although October and May may be regarded as transitional months. The seasonal features are associated directly with the motion and development of the great pressure systems of the Atlantic, Eurasia and Africa. The changes in these pressure systems during the year can be seen in Figures 1.7 to 1.18 which show the normal pressure at mean sea level for each month of the year.

Cool season. In the cool season the chief features are as follows:

(i) The permanent subtropical "Azores anticyclone" centred over the Atlantic. At this period it is in the southern part of its annual wandering. From this anticyclone there is commonly a ridge of high pressure, sometimes extending over Spain and sometimes along the south of the Mediterranean through Algeria and Libya towards Egypt.

(ii) The great continental anticyclone of Eurasia, which at times extends south over the Balkans or north and west over Scandinavia, central Europe or the British Isles.

(iii) To the south of the Atlantic high-pressure system there is generally low pressure over the North African desert and the tropical Atlantic, including occasional cyclonic activity of some vigour.

(iv) To the north of the Atlantic high-pressure system is the zone through which depressions pass eastwards from the Atlantic across northern Europe.

In addition to these predominant features, the migratory arctic anticyclones which move southwards from Greenland into the North Atlantic, and south-eastwards from north Greenland to Scandinavia and Finland are important. Similar systems move southwards from various parts of northern Europe and Asia over the north Russian plain, sometimes reaching south-eastern Europe.

The Atlantic depressions which move eastwards across northern Europe bring frequent waves of cold air from the north-west which penetrate into the Mediterranean and there encounter warm moist air. The resulting vertical instability leads to the development of vigorous depressions which bring considerable rainfall and frequent gales to the Mediterranean. From time to time the eastward march of travelling depressions in the temperate zone is interrupted by cold-air outbreaks from the Arctic via the Norwegian sea or over Russia. At any time between October and May such a cold northerly air stream may break right through to tropical latitudes. The great thermal contrast leads to very active depressions which commonly form in the tropical Atlantic or the desert of North Africa and move into the Mediterranean. The end-product is often a quasi-stationary cold-pool depression.

Spring and summer. Between March and May the North Atlantic anticyclone is rather commonly linked with, or replaced by, high pressure over Greenland, Iceland and northern Europe. At such times the Mediterranean continues to be affected by depressions and troughs associated with each outbreak of cold air from high latitudes; there is a good deal of windiness in the Mediterranean at this season but, perhaps because the sea surface is relatively cool and the lands over which the air flows before reaching the Mediterranean have begun to warm up, the spring depressions do not bring a great deal of rain or very widespread cloudiness.

The quiet sunny weather, characteristic of the Mediterranean summer, is established when the Azores anticyclone intensifies and develops an extension towards the Alps. This development also takes place intermittently during the spring, but seldom becomes firmly established much before mid-June. The Eurasian winter anticyclone collapses rather quickly in April and ceases to represent a potential source of cold air for the Mediterranean. Partly for this reason warm weather is earlier established in the eastern basin than in the western and central Mediterranean, though all parts of the Mediterranean are still liable to disturbances producing windiness and rather disturbed weather in May. Those summers in which the Atlantic anticyclone develops an extension towards Britain and northern Europe rather than towards the Alps are liable to be relatively disturbed in the Mediterranean, which may be penetrated by air of arctic origin by way of tracks over Russia and the Alps or the Balkans.

With the collapse of the Eurasian winter anticyclone comes the rapid development of the great continental depression centred over south-west Asia with an extension westwards over Asia Minor. A similar low-pressure area appears over the heated Sahara. These changes begin in April and are normally completed by June.

The Atlantic depressions are weaker in summer than in winter, but their cold fronts sometimes sweep across the Mediterranean. It is very rare for this to disturb the weak anticyclonic régime over the southern part of the Mediterranean, where subsiding air over the relatively cool sea surface helps to supply the inflow of air into the monsoonal low-pressure region over the Sahara.

The average summer picture over the Mediterranean is of rather steady, light surface winds from between north-west and north-east blowing between the extension of the Atlantic anticyclone and the monsoon lows over Asia and North Africa.

Fig.1.1(*a*) Air masses in the cool season

Fig.1.1(*b*) Air masses in the warm season

CHAPTER 2

AIR MASSES AND FRONTS

AIR MASSES - GENERAL

The air masses of the Mediterranean are mostly those familiar to meteorologists working in more northern latitudes but by the time these air masses reach the Mediterranean they have undergone modification that is sometimes quite considerable. In addition the Mediterranean basin itself may be regarded as a source region of a type of air mass. The main air masses affecting the Mediterranean are:

Maritime Arctic (mA) coming from the Arctic Sea area between Greenland and Scandinavia.

Continental Arctic (cA) which comes directly from northern Russia and perhaps sometimes from northern Siberia.

Maritime Polar (mP) originating in the sea area west and south of Iceland.

Transitional maritime Polar (tmP). This is maritime polar air which has moved for some time over relatively warm sea. The air which enters the Mediterranean has generally been drawn from the sea area west and south of Greenland and moved to the vicinity of the Azores or Madeira and the neighbouring sea areas south of about 44°N.

Continental Polar (cP) originating over Russia and Siberia and moving towards the Mediterranean via the Volga basin or the Aral Sea-Caspian Sea basin.

Maritime Tropical (mT) originating in the region of the Azores and the ocean areas to the south.

Continental Tropical (cT) whose main source is the North African desert.

Mediterranean air (Med.), mainly of polar origin, which has occupied the Mediterranean basin long enough to have acquired special characteristics associated with this region.

Of these, the first seven are well known to meteorologists concerned with higher latitudes. The eighth is mainly of interest in the Mediterranean basin itself and the areas immediately surrounding it.

The air masses which affect the Mediterranean in the cool and warm seasons are shown diagrammatically in Figures 1.1*(a)* and *(b)*, and typical tephigrams showing the upper air structure of the air masses in the cool and warm seasons are given in Figures 1.2 and 1.3. In this connexion it is also useful to consult Figures 1.71*(a)* to *(d)* which show the mean air temperature over the land in February, May, August and November, and to compare them with Figures 1.72*(a)* to *(d)* which show the mean sea temperature in the same months. From November to March the sea is warmer than the air over the neighbouring land areas, while from June to August the reverse is the case. In April, May, September and October the normal temperatures of the sea surface are about the same as the average air temperatures over the land. In all seasons the normal sea temperature increases from west to east in the Mediterranean as well as from north to south.

AIR MASSES IN THE COOL SEASON

Mediterranean air (Med.). In the cool season the chief air streams which invade the Mediterranean area bring arctic and polar air masses from the Atlantic or the continents of Europe and Asia. Tropical air occurs usually in more limited invasions

over a narrow sector and is most often of continental origin. Arctic and polar air masses are rapidly modified by the warm sea surface (this effect being not strictly coincident with the cool season but having its maximum between about October and January); these air masses remain, however, appreciably colder than tropical air. The main modifications are a rise in temperature and an increase in moisture content. The instability is retained or increased, especially between November and March, specifically at times when the temperature difference, sea minus air, is greatest. There may, however, be more stability above about 10,000 feet either in cases when the cold air mass is relatively shallow and does not reach the Mediterranean in greater depth than this, or when the air mass becomes involved in anticyclogenesis and begins to stagnate over the Mediterranean region.

The most important property of Mediterranean air when stagnating over the Mediterranean is that it is convectively unstable.* In such cases, if undisturbed, it does not normally give cumulus tops above about 6,000 feet, but when lifted by convergence or orographically it may give cumulus cloud with tops to 10,000 or 12,000 feet. Heavy orographic rain may fall in this air mass on the western slopes of the mountains of Corsica and Sardinia, the Apennines, the Dinaric Alps and their extensions into Albania and Greece, on the coasts of north-west Africa and the northern coast of Sicily, the north-west coast of Cyrenaica, the western and southern coasts of Turkey and the coasts of Lebanon, Syria and Palestine.

Typical values of temperature and humidity mixing ratios at various pressure surfaces are given in Table 1, based on the period 3-8 January 1950 at Malta. The corresponding tephigram is given in Figure 1.2, curve *(e)*. This shows no very striking features, the lapse rate on the whole being rather less than saturated-adiabatic but with a slightly more stable layer from 900 to 700 millibars and relative humidity falling from about 80 per cent at the surface to below 50 per cent at 500 millibars.

Table I

Mediterranean air in the cool season

Average properties at Malta, 0200 G.M.T., 3-8 January 1950

Pressure mb.	*Temperature* °F	°C	*Mixing ratio* gm. /kg.
Surface	+ 52	+ 11	7.1
900	+ 42	+ 6	5.2
850	+ 38	+ 3	3.9
800	+ 34	+ 1	2.9
700	+ 25	- 4	1.8
600	+ 11	- 12	1.2
500	- 7	- 22	0.6
400	- 31	- 35	0.2

It is important to realize, however, that these values and properties apply only in cases where the depth of the unstable air mass is limited, either because the initial outbreak was fairly shallow or because it has subsequently become involved in a measure of anticyclonic subsidence in the levels above 10,000 to 12,000 feet. In all other cases the characteristics displayed are those resulting from Mediterranean influence upon fresh polar or arctic air streams as described in the following paragraphs.

*A column of air is said to be "convectively unstable" if there is a layer in the column which becomes unstable when it is lifted bodily to a sufficient height. This condition exists for a layer in which the wet-bulb potential temperature decreases with height (see, for example, "Weather analysis and forecasting"[71]).

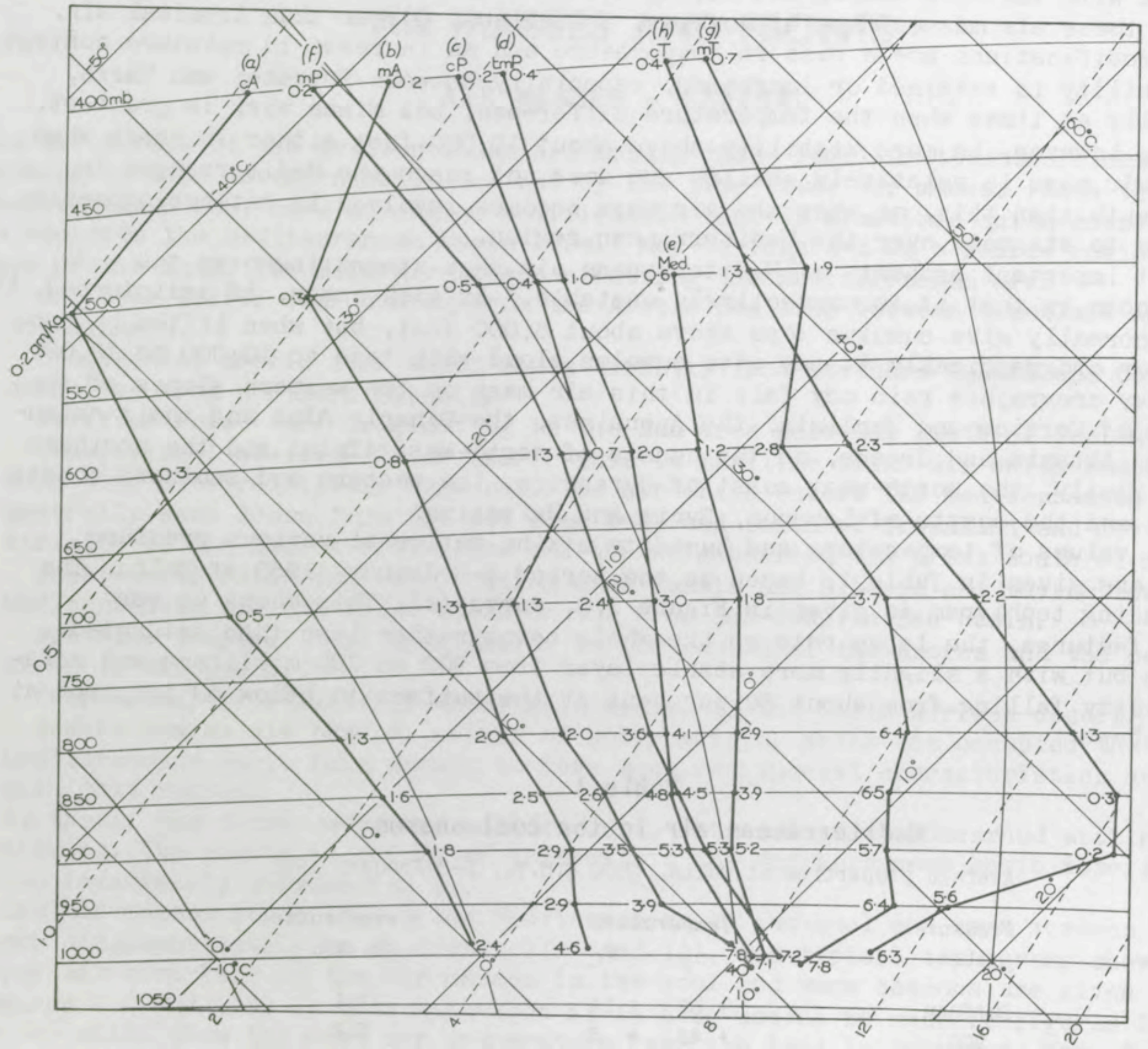

Fig.1.2 Typical tephigrams in the cool season
(a) Nicosia, 1500 G.M.T., 5 February 1950, (b) Malta, 1400 G.M.T., 3 March 1949, (c) Malta, 1400 G.M.T., 14 January 1950, (d) Gibraltar, 1500 G.M.T., 2 January 1949, (e) Malta, 0200 G.M.T., 7-8 January 1950, (f) Malta, 1400 G.M.T., 15 February 1950, (g) Gibraltar, 0500 G.M.T., 21 February 1947, (h) Benina, 1500 G.M.T., 5 January 1949.
The figures beside plotted points are humidity mixing ratios in grams per kilogram.

Maritime arctic and maritime polar air. These three air masses (*mA*, *mP* and *tmP*) have been warmed considerably before they reach the Mediterranean. As a rough guide it may be said that in moving from latitude 55°N. to 35°N. they are warmed by 10° to 15°F. at all levels up to about 500 millibars (approximately 18,000 feet in cold air). Figure 1.2 shows typical tephigrams of these three types of air (under this heading) in the Mediterranean in the cool season.

The main channels by which these air masses reach the Mediterranean are via the Rhône-Saône gap, the Garonne-Carcassonne gap, and the Strait of Gibraltar-Alboran Channel. In addition to the relatively strong blasts of the cold air mass passing through these topographic "funnels", considerable bodies of air may be lifted over the mountains in amounts which increase with the instability of the air. When the air is lifted over the Alps, the Massif Central, the Apennines and the Iberian plateau, intense convection and thunderstorms may develop, with heavy precipitation. In this way the air stream loses a considerable part of its moisture and this, combined with the down-slope motion in the lee of the mountains, usually brings fair or fine weather to the east coast of Spain, the shores of the Gulf of Lions, or the lee of the Atlas mountains, depending on the trajectory. This is the basis of the famous blue-sky winter climates popularly associated with the Mediterranean, but which are really predominant only along limited sections of the coast, especially in the lee of the Alps and the Spanish table-land.

Further passage over the relatively warm Mediterranean causes the moisture content to increase again. This and warming from below renew the instability and cumulus clouds and showers develop. This is particularly so if such air masses arrive in autumn when the sea is still very warm. On such occasions, especially with maritime arctic air, violent thunderstorms and torrential showers occur.

During the cool season polar or arctic air sweeps over the whole Mediterranean about five to six times a month. Such outbreaks commonly lead to several days of cyclonic activity and windiness in the Mediterranean, and in extreme cases damaging gales and high seas occur. The shower activity gradually dies out when the air begins to stagnate and subsidence sets in in the upper levels.

The special characteristics of each of the three types of air under this heading are now considered.

Maritime arctic air (mA). Outbreaks of maritime air do not often spread over the Mediterranean - seldom more than two to four times a year; they are most likely about the end of February. The air moves southwards in the rear of depressions over Scandinavia, the north German plain and eastern Europe, with the Azores anticyclone in a northerly position and generally with the southward extension of an arctic anticyclone in the rear of the depression (weather type A - see Chapter 4). It travels over the North Sea and reaches the Mediterranean mainly via the Rhône-Saône gap. It is one of the air masses responsible for the mistral of the western Mediterranean (see page 72). Over the Mediterranean it becomes extremely unstable, and may give cumulonimbus with tops to 30,000 feet or higher with heavy showers and sometimes snow in the more northern areas and in the mountains. Visibility is very good except in showers. (Etna has occasionally been seen from Malta in these conditions - a distance of 130 miles.) The cloud base usually remains above 1,500 feet, but may lower to 500 feet in showers. Maritime arctic air invasions are generally of rather short duration, limited to a few days and the air does not usually remain in the western Mediterranean for long. As it spreads over the eastern Mediterranean it is rapidly transformed into Mediterranean air.

Figure 2.1 for 3 March 1949 gives a typical example of an incursion of maritime arctic air into the western Mediterranean. The cold front entered the Mediterranean on the night of 1-2 March. A depression formed on the front in the Gulf of Genoa and moved east-south-east. The tephigram for Malta on 3 March 1949 is given in Figure 1.2, curve (*b*). This shows a lapse rate very nearly at the saturated-adiabatic rate up to

700 millibars and with fairly high humidities. Above 500 millibars is a more stable layer.

An intense outbreak of maritime arctic air often results in the formation of a "cold pool" in or near the Mediterranean, generally in association with a "blocking" situation in which the normal eastward travel of depressions across Europe is halted or slowed down for a number of days. These situations are described in Chapters 3 and 4. An example is the incursion of 11-17 February 1938 when an anticyclone was more or less stationary to the south-west or west of the British Isles. With only a short break maritime arctic air moved into the Mediterranean for 48 hours. On the 11th and 13th lee depressions formed in the Gulf of Genoa, and the second of these remained in the same general area till the 18th. Figures 2.2(*a*) and (*b*) show the synoptic situation on 13 February 1938 with tephigrams for Trappes (near Paris) and Venice.

Other examples of maritime arctic air invasions are referred to under weather type A in Chapter 4.

Maritime polar air (mP). This is the most frequent invading air mass of the Mediterranean throughout the cool season. The air mass advances south-eastwards in the rear of a depression moving east across Europe, with the Azores anticyclone extending over western Europe behind it. This air usually reaches the Mediterranean via the Garonne-Carcassonne gap or Rhône-Saône gap, and over the Iberian plateau. Invasions of this air mass are frequent but usually short-lived; the supply is cut off as a new Atlantic depression approaches Europe, and a new invasion generally arrives in the rear of each depression. Several waves may follow one another - sometimes as many as five or six - in close succession. In some years invasions cease for a time in midwinter when high pressure persists over the Iberian peninsula. Over the western Mediterranean this air is very unstable and may give cumulonimbus to well over 20,000 feet with some tops to 40,000 feet.

Figures 2.3(*a*) and (*b*) show the synoptic situation on 14 February 1950 together with the tephigram for Malta for 15 February, which is also shown in Figure 1.2, curve (*f*). This is warmer than curve (*b*) of Figure 1.2 but similar above 900 millibars, apart from the absence of a stable layer at the top, and is also fairly moist. Maritime polar air from the southern extremity of Greenland has spread over the western Mediterranean, in association with depressions extending from the Baltic to near Iceland and a further deep depression is moving east-north-east over the Atlantic. A lee depression has formed over the northern Adriatic.

Invasions of maritime polar air occur chiefly with weather types A, B and C (see Chapter 4).

Transitional maritime polar air (tmP). This air appears frequently during the cool season in the southern part of the western Mediterranean. After having travelled from near southern Greenland to the neighbourhood of the Azores and then eastwards it usually enters the south-western Mediterranean through the Strait of Gibraltar and the Alboran Channel. Part of it may be diverted to the south of the Atlas mountains.

It is very moist and convectively unstable, giving heavy rainfall in the Strait of Gibraltar or when lifted over the Iberian plateau, the Atlas mountains, the Apennines or the Dinaric Alps. The southern flank of this air stream, however, is often rather stable, especially at levels above 5,000 to 10,000 feet, being involved in subsidence in a ridge of high pressure extending east along the coast of North Africa and the Atlas mountains. Cumulonimbus may develop to great heights when the air is fresh further north over the western Mediterranean. Like maritime arctic and maritime polar air it is rapidly transformed to more stable Mediterranean air when subsidence sets in. Transitional maritime polar air enters the Mediterranean chiefly with weather types B and C (see Chapter 4).

An example of the incursion of this type of air is given in Figures 2.4(*a*) and (*b*) which show the synoptic situation on 6 February 1953, together with the tephigram for Gibraltar. The depression off the coast of Spain had moved south-eastwards from mid-Atlantic and the air which passed through the Strait of Gibraltar on the morning of the 6th is estimated to have travelled by a route a little north of the Azores from about 50°N., 40°W. in three to four days. Figure 1.2, curve (*d*) shows a sounding in transitional maritime polar air. This is of interest because it is a little colder than curve (*f*) (in maritime polar air) up to 850 millibars (though this is not typical). The transitional maritime polar air is warmer at higher levels with a more stable lapse rate and high humidity at all levels.

Continental arctic air (cA). This is the coldest air mass in the Mediterranean. Invasions of it are not frequent, perhaps occurring on the average four to five times during the cool season. It normally arrives in the Mediterranean as a deep north to north-easterly current which moves on a direct path from northern Russia when an intense anticyclone is centred over Scandinavia and the north German plain. (It occurs in association with weather types A and B_1, described in Chapter 4.)

On its way to the Mediterranean, the air commonly undergoes considerable modification consisting of:

(i) Subsidence aloft with adiabatic increase of temperature. This is most pronounced in weak streams. There is little or no subsidence in strong currents.
(ii) Heating from below over the land.
(iii) Picking up of a small amount of water vapour in the lower levels.

Continental arctic air reaches the Mediterranean mainly via the Dardanelles, through the Vardar valley in Macedonia, through the Trieste gap or via the Rhône valley. It is one of the air masses responsible for the mistral of the western Mediterranean and the bora of the Adriatic which may give severe gales and dangerous squalls (see details in Chapter 6). The mountain ranges of central and south-eastern Europe form a barrier, diverting much of the air flow towards the north German plain and France, but with a deep vigorous stream which has developed some instability the mountains may afford relatively little protection and considerable movement may take place directly over the Alps, the Dinaric Alps, and at times over the Anatolian plateau in Turkey, giving strong föhn winds on the lee side.

On reaching the Mediterranean the air mass, especially if fast-moving, is characterized by very low temperatures and humidity mixing ratios. The latter may be of the order of 2 grams per kilogram up to 850 millibars (about 5,000 feet) and rapidly decreases above that level becoming less than 1 gram per kilogram at 700 millibars (about 10,000 feet) and of the order of 0.1 to 0.2 grams per kilogram at 600 millibars (about 13,000 feet). Over the warm Mediterranean Sea the air mass is rapidly heated from below and picks up moisture, becoming very unstable as a result. Cumulonimbus develops to 20,000 feet with some tops to 40,000 feet, and heavy squally showers of rain occur, frequently accompanied by thunder and hail. In the northern Mediterranean, especially in the northern parts of the Aegean and Adriatic Seas and in the Gulf of Lions the precipitation may fall as snow. Occasionally the precipitation falls as snow over most of Italy, the Spanish uplands and even as far south as Algiers. Shower and thunderstorm activity develops principally over the sea and windward coasts with cloud base falling to 300-600 feet and visibility dropping to below a mile in showers. Cumulus development is often inhibited by subsidence 12 to 24 hours after the continental arctic air reaches the Mediterranean but in some cases the flow of very unstable air may continue for two to three days. The more prolonged outbreaks are generally associated with a "blocking" situation (see page 50).

The vigorous northerly air stream often extends rapidly southwards while spreading only slowly eastwards, so that arctic air may reach Cyrenaica before it reaches the Dodecanese islands in the eastern Aegean; or it may spread across eastern Libya to the Sudan before it reaches lower Egypt. The arrival in Libya of continental arctic air modified after passage over the sea can lead to frequent showers on the Tripolitanian coast without much violent activity, but at the same time with marked activity on the uplands of Cyrenaica. The cold front occasionally becomes quasi-stationary in the southern part of the Mediterranean in winter, giving two or three days of medium cloud cover with intermittent precipitation.

Figures 2.5(*a*) to (*e*) show the synoptic situation from 1 to 3 February 1949, together with the tephigram for Malta on 3 February. Continental arctic air is advancing into the western and central Mediterranean along characteristic tracks and low pressure is developing over most of the Mediterranean Sea. The air is not spreading so rapidly over the Aegean as it is over the western Mediterranean.

Figure 2.6(*a*) shows the synoptic situation on 5 February 1950, when an intensely cold continental arctic air stream moved into the eastern Mediterranean even though active Atlantic depressions were passing across western Europe. It is noteworthy that in such cases the northern part of the Russian anticyclone usually moves east more rapidly than its southern end, thereby tightening the gradient on its south-east side and impelling cold air rapidly southwards towards the Mediterranean. On this occasion, although there was snow in the northern Aegean, the coldest air to reach the Mediterranean moved over the Anatolian plateau to Cyprus and thence to Palestine. The tephigram for Nicosia, Cyprus, on 5 February in Figure 2.6(*b*) and Figure 1.2 curve (*a*) shows intensely cold air, which even after warming over the sea gave heavy snow in Haifa. This shows the very cold and unstable air extending up to 500 millibars. A depression moved south across Anatolia into the Cyprus area and waves of arctic air moved southwards but became rapidly shallower over lower Egypt with consequent obliteration of the instability phenomena. This may be seen from the tephigram for Cairo Airport, also shown in Figure 2.6.

As in the case of maritime arctic air, intense outbreaks of continental arctic air often result in the formation of "cold pools" and "blocking" situations; these occurrences are discussed in Chapters 3 and 4. Additional examples of continental arctic air invasions are listed under weather types A and B_1 in Chapter 4.

Continental polar air (cP). This air is of frequent occurrence in the Adriatic and northern Aegean during the cool season. It most frequently moves into the Black Sea and the Mediterranean from the basin of the Aral and Caspian Seas. The lower layers may be very cold, but the cold layer is frequently only 3,000 to 6,000 feet deep, with relatively warmer air above, due partly to subsidence and partly to its past history. (A typical tephigram is shown in Figure 1.2, curve (*c*).)

The air mass moves into the Mediterranean as an easterly or north-easterly stream associated with an anticyclone or ridge of high pressure to the north, usually extending from Russia. On occasions the ridge of high pressure over Europe may be an extension from the Azores anticyclone and an easterly air stream from southern Russia may be induced to move into the Mediterranean along the southern flank of this high-pressure system.

This air, being more stable than continental arctic, blows chiefly through the mountain gaps and there is not much movement over the mountain ranges. Often the current may be almost completely shut out from the Mediterranean except for very limited seepage through the gaps. Thus the lee side of mountains is much more sheltered than with less stable air streams. With intensifying high pressure over the Balkans or the Hungarian plain, gales may blow through the mountain gaps (for example, the bora). Ravine effects intensify the bora in some localities (for details see page 77) while winds may be only light or moderate on parts of the eastern shores of the Adriatic; the north-easterly winds do not always reach the western shores. However, an incursion of continental polar air will normally cause the development or rejuvenation of a depression in the Mediterranean, and gales developing near the depression may involve very fierce and extensive bora affecting most of the Adriatic. Similar effects occur with bora-type winds in the Aegean.

Continental polar air is often stable above 850 millibars (5,000 feet) and may give no showers over the Mediterranean. If, however, the air above this level is of maritime polar origin, convective instability may be present. In this case considerable showers may develop as a result of orographic lifting and heavy rain may fall at the front between this air and Mediterranean air. Figure 1.2, curve (*c*) (in continental polar air) shows a stable layer between 700 and 600 millibars separating two layers of almost neutral stability. There is slight convective instability present, however, from 900 to 730 millibars.

Figure 2.7 shows the synoptic situation on 25 January 1949, with high pressure developing over the Balkans and continental polar air moving into the Mediterranean intensifying a depression which has moved into the Cyprus area. Bora-type winds blow over the Aegean, and at least two waves of continental polar air move across the eastern Mediterranean, giving heavy, squally frontal rain and showers. Invasions of continental polar air occur chiefly with weather types A, B and D, examples of which are listed in Chapter 4.

Maritime tropical air (mT). Invasions of this air into the Mediterranean are not common. It generally enters the Mediterranean as a deep south-westerly stream from the region south of the Azores when a deep depression is moving eastwards across Britain or France (weather type C, see Chapter 4). But, as the cold front of the depression approaches the Mediterranean, the supply of maritime tropical air is cut off and becomes replaced by a continental tropical current from Africa. Thus maritime tropical air seldom penetrates beyond the central Mediterranean, and even when it reaches as far as that it has already been modified for the most part by subsidence.

Although moist at all levels, the air is convectively stable. As a result there is considerable deflection of the flow by the Iberian plateau and the Atlas mountains, and not much lifting over the mountains. There is usually a considerable slackening of the pressure gradient over the western Mediterranean, and even in the Strait of Gibraltar the accompanying vendaval (see page 81) is not often strong until the approach of the cold front.

At the warm front ahead of this air there are in the western Mediterranean the usual stable layer clouds, with rain or drizzle and poor visibility, particularly over northern Italy when the air ahead of the front is cold, stagnant maritime polar. Stratocumulus cloud develops in the maritime tropical air mass, tending to disperse overland during the day. The warm front weakens as it proceeds further east, except in late winter when the prefrontal southerly air stream off Africa may be fairly cold. The maritime tropical air stream may move slowly over the western Mediterranean for several days, and penetrate from there to central Germany. In the zone of subsidence on the southern flank of the air stream in the Mediterranean, particularly in the lee of mountains, clear skies prevail.

Figure 2.8(*a*) shows the synoptic situation on 21 February 1947 when a large-scale invasion of maritime tropical air into the Mediterranean occurred. The tephigram for Algiers of the same date is given in Figure 2.8(*b*) and shows the characteristic properties of maritime tropical air. The tephigram for Gibraltar on the same day is given in Figure 1.2, curve (*g*). This shows an inversion to 950 millibars with a lapse rate approximating to the saturated adiabatic above this, and moderate humidity at all levels except near the surface which is dry.

Continental tropical air (cT). In the cool season this air comes from that part of North Africa beyond the immediate influence of the Mediterranean. It is induced to flow northwards ahead of depressions moving through the Mediterranean, the flow usually being strongest in the sector 100 miles or so ahead of the cold front. The relics of any warm front of Atlantic origin die out as the continental tropical air stream gets drawn into the advancing depression. The front of the advancing continental tropical air is of quite separate origin, sometimes having a previous history as the southern limit of cold air from eastern Europe. During the greater part of the cool season continental tropical air rarely spreads very far over the Mediterranean, at any rate in the lower layers of the atmosphere. It then occurs chiefly in occluding warm sectors. It is prominent from the beginning of March onwards and especially in April or May when it may spread right across the Mediterranean and even advance to southern England or the north German plain. It is also prominent in September and October and occasionally even in November, when depressions again begin moving through the Mediterranean. If there is a blocking ridge of high pressure over the Balkans (often as an extension of a high-pressure system over Russia or central Europe towards Cyrenaica) a flow of continental tropical air may continue for several days on the west side of the ridge. (It occurs in association with weather type A_1, described in Chapter 4.)

The southerly continental tropical air stream is known as scirocco in Italy, Malta and the Near East, as chili in Algeria and Tunisia, as ghibli in Libya, and as khamsin in Egypt. The properties in the source region over Africa are radically different from those it acquires after even the short sea crossing to Malta. Over its source region in Africa this air is very hot and dry. Along the North African coast in May the surface temperature may be as high as 120°F. and the relative humidity as low as 3 per cent. The air mass has a very high lapse rate, usually the dry adiabatic lapse rate up to 600 millibars (approximately 14,000 feet in this air mass) or 500 millibars (19,000 feet) and is convectively unstable. The highest temperatures are actually reached towards the end of the air's passage over the Sahara towards the Mediterranean coast.

If the scirocco is strong (winds between south-east and south-west sometimes reach force 6 to 8) and has a long fetch over the deserts of North Africa, it may carry great quantities of dust which reduce the visibility over the North African coasts to less than 1,000 yards in some cases and to less than 100 yards just ahead of the cold front. Out to sea as far as Malta visibility may be reduced to about two miles. Duststorms are associated particularly with the strong winds ahead of the cold front. The belt of strong winds may extend up to several hundred miles along the stream but at any one time its width is seldom great, commonly from twenty to fifty miles. These winds and duststorms ahead of a cold front during its progress eastwards through the Mediterranean have been known to affect successively the whole region from western Libya to Iraq. Traces of Saharan dust may be carried as far as 50°N. with the continental tropical air and the white to yellow haze and glare are well known in all parts of southern Europe, greatly reducing the ultra-violet intensity and sunburning properties of the sunlight. Rain which falls from (or through) this air often deposits yellow muddy marks and gives rise to accounts of "raining mud" and "red rain". Such effects are most pronounced when the dust content is great and the rainfall confined to a few drops. Desert insects also accompany the continental tropical air stream and in exceptional cases one or two locusts have been known to reach the coast of England. Usually, however, the air advances slowly northwards over the sea, picking up moisture in the lower layers and giving low stratus, drizzle and rain, particularly in areas of convergence associated with depressions or when lifted orographically at the coasts of Europe and the Mediterranean islands (even Malta). These processes tend to wash the air clean by extracting the dust.

Advances of continental tropical air over the Mediterranean after a cold spell give the most active warm fronts in the central and eastern Mediterranean, sometimes producing copious rainfall and thunderstorms. Outbreaks of thundery rain and very active cumulonimbus, dangerously embedded in layered cloud, can be experienced even over the Gulf of Sidra not far north of the Libyan coast. Although this activity is initially confined to medium and high levels, the heavy precipitation causes a steady development down to lower levels (see also page 22).

The Atlas mountains form a considerable barrier against southerly air streams and, apart from local currents through gaps such as the Biskra gap south of Algiers, it is unusual for an appreciable flow of continental tropical air to affect the western Mediterranean from the south. But it may reach the western Mediterranean as a south-easterly flow from Cyrenaica, Tripolitania or Tunisia. The favourite tracks for the scirocco are as a south or south-west wind from Tripolitania blowing towards Italy or the Balkans and as a south-east wind from Cyrenaica. These favoured paths appear to be determined partly by the mountains in the central Sahara.

The synoptic chart for 24 December 1946 (Figure 2.9(*a*)) shows continental tropical air spreading over the eastern Mediterranean during the winter. The synoptic chart for 7 May 1949 (Figure 2.10(*b*)) shows continental tropical air spreading over the Gulf of Sidra. (A similar case may be seen in Figure 2.11(*a*).) The accompanying tephigrams for Cairo and Benina (Figures 2.9(*b*) and 2.10(*e*)) show the typical characteristics of continental tropical air at the respective times of year. Another typical tephigram for January is given in Figure 1.2, curve (*h*). This shows a marked inversion up to 900 millibars with a steep lapse rate conditional above. There is extremely dry air near the top of the inversion.

Figures 2.12(*a*) and (*b*), for 23-24 May 1953, show an example of continental tropical air spreading over western Europe as far as the British Isles, and resulting in unusually high temperatures for the time of year in Spain, France and England. Figure 2.12(*c*) gives the tephigram for Gibraltar on 24 May 1953. The analysis, which is taken partly from French North African sources, indicates that an old frontal system originating in the temperate zone and now lying within the tropical air masses over North Africa still has some importance.

Continental tropical air can enter the Mediterranean with all weather types except E, but especially with types A_1 and B_3 described in Chapter 4, where further examples are mentioned.

AIR MASSES IN THE WARM SEASON

Mediterranean air (Med.). During the warm season the modifications which take place in the invading air masses to produce Mediterranean air are rather different from those of the cool season. The air which flows into the Mediterranean area is mainly polar air from the north-west or north but it has been warmed and dried in its passage over the European continent. As it moves into the Mediterranean basin it is cooled from below by the relatively cool sea (these effects being not strictly coincident with the warm season but coming into operation gradually in April and May, especially after warm spells over Europe, and lasting till about July). As the winds are normally light, the air does not travel far before undergoing considerable modification. A low-level inversion forms which induces some stability, but above this inversion the air is convectively unstable and in areas of active convergence showers and thunderstorms may develop especially in the northern parts of the Mediterranean between Spain and the Adriatic and over the mountains in Italy, French North Africa and the larger islands in the western basin. On the whole, however, the weather is fair or fine in air that has been warmed over Europe and somewhat cooled again over the Mediterranean in the spring and early summer months. At this time of the year rainfall amounts are seldom great and generally dwindle from March till the usual dry season begins in late May or June. Any rainfall which does occur is practically confined to fresh outbreaks of cold air which have passed quickly across Europe where they bring the characteristic cool spells of spring (March to May, occasionally June).

Over the sea the air is normally free of cloud, but during the night and early morning stratocumulus or stratus may form in windward coastal areas, with perhaps local fog, for example in the Strait of Gibraltar and at short distances inland from the North African coast.

As an example of this air-mass type, Table 2 gives the mean values of temperature and mixing ratio for Malta over the period 7-13 July 1950. These mean values are also shown on the tephigram in Figure 1.3, curve (*d*). The fact that this is not an individual sounding is brought out by the absence of any striking individual features. The only fact worthy of note is the stable layer from about 850 to 800 millibars which can therefore be assumed to be an average condition.

Table 2

Mediterranean air in the warm season

Average properties at Malta, 1400 G.M.T., 7-13 July 1950

Pressure mb.	*Temperature* °F.	°C.	*Mixing ratio* gm./kg.
Surface	85	+ 29	14.1
900	72	+ 22	8.7
850	67	+ 19	7.4
800	65	+ 18	4.4
700	54	+ 12	3.0
600	38	+ 3	2.1
500	22	- 6	0.9
400	0	- 18	0.3

These values can be compared with the average figures in *Med.* air for July given in Table 3 and for all air masses in Table 8 in Volume 2.

Arctic air (mA, cA). Invasions of arctic air, maritime and continental, into the Mediterranean in the warm season are rare, and when they do occur the air has generally been considerably modified by passing over the heated continent of Europe. The resulting weather in the Mediterranean is similar to that occurring with polar air (see following section) but more disturbed, and convection at the front or within the cold air mass is likely to be more active. In the warm season, as in the cold, an invasion of maritime arctic or continental arctic air is often associated with a "blocking" situation and may bring a "cold pool" to the Mediterranean. Cold pools are uncommon in the summer months, but when they do occur they are likely to be accompanied by thundery activity and unseasonable rain (see further in Chapter 3).

Figure 2.13, for 21 July 1951, shows maritime arctic followed by continental arctic air entering the Mediterranean. This is a weak invasion typical of the summer and not accompanied by blocking or a cold pool. No depression formed in the Mediterranean and the main effects of the invasion were strengthening of the etesian winds and a clearance of low stratus on the North African coast.

An example of continental arctic air moving into the eastern Mediterranean while maritime polar air is invading the western end is given in Figure 2.14 which shows the synoptic situation on 22 August 1951. As the arctic air moved into the eastern Mediterranean it gave thunderstorms over the Balkans and cleared away low stratus on the Nile delta.

An example of an invasion of maritime arctic air to the Mediterranean in July in association with a blocking situation and cold pool is given in Figures 2.15(*a*) to (*e*) and described in Chapter 4. An example of the invasion of continental arctic air in spring may be seen in Figures 2.11(*d*) to (*f*).

Maritime polar air (mP). In the warm season relatively weak invasions of maritime polar air from temperate latitudes may reach the Mediterranean in the rear of depressions moving eastwards across Europe; but pressure normally rises rapidly over western Europe in such streams and the polar air is quickly modified over France and

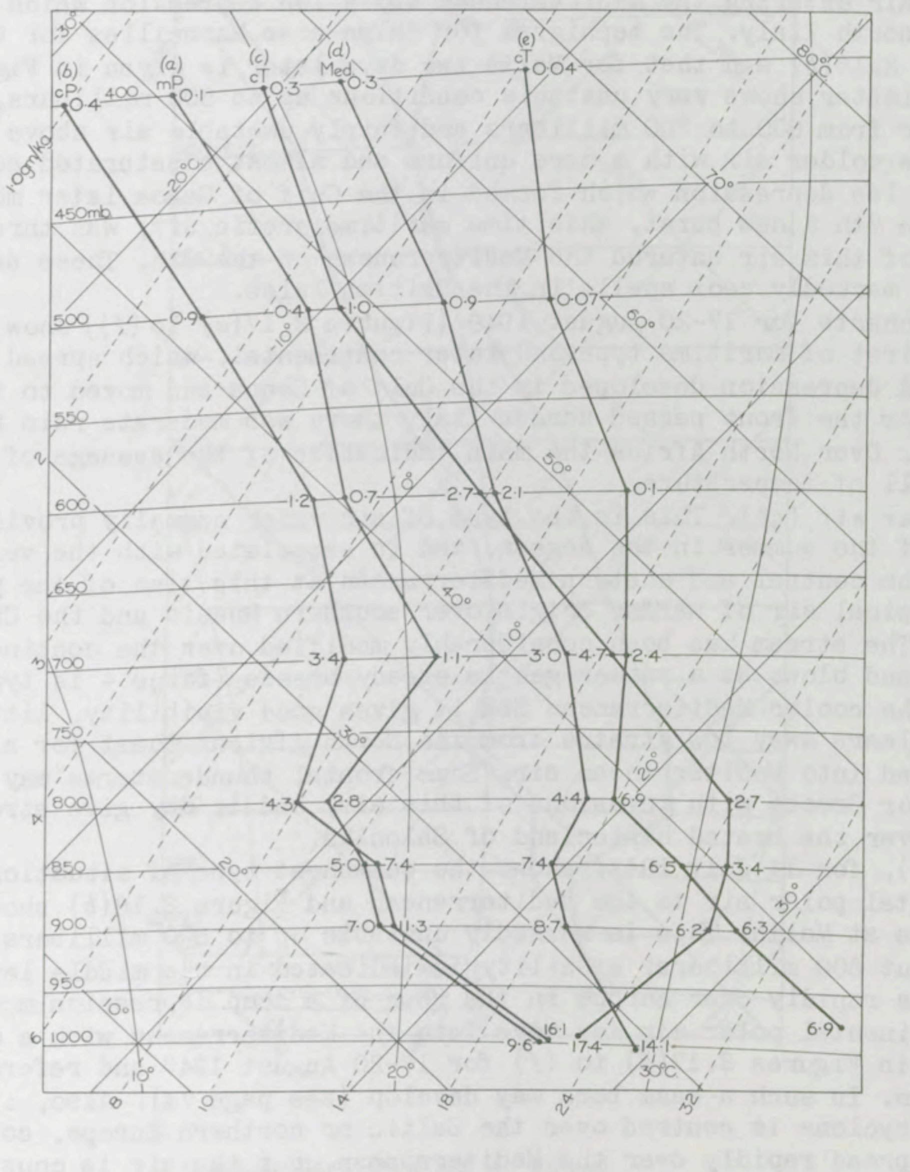

Fig.1.3 Typical tephigrams in the warm season (a) Malta, 1500 G.M.T., 8 July 1948, (b) Malta, 1700 G.M.T., 14 July 1947, (c) Malta, 1700 G.M.T., 9 July 1947, (d) Malta, 1400 G.M.T., 7-13 July 1950, (e) Nicosia, 1400 G.M.T., 19 July 1949. The figures beside plotted points are humidity mixing ratios in grams per kilogram.

the western Mediterranean to become Mediterranean air. It is seldom that cumulonimbus develops in this air mass in the Mediterranean, but thundery activity may occur ahead of and at the cold front. This air gives good visibility and clears away low stratus from the Strait of Gibraltar and the Alboran Channel. When invasions of maritime polar air occur, a north-westerly mistral may blow for a short time over the western Mediterranean, but strong to gale winds are not frequent. If the upper air stream moves over the Alps, initial overrunning of stagnant warm air in the Po valley and northern Adriatic may give rise to heavy thunderstorms.

The synoptic situation on 6 July 1948 (Figure 2.16*(a)* shows a vigorous stream of maritime polar air entering the Mediterranean and a lee depression which has developed over north Italy. The tephigram for Salon near Marseilles for 6 July is shown in Figure 2.16(*b*) and that for Malta two days later is given in Figure 1.3, curve (*d*). The latter shows very unstable conditions up to 800 millibars, an almost isothermal layer from 800 to 700 millibars and fairly unstable air above this, while the former shows colder air with a more uniform and almost a saturated adiabatic lapse rate. The lee depression which formed in the Gulf of Genoa later moved eastwards and by the 7th a new burst, this time maritime arctic air, was threatening. The cold front of this air entered the Mediterranean on the 9th. These same cold outbreaks produced markedly cool spells in the British Isles.

The synoptic charts for 17-20 August 1949 (Figures 2.17(*a*) to (*f*)) show an invasion of polar air, first of maritime type and later continental, which spread over the Mediterranean. A depression developed in the Gulf of Genoa and moved to the eastern Mediterranean. As the front passed across Italy there was moderate rain followed by rapid clearance. Over North Africa the main indication of the passage of the front was a slight fall of temperature.

Continental polar air (cP). This is the type of air which normally provides the etesian winds of the summer in the Aegean, and is associated with the very settled conditions of the central and eastern Mediterranean at this time of the year, though continental tropical air of warmer origin over southern Russia and the Caspian is also drawn in. The stream has been considerably modified over the continent by warming and drying and blows as a rather gentle steady breeze (force 4 is typical). When it moves over the cooler Mediterranean Sea it gives good visibility, little cloud, and generally clears away low stratus from the North African coast for a time. It is rapidly converted into Mediterranean air. Some frontal thunderstorms may occur in northern Italy or Greece with invasions of this air, and it may give strong dust-raising winds over the heated hinterland of Salonika.

Figure 2.18(*a*), for 14 July 1947, shows the commonest type of situation which brings continental polar air to the Mediterranean and Figure 2.18(*b*) shows a sounding in this air mass at Malta. This is markedly unstable up to 800 millibars and unstable again above about 600 millibars; stability is indicated in the middle levels. If high pressure spreads rapidly over Europe in the rear of a deep depression moving eastwards then continental polar air may move into the Mediterranean with a more sudden burst as shown in Figures 2.17(*a*) to (*f*) for 17-20 August 1947 and referred to in the previous section. In such a case bora may develop (see page 74). Also, if a quasi-stationary anticyclone is centred over the Baltic or northern Europe, continental polar air may spread rapidly over the Mediterranean, but the air is considerably modified before reaching the sea. An example is given in Figures 2.19(*a*) and (*b*) for 27-28 July 1948. The tephigram for Iserlohn in Germany (51°23'N., 07°40'E.) is also given (Figure 2.19(*d*)) to show how the air is modified over the continent. This may be compared with Figure 1.3, curve (*b*), in a similar air mass at Malta. The Iserlohn sounding shows the warming effect over the continent with dry air and a dry adiabatic lapse rate up to 800 millibars. The Malta ascent while being colder at all levels is especially so at about 800 millibars. The air at Malta appears to have been cooled up to about 800 millibars by passage over the sea and then rewarmed at the bottom to

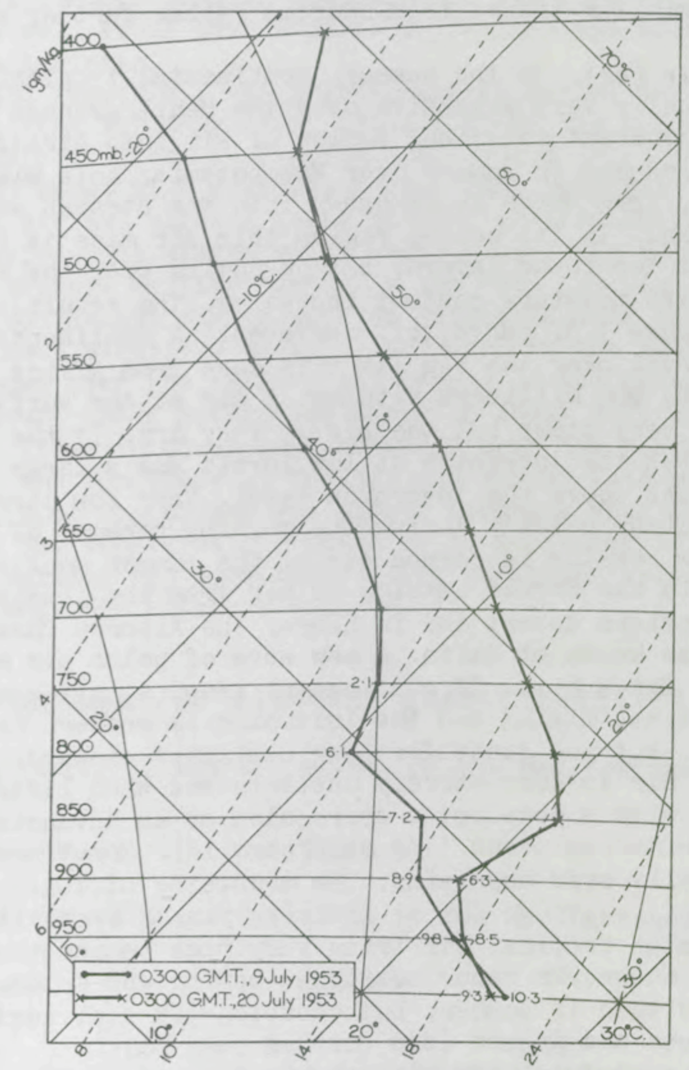

Fig. 1.4 Etesian winds at Athens
The figures beside plotted points are humidity mixing ratios in grams per kilogram.

produce a dry adiabatic lapse rate up to 900 millibars. Figure 1.4 gives tephigrams of etesian winds at Athens on two occasions in July 1953. Both ascents show a lapse rate slightly greater than saturated adiabatic in the middle and upper levels. In some cases but not always there is an inversion at about 900-800 millibars.

Maritime tropical air (mT). This air is of little importance in the Mediterranean during the warm season. It may reach the north-west Mediterranean through the Garonne-Carcassonne gap, but after its passage over the mountains and heated land of southern France and Spain its characteristics on coming over the (cooler) sea surface again in the Mediterranean do not differ in any important respect from those of maritime polar air on similar tracks from sources rather further north over the Atlantic.

Continental tropical air (cT). In the summer, continental tropical air from Africa is not very common nor usually very extensive over the Mediterranean Sea. This is because of the almost constant monsoonal inflow of air into Africa. Continental tropical air is also produced in summer over Mesopotamia, Asia Minor and the lowlands around the Caspian Sea, from where it is drawn into the etesian winds over the Aegean and eastern Mediterranean. In its source region this air mass is hot and dry with dry adiabatic lapse rate in the lower layers, but on coming over the Mediterranean it is cooled from below and its moisture content increases. The resulting state is typified by the tephigram in Figure 1.3, curve (*c*), representing continental tropical air after a fairly short track over the sea (in this case from Africa to Malta). This shows an inversion up to 900 millibars with moist air at the surface. Above 800 millibars the lapse rate is very steep but the air is very dry. If the air returns inland, night cooling accentuates the inversion at low levels and a large decrease in moisture content persists above the inversion level. Very low stratus develops with patches of fog, which clear quickly during the morning because of the rapid temperature increase. This low stratus is common during the summer months in the Nile delta (where it occurs even in the warmer samples of air from the etesian winds), in the coastal strip of the western desert and in Libya, the Alboran Channel and the Strait of Gibraltar. It is also known at Malta. A new wave of polar air will bring clear nights without stratus for a time. If continental tropical air moves rapidly over the sea, there is more vertical mixing and the inversion is weaker. In this case the air remains relatively dry, hot and dusty for long distances seaward.

Continental tropical air is convectively unstable and when lifted in an area of convergence associated with a developing depression or an advancing cold front may give thundery rain from medium cloud (see also page 16). Sometimes heavy thunderstorms develop, especially over mountains. The mountains of Tunisia are important in this connexion.

Outbreaks of continental tropical air bring very high temperatures to the north coast of Africa. These outbreaks occur mostly in spring and autumn when onshore breezes are less marked than in summer; but occasionally continental tropical air may spread north between June and August (see further page 168).

The synoptic chart for 19 July 1949 with the tephigram for Nicosia (Figures 2.20(*a*) and (*b*)) show continental tropical air from Mesopotamia entering the eastern Mediterranean. This is also a situation in which continental tropical air from the Caspian has flowed around the north of Turkey but is beginning to be cut off as the cold front from a European depression approaches. High pressure over the Black Sea first induces the flow, and it continues until the cold front of a new wave of polar air reaches the southern Aegean. The synoptic chart for 14 July 1949 with the tephigram for Gibraltar (Figures 2.21(*a*) and (*b*)) show continental tropical air from Africa slowly encroaching over the south-western Mediterranean. The flow is first induced as a centre of high pressure over Spain is cut off from the Atlantic ridge and moves east and south-east towards Tunisia and the Gulf of Sidra. The flow continues until a new wave of polar air reaches southern Spain.

A flow of continental tropical air into the western Mediterranean may be induced by the development of a thermal depression to the south of the Atlas mountains combined with a ridge of high pressure to the north-east. The approach of a fresh tongue of polar air from the north or north-west may cause the African depression to deepen, and the consequent increase in the continental tropical air current is liable to retard the arrival of cold air. At some stage a lee depression may appear north of the Atlas mountains, and occasionally this leads to the transference of the main centre of low pressure north into the Mediterranean Sea. This development, however, is more liable to occur in the autumn and winter, from about September onwards, than at the height of summer. Similar sequences in the central Mediterranean lead to waves forming on the cold front over Algeria or Tunisia and travelling north-east towards Italy or the Adriatic.

A period of scirocco (southerly and south-easterly winds) in the central Mediterranean, sometimes lasting for many days, often follows the first autumnal invasion of cold air. An example is given in Figures 2.22(*a*) and (*b*). The preliminary chart for 13 September 1953 shows high pressure moving east behind the cold front. Continental tropical air was already being steered towards Spain and Portugal but the axis of the high-pressure system moved east as maritime polar air pushed in from the Atlantic to the western Mediterranean. By the 20th the high-pressure system had become centred over south-east Russia with an extension over the Balkans towards Cyrenaica. Then followed about two weeks of scirocco in the central Mediterranean. High pressure continued over the Balkans and Cyrenaica and became associated with successive high-pressure cells moving eastwards in about latitude 50°N. Successive cold fronts from the Atlantic advancing eastwards over the western Mediterranean were halted at about the longitude of Tunisia and thrown into waves, while to the east of them the scirocco air stream was always stronger when the front was near. Figure 2.22(*c*) gives the tephigram for Malta on 19 September 1953. This shows fairly stable air near the surface but some instability at higher levels up to about 500 millibars, with moderate moisture content.

SUMMARY OF AIR-MASS CHARACTERISTICS

The typical characteristics of the air masses of the Mediterranean are summarized in Table 3.

Table 3

Air-mass characteristics in the Mediterranean

January

	1000 mb.				850 mb.				700 mb.				500 mb.			
	Temp. °F.	Temp. °C.	x gm./kg.	θ_w °C.	Temp. °F.	Temp. °C.	x gm./kg.	θ_w °C.	Temp. °F.	Temp. °C.	x gm./kg.	θ_w °C.	Temp. °F.	Temp. °C.	x gm./kg.	θ_w °C.
mA	39	4	4.6	+ 3	22	− 6	2.2	+ 1	+ 6	−14	1.3	+ 4	−27	−33	0.3	5
cA	34	1	2.4	− 2	17	− 8	1.7	− 1	− 6	−21	0.4	− 2	−33	−36	0.2	3
mP	51	11	7.2	+10	34	+ 1	3.5	+ 7	+14	−10	1.4	+ 6	−15	−26	0.4	9
tmP	53	12	7.8	+11	35	+ 2	4.0	+ 8	+19	− 7	1.6	+ 8	−10	−23	0.4	10
cP	45	7	4.5	+ 5	29	− 2	2.6	+ 4	+ 9	−13	1.3	+ 4	−11	−24	0.4	10
mT	..	..	..	..	50	+10	6.0	+14	+35	+ 2	2.5	+13	+ 6	−14	1.0	15
cT	..	..	..	..	66	+19	1.8	+13	+41	+ 5	1.3	+13	+ 2	−17	0.6	14
Med.	57	14	7.0	+11	37	+ 3	3.7	+ 8	+26	− 3	2.5	+11	− 3	−19	0.9	13

Table 3 (continued)

July

	1000 mb.				850 mb.				700 mb.				500 mb.			
	Temp. °F.	Temp. °C.	x gm./kg.	θ_w °C.	Temp. °F.	Temp. °C.	x gm./kg.	θ_w °C.	Temp. °F.	Temp. °C.	x gm./kg.	θ_w °C.	Temp. °F.	Temp. °C.	x gm./kg.	θ_w °C.
mP	..	..	..	..	46	18	6.0	13	28	- 2	2.5	11	- 2	-19	0.8	13
cP	79	26	16.1	23	55	13	6.7	16	39	+ 4	3.4	15	+ 6	-14	0.9	15
cT (from Africa)	..	..	..	..	78	26	4.5	18	56	+13	2.5	17	+14	-10	0.5	16
cT (from Mesopotamia)	..	..	..	..	76	24	5.0	18	58	+14	2.4	17	+28	- 2	0.6	19
cT (Habbaniya)	107	42	6.5	20	85	29	3.6	18	60	+16	2.3	18	+29	- 2	0.6	19
Med.	85	29	14.1	22	67	19	7.4	18	54	+12	3.0	17	+22	- 6	0.9	18

	April Temperature at						*October* Temperature at					
	850 mb.		700 mb.		500 mb.		850 mb.		700 mb.		500 mb.	
	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.
mP	34	1	12	-11	-15	-26	41	5	25	- 4	- 7	-22
cT	75-85	25-30	52	+11	+12	-11	70-75	20-25	45	+ 7	+10	-12
Med.	48	9	32	0	+ 4	-16	55	13	38	+ 3	+ 7	-14

x = mixing ratio. θ_w = wet-bulb potential temperature

FRONTS

General. In the Mediterranean, as in higher latitudes, the most active and important fronts are characterized by strong thermal contrast, great cyclonic vorticity - which may be marked by strong cyclonic curvature (sharp trough) and/or strong wind shear (discontinuity of wind speed) - both at the surface and in the frontal zone aloft, and by sufficient humidity and convective instability in the uplifted air mass to encourage the development of great cloud masses and precipitation. Indeed the frequency of instability in the uplifted, warmer air masses in the Mediterranean leads to one or two special features such as a noteworthy tendency for altocumulus castellanus, and sometimes cumulonimbus, in warm-front cloud systems and a fair frequency of warm-front thunderstorms. (This is also characteristic of warm fronts in the United States of America when tropical air from the Gulf of Mexico constitutes the uplifted air mass.) In the regions surrounding the Mediterranean, clusters of thunderstorms commonly break out near the tips of warm sectors, even at the very young stage (that is, open wave on a trailing front) and may be used to identify the position of frontal waves on a trailing front from sferic reports when these are available and their positions well enough fixed. Another result of prevalent convective instability in both the warmer and colder air masses in the Mediterranean is probably seen in the characteristically quick development of cyclonic circulations in the region: the resulting depressions generally remain rather small by comparison with those in higher latitudes, but they are important on account of the rapidity with which gales and precipitation, often thundery, develop within them and the abrupt acceleration of those portions of the frontal systems which come within the deepening system.

Fig.1.5(a) Prevailing surface winds for January
Heavy arrows mean that prevailing wind direction occurs in ⩾ 50% of observations. Other arrows represent most frequent wind direction.

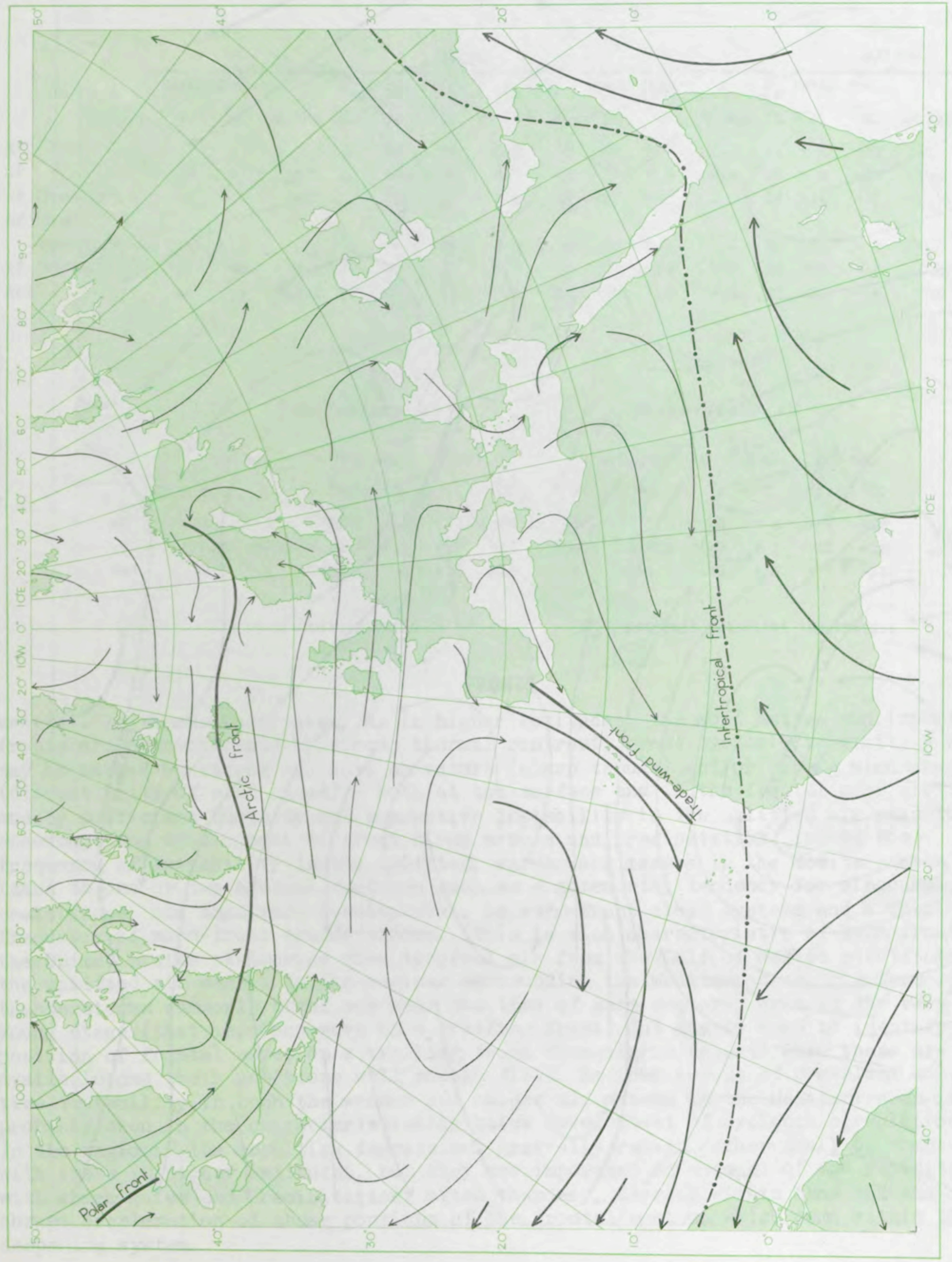

Fig.1.5(*b*) Prevailing surface winds for July. *Heavy arrows mean that prevailing wind direction occurs in* ⩾ *50% of observations. Other arrows represent most frequent wind direction.*

Characteristic positions for the main fronts affecting the Mediterranean in summer and winter are indicated on Figures 1.5(*a*) and (*b*), which also show the prevailing surface wind streams. The frontal positions follow directly from the wind pattern and are in good general agreement with those given by Bergeron[10] and Petterssen[70]. The main frontal zones, however, oscillate over a wide range of latitudes with the varying arrangement of the general circulation over the northern hemisphere. It will be noticed that in winter the Mediterranean is occupied by one of the normal frontal zones on which disturbances continually develop, whereas in summer the normal condition is without fronts in the Mediterranean, although Bergeron's "trade-wind front" (*Passatfront*), which marks the limit of the main stream of the cool maritime polar air of the Atlantic, is near enough to invade the Mediterranean at times. The Mediterranean front of the cool season penetrates well south into the western Sahara in the late winter, and this front and the disturbances travelling along it are at times propagated eastwards right across Asia as the main Asiatic polar front. At this period it is sometimes called the Saharan front or desert front and there may be 30°-40° F. temperature discontinuity across it.

The complicated orographic features of the Mediterranean basin exert important influences on the movement of invading air masses and on the structure of the corresponding frontal systems (see pages 29-30). At times the picture may be very complex and frontal analysis not at all easy. There may be several waves of maritime or continental polar air affecting the area, while at the same time Mediterranean and continental tropical air are in evidence. These complicated situations occur chiefly in the cool season (for example, with weather type B_3 - see Chapter 4). In the warm season the frontal systems are fewer but often difficult to analyse, because below about 5,000 feet the fronts tend to become obliterated by surface-temperature influences and sea-breezes which dominate the surface weather map. The difficulty of frontal analysis on the surface chart can often be overcome by making use of the 850-millibar wind field. Fronts often have to be advanced against the apparent gradient given by the surface chart. The analyst should think carefully before concluding that a front has become unimportant. It is better to retain a front for too long than omit it too soon. This is particularly important if interest extends to the southern and eastern Mediterranean. For example, in the warm season a new supply of polar air to these regions, even though the front of this polar air mass has not been masked by any cloud and weather in the latter stages of its journey, will clear away low stratus and prevent its recurrence for a few days. Rising dust may also accompany any residual squall line, even after the cloud systems have long since dissolved.

Frontogenesis and frontolysis. The broad principles governing frontogenesis and frontolysis are the same everywhere but there are one or two aspects which are of special importance in the Mediterranean and surrounding regions, in particular the great contrast in temperature and humidity between air masses originating over the Sahara on the one hand and Europe, the Mediterranean or the Atlantic on the other.

Figures 2.23(*a*) and (*b*) taken from a paper by Lamb[52] illustrate a case in which such contrasting air masses over neighbouring unlike geographical regions were associated with frontogenesis (consolidation and sharpening) over the Atlas mountains. The chart for 0000 G.M.T. on 19 June 1945 (Figure 2.23(*a*)) shows a rather complex situation with parallel fronts over North Africa associated with the very old depression over Spain. Pressure gradients are weak but a frontogenetic col is marked on the chart near Algiers, and the temperature contrasts between the air masses approaching one another at this point are great. By 1200 on the same day (Figure 2.23(*b*)) the situation in the frontogenetic belt has been reduced to a single sharp front. The resulting simple warm sector over the western Mediterranean continues northward aloft as a broad expanse of altocumulus castellanus cloud over France; and its trough line extends westwards as an upper cold front over the Bay of

Biscay. Aircraft flying along the Atlas mountains *en route* from Malta to Rabat reported severe thunderstorms in frontal medium cloud in the region where the front is shown, while the general increase in activity of the depression system is demonstrated by the much greater number of reports of lightning and atmospherics shown at 1200 G.M.T. on the 19th, than at the previous midnight (compare Figures 2.23(*a*) and (*b*)). Recent thunderstorms were reported on both charts but none at the hour of observation at the stations used. The transformation of the frontal pattern went a stage further during the afternoon and evening of the 19th. The westerly breezes developing behind the pressure trough associated with the upper cold front over the Bay of Biscay brought in cool Atlantic air to south-west France. The trough now corresponded to the main temperature contrast on the surface map between the cool oceanic air (polar maritime) and the strongly heated European and African air masses with high surface temperature (polar continental and tropical continental). This situation is already apparent in Figure 2.23(*b*). As a result the upper front quickly extended itself down to the surface as a normal cold front which, together with the wide belt of high-level instability cloud and thunderstorms ahead of it, became the dominant feature of the map, leaving merely traces of the old occlusions over Spain as relics of little consequence.

Rapid changes of the isobar pattern under the influence of considerable pressure falls, and the release of instability aloft, superimposed on a previously flat situation, made the stages of this quick development (Figures 2.23(*a*) and (*b*)) hard to follow in detail.

Frontolysis is most commonly produced by prolonged subjection of the air masses on either side of the front to like influences, especially of strong surface heating. Subsidence in anticyclonic conditions favours obliteration of the surface air-mass differences after the frontal cloud sheets have been thinned and narrowed, and the strong surface heating particularly over the African desert in the warm season produces characteristic features in the air masses coming over it which tend quickly to obliterate pre-existing traces of different air-mass history. Nevertheless it is not unknown for fronts to survive over the Sahara and later emerge again northwards, especially in the colder months and when the circulation pattern continues to favour confluence of different air streams.

The meteorologist in the Mediterranean is often concerned with weakening fronts and it is important to assess correctly the prospects of their survival and later reactivation when thermal contrasts and moisture supply are increased, for instance when a more confluent pattern of wind flow develops or when an apparently minor frontal cloud belt (often only cirrostratus or altostratus) from Africa comes out over the sea. Warm fronts from the south rapidly increase in raininess and liability to thunderstorms when they come over the Mediterranean, especially in autumn. The air having been heated strongly at the surface over Africa is already unstable and acquires much additional moisture over the sea. The rapidity with which the front becomes active is striking. Even when a front is decaying, it is important to remember that the surface wind discontinuity (which may readily become a line of squalls and rising dust or sand over the heated desert and may be disconcerting to small craft over the sea) often survives long after the frontal cloud sheets have completely disappeared and continues to advance over great distances. As a front weakens first the precipitation ceases or becomes very patchy, and next the cloud systems of the lower and middle tropopause disappear; on the whole it is the high cloud and traces of the surface wind discontinuity which are the last to go.

Cold fronts. An invasion of very cold air into the Mediterranean in the cool season leads to vertical instability in the air mass, but this is not confined to the frontal zone. The activity of the actual frontal zone will depend largely on the thermal contrast there with the air which is being replaced and the degree of convective instability in that air. Thus the most active cold fronts are likely to be those with continental tropical air ahead, especially if the latter has had an opportunity to pick up moisture from the sea (see, for example, page 22). Duststorms occur with strong winds ahead of these cold fronts (see page 16) in regions where the surface is loose and dry.

It should be noted that continental tropical air over the continent of North Africa has a very low dew-point - generally lower than that of maritime polar air in the Mediterranean, even though the temperature of the continental tropical air is appreciably higher than that of the maritime polar. Thus when a cold front passes east along the north coast of Africa, places at which the continental tropical air mass was blowing as an offshore wind characteristically experience a substantial rise of dew-point with the arrival of maritime polar air from the sea.

Warm fronts. Warm fronts occasionally enter the Mediterranean from north-west or west, but in most of the region these fronts are not of much importance. Already weak, they get weaker as the prefrontal air mass is increasingly drawn from Africa (see, for example, page 15). The most active warm fronts are those from the south which bring continental tropical air from the desert regions of North Africa after cold air has penetrated well south across the North African coast. Such circumstances arise from time to time between October and April, and seldom outside that period. Warm fronts of this type give plenty of rain once the warm air has moved out over the sea and are characterized by cumulonimbus and thunderstorms, especially rather high-level cumulonimbus, often with stratus and fractostratus underneath. The behaviour of warm fronts ahead of maritime tropical air is described on page 15. For the reasons given in Chapter 3 (pages 38-40), when a warm front passes a North African station and dry continental tropical air replaces polar or Mediterranean air, the dew-point at that station is likely to fall.

Occlusions. The occlusions are a form of front which are little used by the synoptic analyst in the Mediterranean. When they are present they usually have characteristics similar to a cold front with a greater or lesser degree of instability.

Effect of mountain barriers. The movement of fronts is commonly delayed by mountain ranges. In many cases the front is held back along the windward face of the mountains and advances only on narrow sectors, fanning out with the wind stream that has passed through the main gaps. Thus it frequently occurs that cold fronts advance quickly south-east across the western Mediterranean on a limited sector with air that has come through the Rhône or Carcassonne gaps, whilst precipitation and frontal cloudiness continue along the northern face of the Alps. In other cases the fronts of deep, cold air masses pass quickly over the mountain barriers almost without hindrance: the precise circumstances which determine this alternative behaviour have still not been completely discovered. In general, however, the more stable the air mass the more likely it is to be diverted round, rather than over, a mountain barrier (see page 2). Sometimes only the upper part of the front and frontal cloud systems passes over the mountain range, and the lower portions of the system do not always reappear to leeward. This is particularly liable to happen in the Mediterranean in summer time, when the relatively cool sea surface and weakly anticyclonic régime produce continued conditions of subsidence and stability below about 5,000 feet. On the other hand, when a cold front crosses a range of mountains and there is stagnant, moist, warm and rather unstable air on the lee side, overrunning of this air by the cold air quickly leads to violent convectional overturning and heavy, thundery rain. This case is common in the Mediterranean in late summer and autumn.

In nearly all cases the immediate lee of the mountains in a strong wind current is sheltered from the frontal clouds and weather and gets no more than a short period of lenticular cloud types as the front passes. Thus in the immediate lee of the mountains the chief effect of a cold front is a fairly abrupt arrival of air down the mountain slopes which, although liable to be gusty, will normally be dry and relatively warm as a result of firstly having lost most of its moisture in rising over the mountains, and secondly dry adiabatic warming (föhn) taking place on descent.

The most important warm fronts, being those ahead of continental tropical air from the desert regions of North Africa, are affected by the Atlas mountains which generally form an effective barrier. The result is that the movement of active warm fronts entering the Mediterranean from Africa is restricted to Tripolitania and the region to eastward where there is no barrier of consequence.

CHAPTER 3

DEPRESSIONS AND ANTICYCLONES

DEPRESSIONS - GENERAL

The depressions of the Mediterranean may be classified by their origin into the following groups:

(i) Depressions which enter the Mediterranean basin from outside (for this purpose we include the region immediately south of the Atlas mountains as part of the Mediterranean basin). Such depressions number about seven per year or nine per cent of all Mediterranean depressions. They enter almost invariably from the Atlantic, generally through the Strait of Gibraltar or through the Garonne-Carcassonne gap.

(ii) Thermal depressions which form mainly in summer as a result of surface heating over land, especially where surrounded or nearly surrounded by sea. They develop between May and October over Spain, the Po valley, central and southern Italy, Tunisia, the Sahara, and the greater islands such as Sicily. The Asiatic monsoon depression of the summer months is of similar origin and its extension over Turkey is of importance to the Mediterranean region. The low-pressure area which dominates the central Sahara during the warm season (see page 5) is also of thermal origin. Compared with the Asiatic and African lows, the thermal depressions over Mediterranean lands and islands are generally relatively shallow and of a local nature. They occur at times when the broad features of the Mediterranean weather are settled and they normally remain stationary while such conditions last. They may produce local thunderstorms. If a new air stream invades the area a thermal depression may develop into a normal frontal depression. In other cases it may become caught up in the movement of another depression and contribute to its development.

(iii) Lee depressions which form on the lee side of a mountain range when a deep vigorous current moves towards the range (see page 3). The initiating currents are nearly always arctic or polar air sweeping towards the Mediterranean from a direction between west and north-east. In such cases, when the cold front has crossed the mountains it generally leads to the intensification of the lee depression and is drawn into its circulation. Lee depressions also form north of the Atlas mountains when a strong southerly air stream impinges on that range.

(iv) Wave depressions. Sometimes when cold air crosses the mountains into the Mediterranean a wave forms on the cold front in an area not occupied by the lee depression. In such cases the wave generally travels along the front, develops and absorbs the shallow lee depression. Wave depressions are also liable to form on trailing fronts in the Mediterranean area or over North Africa, especially when the currents on each side are in opposing directions. The place of formation of waves is often determined by orography and the large-scale features of the general circulation. A favoured region is that between Sicily and Tunisia (see further page 43).

(v) Troughs. During the cool season troughs persist for considerable periods in the Alboran Channel and the Adriatic Sea. In the Alboran Channel the trough gives predominantly north-east air flow in the north of the channel and south-west to west flow in the south of the channel. In the Adriatic Sea the western shores often have north-west to north winds while the eastern shores have east to south-east winds. (In the Adriatic the isobaric forms have a good deal of resemblance to those in the Davis Strait west of Greenland, which may be more familiar to northern meteorologists.) There is a tendency at all times of the year for a depression or trough to form in the northern Red Sea. In these three areas troughs are more likely to form than lee depressions.

Areas of formation. The great majority of Mediterranean depressions originate within the region as lee depressions or wave depressions, the average number forming in this way being about 69 per year or 91 per cent of all Mediterranean depressions. They may be grouped according to their areas of formation as follows:

(i) The western Mediterranean area extending from the Balearic Islands and the Gulf of Lions to the Gulf of Genoa and thence to the Po valley and the north of the Adriatic Sea. The great majority of depressions form near the Gulf of Genoa and are therefore called "Genoa" depressions. This is by far the most favoured area for the formation of depressions and accounts for about 52 per year or 69 per cent of Mediterranean depressions.

(ii) The area south of the Atlas mountains. Depressions forming in this area are called Saharan depressions and are chiefly important in spring. Their frequency is about 14 per year or 18 per cent of Mediterranean depressions.

(iii) The central and eastern Mediterranean. The number of depressions actually forming in this area is small, about three per year or 4 per cent of Mediterranean depressions. In the central Mediterranean they form chiefly in the winter months while in the east mainly in autumn and spring. More commonly, old weak depressions become rejuvenated in the eastern Mediterranean. The favourite place for formation or rejuvenation of depressions is the neighbourhood of Cyprus, whence they are called "Cyprus" depressions.

DEPRESSION-FREE DAYS

It is exceptional for the whole of the Mediterranean at one time to be free from depressions, or from depressions on the point of entering the region, especially in winter. In the period 1926-35 the average number of such depression-free days in each month was as follows:

Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
½	1½	½	½	⅓	2	5	7½	4	2½	½	½	25

These figures show, as would be expected, that the most settled weather is in July and August. The figure for February is rather too high as a result of the exceptionally quiet February of 1926 when there were eight consecutive depression-free days. In the period 1926-35 the longest single periods when there were no depressions or incipient depressions in the whole area were 19 days in July, 19 days in August and 19 days covering August-September. In individual localities the undisturbed periods are of course much longer, the uniformity from one day to the next during the summer periods being specially remarkable in the eastern Mediterranean.

DEPRESSION TRACKS AND FREQUENCIES

Figure 1.6 shows the main tracks of depressions into and through the Mediterranean. This also shows their average annual frequencies. Further information, including seasonal frequencies, is given in Table 4. Figure 1.6 is based on *United States Historical Weather Maps* 1926-39 and post-war series 1945-52[92] as well as British, German, Italian and Greek *Daily Weather Reports.* The tracks may be arranged as follows (annual frequencies in brackets):

1. Those entering the western Mediterranean from the Atlantic (7).
   - 1*a*. Across the Bay of Biscay and through the Garonne-Carcassonne gap (3). (Van Bebber's V(*a*))[87].
   - 1*b*. Through the Strait of Gibraltar and the Alboran Channel (4).
2. Those radiating from the area south of the Atlas mountains (Saharan depressions) (14).

Fig.1.6 Tracks of Mediterranean depressions
Average annual frequencies are shown in brackets.

2*a*. Through the Biskra gap to the western Mediterranean (1).
2*b*. North-eastwards across southern Tunisia or the Gulf of Sidra towards the central Mediterranean (7½).
2*c*. Slightly north of the coast and sometimes over the desert just south of the Cyrenaican highlands, then towards the Cyprus area (4½).
2*d*. Eastwards well south of the North African coast, then turning north-eastwards via lower Egypt to the Cyprus area (1).

3. Those radiating from the western Mediterranean area (60).
3*a*. North-eastwards from the Gulf of Genoa or the Po valley towards the plain of Hungary (11). (Van Bebber's V (*b*)).
3*b*. South-east from the Gulf of Genoa or the Po valley to the southern Adriatic and then north-east to the Ukraine (4½). (Van Bebber's V(*c*)).
3*c*. South-east from the Gulf of Genoa or the Po Valley towards the central Mediterranean (26). (Van Bebber's V(*d*)).
3*d*. South-east from the Balearics to the central Mediterranean (18½).

4. Those radiating from the central Mediterranean (51).
4*a*. North-eastwards to the Black Sea (30).
4*b*. Eastwards to the Cyprus area (21).

5. Those radiating from the Cyprus area (23).
5*a*. East-north-east to north-east (10½).
5*b*. East (11).
5*c*. South-east (1½).

These tracks are a special classification for the Mediterranean and are not the same as the well known classification of North Atlantic depressions due to Van Bebber. A given depression may follow these tracks in various combinations. Thus any of the tracks 1*a*, 1*b*, or 2*a* may be combined with any of the tracks 3*a* to 3*d*. The track 3*b* is normally followed only in summer and autumn. Some depressions move north-east from the Balearics to the Gulf of Genoa and then follow 3*c*. Any of the tracks 2*b*, 3*c* or 3*d* may be followed by 4*a* or 4*b*. In the summer there is a tendency for depressions on tracks 2*b* and 3*d* to fill up before reaching the Central Mediterranean. Depressions forming in the central Mediterranean normally follow 4*b*.

The average number of depressions arriving in the Cyprus area is about 26 or 27 in a year (that is, by tracks 2*c*, 2*d* or 4*b*). If we add the number forming in the region we get a total of about 28 per year in this area. Of these some move eastwards and others stagnate in the region until they fill up or become rejuvenated. A certain number of depressions skirt the Cyprus area itself and cross the Anatolian plateau. For the purpose of Table 4 and Figure 1.6 these have been treated as passing through the Cyprus area.

The frequencies given here, in Table 4 and in Figure 1.6, are bound to show a rather cut-and-dried picture and a self consistency which would be deceptive if taken too literally. They may give the impression that depressions move in a much more regular manner than in fact they do. Many depressions behave in irregular ways which cannot be fitted into any particular scheme. In an earlier survey it was estimated that only about 50 per cent of Mediterranean depressions followed tracks which could be reasonably classified. There are, for example, depressions which form and fill up locally and are relatively short-lived, while others may be too weak to include in such a survey although they may be of local significance. Retrograde (that is, westward) motion also occurs at times. This may be only apparent - due to the filling up of a depression and the formation of another depression further west. True westward and south-westward motion may occur when another more active depression passes eastwards to the south of the first, resulting in a tendency for the depressions to rotate about each other in an anti-clockwise direction. Retrograde motion also occurs occasionally when a depression becomes embedded in a deep, vigorous east or north-east air stream (see for example page 40). On such occasions a tongue of warm air in the upper levels often pushes north and west round a southward extending tongue of cold air, the latter perhaps in association with a cold pool (see below). If the depression is suitably situated on the southern edge of the warm tongue it is likely to be steered thermally towards a westerly point. Westward or south-westward tracks occur chiefly in the northern parts of the Mediterranean and in the western basin.

Table 4

Approximate annual and seasonal frequencies of depressions on tracks and in areas shown

(Based on the years 1926-39, 1945-52)

Radiating from	Track	Year	Winter Dec.-Feb.	Spring March-May	Summer June-Aug.	Autumn Sept.-Nov.
		Number of occasions				
1. Atlantic	1*a*	3	1	1	0	1
	1*b*	4	2	1	0	1
	Total	7	3	2	0	2
2. South of Atlas mountains	2*a*	1	½	½	0	0
	2*b*	7½	1	3	1½	2
(Saharan depressions)	2*b*-F*	1	0	0	1	0
	2*b*-4*a*	3½	½	1½	½	1
	2*b*-4*b*	3	½	1½	0	1
	2*c*	4½	½	3½	½	0
	2*d*	1	0	1	0	0
	Total	14	2	8	2	2
3. Western Mediterranean	3*a*	11	1½	3	4½	2
	3*b*	4½	0	0	2½	2
	3*c*	26	11	8½	½	6
(Genoa depressions)	3*c*-4*a*	17½	7	5½	½	4½
	3*c*-4*b*	8½	4	3	0	1½
	3*d*	18½	6½	5	2½	4½
	3*d*-F	1½	0	0	1½	0
	3*d*-4*a*	9	3½	2½	½	2½
	3*d*-4*b*	8	3	2½	½	2
	Total	60	19	16½	10	14½
4. Central Mediterranean	4*a*	30	11	9½	1½	8
	4*b*	21	9	7	½	4½
	Total	51	20	16½	2	12½
5. Cyprus area	5*a*	10½	4	3½	1	2
	5*b*	11	4	6	0	1
	5*c*	1½	1½	0	0	0
	F	5	0	3	0	2
	Total	28	9½	12½	1	5
AREAS						
South of Atlas mountains						
Number forming (n_1) (Saharan)		14	2	8	2	2
Western Mediterranean						
Number entering (1*a*, 1*b*, 2*a*)		8	3½	2½	0	2
Number forming (n_2) (Genoa)		52	15½	14	10	12½
Total		60	19	16½	10	14½
Central Mediterranean						
Number entering (2*b*, 3*c*, 3*d* less F)		49½	18½	16½	2	12½
Number forming (n_3)		1½	1½	0	0	0
Total		51	20	16½	2	12½
Cyprus area						
Number entering (2*c*, 2*d*, 4*b*)		26½	9½	11½	1	4½
Number forming (n_4)		1½	0	1	0	½
Total		28	9½	12½	1	5
Whole Mediterranean						
Number entering (1*a*, 1*b*)		7	3	2	0	2
Number forming (n_1, n_2, n_3, n_4)		69	19	23	12	15
Total		76	22	25	12	17

*F = "fills up"

COLD POOLS AND COLD LOWS

A cold pool may be defined as a deep mass of cold air entirely surrounded at most levels by relatively warm air, and appears as one or more closed lines in the thickness isopleths for any deep atmospheric layer. When an outbreak of arctic or polar air occurs and cold air moves southwards it is frequently associated with a cold trough aloft which is a clearly marked feature in the thickness pattern. With an intense outbreak bringing cold air to low latitudes (30°- 40°N.) the tip of this trough in the thickness pattern sometimes becomes cut-off, thus producing a cold pool in low latitudes. The cutting-off process is generally due to the more rapid eastward movement of the northern part of the trough together with advection of warm air north and north-east on the west side of the trough, frequently associated with the building up of an anticyclone to the north of the developing cold pool. At the same time a depression (called a "cold low") is often maintained or develops to the south of the anticyclone in association with the cold pool. Advection of cold air into the region of the cold pool is commonly maintained in the lowest 3,000 to 5,000 feet.

These features of the development of a cold pool may be present in varying degrees, and in individual cases one or more may be entirely absent. In some cases the depression associated with the pool is the dominant surface feature, and in other cases the surface anticyclone may be the main feature while the depression is vestigial or entirely absent. When both depression and anticyclone are well developed the stage is set for a typical "blocking situation" in which the normal eastward drift of depressions and anticyclones in middle latitudes is halted or slowed down, sometimes for many days, and the upper westerlies of middle latitudes are diverted, split and weakened (see further in Chapter 4).

A cold pool in the Mediterranean will maintain its vigour while advection of cold air in its lower layers continues. When the supply ceases it generally suffers stagnation and gradual decay by warming *in situ*, although it does not necessarily remain stationary during this period. On occasions a cold pool may be carried north and become reabsorbed into the colder air of higher latitudes.

Whatever the origin of a cold pool, when it moves into low latitudes it is liable to be the seat of instability, especially over warm sea. In the Mediterranean area, cold pools are generally associated with depressions from the beginning. These accompanying cold lows are therefore liable to be marked by abnormal precipitation and thundery activity and if, as often happens, a blocking situation is present, they may remain more or less stationary for many days. If a cold pool exists in the Mediterranean without any associated low then there is a strong probability that a depression will develop in the region, or a depression moving into the region will intensify. If a cold front enters the Mediterranean the presence of a cold pool generally indicates the site where a depression will form on the front.

Approximate frequencies of cold lows in various parts of the Mediterranean are given on page 117.

An example of a cold pool in the Mediterranean without any sign of a surface depression is given in Figures 2.24(*a*) to (*e*). The cold front of an outbreak of maritime arctic air reached the western Mediterranean on 2 August 1953 and a lee depression which had formed in the Gulf of Genoa produced a wave on the cold front which moved eastwards. Figure 2.24(*a*) gives the surface synoptic chart for 4 August, a situation when arctic air covered most of Europe and parts of the Mediterranean. The thickness chart, Figure 2.24(*b*), shows a cold trough extending southwards towards the western Mediterranean. By the 6th the arctic air had covered most of the Mediterranean basin and its supply had been cut off by the advance of another depression eastwards from the Atlantic to the Baltic (Figure 2.24(*c*)). No depression appears in the Mediterranean at this time but a cold pool is clearly shown on the thickness chart (Figure 2.24(*d*)). The point of interest is the outbreak of thunderstorms and rain occurring in the region of the cold pool and not elsewhere. These would hardly have been expected from indications on the surface chart alone.* The tephigram for Malta on the same day is shown in Figure 2.24(*e*) and this shows conditional instability from 850 to 500 millibars. The cold pool had dissipated by 8 August.

A typical cut-off cold low in the south-eastern part of the North Atlantic is shown in Figure 2.25. Examples of cold pools in the Mediterranean associated with blocking situations are given in Chapter 4.

GENERAL FACTORS DETERMINING THE FORMATION AND MOVEMENT OF DEPRESSIONS

It is easier to define preferred tracks for depressions in the Mediterranean than over the Atlantic and much of northern Europe, because of the pronounced relief and strong topographical influence in the Mediterranean region. Nevertheless depressions do occasionally move on erratic paths - for example, across the Turkish (Anatolian) plateau. Depressions in the Mediterranean are generally small by comparison with those of higher latitudes; but their development is characteristically rapid so that within 100 to 200 miles of the centre, strong pressure gradients may develop in the course of 12 to 18 hours and quickly distort the frontal pattern and alignments. Gales may spring up correspondingly quickly, and the correct forecasting of local weather detail and timing of frontal passages calls for considerable alertness.

When depressions form in, or pass through, the Mediterranean there is often a quasi-stationary anticyclone farther north which imposes a certain persistence on the general situation. Unsettled weather in the Mediterranean continues whilst this general situation lasts, and the factors determining its onset and breakdown are often most easily seen by watching the formation and decay of the anticyclone in higher latitudes.

The development and steering of the individual depressions in the Mediterranean is associated with the general thermal pattern and winds in the upper troposphere, as in middle and high latitudes. Methods of using upper air patterns are described elsewhere (see, for example, "Handbook of aviation meteorology"[62]). (As a matter of practical convenience the winds on the 700-millibar chart may often be taken as representative of the upper flow. It is better to make use of the 1000-500-millibar thickness pattern and perhaps better still to use the wind charts for even higher levels, if these are available. The 200-millibar chart most nearly represents the level of maximum wind in the Mediterranean, and this will be found most helpful in connexion with the movement of depressions. Thunderstorms generally travel with the winds at about 700 millibars). The forecaster using these methods in the Mediterranean region must, however, allow for the effects of orography.

It should be understood that the large-scale features of the flow pattern which determine the formation and maintenance of systems in and around the Mediterranean can only be followed by watching an area extending far outside the Mediterranean, especially to the west and north. This is the reason why the illustrative charts necessarily cover northern Europe and much of the Atlantic. There are several factors which may contribute to the formation of a depression in the Mediterranean, such as

(*a*) the presence of a baroclinic or frontal zone
(*b*) lee effects in a strong air stream, and
(*c*) instability in the air mass.

In considering a particular case the relative importance of these should be weighed.

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* The rainfall at Valletta, Malta, on the 6th was 1.20 inches and the total for the month was 1.68 inches. At Nadur, Gozo, the total for August 1953 was 2.40 inches. These should be compared with the normal for Valletta of 0.2 inches and that for Nadur which is of the same order. The month of August is usually rainless at both places.

If a baroclinic or frontal zone is present, the ordinary rules concerning development in connexion with the jet stream (which is normally associated with a baroclinic zone) apply in the Mediterranean as elsewhere; this implies a tendency for cyclogenesis on the right-hand side of the entry of the jet stream and at the left-hand side of the exit, and anticyclogenesis on the left side of the entry and the right side of the exit. There are the strongest developmental effects. In the case of a northerly jet stream, however, there is some noticeable tendency to cyclogenesis all along the right-hand (west) side of the stream and a corresponding anticyclogenetic influence along the left (east) of the stream. In such cases, therefore, the ordinary tendency for anticyclogenesis on the right-hand side of the exit of the jet stream is counteracted to some extent and the effect may even be reversed. This may become apparent through the formation of small cyclonic features anywhere from the Bay of Biscay to the Balearics in the case of northerly outbreaks invading the Mediterranean.

In the case of an invading air mass of arctic or polar origin a lee depression generally forms first, before the front of the air mass has crossed the mountains. With invasions of continental arctic air from the north-east or north there is a tendency for the lee depression to form to the south or south-east of the mountain range and on the eastern flank of the invading current. However, other factors may affect the site of formation of the lee depression, depending on the state of the air mass on the lee side. Such factors might be the existence of a frontal zone already in the area or a thermal depression, an upper cold pool, or an older depression. When the cold front has crossed the mountains it eventually becomes associated with the lee depression and generally leads to its development. Sometimes, however, a wave may form on the front after it has crossed the mountains into the Mediterranean basin, and in such cases the wave generally develops and absorbs the relatively shallow lee depression.

DEPRESSIONS ENTERING THE MEDITERRANEAN AREA

Depressions enter the Mediterranean area chiefly on tracks 1*a* and 1*b*. Depressions on track 1*b* normally appear when there is a stationary anticyclone over Europe (weather type D - see Chapter 4) and pressure is relatively low over the Mediterranean giving an easterly flow of continental arctic or polar air over the northern Mediterranean. These depressions have generally formed as secondaries to more northerly depressions moving east or north-east to the north of the stationary anticyclone. Two such depressions passed into the Mediterranean in January 1947 during a blocking situation caused by a stationary anticyclone over the British Isles - the first on the 24th (see Figure 2.26) and the second on the 28th. A similar case occurred in January 1950 when there was a blocking anticyclone centred over the north German plain. As before two depressions entered the Mediterranean, the first on the 23rd (see Figure 2.27) and the second on the 27th. In similar conditions a depression may occasionally pass eastwards from the Atlantic over the west coast of Morocco and south of the Atlas mountains, but this track is rare.

The more northerly track 1*a* is followed when the stationary anticyclone is further north and also at the very onset of blocking situations when a polar or arctic outbreak occurs but before the development of the associated blocking anticyclone. Intermediate tracks across Spain also occur, for example in February 1947 when a depression moved across the Iberian plateau on the 17th (see Figure 2.28). For the purpose of Figure 1.6 and Table 4, these are treated as belonging to track 1*b*.

Depressions sometimes enter the eastern Mediterranean from the east when there is high pressure extending from the Volga basin or the Caspian to the Black Sea, but such a track is rare. In similar conditions a depression may occasionally move southwards across the Anatolian plateau. This track is also rare. For an example, on 4-5 February 1950, see page 14 and Figure 2.6(*a*).

WESTERN MEDITERRANEAN DEPRESSIONS

(Genoa depressions). These form frequently when the Atlantic polar front lies near southern France. The position of formation depends on where the strongest flow is directed. If a north-westerly stream is flowing across the English Channel to the Alps then the depression is most likely to form in the Gulf of Genoa or the Po valley; if a northerly or north-westerly stream blows across the Bay of Biscay then the depression is most likely to form in the Gulf of Lions. If the stream is more westerly than north-westerly across Europe (for example, with weather type C) then most of the air is deflected into the Danube valley and the Genoa depression is correspondingly weaker.* Depressions or troughs of secondary importance may form in the lee of the Iberian plateau or in the lee of the Atlas mountains while a major depression is developing in the Gulf of Genoa. If a north or north-easterly stream of continental polar or arctic air flows towards the north-west Mediterranean, lee depressions are most likely to form in the eastern part of the area or in the Tyrrhenian Sea. If an easterly flow of continental polar air extends across France with a westerly flow of maritime polar air in the Mediterranean (a type B situation - see Chapter 4) a lee depression generally forms in the region of the Balearic Islands. This usually moves rather slowly eastwards on the southern flank of the easterly stream as the maritime polar air spreads over the Mediterranean.

Depressions forming in the northern part of the western Mediterranean, that is, the Gulf of Lions, Gulf of Genoa or the Po valley, generally follow track 3*c* and later 4*a* or 4*b*. Those that form in the Balearic region most frequently move along 3*d* followed by 4*b*. When there is a pronounced trough in the upper-wind pattern with warm air moving northwards towards the Adriatic, the Genoa depression moves in a north-north-east to north-east direction across the middle of Europe. The tracks 3*a*, 3*b*, 4*a* are mainly associated with a strong south-westerly wind aloft. On occasions several Genoa depressions in succession may take these north-easterly tracks. This is most likely to happen in spring. The track 4*b* is followed when there is high pressure over the Balkans and Turkey or the Black Sea, forcing depressions to take the more southerly route towards the Cyprus area.

The frequencies of tracks 3*a* and 3*b* increase as summer approaches. At this time of year these tracks are followed by about 70 per cent of the western Mediterranean depressions. Thunderstorms occur ahead of and at the cold fronts of these depressions, being most frequent in northern Italy. An example of a depression on track 3*b* is given in Figures 2.11(*d*) to (*f*) for 16-19 April 1954.

Depressions moving on the track 3*c*/4*a* are associated with north-west to north mistral followed by north-easterly levanter and bora winds (see Chapter 6). Showers in the air behind the cold front decrease in frequency and intensity as the front moves eastwards. If the depression is deep there will be strong or gale force south-westerly winds ahead of it which may extend as far as the coast of North Africa and cause sandstorms. An example of a depression on this track giving mistral across the western Mediterranean is given in Figures 2.30(*a*) and (*b*) for 1-2 February 1953.

Depressions occasionally follow track 3*c*/4*b* in summer, but infrequently. An example is given in Figures 2.17(*a*) to (*f*) for 17-20 August 1949.

Deep depressions moving on the track 3*d*/4*b* give duststorms over North Africa ahead of the cold front, usually clearing with the passage of the front. Even a comparatively weak depression on this track may give local duststorms in the neighbourhood of the eastward-moving cold front.

Depressions on track 3*d* in summer often fill up over the Balkans or the Ionian Sea. This generally happens when they have been associated with an invasion of maritime polar air.

The winds ahead of depressions moving on tracks 3*c* and 3*d* are often south-easterly or southerly, especially in the Adriatic and Aegean Seas. These winds are

* On one occasion, however, a very deep Atlantic depression (centre 940 millibars) which moved eastwards near Iceland giving a broad westerly stream over Europe and Spain, produced a Genoa depression with a centre of 988 millibars. This was on 16 February 1953 (see Figure 2.29). The depression moved on track 3*b*.

usually called scirocco in this area and bring low stratus cloud and poor visibility to the northern Mediterranean. The front between Mediterranean and continental polar air brings layered cloud and rain. With a very deep depression on track *3d* a very hot and dusty stream of continental tropical air may be carried northwards.

On rare occasions a western Mediterranean depression may move south-westwards from the region of the Tyrrhenian Sea towards the Atlas mountains. This may happen if there is a very vigorous southward thrust of continental polar air (weather types B or D, see Chapter 4). Although infrequent, this development may give extremely dangerous flying conditions over the Atlas mountains with thick layered cloud obscuring the peaks, and severe icing of aircraft. There is a great difference between these conditions and the occasional showers which would probably have occurred if the depression had moved as usual on a track south-eastwards.

An example of the development of a Genoa depression due to an invasion of maritime arctic followed by continental arctic air is given in Figures 2.31(*a*) and (*b*) which show the synoptic situation on 3-4 January 1954. This is a type A/B_3 situation (see Chapter 4). The lee depression formed ahead of the cold front, C_A, and developed rapidly. In this situation heavy layered clouds would be experienced at the cold front, with heavy showers in the rear of the depression which would follow track *3c/4a*. Wave development over Tunisia and near the Sicilian narrows delayed the passage of the cold front across the central Mediterranean on 5-6 January, a common occurrence in this region. Malta had over 24 hours of improving weather, at times with subsidence and totally clear skies, as the cold front approaching from the north-west slowed down with the formation of small waves. The winds in the upper troposphere over the southern and eastern Mediterranean and North African seaboard developed into a jet stream of extreme intensity on 3-10 January as the cold air mass spread south over most of the region. At Benina the wind at 200 millibars was 265°, 190 knots, at 0200 G.M.T. on the 3rd, and at Malta 270°, 180 knots, at 0200 G.M.T. on the 4th. There was a cold pool over the western Mediterranean from the 4th till the 10th (see further page 114).

Figures 2.32(*a*) to (*f*) give an example of a depression on track *3c/4b* followed by two on track *3d/4b* during the period 8-13 February 1954.* This is a type B situation (see Chapter 4) with maritime polar air moving eastwards over the southern and central Mediterranean and continental polar air moving westwards over the northern Mediterranean. Considerable rain occurs in this situation, especially in the northern Mediterranean, with long fair periods in the south.

SAHARAN DEPRESSIONS

These depressions form in the lee of the Atlas mountains, either when a north-westerly air stream moves over the Atlantic towards the Atlas range, or when a north-easterly wind is blowing over the western Mediterranean towards these mountains. The depressions give rise to scirocco or khamsin winds and are therefore sometimes called scirocco or khamsin depressions by British meteorologists. There is at all times of the year a tendency for lee depressions to form south of the Atlas mountains, but they form most frequently in spring when the "Mediterranean" frontal zone has moved well south into the western Sahara (see page 27). During this transitional period (April-May) the sea temperatures are still rather low and the Mediterranean front is often very sharply defined. In addition the north-east to easterly wind which usually becomes established at this time over the western part of North Africa increases the cyclonic flow around the depressions. During these two months and to a lesser extent in October we have the greatest activity of Saharan depressions, and they are at that time perhaps the most important type of Mediterranean depression. The rainfall from such depressions is greatest in autumn when the sea is warm; in spring, although rain and cloudiness still occur with these depressions, their most prominent effects are windiness and temperature changes.

* On 8 February 1954 a very strong jet stream was observed over Malta, giving 250°, 222 knots, at 271 millibars at 0200 G.M.T.

Saharan depressions develop most readily when a polar or arctic air stream from the north-west (maritime polar, maritime arctic) or north-east (continental polar, continental arctic) flows in their rear. When this happens there is a corresponding induced flow of continental tropical air northwards, often bringing dust with it to give the duststorms which are most common over North Africa in May. A common situation for the formation of Saharan depressions is when continental polar or arctic air covers the Mediterranean and spreads well over North Africa, resulting in relatively high pressure over the northern Mediterranean (weather type D - see Chapter 4). On such occasions the Saharan depressions may be the only important low-pressure systems in the Mediterranean area.

Figures 2.33(*a*) and (*b*) for 5 and 8 May 1951 show the passage of a cold front bringing maritime arctic air to the western Mediterranean and across the Atlas mountains. A Saharan depression formed south of the Atlas mountains and moved eastwards to the central Mediterranean. After that it took an exceptional track to the plains of Hungary, sheared by the 500-millibar wind (charts 2.33(*c*) and (*d*)). Saharan depressions may develop and move quickly eastwards if a good supply of arctic or polar air is maintained. Otherwise they may remain almost stationary for days; but on the whole slow development is more common than rapid development and movement.

If a trailing front lies just south of the North African coast, then the presence of a trough of low pressure to the north is liable to produce a sympathetic wave on the trailing front and, if other conditions favourable for cyclogenesis are present, a Saharan depression may develop. This is most likely to occur if a depression is moving through the Mediterranean, or southern Europe, and particularly in a situation when a trough extends northwards from the Mediterranean to Scandinavia (for example, type A_1, see Chapter 4). Examples are given in Figures 2.34(*a*) and 2.10(*a*) to (*d*).

A Saharan depression generally begins to move eastwards along the Mediterranean front, but normally it soon begins to take a more northerly track and the wave which has developed on the front occludes. If there is pronounced northward steering towards Europe the depression moves on track *2b* followed by *4a*. If there is an anticyclone established over the Balkans and the Black Sea, the depression will move on track *2b/4b* or *2c*, keeping near to the African coast. On rare occasions a depression that has formed south of the Atlas mountains moves northwards through the Biskra gap to the western Mediterranean (track *2a*). Some cases of depressions which apparently move north across the Atlas mountains are, however, really the result of the formation of a lee depression on the north side of the mountains due to a current of continental tropical air moving northwards towards the south side. This may result in the transference of the main centre of low pressure from south to north of the Atlas mountains (see page 23). With a depression following track *2b/4a* duststorms develop first over North Africa, but cease when the depression moves northwards. Frontal rain develops over the central Mediterranean and the Aegean (see Figures 2.11(*a*) to (*d*) for example). If a depression follows tracks *2b/4b* the duststorms may continue right along the North African coast as the depression moves eastwards, and there may be rain to the north of the depression. In autumn weak depressions moving on track *2b* may become stationary in the Gulf of Sidra. Thunderstorms develop in the easterly air stream to the north of the depression and may recur in the area for perhaps two or three days.

The track *2c* is maintained if there is a continued flow of polar air behind the depression. There may be frontal rain ahead of and to the north of the depression, and showers in the polar air in its rear. This is most likely to occur with a Saharan depression of winter or early spring; in April and even May the air ahead of the depression is very dry, and duststorms are likely to occur in the strong to gale force winds that blow both from south-east ahead of the warm front and from south-west in the warm sector just ahead of the cold front. Visibility may be reduced to well below 200 yards in the duststorms; dust may be carried upwards to 15,000 or 20,000 feet at times, and far northwards over the sea. The duststorms cease when the wind veers to north-west and decreases. An example of a depression on the track *2c* is given in Figures 2.35(*a*) to (*e*).

Although depressions on track *2d* are not frequent they are the most troublesome to the forecaster owing to the scarcity of observations in the neighbourhood of the track, and because they may bring gales and duststorms to lower Egypt, lasting for twelve hours or more. Sferic observations, if available, should give the most useful indication of the presence and position of such a disturbance, as it is likely to give thunderstorms at least at medium to high levels near the tip of the warm sector. Failing these, the first sign that development is taking place is a steady fall of pressure over a wide area of Cyrenaica and Egypt, although only small waves may be apparent on the Mediterranean front. The wisest course the forecaster can then take is to predict the development of a depression which will move towards lower Egypt, causing gales and duststorms. More detail can be added later if the situation demands. A notable example in the period 9 to 11 March 1946 is shown in Figures 2.36(*a*) and (*b*). South to south-westerly gales blew throughout the night and much of 10 March in the Nile delta, while over the western coasts of lower Egypt the wind was light. Visibility was almost nil in the duststorm which accompanied the gale. Another example of rapid and unexpected development over Egypt is given in Figures 2.37(*a*) and (*b*) for 29 to 30 March 1953.

An interesting but rather rare case is mentioned by M. Berenger[9] of a Saharan depression which drew in a tongue of equatorial air from the Gulf of Guinea, giving the depression a warm sector of very hot, humid air with pronounced convectional instability. On 13 March 1953 a wave developed on a cold front which lay in the region of the Atlas mountains. Equatorial air from the south-south-west was drawn into the circulation and the depression became very active, producing considerable rainfall as well as thunderstorms and duststorms over the Sahara and the North African coast. In southern Algeria about 0.8 inches of rain fell in the desert in 24 hours. The synoptic situation on 14 March 1953, mainly after Berenger, is shown in Figure 2.38. Moist, equatorial air may very occasionally reach the central Sahara if its track avoids the southern mountain ranges. But this air mass seldom, if ever, reaches the North African coast. The few Saharan depressions shown in Table 4 for the summer season occur, in fact, in early June and should be regarded as belonging to an extended spring season rather than summer.

CENTRAL AND EASTERN MEDITERRANEAN DEPRESSIONS

Lee depressions occasionally form in the northern Ionian Sea, the southern Aegean Sea and the region of Cyprus; but the formation of new depressions in these areas is rare and normally confined to the winter months, December to February. What more usually happens is that depressions already in the area become rejuvenated and develop rapidly as a north-easterly continental polar air stream or a north to north-easterly continental arctic air stream moves towards the central Mediterranean. Occasionally, however, a vigorous invasion of continental arctic air may give rise to the formation and rapid development of a depression in the central or eastern Mediterranean. The development of a new depression in the central or eastern Mediterranean is more difficult to forecast than the rejuvenation of one already in existence, but the properties of the invading polar or arctic air mass are usually the most important factors in the situation. The more vigorous and direct the southwards flow of the air the greater will be the chances of development of a depression.

Depressions forming in the northern Ionian or southern Aegean Sea as a result of an invasion of continental arctic or polar air may move south or even south-west at first but later normally move eastwards to the Cyprus area. Heavy rain falls in the current behind the depression with winds of gale force near and to the north of the depression, north-easterly backing to north-north-west as the depression moves eastwards. The depressions associated with continental polar air are generally less intense than those associated with continental arctic air. An example of the formation of a central Mediterranean depression which later moved on track *4b* is given in Figures 2.5(*a*) to (*d*).

Cyprus depressions form usually in late autumn and early spring when a deep stream of continental arctic air moves towards the eastern Mediterranean. The associated weather is that to be expected from a vigorous southward burst of continental arctic air over the relatively warm sea. Strong to gale squally winds with heavy showers occur over the eastern Mediterranean. The showers may penetrate well inland into Africa and duststorms may precede the showers. Figures 2.39(*a*) to (*c*) show the development of a Cyprus depression in late autumn (16-18 November 1953). A lee depression developed while a cold front, preceding continental arctic air southwards, approached the Anatolian plateau. Figures 2.40(*a*) and (*b*) for 6-7 March 1953 show another typical Cyprus depression which gave heavy squally showers over the eastern Mediterranean. An example of the formation of a Cyprus depression as a result of an invasion of continental polar air from the Aral Sea - Caspian Sea basin is given in Figures 2.41(*a*) and (*b*) for 15-16 December 1948.

The region between Sicily and Tunisia is a favourite one for the initial formation of wave depressions. These may develop into vigorous depressions in the central and eastern Mediterranean. Cases have been mentioned on pages 23 and 40. Waves form very frequently near Tunisia on cold fronts arriving from the north-west and delay the arrival of the north-west air stream at Malta by one or two days. Delay may again occur as a result of further waves before the front reaches Benghazi and Cyrenaica. Formation of waves in the central Mediterranean is especially likely to occur in type A_1 situations (see Chapter 4 and a further example in Figure 2.42).

ANTICYCLONES

It was indicated in Chapter 1 how the positions of the great semi-permanent anticyclones were responsible for the main characteristics of Mediterranean climate. In the same way the day-to-day movements of these anticyclones have a profound influence on the short-term variations of weather in the area. Transitory anticyclones also exert their influence on day-to-day weather, especially if they become quasi-stationary and create a blocking situation in more northern latitudes (see Chapter 4). This is so in spite of the fact that the big migratory anticyclones of northern latitudes seldom extend over the Mediterranean area. The positions of these anticyclones, and their associated warm ridges and steering currents in the upper air, determine the general pattern of the weather in the Mediterranean. This will be fairly clear from what has already been said on air masses and depressions and will become more so when we come to describe weather types and winds. It is therefore obvious that for successful forecasting a close study of the movements of anticyclones is necessary.

Although the major travelling anticyclones do not normally enter the Mediterranean area, anticyclones of small intensity do drift into and pass through the Mediterranean from time to time. These in general give fine weather and light winds. Again, small weak centres of relatively high pressure occur, especially in the warm season, over the southern Mediterranean just north of the African coast and particularly in the Gulf of Sidra (see, for examples, Figures 2.43(*a*) and 2.21(*a*)). At other times an area of high pressure over the Mediterranean generally appears as an extension from an anticyclone whose main body lies outside the area.

In summer the Azores anticyclone develops an extension which at different times may be directed east, east-north-east or north-east and parts often break off to form separate anticyclonic cells. Extensions to the east over the Mediterranean or east-north-east towards the Alps and southern Europe are the commonest. In the former case (weather type E - see Chapter 4) the southern Mediterranean enjoys fine settled weather even though the ridge or the anticyclonic cell may appear weak by northern standards (that is, pressures of about 1016 millibars). The northern part of the Mediterranean may then feel the effects of Atlantic depressions passing across Europe and thunderstorms occur at intervals over the Alps and northern Italy. When the ridge extends east-north-east towards the Alps (weather type D) the Mediterranean is cut off from Atlantic depressions and the whole area is normally quiet and fine. The east and east-north-east extensions to the Azores anticyclone generally become established during June (about the 10th to the 20th is the commonest time) and mark the beginning of the settled summer régime in the Mediterranean. In some years, however, the Atlantic anticyclone shows more tendency to extend north-east towards the British Isles and Scandinavia or the Arctic seas (weather type A) and when this type occurs it tends to persist. These are the finest summers in Britain while southern Europe, the Alps and the Mediterranean are relatively disturbed. These three types of extension of the Azores anticyclone show clearly in the 1015-millibar isobar of the normal pressure chart for June (Figure 1.12).

The latter part of August to mid-October is a period when anticyclones commonly travel eastwards across Europe. This is reflected in the long ridge which appears on the normal pressure chart for September (Figure 1.15). Weather in the Mediterranean continues largely undisturbed except for such brief thundery rains as are associated with the cold outbreaks (chiefly in the north) between the travelling anticyclones. By the latter part of September the anticyclones tend to become slow-moving over eastern Europe and the Balkans. At such times scirocco affects the central Mediterranean, sometimes for periods prolonged over seven to ten days or more, while the western Mediterranean may experience quite disturbed weather (see page 23 and weather type A_1 in Chapter 4).

In winter the trough dividing the Azores and Eurasian anticyclones is nearly always somewhere in the Mediterranean. It is generally the site of one or more depressions and its position varies. The average positions may be seen on the normal pressure charts for November to February (Figures 1.7, 1.8, 1.17 and 1.18).

The variability of weather from year to year may be accounted for by variability in the movement and development of the anticyclonic systems, especially over Europe. In some summers there may be little eastward or north-eastward extension of the Azores anticyclone. In some winters arctic anticyclones may not show any activity and even the Eurasian anticyclone may remain far to the east. The resultant year-to-year variations of weather in the Mediterranean can be as notable and disconcerting as those in more northern latitudes. Thus a traveller, having been warned about the duststorms that occur in spring along the North African coast, may go there one year and meet with none, while in another year they may be frequent and unpleasant. The vagaries of the anticyclonic systems may also cause variations in the times of change from one seasonal type to another; for example the cool season may be a month late in commencing or a month late in ending. (Very early beginning or ending is not common.) The length of the rainless season in Malta is usually about three to three and a half months, but in extreme cases may last up to six months, or (once or twice in a hundred years) there may be some rain in every month.

CHAPTER 4

TYPES OF WEATHER SITUATION

The classification of synoptic situations into "weather types" is a rather artificial procedure but it is often very useful as it enables us to speak in general terms about situations whose main features are of frequent occurrence and therefore of some importance. In order to be of practical value the number of types must not be too large and in dealing with an area of the size of the Mediterranean it is therefore necessary to concentrate on the main features only. For this reason it is inevitable that situations will occur which cannot be conveniently classified at all, and some will have features intermediate between two or more types. Such difficulties are, however, bound to occur in any classification of synoptic situations which by their nature have an infinite variety.

The classification here adopted is based mainly on the positions, relative to the Mediterranean area, of the anticyclones which exert a controlling influence on the developments occurring in the area and, to a smaller extent, on the positions of major low-pressure systems surrounding the area. It will be seen that the positions of depressions in the Mediterranean are not used as criteria for weather types. Thus for a given weather type a variety of positions is possible for one or more Mediterranean depressions. This has the advantage that the passage of a depression through the Mediterranean does not necessarily involve the change of a weather type. A given weather type determines the broad features of Mediterranean weather and its development, but not the details of local weather. The following are brief descriptions of the five main weather types used in the present classification:

Type A. An anticyclone or ridge of high pressure lies over the north-eastern Atlantic or the British Isles. To the east of this lies a depression causing a flow of northerly (north-west to north-east) winds towards the Mediterranean over the British Isles, the North Sea, or Scandinavia. Pressure is relatively low over the Mediterranean.

Type B. Northern Europe is dominated by an anticyclone. Pressure is relatively low over the Mediterranean.

Type C (westerly type). A deep depression (or a sequence of depressions) dominates the middle latitudes of Europe, and westerly winds prevail over most of the Mediterranean.

Type D (easterly type). An anticyclone dominates central and southern Europe giving easterly winds over most of the Mediterranean. Pressure is relatively low over northern Europe.

Type E (anticyclonic type). An anticyclone or ridge of high pressure covers the greater part of the Mediterranean area giving generally light winds, mainly westerly in the north, easterly in the south, and northerly in the east. Pressure is relatively low over central or northern Europe.

It may be noted that, according to the above descriptions, types A or B could occur in combination with C. In such cases we prefer to classify as A or B rather than C and we use type C only when A or B are not applicable. In the same way it might be supposed that types A and D could occur simultaneously, but in practice the combination is so improbable that the two types may be regarded as mutually exclusive. On the other hand transitional stages between the two are possible as is generally the case between any types. We shall now consider each type in turn.

Type A. An anticyclone or ridge of high pressure lies over the north-eastern Atlantic or the British Isles. To the east of this lies a depression causing a flow of northerly (north-west to north-east) winds towards the Mediterranean over the British Isles, the North Sea, or Scandinavia. Pressure is relatively low over the Mediterranean. The anticyclone or ridge of high pressure may be migratory or it may have formed *in situ* and often appears as an extension northwards of the Azores anticyclone or as a bodily transfer northwards of the same anticyclone.

This type which is commonest in winter and spring brings maritime arctic, maritime polar, continental arctic or continental polar air to the western or central Mediterranean and cyclogenesis normally occurs as a result in these areas especially in winter. The type of air brought to the Mediterranean depends on the position of the anticyclone. If the anticyclone is in a westerly position without much extension northwards it brings maritime polar air across the British Isles to the western Mediterranean. Figures 2.44(*a*) to (*c*) show a winter example and Figures 2.16(*a*) and 2.17(*a*) and (*b*) show summer examples. Cyclogenesis may occur in the western Mediterranean. For the type of weather to be expected in such situations see pages 12, 19, 39 and 72-74.

If the eastern edge of the anticyclone lies over the British Isles and it extends well to the north, the air brought south is maritime arctic, flowing over the North Sea to the western Mediterranean. Winter examples are shown in Figures 2.2(*a*), 2.30(*a*) and 2.31(*a*) and (*c*) (2.7(*c*) represents a phase between successive invasions of arctic air); spring examples in Figures 2.1, 2.45(*a*) and 2.46; a summer example in Figure 2.15(*a*), and an autumn example in Figures 2.47(*a*) and (*c*). Cyclogenesis generally occurs in the western Mediterranean. The weather associated with such a situation is described on pages 11, 18, 39 and 72.

If the anticyclone lies over the British Isles the air brought south is continental arctic or polar, flowing over Scandinavia to the western or central Mediterranean. A winter example can be seen in Figures 2.5(*a*) and (*b*); a spring example in Figures 2.11(*c*) to (*f*), and summer examples in Figures 2.13 and 2.17(*d*) and (*e*). In this case cyclogenesis may occur in the west or central Mediterranean or the southern Aegean. Associated weather conditions are described on pages 13, 18, 39, and 42.

It is not convenient to regard these cases as separate sub-types as they often merge imperceptibly into one another as a result of slight movements in the anti-cyclone or depression. For example if the anticyclone moves eastwards an invasion of maritime polar air may be followed by one of maritime arctic and then continental arctic or polar. The commonest, however, is for maritime arctic air to be followed by continental arctic as described on page 18 and shown in Figure 2.13. An example of maritime polar air followed by continental polar is given on page 20 and in Figures 2.17(*a*) to (*e*).

Situations of type A develop most frequently into type B, sometimes to types C or D. They are often associated with blocking, especially the "meridional" type of blocking (see page 50). One could divide the type into a number of sub-types according to the pressure distribution further east. We shall, however, only mention one sub-type of interest based on this kind of classification.

Sub-type A_1. In this case an extensive anticyclonic area also lies over eastern Europe and a trough extends from the Mediterranean north or north-eastwards between the two anticyclones. While this situation persists continental tropical air is fed into the south-east side of the trough while polar or arctic air enters in the north-west. Thus the situation is very favourable for frontogenesis. When a cold front enters the western Mediterranean it is liable to be thrown into waves which travel north or north-eastwards along the trough (see page 43). The commonest position for the trough is in the central Mediterranean where the southerly stream of continental tropical air from Libya may be maintained for several days. In this

situation the high pressure on the east sometimes has an extension southwards into Cyrenaica (see page 16). The commonest depression tracks in this situation are therefore 3*a*, 3*b* or 4*a*. The trough may remain stationary for several days especially in October when it gives disturbed thundery weather over the western Mediterranean (see page 44). In winter the balance between the two anticyclones is more easily upset, Saharan warm air being easily and rather quickly occluded even in the Mediterranean, and this sub-type does not usually last for long. In spring, Saharan depressions are likely to form with this type either through the penetration of maritime arctic or polar air to the south of the Atlas mountains (see, for example, page 41 and Figure 2.35(*a*)) or due to a sympathetic wave on an old front lying south of the North African coast (see page 41). The situation may be terminated by a rise of pressure in the middle or northern part of the trough and a gradual change to type D.

A winter example is given in Figure 2.42 which shows the closing stages of a "meridional" block (see page 50) in which maritime polar air is following an initial invasion of maritime arctic air to the western Mediterranean. A cold pool formed over the British Isles on 9 December 1955 and by the 14th had moved south to Morocco. A Saharan depression formed south of the Atlas mountains on the 12th and moved across the Atlas mountains (probably by transference - see pages 23 and 41) to the position shown in the figure on the 15th. Note the cold front on which waves have developed between Sicily and Tunisia and the stream of continental tropical air (scirocco) flowing northwards over Italy and the Adriatic. In such a situation the warm front gives much rain, low cloud and poor visibility. Similar conditions occur in the Aegean if the trough lies further east.

Figures 2.48(*a*) to (*d*) for 22-24 October 1951 show an autumn example which also involved a blocking situation. Maritime arctic air was brought south to the western Mediterranean on 22 October 1951 and a cold pool moved over the Pyrenees on the 24th. The anticyclone over the north-eastern Atlantic remained almost stationary till the 24th after which it spread across Europe and cut off a cold low in the Gulf of Genoa, associated with a cold pool over the Balearics. The type A_1 situation lasted for the three days from the 22nd to 24th inclusive.

Other spring examples may be seen in Figures 2.10(*d*) and 2.45(*c*).

Type B. Northern Europe is dominated by an anticyclone. Pressure is relatively low over the Mediterranean. The anticyclone may appear as an extension of the Azores anticyclone or (in winter) of the Eurasian anticyclone. In some cases the north European anticyclone may also cover central Europe even to the borders of the Mediterranean; in other cases pressure may be relatively low over central Europe.

In March to May the anticyclone over northern Europe may be one that has moved southwards from Arctic regions (see example in Figure 2.49). On other occasions the anticyclone may be one that has moved or extended eastwards involving a change from type A to type B (see examples in Figures 2.15(*a*) and (*c*), 2.31(*a*) and (*b*), and 2.35(*a*) and (*c*)). With this type, continental arctic or polar air is brought to the Mediterranean from the north-east or east, the actual path of the air depending on other details of the pressure distribution. In some cases of type B a marked trough lies between the Azores and the northern European anticyclones and maritime polar or transitional maritime polar air flows in a westerly or north-westerly stream into the Mediterranean in addition to continental arctic or polar air from east or north-east. The result is often a rather confused low-pressure area over the Mediterranean. Thundery showers may then persist for some days, especially over the north and central Mediterranean. In other cases the two anticyclones may be connected by a ridge which effectively prevents any flow of air at the surface from the west or north-west into the Mediterranean. This type is often associated with blocking, especially "diffluent" blocking (see page 50). If the north European anticyclone moves southwards type B changes to type D. Examples are given under type D.

It is convenient to recognize three main sub-types depending on the pressure distribution further east.

Sub-type B_1. To the east of the north European anticyclone lies a depression over Russia or western Siberia.

With this sub-type, continental arctic or polar air is brought south from northern Russia and may flow into the Mediterranean anywhere from France to Turkey. Cyclogenesis may occur, especially in winter, in the Adriatic, Aegean or Cyprus area, depending on where the air enters the Mediterranean. In winter strong to gale north-easterly winds may develop over the Mediterranean, that is, bora in the Adriatic and similar winds in the Aegean, tramontana over the Tyrrhenian Sea and levante and levanter in the western Mediterranean. At the same time maritime polar or transitional maritime polar air may be flowing into the western Mediterranean from the west or north-west, and cyclogenesis may also occur in this area. Examples of this sub-type can be seen in Figure 2.50(*a*) (winter); Figures 2.35(*c*) and (*e*) and 2.49 (spring); Figures 2.15(*c*) and 2.42(*a*) (summer); and Figure 2.39(*a*) (autumn). The associated weather is further described on pages 13-15, 19-20 and 42.

Sub-type B_2. The north European anticyclone extends into Siberia and there is low pressure south of it from the eastern borders of the Mediterranean eastwards.

This type, as would be expected, is commonest in the cool season when the north European anticyclone would generally appear as a westward extension of the Eurasian anticyclone. Continental polar air is brought from the Aral-Caspian Sea basin and generally flows into the north of the Mediterranean somewhere east of Greece - the Dardanelles gap being a favourite point of entry. At the same time maritime polar or transitional maritime polar air may be flowing into the western Mediterranean. Cyclogenesis may occur in the Aegean or Cyprus area and if maritime polar air is flowing into the western Mediterranean, depressions may also develop in that area. In some winters this weather type dominates Europe and the eastern Mediterranean. Examples of this sub-type can be seen in Figures 2.32(*a*) and 2.51(*d*) (winter) and 2.52(*a*) (autumn), and the weather conditions are described on pages 14, 20, 39 and 42. The normal pressure maps for the spring and autumn months April and October approximate most closely to this sub-type (see Figures 1.10 and 1.16).

Sub-type B_3. The north European anticyclone extends into Siberia eastwards and pressure is also high southwards to Syria and Palestine.

Like B_2, this sub-type occurs mainly in the cool season. Continental tropical air enters the eastern Mediterranean from the south-east while continental polar air may enter from the north-east. In cases where a ridge connects the Azores and north European anticyclones the Mediterranean is effectively surrounded on all sides except the south by relatively high pressure. Examples can be seen in Figures 2.29 and 2.31(*b*) (winter) and (less typically) in 2.33(*b*) and (*d*) (spring). Under these circumstances a deep low in the Mediterranean may have a tight pressure gradient on any side but the south.

When there is a well marked trough between the Azores and north European anticyclones, maritime polar or transitional maritime polar air may enter the western Mediterranean and may pass right across the southern side as a westerly flow. At the same time continental polar air may be giving bora in the Adriatic or similar winds in the Aegean. In such situations, with so many different air masses affecting the area at the same time, the analysis may be very complicated. In winter there may be several depressions moving eastwards through the Mediterranean. Cyclogenesis may occur over Libya, south of the Gulf of Sidra, with depressions moving along tracks *2c* or *2d*. Heavy rain may fall ahead of the depressions, even along the coast of Egypt which normally experiences only showers. Examples can be seen in Figures 2.9(*a*) and 2.51(*a*) and (*b*) (winter), Figures 2.36(*a*) and (*b*) (spring) and Figure 2.34(*a*) (autumn). The normal pressure maps for the cool-season months November to March approximate most closely to this sub-type (see Figures 1.17, 1.18, and 1.7 to 1.9).

Type C (westerly). A deep depression (or a sequence of depressions) dominates the middle latitudes of Europe and westerly winds prevail over most of the Mediterranean.

As already stated we exclude from type C any situation which can be classified as of type A or B. In the extreme west of the Mediterranean, winds may be between south-west and north-west and in the extreme east they may be south-west to south. If secondary depressions form in the Mediterranean the winds may locally depart even more from the general westerly direction.

This is almost exclusively a winter type since similar situations over northern and central Europe in summer are generally accompanied by an anticyclonic region over the Mediterranean. It brings maritime polar, transitional maritime polar and occasionally maritime tropical air to the western Mediterranean and the air masses may pass right through to the east with gradual modification. Strong mistral and vendaval may occur in this type if the European depression is suitably situated and developed. There may be only a slight and gradual veer of wind as the front of a new burst of maritime polar air passes into the Mediterranean. Rainfall may be prolonged and winds of gale force last for a day or more. Cyclogenesis is generally weak in the Mediterranean with this type (see page 39). Examples may be seen in Figures 2.3(*a*), 2.8(*a*) and 2.53(*a*) to (*d*), all of which are winter cases. The associated weather is described on pages 12, 15, 73 and 81.

Type D (easterly). An anticyclone dominates central and southern Europe giving easterly winds over most of the Mediterranean. Pressure is relatively low over northern Europe.

In the extreme west the winds may be south-easterly and in the extreme east they tend to be north-easterly or northerly. If a depression develops in the Mediterranean the winds depart locally from the general easterly direction. The condition that pressure should be relatively low over northern Europe is included in the definition of this type in order to avoid confusion with cases of type B in which the north European anticyclone also extends over central and southern Europe.

This type may develop by the eastward extension of the Azores anticyclone over central Europe (perhaps following a spell of type C); or it may develop from type B by the southward movement of an anticyclone from more northern latitudes (see, for example, Figures 2.19(*a*) and (*b*) which change from B_1 to D, Figures 2.39(*a*), (*b*) and (*c*) which are successively of types B_1, B_2/D and D, and Figure 2.27 which is intermediate between B_2 and D); or it may develop from type A by the south-eastward movement of an anticyclone from the Atlantic (see, for example, Figures 2.5(*a*) to (*d*), 2.26 and 2.47(*a*) to (*g*). This type and type E are the commonest types of the summer in the Mediterranean and at that season are associated with mainly quiet, fine weather (see page 43), although thundery rain or showers may occur over the Balkans.

With this type the Mediterranean is occupied mainly by continental polar air gradually being modified to Mediterranean air but in all seasons except summer the area is seldom free from depressions which bring in other air masses such as continental tropical and maritime polar. Saharan depressions are likely to form in the lee of the Atlas mountains, especially in April or May when the African low-pressure system has moved to a northerly position (see page 41 and examples in Figures 2.11(*a*) and 2.38). Depressions also occasionally enter the Mediterranean from the Atlantic with this type (see page 38 and examples in Figures 2.26 to 2.28). In the cool season, if a new wave of continental polar air enters the Mediterranean from the north-east, cyclogenesis may occur in the central Mediterranean or Cyprus area (see page 42 and Figures 2.39(*b*) and (*c*) and 2.40(*a*) and (*b*)). Any such depression may develop quite considerably in which case a tight gradient appears on its northern side and strong east and north-east winds are experienced in the north of the Mediterranean, that is, bora, tramontana and levante (see Chapter 6 and Figure 2.26). A winter example with no depressions of importance in the

Mediterranean is given in Figure 2.54(*a*). Other examples of this type can be seen in Figures 2.5(*d*) and 2.7 (winter); Figure 2.12(*a*) (spring); Figures 2.19(*b*), 2.24(*a*) and (*c*) and 2.55(*a*) and (*b*) (summer); and Figures 2.20, 2.25 and 2.47(*f*) and (*g*) (autumn).

This type is often associated with a "diffluent" blocking pattern (see below). The normal pressure charts for the warm season months May to September approximate most closely to type D (see Figures 1.11 to 1.15).

Type E (anticyclonic). An anticyclone or ridge of high pressure covers the greater part of the Mediterranean area, giving generally light winds, mainly westerly in the north, easterly in the south and northerly in the east. Pressure is relatively low over central Europe.

The anticyclone or ridge often appears as an extension of the Azores anticyclone. It may develop from type D by the southward movement of the anticyclone or ridge from southern Europe. This type and type D give the typical Mediterranean summer but may occur in any season. In summer the highest pressure values in the anticyclones are commonly no more than about 1015 millibars.

Quiet undisturbed weather is normally experienced and even in midwinter this type may last for several days. A January example is given in Figure 2.43(*a*) and a spring one in Figures 2.37(*a*) and (*b*). In summer, type E almost always takes the form of a ridge extending from the Azores anticyclone across the western and central Mediterranean. The northern borders of the Mediterranean may then be disturbed by depressions passing from west to east over Europe, their cold fronts just penetrating to the northern Mediterranean (see page 43). In such cases the polar air seldom spreads far into the Mediterranean, but thundery rain or showers may occur in the northern Mediterranean, especially in the Po valley, when a thermal low has formed there. An example is given in Figure 2.56 for 24 July 1950, which is typical of a type E situation in summer. The upper air charts corresponding to this type show a westerly flow over Europe with high values of the contour heights over the Mediterranean. The development and passing away of this type are perhaps most easily foreseen by following the rises and falls of surface pressure over the Mediterranean.

Blocking

Type A situations are very often associated with the phenomenon known as "blocking", that is, blocking of the "normal" westerlies of middle latitudes. This is a combined feature of both the surface and upper air synoptic charts. The blocking pattern begins with an outbreak of arctic or polar air from northern latitudes, a favourite place being between longitudes 20°W. and 20°E. This stream is deep and commonly reaches above the 300-millibar level. The southward advection of cold air produces a well marked "cold trough" in the thickness isopleths. Simultaneously with the cold outbreak there is advection of warm air northwards in the upper levels to the west of the cold outbreak, showing as a "warm ridge" in the thickness pattern, and resulting in the development or intensification of an anticyclone or ridge at the surface on the west side of the cold air stream. The development of this anticyclone helps to reinforce the northerly current and so a self-maintaining system is set up. At the same time the deflection of the upper westerlies, especially the zone of strong winds known as the jet stream, into a northerly stream at the longitude in question has the effect of holding up the normal eastward march of travelling depressions and anticyclones in the temperate zone, and the large-scale features of the general circulation over the Atlantic-European sector of the hemisphere develop a stationary pattern for a while. Hence the term "blocking". The pattern may remain stationary for several days, or there may be slow movements either to the east or to the west.

A further stage of development leading to a second type of blocking often occurs in which the northern part of the warm tongue in the thickness isopleths curves

eastwards and cuts off a part of the cold trough to the south. The result is a "cold pool" which appears in the thickness charts as a number of closed isopleths as described on page 34. On the surface charts the blocking anticyclone appears to spread eastwards while a quasi-stationary cold low, associated with the upper cold pool may be cut off to its south. The result is generally a type B or D situation. At this stage the contours at 500 or 300 millibars normally show a pattern similar to that of the surface map, often with the formation of a "split" jet stream, one branch of the strong upper westerly winds passing north of the warm high and the other to the south of the cold low. The forms of the jet stream in these two types of blocking pattern have led to the terms "meridional block" and "diffluent block" respectively.

Depressions approaching a blocked situation from the west are mostly diverted to the north, but some develop towards the south-east and either pass south of the blocking anticyclone or become stationary and stagnate. An anticyclone approaching a blocked situation from the west often contributes to the strengthening or rejuvenation of the blocking pattern, sometimes accompanied by a new outburst of arctic or polar air. In some cases of this sort there is an effective westward shift of the block.

Blocking situations occur most frequently between October and May, with October to November and March to May the favoured periods. The frequency varies from one year to another but has certain well known peaks (for example, north European anticyclones (type B) about the third week in October and of each succeeding month until March, whereas the North Atlantic anticyclones (type A) culminate in May and June, being most intense in March and May). At such times the arctic or polar air stream may break right through to tropical latitudes. The favourite paths for these outbreaks are:

(i) Over or near the British Isles and past the coast of Portugal to the eastern Atlantic in the Madeira region;
(ii) Over France, thence south-westwards over the western Mediterranean and over or round the Atlas mountains to the western Sahara;
(iii) Over France and thence south-eastwards through the length of the Mediterranean;
(iv) Over Russia and the Aegean to the eastern Mediterranean, but sometimes diverted westwards along the Alps to the Rhône gap and the western Mediterranean.

The first three paths occur with type A situations and the fourth with type B.

The great temperature contrast between the cold air stream and both the ground or sea surface over which it is passing and the neighbouring warm air masses results in considerable vertical instability and the formation of very active, though normally rather small, depressions. If the arctic air reaches the tropical Atlantic, frontal wave disturbances may form there and move north-eastwards into the Mediterranean, often carrying the main low-pressure centre eastwards into the northern Mediterranean with them. When, on the other hand, the cold-air outbreak ends rather over north-west Africa, waves form on the trailing cold front south of the Atlas mountains and travel east or east-north-east towards the central Mediterranean. These situations often culminate with a quasi-stationary cold low centred either in the Gulf of Genoa, the northern Adriatic or the central or eastern Mediterranean.

A winter blocking situation is partly illustrated in Figures 2.31(*a*) to (*d*). The block formed on 24 December 1953 and several waves of arctic air invaded the Mediterranean. The invasion of 4 January 1954 is shown in Figures 2.31(*a*) to (*c*), and described on page 40. Figure 2.31(*b*) shows the anticyclone spreading eastwards in association with warm air advection aloft. At this time there was a cold pool over the Pyrenees. By the 6th a separate anticyclonic cell had formed over eastern Europe (Figure 2.31(*c*)) and a well marked split jet appeared in the upper levels forming a diffluent block (Figure 2.31(*d*)). This, however, was short-lived owing to the arrival west of the British Isles of an anticyclone which had originated in north-west Canada on 1 January 1954. This renewed the blocking situation and by the 7th a typical meridional pattern had reformed in the upper levels. The blocking lasted till 11 January. The surface features of a blocking situation in February are described on page 12 and in Figure 2.2(*a*), and other cases in December and October on page 47.

A blocking situation which lasted from 23 February to 19 March 1955 is partly illustrated in Figures 2.45(*a*) to (*g*). The block began with a weak anticyclone which built up over the Norwegian Sea between 21 and 23 February. By the 24th a cold pool had formed a little north-west of Portugal. It was receding north on the 26th and the upper blocking pattern weakened, but the surface anticyclone remained firmly established over southern Scandinavia. By 1 March the anticyclone was centred over north Germany and continental arctic áir was being brought south to the northern Mediterranean. A cold pool had developed over the Balearics and renewed warm advection aloft was taking place to the west of this which brought about intensification of the anticyclone. At this time the block showed a tendency to move east but on 4 March an anticyclone, which had moved from mid-west Canada, arrived to the west of the British Isles. It caused a transference of the main blocking pattern westwards and produced a fresh outburst of maritime polar followed by maritime arctic air. Figure 2.45(*a*) shows the synoptic situation on 5 March soon after maritime polar air had entered the Mediterranean with the formation of a Genoa depression. The 300-millibar chart (Figure 2.45(*b*)) shows a good meridional block with strong upper northerlies over the British Isles and the North Sea. Figures 2.45(*c*) to (*e*) show the situation on 8 March with a cold pool over south-west France and its associated cold low over the western Mediterranean. On 12 March the westerly jet stream at 300-millibars was re-established in a very northerly position but in other respects the blocking pattern remained stationary. A further anticyclone from the west reinforced the block on the 15th and resulted in a slight shift westwards. A new wave of maritime arctic air was brought south and entered the Mediterranean on the 18th; at the same time the jet stream was again diverted into a strong north-northwesterly current over the British Isles. The end of the block came on the 19th to 20th when the anticyclone moved north, the jet stream at 300 millibars was more or less cut off, and a new one began to form in a more southerly latitude. On the 20th to 21st Atlantic depressions were beginning to move over southern Europe and the Mediterranean. The situation on 19 March is shown in Figures 2.45(*f*) and (*g*).

A summer example is shown in Figures 2.15(*a*) to (*e*). In this case maritime arctic air moved south but only just reached the Mediterranean. Figure 2.15(*a*) shows the surface situation on 5 July 1955 with the cold front crossing the Alps and a weak lee depression in the Po valley. The depression remained weak and moved along track 3*a*. The 300-millibar chart for the same day (Figure 2.15(*b*)) shows a strong northerly stream over the British Isles constituting a meridional block. The second stage of development, to a diffluent block, is shown in Figures 2.15(*c*) and (*d*) for 9 July. At the surface the anticyclone has spread eastwards across northern Europe (type B_1), while at 300 millibars the two branches of the jet stream can be clearly seen - one near Iceland, the other over the Mediterranean. The resulting cold pool over the Adriatic is shown in Figure 2.15(*e*) associated with a weak low at the surface (Figure 2.15(*c*)).

Figures 2.47(*a*) to (*j*) give an autumn example which began on 5 October 1953. A lee depression formed in the northern Adriatic on the 5th while the cold front of maritime arctic air was crossing the Alps (Figure 2.47(*a*)). On the 7th a wave depression formed on the cold front in the Tyrrhenian Sea (Figure 2.47(*c*)); this moved to the Aegean and remained stationary there from the 10th to the 12th. Figure 2.47(*d*) shows the strong meridional blocking pattern on the 7th. The situation on the 10th is shown in Figures 2.47(*g*) to (*j*). The warm tongue of the thickness pattern had penetrated north and east and cut off a cold pool over the Adriatic

(Figure 2.47(*h*)). This was accompanied on the surface (see Figure 2.47(*g*)) by the eastward spread of the blocking anticyclone to a position over central Europe (weather type D). Figure 2.47(*j*) shows a splitting of the jet stream of 225 millibars though, at this level, signs of the warm anticyclone are missing. The cold pool remained stationary from the 10th till the 14th while the blocking pattern drifted slowly eastwards from the 13th onwards.

CHAPTER 5

PRESSURE

The movements of the main pressure systems in and around the Mediterranean have been described in Chapters 1, 3 and 4. Charts of normal pressure for each month are given in Figures 1.7 to 1.18. These pressure distributions indicate approximately the directions of the prevailing winds in each month and may be used to supplement the information contained in Figures 1.5*(a)* and *(b)*.

DIURNAL VARIATION OF PRESSURE

At all times and in all places the diurnal variation is superimposed on the changes due to movement and development of highs and lows. In low latitudes the diurnal variation of pressure becomes more noticeable partly owing to its greater amplitude and partly because it is on the whole less obscured by the day-to-day movem nts and developments of pressure systems. For the latter reason, in the northern part of the Mediterranean, the diurnal variation is more noticeable in the relatively quiet conditions of the summer than in winter. When the diurnal variation is relatively large, as in North Africa, it is advisable to make allowance for this when using pressure tendencies for forecasting purposes. If the form of the diurnal variation is not known, the safest procedure is to use only pressure changes over 24 hours. The mean diurnal variation of pressure for the four mid-season months at a few stations is given in Table 5. From this we may deduce the mean pressure tendency (change of pressure over the last three hours) at the synoptic hours of observation. The results are given in Table 6. Although the data in Table 5 for Marseilles and Naples are old there are no recent data available in this form. There is no reason to think that any material alteration has since taken place.

USE OF PRESSURE TENDENCIES

If due allowance is made for the diurnal variation, pressure tendencies can be used as an aid in tracing the movement of cold fronts entering the Mediterranean from the north. This can be done by plotting the variation of pressure with time at key stations. For example, during July and August the fall and rise of pressure at Odessa give warning of colder air moving towards the Euphrates valley; the fall and rise of pressure at Trabzon or Sinop on the southern shores of the Black Sea are normally followed by the movement of polar air towards lower Egypt. Again, in the western Mediterranean, the fall and rise of pressure at Gibraltar generally presage westerly and easterly winds respectively.

EXTREMES OF PRESSURE

Recorded values of extremes of pressure for limited periods are given for a few stations in Table 7. Extreme values from daily values at a fixed hour over the period 1919-1938 are given for a few stations in Table 8.

Table 5

Diurnal variation of pressure - difference from the daily mean

(a) Marseilles. 43°18'N., 03°03'E., 246 ft. Period 1878-87

Hour (G.M.T.) — *Hundredths of a millibar*

	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100
January	+07	+03	+03	-08	-26	-37	-33	-11	+22	+60	+80	+70
April	+25	+18	+09	00	-09	-01	+13	+26	+34	+38	+39	+31
July	-22	-29	-33	-32	-19	-04	+17	+32	+40	+45	+47	+45
October	+24	+19	+12	+02	-06	-10	-06	+10	+28	+40	+32	+18

Hour (G.M.T.) — *Hundredths of a millibar*

	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300
January	+28	-04	-17	-24	-28	-31	-30	-26	-18	-05	+10	+15
April	+16	+02	-12	-28	-41	-51	-61	-52	-25	-04	+12	+21
July	+41	+29	+13	-07	-24	-37	-36	-26	-11	-05	-09	-14
October	+04	-11	-25	-33	-41	-44	-38	-28	-12	+11	+26	+28

Authority: Bibliography No. 3

(b) Naples. 40°52'N., 11°55'E., 489 ft. Period 1870-79

Hour (G.M.T.) — *Hundredths of a millibar*

	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100
January	+02	+07	-01	-20	-35	-30	-10	+14	+39	+58	+51	+16
April	+22	-02	-28	-44	-43	-28	-08	+14	+34	+47	+49	+32
July	+11	-10	-26	-32	-25	-08	+15	+33	+42	+45	+42	+32
October	+17	+02	-16	-32	-43	-40	-20	+14	+45	+55	+54	+30

Hour (G.M.T.) — *Hundredths of a millibar*

	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300
January	-29	-51	-54	-45	-32	-13	+06	+19	+27	+29	+28	+20
April	+08	-16	-40	-52	-53	-43	-18	+10	+34	+43	+44	+38
July	+13	-08	-26	-42	-50	-52	-40	-16	+13	+30	+32	+27
October	-02	-34	-50	-56	-48	-28	-01	+17	+31	+39	+37	+29

Authority: Bibliography No. 3

Table 5 (continued)

Diurnal variation of pressure - difference from the daily mean

(*c*) Algiers/University. 36°46'N., 03°03'E., 194 ft. Period not given

Hour (G.M.T.) — Hundredths of a millibar

	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100
January	+36	+12	+01	-10	-34	-44	-29	-04	+20	+46	+54	+54
April	+35	+12	-13	-33	-44	-44	-30	+01	+23	+35	+36	+29
July	+00	-21	-41	-53	-51	-31	-11	+11	+32	+51	+58	+60
October	+17	-03	-29	-57	-60	-55	-27	+03	+28	+51	+55	+49

Hour (G.M.T.) — Hundredths of a millibar

	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300
January	+18	-43	-59	-60	-55	-46	-28	+02	+23	+40	+48	+53
April	+14	-07	-29	-48	-53	-49	-31	00	+30	+56	+60	+55
July	+55	+28	+10	-07	-27	-43	-45	-33	-12	+16	+22	+20
October	+17	-21	-36	-41	-39	-29	-04	+24	+39	+45	+45	+40

Authority: Bibliography No. 1

Figures for even hours are interpolated

(*d*) Ksara, Lebanon. 33°49'N., 36°00'E., 3,014 ft. Period 1921-45

Hour (G.M.T.) — Hundredths of a millibar

	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100
January	+12	-05	-29	-31	-08	+17	+64	+81	+84	+28	-37	-83
April	-17	-28	-35	-20	+09	+37	+55	+64	+57	+33	+05	-24
July	+08	+01	+04	+17	+41	+65	+61	+51	+33	+09	-16	-36
October	+04	-07	-03	+09	+27	+65	+93	+95	+73	+28	-31	-81

Hour (G.M.T.) — Hundredths of a millibar

	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300
January	-91	-81	-68	-49	-08	+19	+37	+43	+41	+31	+16	+17
April	-59	-80	-84	-75	-51	-16	+27	+49	+52	+51	+40	+09
July	-65	-84	-99	-99	-71	-41	+04	+45	+57	+55	+39	+20
October	-105	-113	-108	-89	-51	-09	+20	+43	+45	+41	+32	+20

Authority: Bibliography No. 19

Table 5 (continued)

Diurnal variation of pressure - difference from the daily mean

(*e*) Luqa, Malta. 35°51'N., 14°29'E., 261 ft. Period July 1946 - April 1949

Hour (G.M.T.) — millibars

	0000	0300	0600	0900	1200	1500	1800	2100
January	0	-.3	-.2	+.6	-.3	-.6	0	+.5
April	+.2	-.2	-.1	+.6	+.2	-.6	-.5	+.5
July	+.1	-.3	+.1	+.4	+.2	-.3	-.3	+.4
October	+.2	-.4	-.1	+.5	-.1	-.5	-.1	+.4

Authority: Data held in Meteorological Office, London

Table 6

Mean pressure tendencies - pressure changes in the last three hours

Hour (G.M.T.) — millibars

	0000	0300	0600	0900	1200	1500	1800	2100
(*a*) Marseilles								
January	+.1	-.1	-.3	+.9	-.3	-.5	-.1	+.3
April	+.2	-.3	+.1	+.3	0	-.3	-.3	+.3
July	-.2	-.1	+.5	+.3	0	-.5	-.3	+.3
October	+.1	-.2	-.1	+.5	-.4	-.4	0	+.5
(*b*) Naples								
January	-.3	-.2	+.1	+.7	-.9	-.2	+.5	+.2
April	-.2	-.7	+.4	+.6	-.4	-.6	+.3	+.6
July	-.2	-.4	+.5	+.3	-.3	-.6	0	+.7
October	-.2	-.5	+.1	+.7	-.6	-.5	+.6	+.4
(*c*) Algiers								
January	0	-.5	-.2	+.8	-.3	-.8	+.3	+.7
April	-.2	-.7	0	+.6	-.2	-.6	+.2	+.9
July	-.2	-.5	+.4	+.6	0	-.6	-.4	+.6
October	-.3	-.7	+.3	+.8	-.3	-.6	+.4	+.5
(*d*) Ksara								
January	-.2	-.4	+1.0	-.4	-1.2	+.4	+.9	-.1
April	-.7	0	+.8	-.2	-.9	-.2	+1.0	+.2
July	-.5	+.1	+.4	-.5	-.7	-.3	+1.0	+.5
October	-.4	+.1	+.8	-.7	-1.3	+.2	+1.1	+.2
(*e*) Malta								
January	-.5	-.3	+.1	+.8	-.9	-.3	+.6	+.5
April	-.3	-.4	+.1	+.7	-.4	-.8	+.1	+1.0
July	-.3	-.4	+.4	+.3	-.2	-.5	0	+.7
October	-.2	-.6	+.3	+.6	-.6	-.4	+.4	+.5

Table 7

Highest and lowest recorded pressures at mean sea level

(*a*) Gibraltar (1922-38 and 1949-56)

millibars

	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Highest	1036.6	1038.3	1033.1	1028.5	1027.7	1025.7	1025.5	1023.8	1028.2	1030.3	1031.1	1034.3	1038.3
Lowest	990.0	994.5	993.3	994.7	1002.9	1004.1	1006.3	1007.8	1006.4	995.1	992.9	994.6	990.0

Sites: 1922-38 Various

1949-56 North Front, 36°09'N., 05°21'W., 11-24 ft.

(*b*) Cartagena (1877-1900)

millibars

	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Highest	1045	1039	1033	1028	1028	1025	1026	1027	1029	1031	1034	1035	1045
Lowest	987	991	990	988	996	1003	998	1002	1002	993	995	995	987

Site: 37°36'N., 00°47'W., 43 ft.

(*c*) Malta (1936-45 and 1949-56)

millibars

	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Highest	1033.1	1034.8	1033.7	1031.0	1027.9	1024.7	1022.0	1024.1	1029.2	1028.9	1034.3	1032.8	1034.8
Lowest	994.9	989.9	989.2	998.5	998.2	999.9	1005.4	1004.4	1003.2	999.8	998.1	996.8	989.2

Sites: 1936-45 Valletta, 35°54'N., 14°31'E., 233 ft.

1949-56 Luqa, 35°51'N., 14°29'E., 261 ft.

(*d*) Tripoli/Idris Airport (1949-56)

millibars

	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Highest	1033.2	1035.2	1031.2	1032.0	1025.5	1025.4	1022.3	1023.2	1023.7	1025.5	1033.2	1032.4	1035.2
Lowest	997.0	995.9	989.4	996.5	999.1	1001.8	1002.9	1004.3	1003.8	1003.8	1002.0	1000.6	989.4

Site: 32°41'N., 13°10'E., 277 ft.

(*e*) Nicosia (1949-56)

millibars

	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Highest	1032.0	1032.7	1028.7	1025.4	1020.0	1016.9	1011.8	1015.7	1018.3	1023.3	1031.4	1029.7	1032.7
Lowest	996.6	994.9	993.0	996.5	1000.7	999.7	998.7	998.8	1001.8	1005.7	999.2	999.5	993.0

Site: 35°10'N., 33°22'E., 505 ft.

Table 8

Highest and lowest recorded pressures at mean sea level from daily observations at a fixed hour, 1919-38

(*a*) Perpignan, 0700 G.M.T.

millibars

	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Highest	1039.1	1039.0	1036.2	1031.9	1033.9	1028.4	1025.9	1028.3	1029.8	1032.3	1035.0	1041.1	1041.1
Lowest	973.1	987.1	988.5	991.8	997.5	998.0	1001.6	1002.2	997.1	984.1	986.6	987.8	973.1

(*b*) Rome, 0700 G.M.T.

millibars

	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Highest	1040.3	1037.8	1032.6	1028.3	1027.0	1026.3	1026.2	1029.1	1030.5	1036.0	1036.5	1040.7	1040.7
Lowest	980.3	987.1	988.9	990.8	994.8	999.8	1001.7	1000.2	995.8	992.1	989.0	992.6	980.3

(*c*) Algiers/University, 0700 G.M.T.

millibars

	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Highest	1038.3	1037.1	1034.4	1029.2	1029.0	1025.1	1024.4	1024.3	1027.4	1030.6	1037.1	1035.4	1038.3
Lowest	995.3	992.4	993.3	996.3	995.7	1003.5	1003.3	1006.4	1004.2	998.0	998.1	996.6	992.4

(*d*) Athens, 1300 G.M.T.

millibars

	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Highest	1037.5	1033.0	1032.0	1025.5	1031.0	1022.7	1019.5	1022.6	1027.9	1028.0	1032.6	1037.0	1037.5
Lowest	991.0	988.0	990.5	996.3	998.6	1001.2	1002.7	1002.7	1002.3	998.3	994.5	997.1	988.0

(*e*) Cairo/Helwan, 1300 G.M.T.

millibars

	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Highest	1029.0	1028.8	1027.6	1023.8	1021.1	1017.6	1017.5	1015.9	1020.0	1023.0	1024.5	1031.0	1031.0
Lowest	1004.6	1000.0	998.5	997.9	1000.3	1004.3	1001.1	1003.8	1006.0	1007.1	1006.8	1007.4	997.9

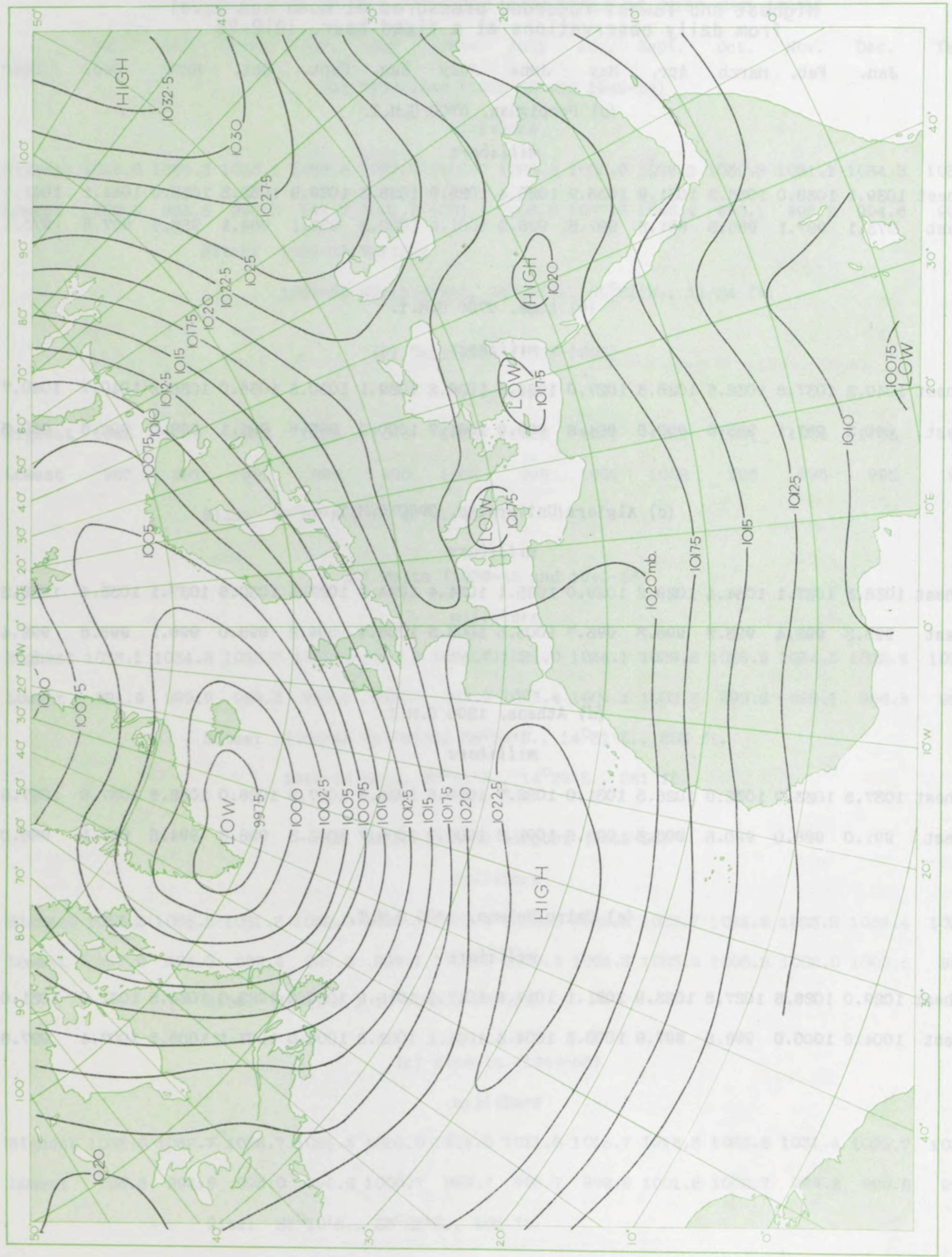


Fig.1.7 Normal sea-level pressure for January

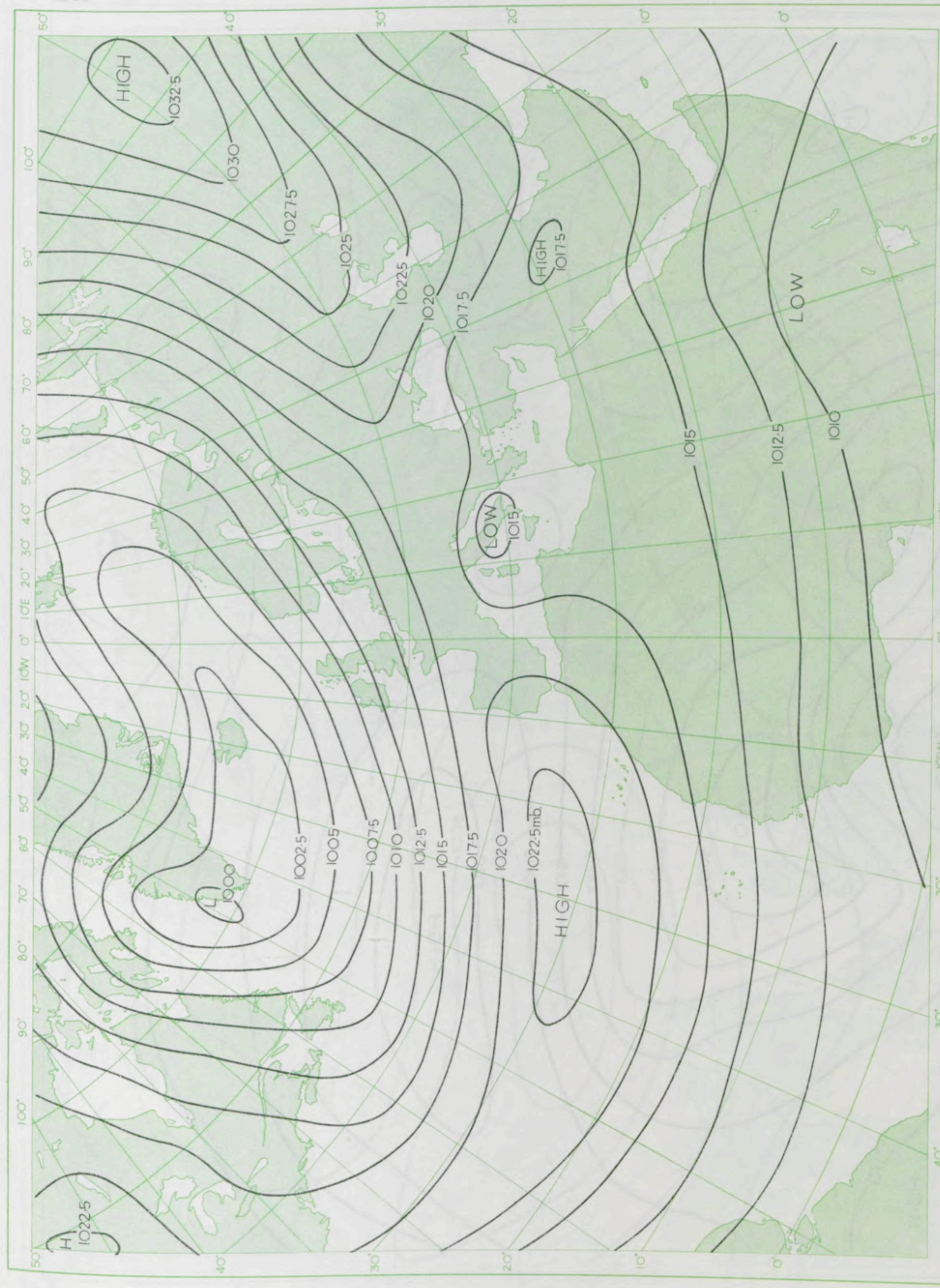


Fig.1.8 Normal sea-level pressure for February

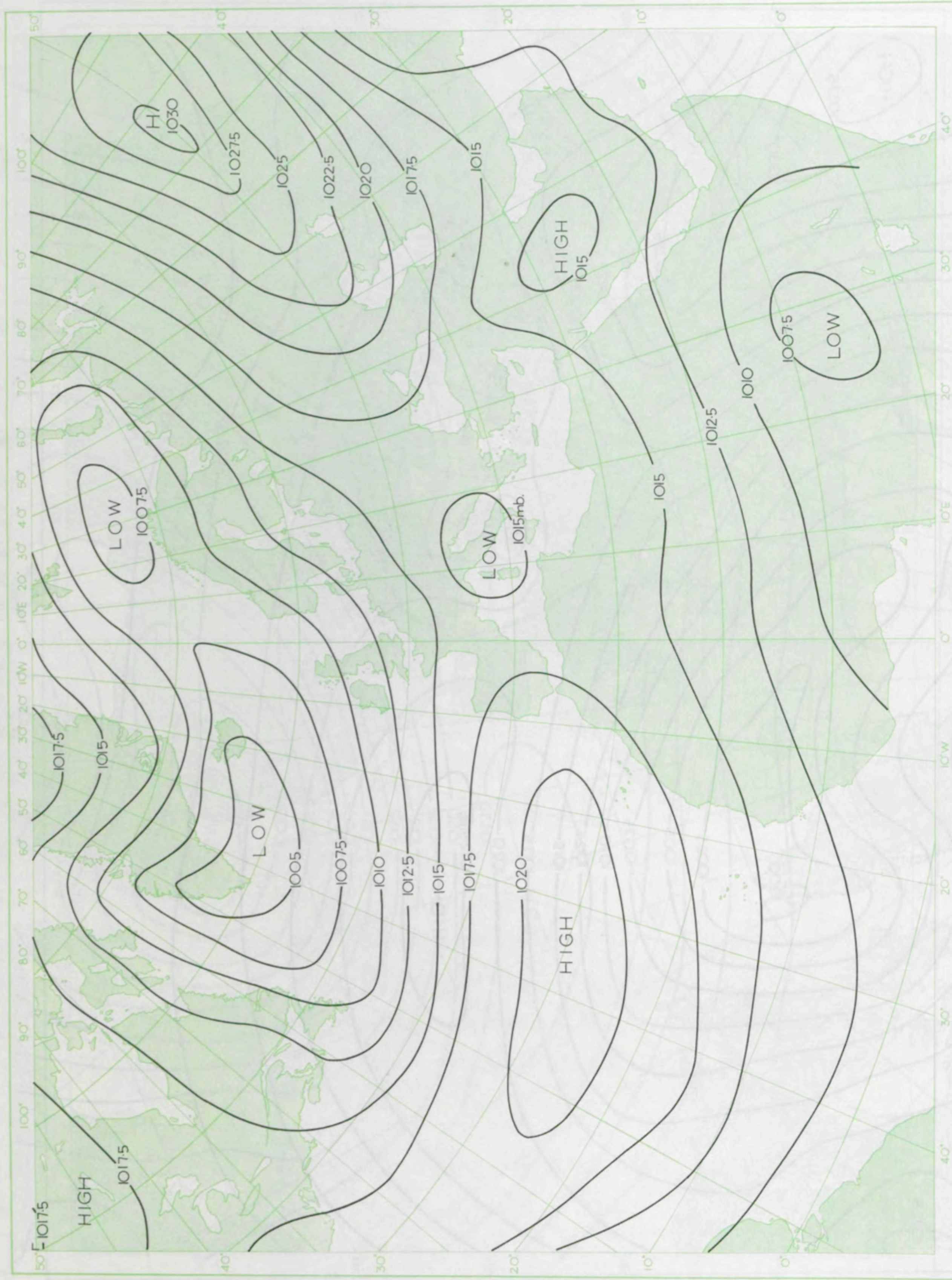


Fig.1.9 Normal sea-level pressure for March

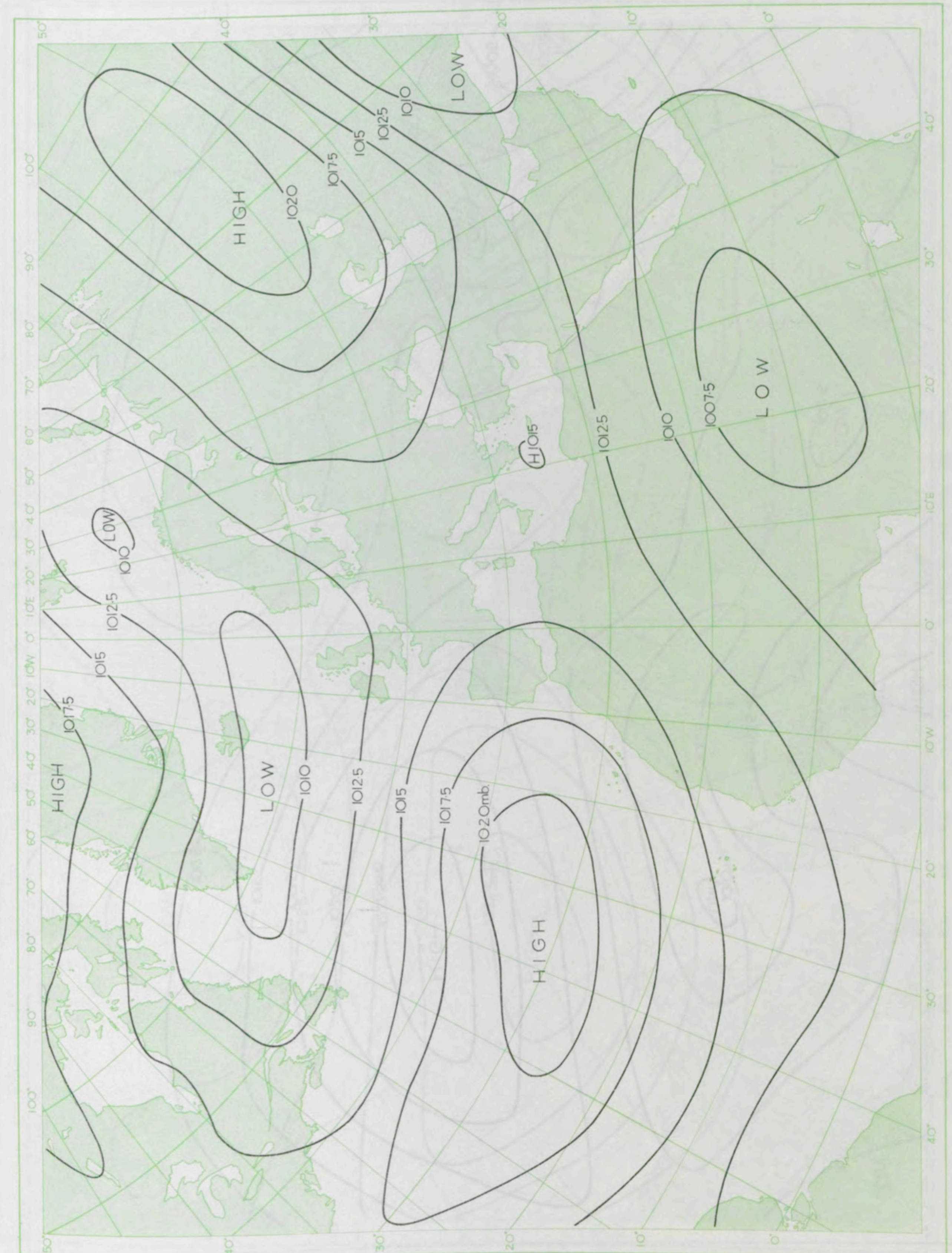


Fig.1.10 Normal sea-level pressure for April

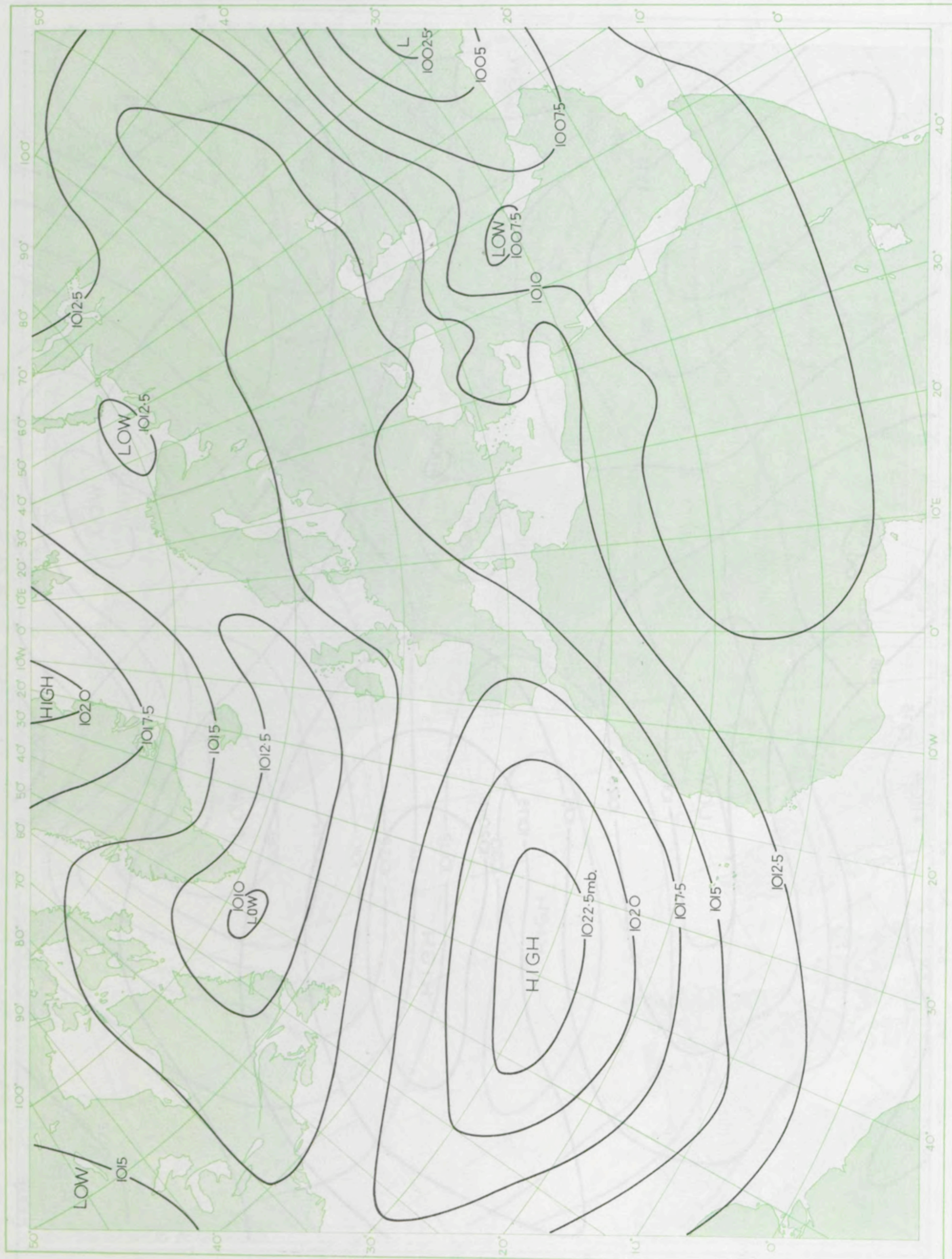


Fig.1.11 Normal sea-level pressure for May

Fig.1.12 Normal sea-level pressure for June

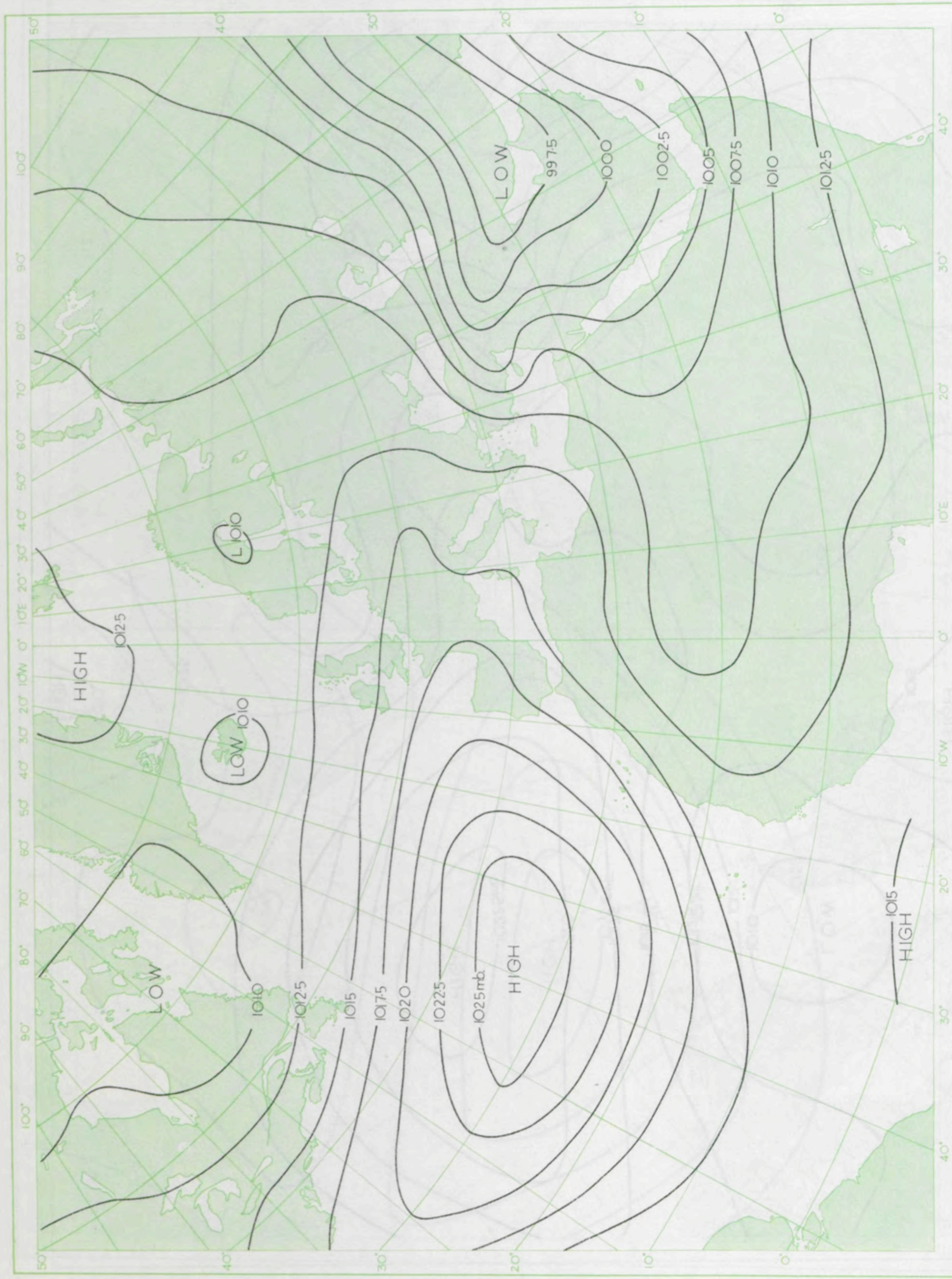


Fig.1.13 Normal sea-level pressure for July

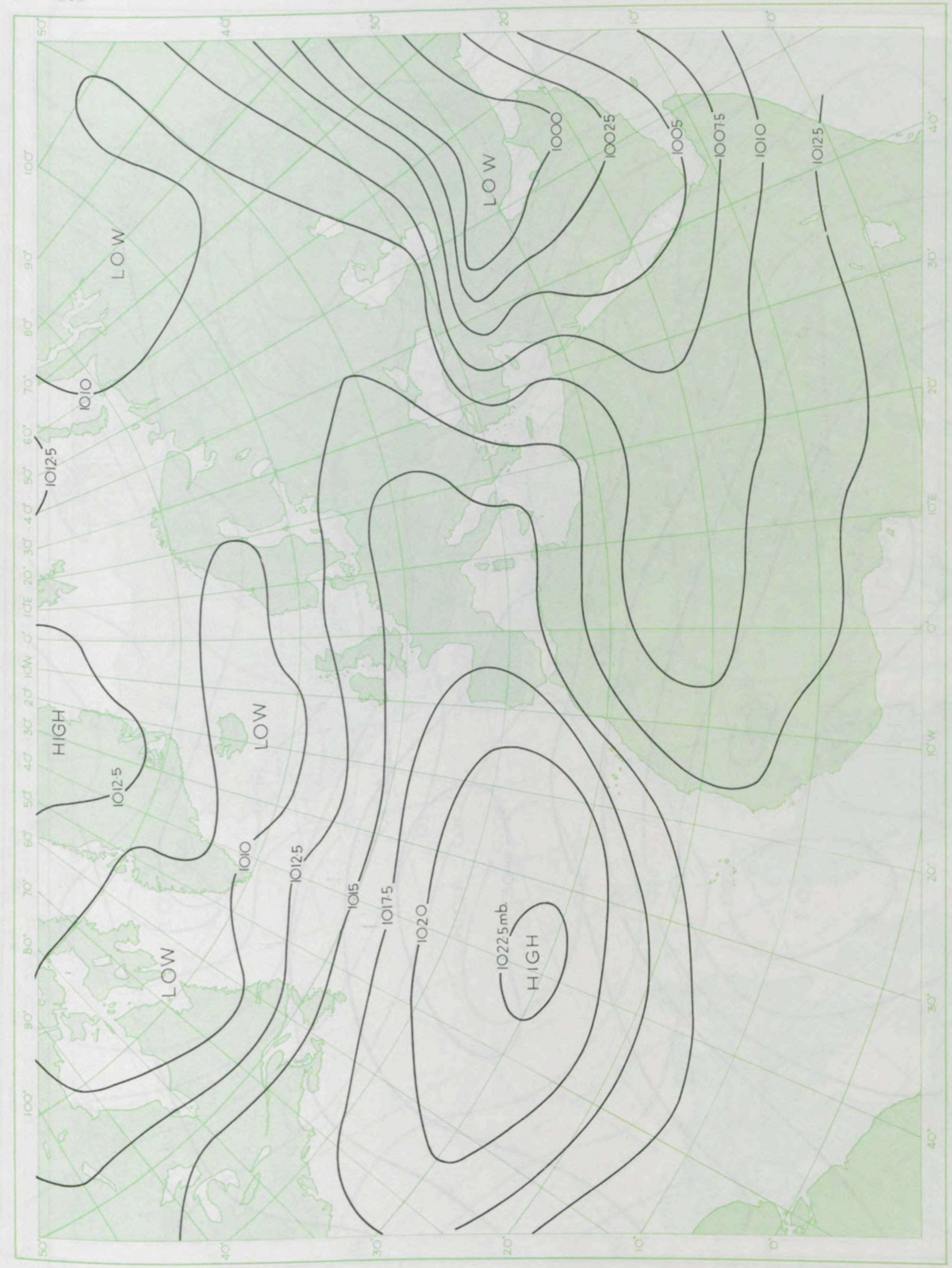


Fig.1.14 Normal sea-level pressure for August

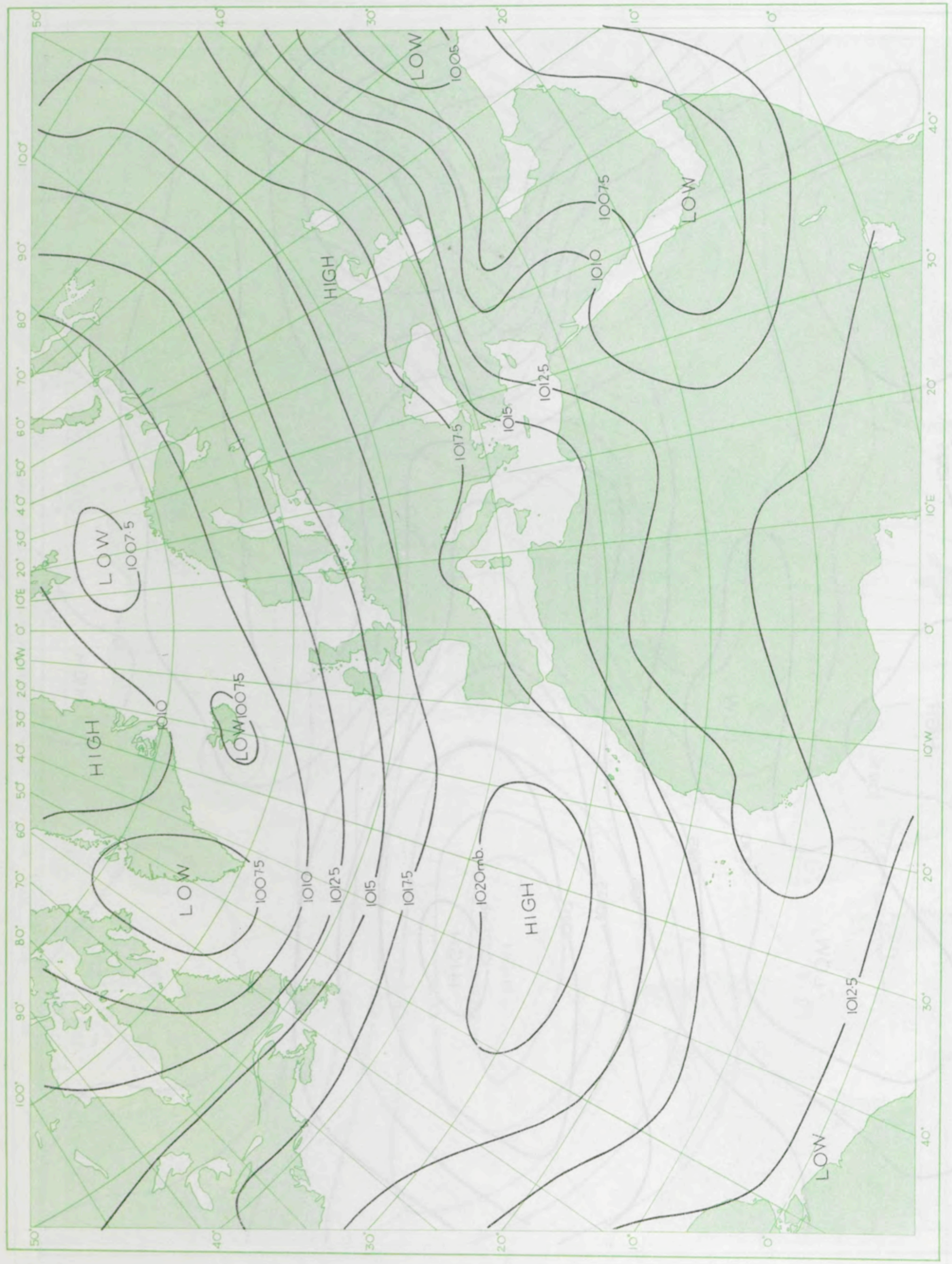


Fig.1.15 Normal sea-level pressure for September

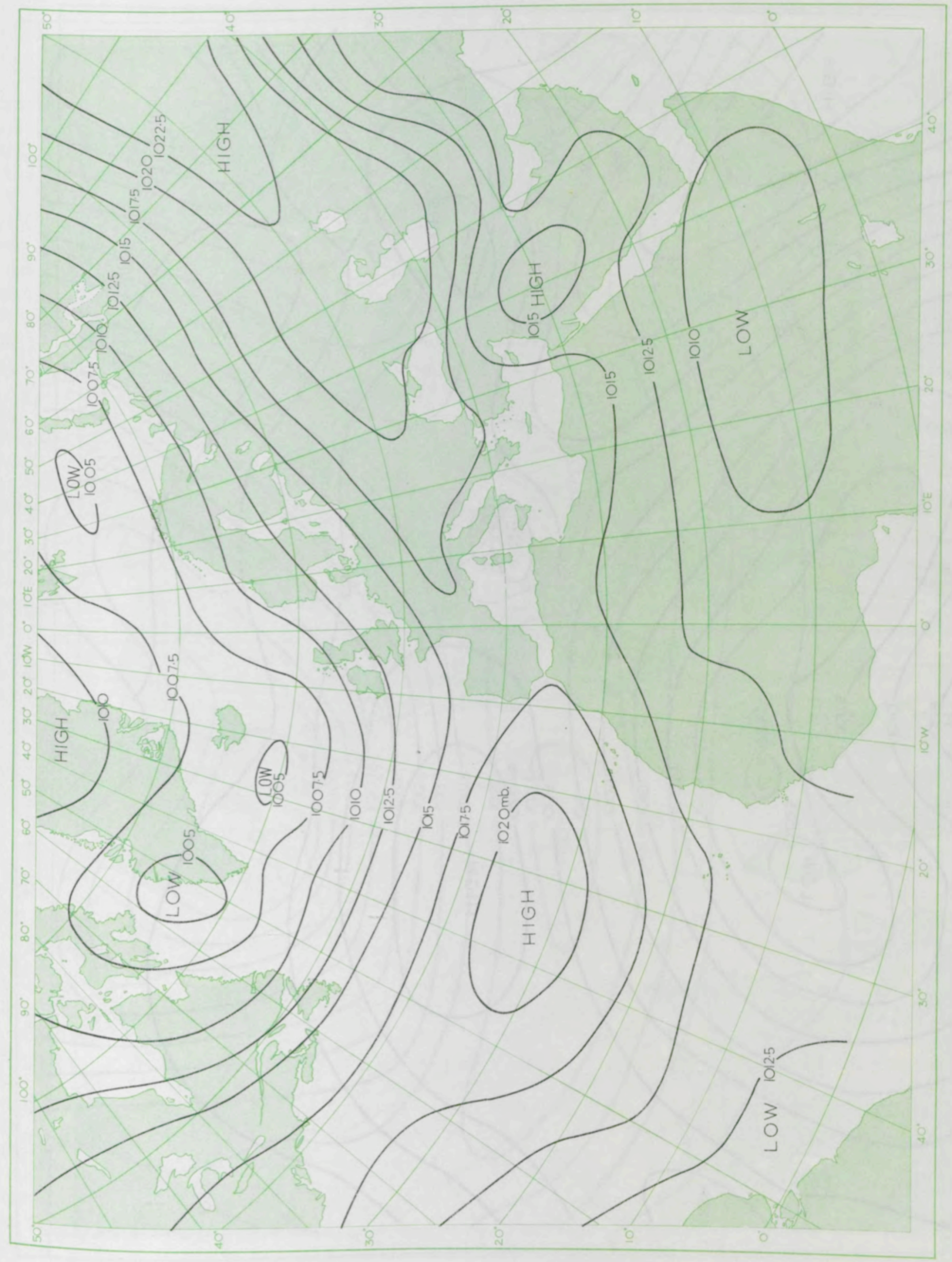


Fig. 1.16 Normal sea-level pressure for October

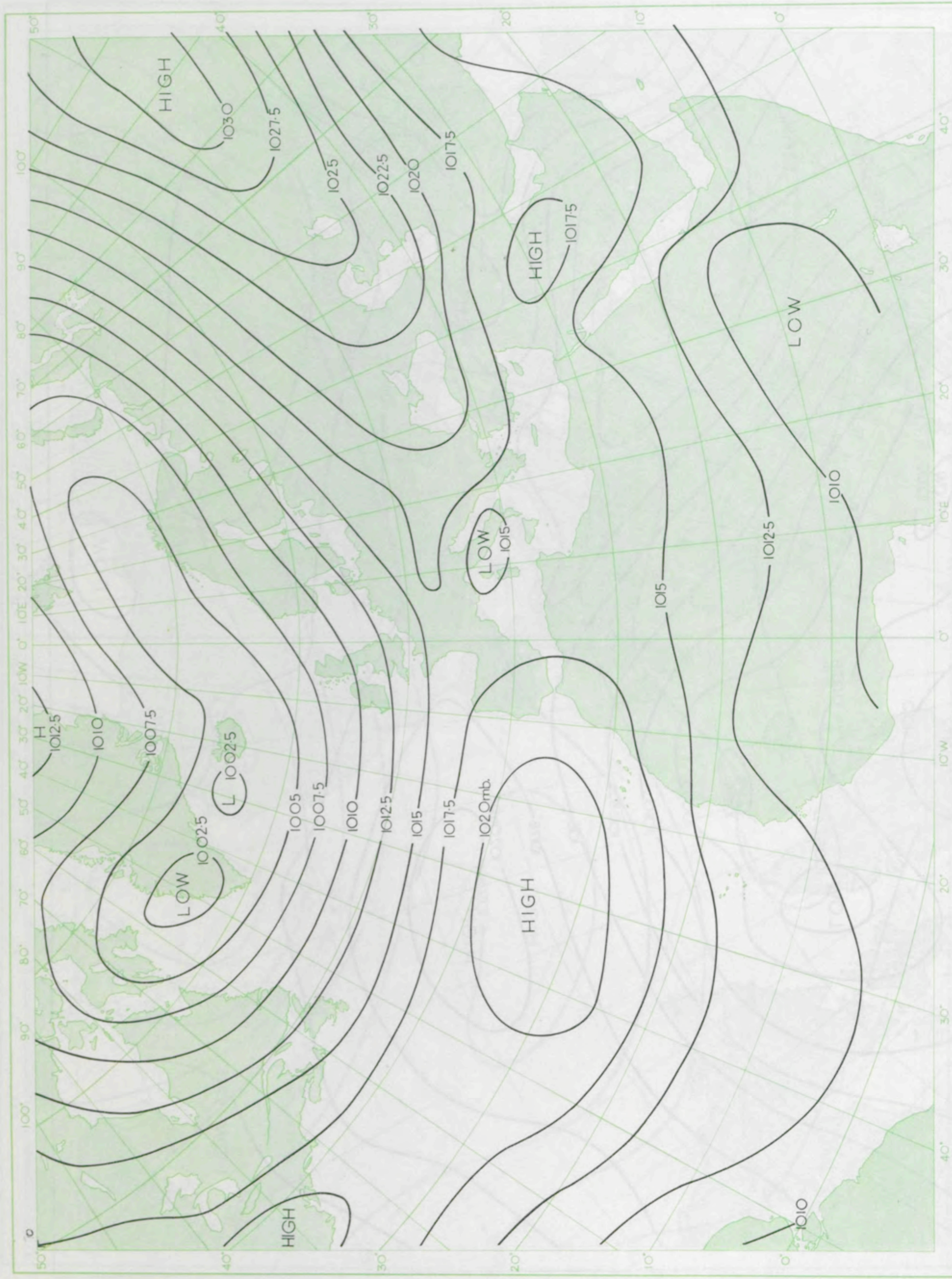


Fig.1.17 Normal sea-level pressure for November

Fig.1.18 Normal sea-level pressure for December

CHAPTER 6

SURFACE WINDS

The geostrophic and gradient wind relationships are only a little less reliable in the Mediterranean than in the latitude of the British Isles. The winds are, however, considerably disturbed by topography. Also sea-breezes are, in many places, effective up to much greater heights than are normally experienced in Great Britain. There is no general wind current dominating the whole region in any season as can be seen from the wind roses in Figures 1.19 *(a)* to *(d)* and the tables of Volume II which show the average frequencies of winds in direction and speed, or from the maps of the mean pressure distribution (Figures 1.7 to 1.18).

The winds in many places in the Mediterranean at levels from the surface up to about 850 millibars (say 5,000 feet) are controlled by purely local surface effects, such as the differential heating of land, sea and mountain or the constraints imposed by topography. As a result the surface winds bear less obvious relationship to the pressure gradient than in many other parts of the world and may be difficult to interpret save in the light of detailed local knowledge. The surface-pressure map itself is considerably influenced by differential heating of land and sea in the warm seasons. The 850-millibar level is about the lowest level at which the winds are fairly consistently related to the pressure gradients throughout the year, and charts for this level have sometimes been found useful in tracking and extrapolating the movement of fronts (see page 27).

REGIONAL WINDS

The mountainous nature of the lands to the north of the Mediterranean, the extensive desert areas to the south and the indented character of many parts of the coast, lead to the occurrence of a large number of regional and local winds having special characteristics. Regional winds are associated with the large-scale topographical features of the surrounding land, such as the main mountain gaps described in Chapter 1, while local winds are associated with minor features of orography and coastline. The more violent manifestations of these winds are often associated with atmospheric disturbances which are too small to be detected on ordinary synoptic charts. Most of the important regional winds have well known names and these are shown diagrammatically in Figure 1.20. They are described below in the following order:

Mistral; bora and winds of bora type including tramontana and grecale; gregale; etesians; levante; levanter; vendaval; libeccio; scirocco including leveche, marin, chili, ghibli and khamsin.

Mistral. This is the commonest name given to the stream of polar or arctic air which enters the western Mediterranean from the north and north-west, mainly through the Garonne-Carcassonne gap and the Rhône valley, but to some extent also over and through smaller gaps in the mountains between the Ebro valley in Spain and Genoa in northern Italy. The name takes a variety of forms in different localities, mistral being the standard French form used in the Riviera, others being mistraou, maistre, magistral (French); maestral (Spanish), mestral (Catalonian), maestro, maestrale (Italian). All these are derived from the Latin *magister* or *magistralis* and refer

to the wind's "masterful" nature. On the Franco-Spanish border it is known as tramontane and in Minorca as tramontana, while the names cers or cierce in the Aude valley and cierzo in the Ebro valley are derived from *cercius*, the old Latin name for this wind.

Over the French Mediterranean coast the wind is characteristically cold and dry, and the dryness is evident even if the air is of maritime origin (martime arctic or polar) having lost much of its moisture in crossing France. When it passes over mountains such as the Iberian plateau it is dried, and warmed adiabatically in its descent into the Mediterranean. In such cases it may be warmer than the air it replaces. In the lee of the Iberian plateau and hills of southern France it usually brings fair or fine weather as a result. Even on the less sheltered parts of the coast the skies are usually clear and rain, hail and snow are uncommon, except at the cold front associated with the onset of the wind and at secondary cold fronts which may follow. As the air stream passes over the Mediterranean Sea it is warmed from below (especially in autumn and winter) and picks up a new supply of moisture. This leads to increased instability with the development of cumulonimbus cloud and showers as described on pages 11-16 and 18.

Mistral occurs chiefly with weather types A and C (see pages 46 and 49). With type A, depressions almost invariably develop in the western Mediterranean as a result of the incursion of polar or arctic air and during the winter months development of these depressions generally causes an intensification of the mistral, often to gale force, especially in the Gulf of Lions. Owing to topography the strength and direction of mistral vary considerably along the coastline across which it blows and it often departs appreciably both in strength and direction from the geostrophic value. The funnelling effects of major and minor gaps cause local strengthening of the wind, the most important places on the coast being at the opening of the Ebro valley between Tortosa and Tarragona, in the region of Perpignan on the Franco-Spanish border, and at the mouth of the Rhône. The wind is liable to be strongest of all in the narrowest parts of the main valleys. The most sheltered parts of the coast are between San Felix and Vilanova in Catalonia and on the shores of the Gulf of Genoa.

During strong north-westerly winds in such places as the Baie de Ciotat (between Marseilles and Toulon), where the ground slopes up steeply towards the north-west, violent squalls are liable to sweep down the mountains. This effect is a general one on the lee side of such high land during strong winds.

There is often a marked diurnal variation of the mistral at coastal stations due to the tendency for a sea-breeze in the afternoon. This effect tends to counteract the ordinary day-time increase of wind due to convective mixing and often results in a slackening of the mistral at this time of day. Thus in summer the mistral reaches its diurnal maximum at about 10 a.m. and in winter at about noon local time.

The mistral tends to be strongest in a fairly narrow belt but in the upper air there is usually a wider belt of north-westerly winds. At 10,000 feet a belt of strong winds may sometimes be detected all the way from the Alps-Pyrenees gap to the Algerian or Libyan coast or as far as the next mountain barrier encountered.

When the mistral blows towards the Balearics it becomes north or north-north-east; it commonly reaches the Gulf of Genoa as a west or south-west wind. It may spread to Algeria and the central Mediterranean in the rear of depressions on track 3*c* (see page 39). Through the Strait of Bonifacio (between Sardinia and Corsica) and in the Sicilian channel the wind becomes west-north-west and blows more strongly as a result of funnelling.

In addition to the widespread mistral described above the name is also applied to a more local wind limited to a few miles on each side of the Rhône valley and to a few miles seawards. This wind is caused by katabatic flow down the valley. If widespread mistral is blowing it may be reinforced by local (katabatic) mistral to give winds locally of gale force. Local mistral reaches its maximum at Montélimar-Ancone where it may be violent at times. Dangerous eddies are said to occur in the lee of high ground, not chiefly in the defile, but where the wind accelerates on entering each of the local plains that form a chain along the river.

East of the coast of the French Riviera north to north-west winds are not commonly known as mistral. Local winds of similar type are, however, found in and around the Gulf of Genoa. Heavy gusts of wind may descend the ravines into the Gulf of Genoa and occasionally become violent. At Genoa these ravine winds are sometimes called maestrale.

Eastwards of the Gulf of Genoa in the Po valley, winds of the mistral type are known as bora and on the west coast of Italy as tramontana. These are described in the next section.

The name maestro is given to the strong north-westerly wind which blows down the Adriatic chiefly in summer in the rear of cold fronts. The name has spread from the western Mediterranean but the wind does not have the characteristics of mistral.

There is no generally agreed lower limit to the speed of a wind which may be described as mistral. The frequency of days with strong mistral (over 21 knots that is, Beaufort force 6 or more) is given in Table 9 which is based on four years, 1924-27, at the six stations, Perpignan, Sète, Montpellier, Nîmes, Montélimar and Marignane.

Table 9

Mean number of days with strong mistral

Speed	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
	Strong mistral at one or more of the six stations												
kt.	*Number of days*												
> 21	10	9	13	11	8	9	9	7	5	5	7	10	103
> 27	8	6	10	9	6	4	4	3	2	2	3	7	64
> 33	4	4	6	5	3	2	0.6	1	0.6	0	0	4	30
> 40	2	2	3	0.5	0.7	0.5	0.3	0.5	0.3	0	0	1	11
	Strong mistral at three or more of the six stations												
kt.	*Number of days*												
> 20	2	2	2	2	1	1	1	0	0.6	0	0	2	14

A spell of strong mistral may last for only a few hours, but on occasions for as many as 12 days without any important lulls. The most frequent length of a spell is about $3\frac{1}{2}$ days. Although gusts of 70 knots in strong mistral are experienced, the proportion of days when mistral reaches gale force on the coast is small. At Perpignan and Marseilles the number of days when mistral reaches gale force is of the order of 10 to 15 in a year. Further out to sea, however, the frequency increases rapidly and in the Gulf of Lions gales reach a mean annual percentage of 6.8, the majority of which is due to mistral (see Figure 1.25). Synoptic charts showing occasions of mistral may be seen in Figures 2.1, 2.2*(a)*, 2.5 *(a)* and *(b)*, 2.30 *(a)* and *(b)* and 2.31 *(a)* and *(b)* (winter); Figures 2.11 *(d)* to *(f)*, 2.35 *(a)* and 2.46 (spring); Figures 2.16 *(a)* and 2.17 *(c)* (summer) and 2.48 *(b)* and *(d)* (autumn).

Bora-type winds. The name bora is used basically for the strong flow of continental polar or arctic air which enters the Adriatic Sea mainly from the north-east

through the Trieste gap and also to some extent over the mountains of the eastern shores of the Adriatic where its characteristic direction is often east-north-east or east. The name is also applied to similar winds on the northern shore of the Black Sea. The word is derived from the Latin and Greek *boreas*, "the north wind". It has been borrowed by the Slavonic languages in which it has come to be used rather loosely for any mountain or ravine wind. In the Italian dialects around the shores of the Adriatic the diminutive form borino, "little bora", is sometimes used, but is again often applied rather loosely without reference to the wind direction.

Bora blows in the Adriatic and similar winds blow in the Aegean when there is a well developed anticyclone over central or northern Europe and relatively low pressure over the Mediterranean (weather types B or D, see pages 47 and 49). On such occasions cyclogenesis often occurs over the seas and the developing depressions tend to strengthen the bora. These winds also occur when depressions pass through the Adriatic or Aegean, even when anticyclonic development over Europe is only slight, the essential condition being that pressure should be higher on the European side of the mountains. The high pressure commonly develops an extension over the Balkan interior. The cyclonic type of bora occurs mainly with depressions on track 3c (see page 39) and gales are most frequent with this type.

The air of bora-type winds, being continental polar or arctic (see pages 13-15 and 20), is cold and dry and brings weather similar to that accompanying mistral. The cold front associated with the first onset brings rain or hail (and occasionally snow in winter) which may be heavy, especially if the air ahead of the cold front is warm and humid (for example, scirocco). While the wind is blowing there may be thick cloud banks over the mountain crest but the cloud dissolves in the air descending from the mountains, and the sky at some distance from the high ground is clear with at most a few cumulus clouds. However, in cases when a depression forms in the Adriatic or northern Aegean the passage of the cold front is succeeded by a characteristic layer of altostratus or altostratus and altocumulus through which the sun breaks from time to time. As the depression moves away, the medium cloud gradually clears. With a depression not far to the south, bora-like north-easterly winds may be accompanied by drizzle but if, as often happens, a warm front associated with a warm moist (scirocco) air mass lies a little to the south, heavy rain or snow may fall in the north-easterly stream.

Spells of bora may last for several days and during these periods secondary cold fronts may arrive, perhaps preceded by a relative lull. Each cold front is accompanied by a violent squall and followed by an increase in wind often to gale force. In such cases the cold front brings little cloud or precipitation and there is hardly any warning of its arrival beyond a small premonitory fall of the barometer. In the Adriatic the lack of warning of such squalls and the fact that the wind blows across the sea towards the western shore, which is devoid of shelter, make bora specially dangerous to sailing vessels.

Winds of bora type are strongest and most frequent in the cool season. They are intensified locally by descending flow on the lee side of mountains, by funnelling through mountain gaps and by ravine effects. Like mistral the air stream becomes increasingly unstable as it moves over the relatively warm sea picking up heat and moisture, and as a consequence heavy cumulonimbus and showers develop.

Bora in the Adriatic. In the Adriatic there is, as a rule, a falling off in the strength and frequency of bora with increased distance seawards from the eastern shore. Nevertheless, along the western shore from Venice to Ancona, bora is frequent. East-north-easterly bora at Trieste blows straight across the Gulf of Venice as a well marked belt of wind without change in direction or lateral spreading, and reaches Venice and Chioggia with only about 30 to 40 per cent decrease in velocity. The velocity falls off very sharply at the edges of this belt. On the coast south of Ancona the wind almost always backs to between north-west and north even in very heavy gales with a north to north-east wind blowing over the sea. At times the north-east wind may extend only a short distance seawards; at other times it blows strongly across the whole breadth of the Adriatic; and quite frequently north-easterly winds which are continuous with it may extend to great distances west of Italy across Corsica and Sardinia and south-west of Malta to the African coast.

The average duration of a bora gale is about 12 hours, but it may last for two days; the average duration of a spell of bora which at some time reaches gale force is about 40 hours, but it may be as long as five days.

At Trieste where the main mountain gap of the Adriatic opens, the hourly wind speed has averaged 70 knots with gusts exceeding 110 knots. The average number of days on which bora blows in Trieste is as follows:

Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
8	6	4	2	1	0.4	0.8	1	2	3	5	6	39

Its average duration is about three days in winter and about one in summer, but rare spells of up to 30 days without any important intermission have been known. Bora is especially prevalent along the eastern shore from Trieste to the Albanian border. In general it is more violent and more frequent on the northern part of the coast, and falls off southwards, but its intensity varies a good deal with locality, depending to a great extent on the configuration of the land. The existence of a coastal plain between the foot of the mountains and the sea considerably reduces its intensity at the coast. Southwards along the eastern shore its direction tends to draw round towards the east; but the same type of wind is experienced as far south as western Greece. South of about 43°N., however, scirocco is more frequent than bora. In summer, bora is generally weaker and less frequent. At this season much of the so-called bora or borino consists of local katabatic winds along the east coast and its direction may be quite varied, but even in summer these local winds can occasionally be quite severe.*

Bora being mainly an offshore wind has a diurnal variation at coastal stations similar to that of mistral - that is, it is often modified by a sea-breeze effect during the day which to some extent counteracts the normal increase of speed due to convectional mixing. The result is a maximum in the morning between 0700 and 1100 local time and another in the evening between 1800 and 2200, with a principal minimum at about midnight.

The greatest intensity of descending flow occurs where the peaks are 2,000 feet or more above sea level and not more than two or three miles from the coast, for example near the Velebit mountains with a peak of 4,760 feet (above Karlobag), Biokovo, 5,780 feet, (above Makarska) in the neighbourhood of Dubrovnik, and from the Gulf of Kotor (Boka Kotorska) to Ulcinj. In cols and ravines, where they correspond to wind direction, the wind may be very strong, for example at Trieste, Dubrovnik, in the Bay of Vrulje (near Makarska, opposite the island of Brač), at Šibenik, Kraljevica, and in the neighbourhood of Senj. Senj is bare of trees as also are the north-east coasts of the nearby islands of Krk, Rab and Pag. More sheltered places are the western coast of Istria, to leeward of the islands of Dugi (Grossa or Lunga), Kornat and Mljet and along the stretch from Cavtat to Oštri point.

When bora blows in the Adriatic it tends to emerge from the Strait of Otranto as a strong narrow stream directed towards north-west Cyrenaica. This narrow belt

* For example, a gust of 53 knots occurred at Trieste on 15 July 1952 at 2230 local time. The squall rose from a light wind in a quarter of an hour and died away to a light wind in the succeeding half hour.

of strong winds, like that associated with mistral, has been observed by aircraft up to 10,000 feet.

Examples of synoptic situations when bora may be expected in the Adriatic can be seen in Figures 2.5 *(a)* to *(d)*, 2.26, 2.27, 2.31 *(b)* and 2.50 *(a)* (winter); Figures 2.11 *(e)* and 2.40 *(a)* (spring); Figure 2.17 *(d)* (summer) and Figures 2.47 *(f)* and *(g)* (autumn).

Bora-type winds in the Aegean. What has been said in general terms of bora applies equally well to the strong north to north-east winds which enter the northern Aegean mainly in winter especially via the Dardanelles gap and the Vardar gap above Salonika in Macedonia. When the pressure distribution favours a north-easterly wind the main entrance is via the Dardanelles gap. In this case a broad north-easterly flow on the Turkish shore of the Aegean does not usually extend further south than the Gulf of Smyrna (Izmir Körfezi). There is strong funnelling of the air stream through the Doro Channel (between the islands of Euboea and Andros) and also through the channel between Crete and the Peloponnesus. The wind becomes northerly in the central Aegean and north-west in the south-east Aegean. When the north-easterly stream is relatively shallow (5,000 feet or less) the Gulf of Thermai, the western thoroughfare of Euboea, the greater part of the Gulf of Corinth and the Gulf of Patrai may remain with weak winds even when strong north-easterly winds are blowing in the open sea. At levels of 1,000 to 2,000 feet on the western side of Euboea the Strait of Trikeri may even have a wind between south and south-west. With a deep north-easterly stream, however, there are strong descending currents at the steep cliffs of the Turkish and Dodecanese coasts, and there may be descending currents on the leeward slopes of the high ground in the Cyclades, Euboea, the Gulf of Thermai and Crete. Particularly violent squalls are experienced off Cape Tainaron (Matapan). In Crete a remarkable ravine type wind occurs at Timbakion which lies on the south side of the island at the foot of Mount Ida (Idhi oros, 8,060 feet). With northerly winds the speed at Timbakion may be two to two and a half times as great as on the north side of the island.

When the pressure distribution favours a northerly flow the main entry is via the Vardar valley. These winds are locally called Vardarac. They flow into the Gulf of Thermai and spread south-eastwards across the Aegean to the Dodecanese islands. Dangerous descending currents occur on the lee side of high ground, especially on the south of Mount Athos, the Pelion peninsula, the east and south side of Euboea, all the islands of the Cyclades with high mountains especially those north of Melos (Mílos), the Gulfs of Patrai and Corinth, and on the western half of the south coast of Crete.

Examples of synoptic situations when bora-type winds may be expected in the Aegean can be seen in Figures 2.7, 2.27, 2.41 *(a)* and 2.54 *(a)* (winter); 2.40 *(a)* and 2.45 *(a)* (spring) and 2.39 *(b)* and *(c)* (autumn).

Bora-type winds in the Tyrrhenian Sea. When strong bora blows in the Adriatic the winds may extend across Italy and the Tyrrhenian Sea as far as Corsica and Sardinia. If they are mainly northerly in direction they are called tramontana, if north-easterly greco or grecale. In the lee of the Apennines and over the Tyrrhenian Sea the air is again dry and often associated with clear weather and cloudless skies. In winter those winds which pass over the Calabrian mountains when they are covered with snow may be violent at times.

Gregale. This is the name given to strong north-easterly winds in the central Mediterranean, including the Ionian Sea and the vicinity of Malta. They occur chiefly during the cool season. These winds can arise in a number of different situations. The commonest situation is similar to that which produces bora, namely high pressure over central Europe and the Balkans with relatively low pressure over the south central Mediterranean. In such cases the wind blows across the mountains of Albania and Greece and the associated weather is similar to that accompanying bora; in fact the winds may be blowing at the same time as bora is blowing in the Adriatic. However, owing to the longer sea track the wind is less cold and dry than bora, except off the west coasts of Albania and Greece. Strong north-easterly winds also occur when depressions pass eastwards along tracks *2b* or *3d* or when a depression develops in the south central Mediterranean. On such occasions there is likely to be much low cloud and poor visibility sometimes with heavy rain. In Malta the name gregale is given to any north-easterly wind above force 4. They are troublesome because the principal harbours are exposed towards the north-east and the wind is liable to blow strongly for two or three days. In the neighbourhood of Malta strong gregale may raise waves of about 20 feet from trough to crest, and on occasions a heavy swell continues for one or two days after the wind has dropped. Table 10 is based on data for 19 years at Malta. The minimum number of spells of gregale in every month was zero. Individual spells may last for periods ranging from a few hours to five days, one or two days being the commonest length of a spell.

Table 10

Gregale at Malta

	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Maximum no. of spells	4	3	2	2	1	1	0	1	1	2	3	3	...
Average no. of spells	1.6	1.1	0.7	0.7	0.2	0.2	0	0.2	0.2	0.5	0.8	0.9	7.1
Average no. of days													
with wind 35-43 knots	0.4	0.9	0.3	0.1	0	0	0	0	0.1	0	0	0.5	2.3
43-50 knots	0.1	0.3	0	0	0	0	0	0	0	0	0	0	0.4

Etesians. During the summer the prevailing winds over the Aegean are associated with the continental depression centred at this time of year over south-west Asia and having an extension over Asia Minor (see Figures 1.12 to 1.14). They are mainly north-easterly in the northern Aegean, northerly in the central and southern Aegean and tend to become north-westerly in the south-east near Rhodes and the coast of Turkey (see Figure 1.5 *(b)*). Since depressions are rare in the Mediterranean at this season the winds are very persistent and in some places have almost the character of trade winds. They extend at times, but with less regularity, to the southern Adriatic and the Ionian Sea. These winds are known as etesians, from the Greek *etēsios*, "annual", or sometimes as meltemi (Turkish). Each year, in late May or early June, there is as a rule an introductory spell of light northerly winds which are called the prodroms (fore-runners). Then, after a break of a week or two, the regular seasonal winds set in. Over the open sea they blow very steadily and as a rule with moderate force, alleviating greatly (at places exposed to them) the trying heat of the midsummer months. Consisting of continental polar air with some admixture of continental tropical, from the region of southern Russia and the Caspian Sea, they are dry and moving over a relatively cool sea they bring good visibility and almost uninterruptedly clear skies (see page 20). Only after travelling some distance over the sea do they begin to develop cumulus cloud.

The maintenance of the etesians depends on the existence of relatively high pressure over southern Europe or the Mediterranean. Thus they are likely to be weakened, or fail temporarily, when a depression moves across the Balkans or Greece. But the rapid building up of high pressure in the rear of such depressions often leads later to an intensification of the etesians, especially when this occurs as a result of the southward movement of an anticyclone from northern Europe (type B becoming type D). Such intensification coincides with the passage of a cold front bringing a fresh and more direct supply of continental polar air (or occasionally

continental arctic) (see page 18 and Figure 2.13). Strong etesians may then extend their influence over the whole sea area between 20°E. and 30°E. and to the coast of North Africa. On such occasions they occasionally reach gale force at the height of summer and have many of the characteristics of the strong bora-type winds of winter. When the etesians are strong they are liable to raise the dust in certain regions, for example round Athens and Salonika, and dust haze may result over a wide area.

The etesians reach their greatest persistence in the southern part of the Aegean, for example at Samos, Melos and Rhodes where the seasonal frequency may reach 80 per cent from the middle of July to August. At Samos the prevailing direction is north-westerly and at Rhodes it tends towards west. At coastal stations of the mainland of Greece the persistence of the etesians is greatly reduced by the effects of convection, both through the diurnal variation in surface wind strength and through the development of land- and sea-breezes. The sea-breeze at Athens is south-south-westerly and when the etesians are weak the sea-breeze may gain the ascendency in the afternoon while over the open sea the etesians prevail (see further page 94). In July and August the etesians at Athens often blow for one or two weeks at a time reaching a speed of 10 to 20 knots in the afternoon and falling to a near calm at night. The average numbers of days per month of uninterrupted etesians at Athens from May to October are 5, 5, 12, 13, 11 and 6 respectively. On the west coast of Asia Minor, for example at Izmir, the wind régime consists mainly of westerly and easterly sea- and land-breezes, the etesians being of little importance.

The etesians may be greatly increased in strength by channelling; this is especially the case in the Doro Channel (between the islands of Euboea and Andros), in the channel between the mainland of Turkey and the Dodecanese islands, and the area between Paros and Naxos as far south as Thira. In the last-named area they may blow with gale force for 10 to 15 hours.

Levante. This is the name given to the winds of long fetch (as opposed to purely coastal breezes), blowing from between north-north-east and east-north-east across the western Mediterranean towards the east coast of Spain. It is a Spanish word and the form llevantades is used for strong to gale winds of the same kind. Four types of levante may be distinguished.

Mild levante. This is typical of summer but also occurs during spells of relatively fine weather in the winter. It is generally associated with an extension of the Azores anticyclone over Spain (in winter) or southern France. A spell is initiated by the arrival of the trailing end of a cold front lying from west-south-west to east-north-east across the western Mediterranean. The north-easterly air stream is relatively shallow and often does not exceed 3,000 feet in depth, the winds above being light south-east or south-west. The cold front is typically accompanied by a bank of cumulonimbus cloud, a squall as the wind changes from south-south-west to north-east and a short period of rain. The frontal cumulonimbus cloud does not normally extend far over the Spanish coast. In the north-easterly stream behind the front the air is clear but gives haze along the coast and mist or cloud on the coastal hills.

Pre-frontal levante. This type often precedes the arrival of a cold front from the Atlantic in the cool season, and occurs with weather types A or C. The north-easterly winds develop as a result of the formation of a lee depression or trough in the region of the Balearics while the Atlantic cold front in crossing the Iberian peninsula. The lee depression may be quite small and weak and only appear on the synoptic chart as a bulge in the isobars round the Balearics. But the associated north-easterly winds and swell may get up quite rapidly, accompanied by low cloud, probably heavy rain and falling temperature. They are only shallow winds extending to about 3,000 feet with south or south-westerly winds above. These conditions are terminated by the arrival of the Atlantic cold front bringing a north-westerly wind preceded by a short intervening calm. Similar developments sometimes occur when a depression crosses the Iberian peninsula. This type of levante does not always reach the Catalonian coast and is always short-lived. It is difficult to forecast because the lee depression does not always develop. If it fails to do so, strong south-westerly vendaval is liable to blow ahead of the cold front instead (see page 81).

Widespread levante. This type is associated with weather types B and D when pressure is high over western Europe and relatively low over the western Mediterranean. The north-easterly wind stream may then be extensive. This levante consists of continental polar or arctic air and may be continuous with bora and tramontana or gregale of the Adriatic and Tyrrhenian seas. In winter the air develops instability as a result of its track over relatively warm sea (see pages 13 - 16); cloud may be heavy and considerable rain may fall on the east coast of Spain. Between November and March it may bring snow to the Catalonian mountains.

Depression levante. This type is associated with a depression south of the Balearics. It may occur when a depression enters the Mediterranean through the Strait of Gibraltar, but more frequently when a depression develops in the area south of the Balearics as a result of an incursion of maritime arctic, maritime polar, continental arctic or continental polar air in winter. It may therefore follow levante of pre-frontal or widespread type. Strong to gale north-easterly winds may occur in these conditions, with continuous heavy rain especially along the Spanish coast lasting as long as the depression remains in the area. Most levante gales are of this type and occur when pressure is high over western Europe. Such gales are commonest in spring and autumn.

Examples of synoptic situations where levante may be expected can be seen as follows: Figure 2.54 *(a)*, a winter example of mild type; Figure 2.26, a winter example of widespread and depression types combined; and Figures 2.35 *(a)* and 2.38 spring examples of depression type. Figure 2.9 *(a)* shows a case when rather weak pre-frontal levante might be expected.

Levanter. In the Strait of Gibraltar and the Alboran Channel between Spain and Morocco, owing to the configuration of the land, winds are mainly from east or west. The easterly wind of the Strait and of the Alboran Channel is known as levanter, being a corruption of the Spanish name levante. These easterly winds blow in the same conditions that produce the levante of mild, widespread and depression types in the western Mediterranean and may be continuous with it. But owing to the channelling effect a much wider variety of pressure distributions is associated with easterly winds in the Strait and Alboran Channel. For example a depression to the south-west of Gibraltar or one to the south over Morocco gives levanter but not necessarily levante. Levanters also occur with weather type E. The shape of the channel causes these winds to be stronger at Gibraltar than in the Alboran Channel, being strongest in the neighbourhood of Tarifa where the Strait is narrowest.

In winter heavy frontal rain may occur with the onset of levanter, and showers are probable in the continental arctic or polar air stream while the wind is blowing. Strong levanter may blow without ceasing for ten days or longer. Weather tends to be worse at the east end of the Strait and the cloud cover, which may be complete at the east end, decreases westwards on the whole.

In summer, levanter generally occurs as a flow of warm subsided air between the Azores anticyclone and the low pressure over North Africa. This air gives frequent fog and low stratus in the Strait. At the east end it always gives heavy dew, frequently mist and sometimes drizzle. These conditions are terminated when a depression passes across the British Isles or France and its cold front begins to cross the Iberian peninsula. Westerlies replace easterlies on the Strait while the front is still some distance to the north, so that even if the front never progresses as far south as Gibraltar the easterlies are interrupted for a while.

Strong levanter is of special importance at Gibraltar on account of the complex and dangerous eddies to which it gives rise in the Bay. Violent eddies are formed in the lee of the Rock; down-currents are stronger and considerably more frequent than up-currents. Except when the levanter is very dry a characteristic banner cloud known as "levanter cloud" forms at the Rock and extends westward for a mile or more. This occurs mainly in winter and spring and with levanters of about force 3 or 4. When the wind is force 7 or more the cloud lifts and disappears (see page 87).

An example of summer levanter giving fog at Gibraltar can be seen in Figure 2.55 *(a)* for 12 August 1954. Figure 2.55 *(b)* shows the wind having changed to a westerly direction a short distance ahead of a cold front. By 16 August the cold front had moved to the central Mediterranean and the wind at Gibraltar had returned to an easterly direction.

Other examples of synoptic situations giving levanter may be seen in Figures 2.5 *(d)*, 2.26, 2.43 *(a)* and 2.54 *(a)* (winter); Figures 2.11 *(e)*, 2.35 *(a)*, 2.37 *(a)* and *(b)*, 2.38 and 2.40 *(a)* and *(b)* (spring); Figure 2.24 *(c)* (summer) and Figures 2.22 *(a)*, 2.39 *(a)* and *(b)* and 2.47 *(f)* (autumn).

Vendaval. This is the name given to the strong west to south-west wind of the western Mediterranean between Spain and the Balearics and of the Gibraltar-Alboran Channel. The wind occurs chiefly with weather type C when there is a deep depression over the British Isles or when a depression enters the Mediterranean across Spain (track 1a). Thus vendaval occurs mainly in the cool season. It is most frequent in October to November and February to March. It reaches its maximum force a little ahead of the cold front, provided that a lee depression does not form in the Balearics region in which case pre-frontal levante from the north-east may develop instead (see pages 79 and 80).

The air mass forming vendaval may be transitional maritime polar in which case it is very humid and convectively unstable (see page 12). Heavy rain, low cloud and poor visibility then occur especially over the Iberian plateau in the Strait of Gibraltar and in the northern part of the western Mediterranean. In midwinter violent squalls and thunderstorms may also be experienced, sometimes with a temporary veer of the wind to north-west. In between squalls the sky may clear for a while. In other cases the air mass is maritime tropical which is more stable and the associated weather is less severe (see page 15). With a passage of the cold front the wind usually moderates but may subsequently freshen from west or north-west. At times there may be only a slight and gradual veer of the wind with the passage of the cold front.

Vendaval tends to blow stronger in the Strait than in the Alboran Channel owing to funnelling, but if the wind is basically south-westerly it may be reduced near the shelter of the North African coast. When snow lies on the mountains of southern Spain, as often happens in February, the south-westerly winds commonly fail to reach the south coast of Spain but fall off and become west or north-west some distance from the coast.

Although vendavales are less frequent off the north-east coast of Spain, this part of the coast is more exposed to them than further south and damage may be caused at ports such as Barcelona.

Examples of synoptic situations when vendavales may be expected can be seen in Figures 2.4 *(a)*, 2.6 *(a)*, and 2.8 *(a)* which are all February cases.

Libeccio. Libeccio is an Italian word used for winds between west and south-west in the maritime areas surrounding Italy from the west coasts of Corsica and Sardinia to the Adriatic Sea, including the Ligurian and Tyrrhenian Seas. South-westerly winds are common in the part of this region to the west of Italy at all times of the year. They blow strongly, especially in winter, when depressions form in, or pass through, the Gulf of Genoa, and with depressions on track 3c. With weather type C libeccio may develop over the whole of the Tyrrhenian Sea, except those parts sheltered by the mountains of Corsica and Sardinia. The strongest winds are then experienced in the Strait of Bonifacio and to the east of it. Strong libeccio raises wild seas at times along the west coast of Corsica from Cape Gargalo to Cape Corse and may give violent westerly squalls (known as raggiature) at Bastia and down the lee-side valleys of the north Corsican promontory, even when the wind is only moderate along the west coast. In summer it is most persistent and lee squalls are very hot and scorching as a result of adiabatic descent. Strong libeccio similarly brings rough seas to the west coast of northern Italy, especially from Rapallo to Leghorn (Livorno). As in Corsica it is accompanied by heavy squalls on the lee side of promontories such as those protecting the harbours of Rapallo and Spezia. This wind usually stops short of the head of the Gulf of Genoa, especially if there is snow on the mountains.

In the Adriatic libeccio is neither frequent nor persistent, but strong south-westerlies occur with depressions in the Adriatic, especially in winter. They are felt mainly on the eastern shore and are specially dangerous on the coast of Istria where poor visibility is liable to hamper observation of the land. In a number of localities strong south-west winds are characterized by violent squalls. Off the mouth of the River Po the south-west winds are liable to sudden shifts towards south-east accompanied by strong squalls (known as furiani) and heavy sea. Violent squalls also occur in the lee of the steep high land during strong south-west winds, notably on the lee-side of Monte Conera and Monte Gargano.

Synoptic situations in which libeccio may be expected can be seen in Figures 2.3 *(a)*, 2.4 *(a)*, 2.30 *(a)*, 2.31 *(b)* and 2.53 *(a)* (winter); Figure 2.36 *(a)* (spring); Figures 2.14, 2.16 *(a)* and 2.56 *(a)* (summer) and Figures 2.34 *(a)* and 2.48 *(b)* and (d) (autumn).

Scirocco. Scirocco, an Italian word, is the name used fundamentally for winds of continental tropical origin when blowing over the Mediterranean Sea and its coasts. Their sources are the desert areas of North Africa and Arabia and their general characteristics have been described on pages 16 and 23. The wind is known by special local names in North Africa, for example chili in Morocco, Algeria and Tunisia, ghibli in Libya and khamsin in Egypt, while in south-east Spain it is called leveche and in the Gulf of Lions marin. The more violent duststorms associated with it in Arabic lands are called simoom or simoon.

It is common to speak of "dry scirocco" and "moist scirocco" but in fact all stages of humidity are found in these continental tropical air masses, depending on the amount of modification the air has received over the sea. The air is at its driest and hottest just before crossing the coast, for instance in Tripolitania where clear skies, very high temperatures and rising dust are characteristic. As it passes over the sea it rapidly picks up moisture and is cooled somewhat in its lower layers, specially in winter and spring. One can best describe the variety of types of scirocco by considering a place like Malta. There continental tropical air from the south-east has a longer sea-track than that from the south or south-west and is therefore likely to be more humid. However, the speed of the wind also has an effect on the humidity. With strong winds, in spite of rapid evaporation, the humidity is likely to be lower both as a result of the shorter time that the air has spent over the sea and because of greater turbulence and mixing causing the water vapour to be carried to higher levels. Thus the most humid scirocco at Malta occurs with light south-east winds, when such heavy dews are experienced that the gutters run with water and low stratus and sea fog are common accompaniments especially in spring and early summer. On the other hand the driest scirocco occurs with a strong south-west wind blowing from Tunisia, when the air may be so excessively dry and dusty as to be injurious to vegetation. Such dry winds are, however, uncommon in Malta, occurring only two or three times in ten years. Both extremes are unpleasant but intermediate stages occur which are less oppressive. What has been said of Malta applies in varying degrees to other parts of the Mediterranean away from the African coast. While the dry scirocco is predominant in the south the proportion of the moister varieties increases towards the north, where low stratus and other manifestations of high humidity are characteristic, especially near windward coasts and slopes.

Outside North Africa itself the scirocco is almost always associated with depressions and blows on their eastern side as they pass through the Mediterranean forming their warm sectors. The extent of the southerly wind stream depends on the track, depth and speed of movement of the depression. Thus with a shallow depression passing near the African coast the scirocco does not penetrate very far north, while with a deep depression moving through the northern parts of the Mediterranean large areas are affected by scirocco. When a quasi-stationary situation arises, as with weather type A_1, scirocco may travel great distances into Europe. The commonest position for the trough with weather type A_1 is in the central Mediterranean and in such situations the southerly air stream out of Libya may be maintained for several days (see pages 16, 23 and Figures 2.22*(a)* and *(b)*, pages 43 and 44, and page 47 and Figure 2.42). Scirocco is specially associated with Saharan depressions (see page 40).

North coast of Africa. Along the North African coast from Gibraltar to Tunisia, scirocco (chili) blows on an average four to five days per month, being slightly more frequent in late spring and early summer. The direction varies between south-east and south-west off the coast, and it is usually light or moderate coming in puffs or gusts, but winds up to gale force occur occasionally. In the cool season it is pleasantly warm but in summer it is very hot; temperature rises rapidly to over 100°F. with the onset of the wind and relative humidity falls to under 20 per cent. The dust may obscure the sun with a yellow or leaden hued veil, but if the wind is, or has been, strong it may bring dense clouds of dust, reducing visibility at times to a few yards.

In Libya scirocco is known as ghibli and generally blows from a direction between south-east and south-west, though in the Tripoli area it blows, not uncommonly, from the east. Some winds between south-east and south-west, however, especially in winter, are not characteristically warm and dry and the name ghibli is not applied to them. The ghibli is most often due to depressions moving eastwards through or just north of Libya (tracks *2c* or *2d*). The ghibli also occurs ahead of a trough extending northwards from a depression centred far to the south of the Sahara. Such troughs usually move slowly eastwards across Tripolitania. Prolonged ghibli conditions also occur in the quasi-stationary situation (weather type A_1) mentioned above. The dustiness varies at different times, and from place to place. Sometimes the wind is the continuation of inland simooms (violent duststorms); on these occasions the atmosphere is very oppressive, while the air is full of fine dust which penetrates everywhere, obscures the sun with a leaden pall and may reduce the visibility sufficiently to prevent ships from entering the port of Tripoli. At other times the wind is light or moderate and there is only the usual summer haze. Dusty ghibli is much more common in Tripoli and Benghazi than north of the hills of Cyrenaica where cultivation is relatively widespread; but it is stated that, in Cyrenaica also, travel through ghibli is often very unpleasant owing to the grit carried by the wind. Off the coast of Cyrenaica a considerable sea runs while the wind lasts, dying down quickly when the wind drops.

During the winter the winds on the shores of Libya are not on the average drawn from far inland, while in summer the mean winds tend to flow inland from the sea. It is in the spring, when Saharan depressions most frequently pass through or near the region, that southerly winds of long fetch from the interior of North Africa are commonest. Consequently spring is the season when ghibli may be expected to occur with greatest frequency. In 1925 there were ten days in April on which ghibli occurred or five days if light ghibli is excluded. From March to October the other months had about five days (one day of light ghibli is excluded) while there were fewer days in the winter months.

The duration of ghibli may be anything from a few hours to five days, and it is popularly believed that severe ghibli, from the first stage of light winds to the end, ordinarily lasts three days; the figure would probably be reduced by formal statistics.

In Egypt the hot, dry, dusty winds are known as khamsin. They always blow from a direction between south-east and south-west. The name, which is an Arabic word meaning fifty, is said to be due to the fact that these winds are specially prevalent during the fifty days following the Coptic Easter. Dry, dusty winds also blow from the south in the winter, but because they are cool they are not normally classed as khamsin. True khamsin occurs chiefly in spring in advance of depressions on tracks *2c* and *2d*. With depressions on track *2c* khamsin normally blows for about a day before the arrival of the cold front, but if the depression is on a more southerly track (*2d*) khasmin may last for three or four days. As the cold front of the depression approaches, the wind becomes southerly and increases, bringing violent duststorms which may reduce visibility to less than 50 yards. With the passage of the cold front the wind veers abruptly to north-west, there is a rapid fall of temperature and increase of humidity, and the dust almost always clears though the wind may continue strong.

Normally there is a marked improvement in visibility when the cold front goes through but if the wind remains strong behind the front, dust is raised wherever the surface is composed of fine sand. Under normal conditions, when the wind decreases behind the cold front and dust is no longer being raised in the locality, the atmosphere may remain hazy for many hours and sometimes for a day or two. This arises from the fact that in bad khamsin conditions enormous quantities of dust are carried to great heights over large areas. Depending on the upper wind régime, dust, gradually settling, may be held in suspension in the air for considerable periods even behind surface cold fronts.

Sometimes, but by no means always, the southerly khamsin sets in abruptly, replacing a light east to south-east wind. The sudden wind change is accompanied by a sharp rise in temperature, fall of dew-point and arrival of a wall of dust. This warm front, which is normally cloudless, heralds the arrival of hot desert air from far to the south which is moving northwards ahead of the advancing cold front. Visibility usually remains bad until the cold-front passage.

Without some clear-cut definition of khamsin it is impossible to give reliable figures of its frequency. The following figures have been given for a period of five years at Alexandria, without any exact definition of what is meant by khamsin:

Frequency of days with khamsin at Alexandria

Jan. & Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1.2	4.0	5.0	4.6	1.6	0.0	0.6	1.4	0.6	0.6	0.6	20.2

At all times of the year hot, dry winds from a southerly direction are normally commoner in Libya than in Egypt.

Palestine and Syria. In this region the dry, hot, dust-laden scirocco, known in its intense form as simoon or samun, originates in the Arabian desert and blows from directions between south-east and south. Although the accompanying clouds of dust or sand are heavy and may limit visibility to a few yards, they are as a rule shallow and the amount of sand transported is not great. Duststorms, which carry sand to higher levels and over greater distances, do occur but are not particularly associated with scirocco. In other respects these winds behave similarly to the khamsin of Egypt.

Leveche. On the south and south-east coasts of Spain from Malaga to Cabo de la Nao scirocco is known as leveche. It blows from directions between south-east and south-west and owing to its short sea passage from Morocco or Algeria is dry and dust-laden. It tends to be strongest between Punta de las Entinas and Cabo de Gata, and is commonest in late spring and early summer. It is associated mainly with depressions on track *1b*.

Marin. In the Gulf of Lions the scirocco is known as marin, and is next in frequency and importance to mistral. It is warm and moist, brings much low cloud, rain and poor visibility, and, though not in general as strong as mistral, raises a heavy sea especially on the coast between Sète and Aigues Mortes. It blows when a depression is developing in the area or when one enters the area across northern Spain or southern France (track *1a*). It also blows ahead of cold fronts associated with depressions farther north. It is more frequent in the north part of the Gulf than in the south, but sometimes in winter, especially when the mountains are covered with snow, the strong wind does not reach the shore, the wind there being light northerly. When the marin is strong it gives the squalls which are characteristic of steep leeward slopes in the path of a strong wind. These occur, for example, on the north coast of the Ile de Port Cros. Marin blows mainly from south-east but is southerly in the southern parts of the Gulf and tends to south-west in the western parts.

Gulf of Genoa and Ligurian Sea. Scirocco in this region blows mainly from south or south-east. It is always warm and very moist and normally brings much rain, low cloud and poor visibility. However, on the Italian Riviera (roughly between Nice and Spezia) if the air stream is far removed from the frontal zone of a depression, the sky may be cloudless during the day-time while at night much low stratus and heavy dews may occur. The wind falls off rapidly towards the coast especially when there is snow on the neighbouring mountains where katabatic breezes are established. Thus there may be strong scirocco at Portofino (near Rapallo) when the wind at Genoa is calm or light north-easterly. Occasionally the strong southerly gales do, however, extend to Genoa in winter and may cause great damage in the port. At times heavy swell is experienced in the Gulf and along the coast, and the water level rises considerably in places (as much as 13 feet). Waves 60 to 70 feet high were reported at Genoa in a gale in February 1955. The rise of water level may precede the setting in of the wind by 24 hours.

Tyrrhenian Sea. In the Tyrrhenian Sea as at Malta (see page 82) the humidity accompanying scirocco varies according to circumstances from very high to quite low values. With depressions passing through the southern part of the Mediterranean close to the African coast the scirocco of the Tyrrhenian Sea is generally from south-east and has a fairly long sea track causing it to be moist. It normally brings overcast skies, drizzle and bad visibility, especially in the vicinity of Sardinia where visibility may be low enough to obscure the coast although good in the offing. On the other hand when a depression is centred in the north or north-west of the Tyrrhenian Sea the scirocco blows more from south-west and, in the southern part of the area especially, it is hot, dry and dust-laden, causing haze and dark skies. At places on the north coast of Sicily and southern Italy the high temperature and low humidity are accentuated by a föhn effect owing to the passage of the air over the mountains. This occurs, for example, at Palermo where an extreme case on 29 August 1885 gave a temperature of 120°F. (49°C.) with 10 per cent relative humidity. This föhn effect can also give hot, dry winds in places where the topography is suitable when elsewhere the scirocco is relatively moist.

Ionian Sea. What has been said of scirocco in Malta applies also to the south-west and west of the Ionian Sea. There is generally a marked inversion at about 3,000 feet where the temperature is commonly between 80° and 90°F. in summer. In the east and north-east parts of the sea, scirocco is generally moist even when the wind is strong. At Zante it occasionally blows with great strength for two or three days and may do considerable damage. Dry scirocco-like winds are experienced on the west coast of Greece and the neighbouring islands, but they are probably all winds of a local nature blowing from the mountains. At Patras these dry winds are very dusty and sometimes violent.

Adriatic Sea. In the Adriatic Sea scirocco is always a moist wind. Unlike bora its onset is generally gradual. As it blows more or less along the length of the sea, the results of long sea fetch become more striking from south to north; humidity increases and the heavy seas become heavier along both the eastern and western shores. Thick scirocco fogs occur increasingly from Pelagosa northwards, especially from October to January (though also at other seasons when the appropriate situation occurs) and the cloud base descends lower and lower while much rain falls. There is, however, a falling off in the frequency of the wind with increasing distance northwards. The highest speeds of scirocco in the Adriatic are not as great as those of bora, but the wind frequently reaches gale force especially in winter and spring and more often in the south than the north. In the Adriatic the average duration of a spell of scirocco which at some time reaches gale force is about 30 hours but the duration may be as long as four to six days. The average duration of a scirocco gale is 10 to 12 hours, but may be as much as 36 hours. The highest speeds likely to be experienced are about 55 knots.

On the western shores of the Adriatic the wind is often preceded by a swell from eastwards and at times the swell continues after the wind has dropped; there is also an increase of the regular sea current setting north-westwards along the eastern shore, and a rise of the sea above its ordinary level. Where the direction of the scirocco coincides with that of the sea-breeze it is apt to subside quickly in the evening after blowing hard all day. Being a sea wind, scirocco is not so much subject to local variations as bora, but it does show variations from place to place. It tends to be southerly near the entrance to the Adriatic and again off the west coast of Istria (though close inland here it is often easterly), and easterly at some places along the north of the western shore such as Ravenna and Pesaro.

Aegean Sea. In the Aegean scirocco is associated with depressions on tracks *4a* and *4b*. As in the Adriatic, the onset is generally gradual, unlike the case of northerly bora-like winds. The air is always moist and brings low stratus cloud, drizzle and poor visibility with heavier frontal and orographic rain. It is specially prominent in the cool season, and in the south and west of the Aegean. Scirocco gales are not frequent, but in the channels between the Dodecanese islands and the Turkish mainland very high scirocco wind speeds may be experienced, especially when a depression is near the southern Aegean (track *4b*).

In parts of Italy the name scirocco is sometimes given to warm winds of föhn type which are not of continental tropical origin and may come from any direction, while in Syria and Palestine there is an easterly wind in winter known as "cold scirocco" from its biting coldness and dry, dusty nature. Such winds are not true scirocco and may be regarded as misnomers.

It should be remembered that the warm sectors of depressions in the Mediterranean do not always consist of continental tropical air; often the air is Mediterranean type. Again, south-easterly winds often blow in advance of warm fronts and in such cases the air is generally of polar origin, perhaps modified sufficiently to be described as Mediterranean. Thus neither warm sectors of depressions nor south-easterly winds necessarily involve scirocco.

Examples of synoptic situations where scirocco occurs may be seen in the following Figures:

South-west Mediterranean : Figures 2.11*(a)* (spring), 2.21*(a)* (summer)
Libya and Gulf of Sidra : Figures 2.27 (winter), 2.10*(b)* (spring), 2.22*(b)* (autumn)
Tyrrhenian Sea : Figure 2.22*(b)* (autumn)
Adriatic Sea : Figures 2.42 (winter), 2.48*(b)* and *(d)* (autumn)
Ionian Sea and Malta : Figures 2.26 (winter), 2.10*(d)* (spring), 2.48*(b)* and *(d)* (autumn)
South-east Mediterranean : Figure 2.45*(c)* (spring)
Eastern Mediterranean : Figures 2.9*(a)*, 2.29, 2.51*(a)* and *(b)* (winter)
Aegean Sea : Figures 2.29, 2.50*(a)* (winter), 2.34*(a)* (autumn)

LOCAL WINDS

The most important effects of funnelling and cases of ravine winds have been mentioned under regional winds (see pages 72-86).

Lee descending winds. Cases have been mentioned under regional winds where strong descending currents occur on the lee side of high ground. Those due to deep polar air streams are the strongest and most dangerous. The speed of these local descending winds may be 10 to 15 knots higher than the wind over the open sea and gusts probably somewhat exceed gradient strength. The wind usually arrives with a sudden squall.

Contrasting winds. Contrasting winds, that is, winds whose directions are more or less opposite at neighbouring places, occur in a number of localities in the Mediterranean. In places sheltered from bora-type winds there may be light south-westerly opposed to north-easterly winds blowing in the open. Strong descending winds blowing on the lee side of high ground may be contrasted with calms or light opposing winds in the vicinity. In the Gulf of Corinth in winter strong northerly winds across the Gulf may co-exist with opposite winds blowing down the sides of the mountains on the south side and calms over the southern part of the Gulf. Again, off the south coast of France there may be north-westerly winds to the west of Cap Sicié when at the same time the wind is easterly to the east of the Cape.

In the Strait of Gibraltar and Alboran Channel strong south-westerly winds and strong easterly winds are sometimes adjacent to each other when a depression passes through the area. Near Tarifa conditions commonly become very bad with violent squalls from various directions, rough sea and torrential rain, often accompanied by waterspouts. Similarly the presence of a depression in the Adriatic may induce south-easterly scirocco along the eastern shore at the same time as inducing bora across the coastal mountains.

Contrasts also occur as a result of katabatic winds, especially when the mountains overlooking a coast are covered with snow. Winds blowing towards the shore may then stop short some distance out to sea where they meet the winds descending the mountain sides. The most important cases are at the heads of the Gulf of Lions and the Gulf of Genoa and on the southern shores of Spain (see pages 81 and 85).

Local eddies at Gibraltar. The situation of the harbour and the alighting area for marine aircraft on the western side of the Rock led to an extensive investigation of the effect of easterly winds on conditions over the harbour and bay. The results of this investigation were published in *Geophysical Memoir No.59*[29]. The development of a landing strip on the north side of the Rock (North Front Airfield) and its increasing use emphasizes the need for a similar investigation of eddies on both the north and east sides, the information at present available being relatively meagre.

Winds between north-east and south-east. When the easterlies are strong there are violent and confused eddies which make conditions dangerous for aircraft and small vessels. Down-currents in the lee of the Rock are stronger than up-currents and are much more frequent. The area of greatest turbulence varies in location with the direction of the wind in the free air, as indicated in Figures 1.21 *(a)* to *(d)* which are based on Plate XXIX of *Geophysical Memoir No.59*. Squall lines seen on the sea surface are a great help in locating the rough areas. The following is a brief summary of the conclusions reached from the investigation described in the above publication; the original Memoir should be consulted for further details.

Wind-tunnel experiments, confirmed by pilot-balloon observations, showed that easterly winds are turbulent for two miles at least on the lee side of the Rock and from sea level up to 5,000 feet or more. Areas of strong turbulence extend to a mile outside the harbour and for a mile from north to south, the disturbed area shifting its position with any change of the free wind direction.

With a due east wind, there are two large permanent vortices as shown in Figure 1.22 (based on Plate XX, C and D of the Memoir). The axes, (CA), of the vortices run more or less horizontally westward from the Rock and curve down (AB) to end vertically on the shore so that their rotating cones are spread well out to sea over the harbour and the bay. With changes of the free wind to north or south of east the vortices progressively shift their axes towards the horizontal, and move round with the wind, the upwind vortex growing in size at the expense of its neighbour until, with the wind 30° north or south of east, that is, 60° or 120° from north, a single large vortex persists, with an axis which stretches horizontally for four miles or more over the bay in the direction of the prevailing wind. In some cases these vortices are 6,000 feet in diameter, and in the contiguous regions of turmoil the winds sweep from the 3,000-foot level, at least, down to the sea within a horizontal travel of three quarters of a mile.

Vertical components of air motion, measured during what was described as a mild season, reached nearly 800 feet per minute and this is taken to imply that over short intervals of time, such as a quarter of a minute, they probably attain 1,500 feet per minute or more, upwards or downwards, even on days when the wind does not exceed a strength of force 6.

Westerly winds. There is evidence of intense down-currents east of the Rock in strong westerly winds and it is possible that with westerly winds risks on the east of the Rock are comparable with those experienced on the west with easterlies, though owing to the different aspect of the Rock to westerlies conditions may be less turbulent.

North Front Airfield. The only runway lies almost due east-west across the narrow strip of land separating the Rock from Spanish territory. On the north the border of the Spanish neutral zone lies within 450 yards of the runway and to the south the sheer north fall of the Rock reaches to within 550 yards of the runway.

With due east or west winds (which are fortunately the commonest) the runway itself is not directly affected by eddies from the Rock, but if the wind has a southerly component the approach to the runway may pass through a danger area and in addition the direction of the wind varies along the length of the runway. A south-westerly wind meeting the Rock is split by it and sweeps around both sides and over the top, the separated streams converging again on the lee side. This "meeting area" coincides with the normal approach to the runway from the east, and here extreme turbulence with considerable vertical currents is to be expected. The area most affected by turbulence is shown in Figure 1.23. Similar conditions are experienced when the wind is from the south-east, and the runway is approached from the west, but they are usually less severe.

An additional Gibraltar wind hazard is caused by what is known locally as a split wind. This is liable to occur in the summer during the afternoon or late morning on a hot day, and when little or no gradient wind is in evidence. Given these conditions, a sea-breeze springs up from the south, strikes the Rock, "splits" around it and does not converge until it reaches the runway area. The turbulence it causes is limited to the lower altitudes only. The area affected is shown in Figure 1.24.

GALES

The distribution of percentage of observations of gales (that is, wind of Beaufort force 8 or more) over the Mediterranean Sea[48] is shown in Figure 1.25. At a number of points the seasonal average gale percentages are also shown. The seasonal figures are given in the order winter, spring, summer and autumn, followed by the annual figure. A line is drawn to the point to which the figures refer. It will be seen that there is a pronounced seasonal variation in the frequency of gales in all parts of the Mediterranean. The spring and autumn frequencies are of the order of half the winter frequencies and summer gales are relatively rare.

The most prominent feature of Figure 1.25 is the area of maximum frequency in the Gulf of Lions while there is a second maximum in the Aegean Sea. There is a general decrease towards the south and east but with a slight increase of frequency in the main straits, for example, the Sicilian narrows, the north of Crete and to a lesser extent in the Strait of Gibraltar and the Alboran Channel. These local increases are all due mainly to funnel effects. A strong shear, between the wind blowing through the gap and slower-moving air on either side, may continue to exist at the surface and up to at least 10,000 feet for 200 or 300 miles downstream, disappearing sooner only when the air stream meets some further mountain barrier. Gales at coastal stations are usually only a third or a quarter as frequent as those over the adjacent sea, except in very exposed places where the frequencies may be almost the same.

Figure 1.26 shows the most frequent directions of gales in the Mediterranean. Percentage frequencies of gales according to month and direction over the sea and coastal areas of the Mediterranean are given in the tables of Volume II. Additional tables of frequencies for smaller selected sea areas are given in Tables 11, 12 and 13 below.

Table 11

Percentage frequency of gales (Beaufort force ⩾ 8) in the five-degree square centred at 35°N., 15°E.

Based on ships' observations from the years 1900 to 1914

	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Total	No. of obs.
				per cent						
January	0	0.8	0.4	0	0	0.3	0.7	0.3	2.5	745
February	0.3	0.1	0	0.1	0.5	0.7	0.7	2.3	4.7	754
March	1.0	0.4	0	0	0	0	0.7	0.5	2.6	626
April	0	0.3	0	0.1	0	0	0.3	0.4	1.1	797
May	0	0	0	0	0	0	0	0	0	649
June	0	0	0	0	0	0	0	0	0	758
July	0	0	0	0	0	0	0	0.3	0.3	929
August	0	0	0	0	0	0	0	0	0	636
September	0	0	0	0	0	0	0	0	0	767
October	0	0	0	0.1	0	0	0	0	0.1	728
November	0.1	0	0.1	0	0.1	1.2	0.7	0.6	2.8	803
December	0.7	1.2	0.3	0.1	0.1	0.2	1.4	1.5	5.5	859
Year (average)	0.2	0.2	0.07	0.03	0.06	0.2	0.4	0.5	1.5	...

Note. As less than 1% of the observations were made in the southern half of this square the results really represent conditions in the vicinity of the Malta channel.

Table 12

Seasonal percentage frequency of gales (Beaufort force ⩾ 8) in the Strait of Gibraltar and the Alboran Channel

Season	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Total	No. of obs.
Strait of Gibraltar (36^0-37^0N., 7^0-3^0W.)										
					per cent					
Dec.-Feb.	0.09	0.04	0.45	0.36	0.04	0.41	0.50	0.36	2.3	1,100
March-May	0	0.16	1.39	0.27	0	0.05	0.05	0	1.9	900
June-Aug.	0	0.04	0.26	0.13	0	0	0	0	0.4	1,100
Sept.-Nov.	0.12	0.04	0	0	0.12	0.12	0.08	0	0.5	1,200
Year	0.05	0.07	0.52	0.19	0.04	0.15	0.16	0.09	1.3	4,400
Alboran Channel (36^0-38^0N., 3^0-0^0W.)										
					per cent					
Dec.-Feb.	0.05	0.05	0.20	0.05	0	0.68	1.89	0.49	3.4	1,000
March-May	0	0.42	0.42	0	0	0.21	0.32	0.10	1.5	900
June-Aug.	0	0	0	0	0	0	0.09	0	0.1	1,100
Sept.-Nov.	0	0	0	0	0	0.12	0.66	0	0.8	1,200
Year	0.01	0.12	0.15	0.01	0	0.25	0.74	0.15	1.4	4,300

Table 13

Annual percentage frequency of gales in selected sea areas

	Area	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Total	No. of obs.
1.	36^0-38^0N., 0^0-4^0E.	0.01	0.09	0.09	0.06	0.03	0.32	0.77	0.17	1.5	3,800
2.	36^0-38^0N., 4^0-8^0E.	0.20	0.09	0.03	0.01	0.03	0.13	0.77	0.42	1.7	3,300
3.	37^0-38^0N., 8^0-10^0E.	0.20	0.16	0.16	0.03	0.03	0.13	0.54	0.93	2.2	1,500
4.	36^0-38^0N., 10^0-14^0E.	0.25	0.09	0.12	0.09	0	0.07	0.76	0.95	2.3	2,800
5.	42^0-44^0N., 3^0-6^0E	1.78	0	0	0.03	0.03	0	0.40	3.85	6.1	1,600
6.	43^0-45^0N., 6^0-10^0E.	0.51	0.51	0.68	0	0.06	0.17	0.51	0.62	3.1	800
7.	42^0-43^0N., 6^0-10^0E.	0.34	0.40	0.27	0	0	0.14	1.69	1.75	4.6	700
8.	34^0-36^0N., 18^0-23^0E.	0.35	0.44	0.39	0.16	0.05	0.06	0.22	0.21	1.9	4,000
9.	38^0-40^0N., 24^0-26^0E.	0.80	0.98	0	0.18	0.87	0.09	0.09	0	3.0	500

Zero is written where the means were less than 0.005.

1,2,3 : North coast of eastern Algeria and Tunisia
4 : North-east coast of Tunisia to Sicily (Sicilian narrows)
5 : Gulf of Lions
6 : Gulf of Genoa
7 : Ligurian Sea
8 : South Ionian Sea
9 : North Aegean Sea

Western Mediterranean. The most important gales are the north-westerly mistrals of the Gulf of Lions. These become west-north-west to the south of the Iles d'Hyères and are mainly south-west to west (libeccio) in the south of the Gulf of Genoa. In the north of the Gulf of Genoa gales from north or north-east are more frequent. Off the western shores of the western Mediterranean the direction of gales is mainly north-west but further east the direction is more northerly. Through the Strait of Bonifacio and south of Sardinia towards Tunisia gales are mainly north-west or west-north-west. In the Alboran Channel the majority of gales are westerly (vendaval) but there is a marked seasonal increase in gales from an easterly direction (levanter) in spring, and in this season levanter gales are more frequent than vendaval. In the Strait of Gibraltar vendaval gales are rather more frequent than levanter gales in autumn and winter, but in spring and summer nearly all the gales are levanter. In the south of the western Mediterranean the most important gale direction is south-west in the west (off western Algeria), and west to north-west in the east (off eastern Algeria and Tunisia).

Mistral gales occur chiefly with depressions on tracks 3*c* or 3*d* and the north-easterly and south-westerly gales of the Gulf of Genoa chiefly with Genoa depressions. Vendaval gales occur with weather type C, with depressions on track 1*b* or when depressions develop in the Balearics region. Levanter gales are chiefly associated with weather type D.

Tyrrhenian Sea. West to north-west gales are commonest and these are often a continuation of the mistral flowing mainly through the Strait of Bonifacio. They are usually associated with depressions on track 3*c*. North and north-east gales (tramontana and gregale or greco) are the next in frequency. They are often continuous with bora and are associated mainly with weather types B and D. Gales from south-west (libeccio) are relatively rare but occur occasionally when depressions form in the region of the Gulf of Genoa. When north-westerly gales blow in the Tyrrhenian Sea they may continue through the Strait of Messina. South-east to south (scirocco) gales through the Strait of Messina may be associated with libeccio in the Tyrrhenian Sea or with depressions on tracks 3*d* or 2*b*.

Adriatic Sea. The majority of gales in the north are north-easterly (bora) while south-easterly (scirocco) gales are commonest in the south. Bora and scirocco gales are about equal in frequency at about 43°N. On the western shores south of Ancona there is a tendency for bora gales to blow from north or even north-west. Bora gales usually occur with weather types B or D especially if there is also a depression in the Adriatic; scirocco gales occur with depressions on track 3*d*. A bora gale in the north and a scirocco gale in the south may occur together in certain circumstances, for example with weather type A_1.

Central Mediterranean. North-westerly gales are commonest and are generally a continuation of the mistral stream flowing through the Sicilian-Tunisian narrows towards Cyrenaica. These are mainly associated with depressions on tracks 3*c* or 3*d*, and there is a high frequency of such gales in the narrows themselves as a result of funnelling. Scirocco gales occur occasionally in the west of the area and these also reach a local maximum frequency in the Sicilian-Tunisian narrows. In the east of the area scirocco gales are usually associated with depressions on tracks 2*b*, 2*c* or occasionally 3*d*. North-easterly gales (gregale) are associated chiefly with weather type D, but gales in the north may occur with type B_2. The number of gregale gales is relatively small in the area as a whole but reaches a notably high value in the region immediately west of Crete, due mainly to a funnel effect, but the frequency varies greatly in different years.

Aegean Sea. North-easterly (bora-type) gales are by far the most frequent in the northern area, occurring with outbreaks of continental polar or arctic air from the Black Sea in weather types B or D. In the Gulf of Thermai polar invasions give gales from north-west to north (vardarac). These north-east to north-west winds continue southwards as north to north-west gales, but in the Doro Channel the air is funnelled to become a north to north-east gale. In the south of the Aegean, scirocco gales are quite frequent, usually associated with depressions on tracks *3d*, occasionally *3c* or *2b*, and with weather type A_1. In the south-west of the area occasional gales occur from south-west to west, usually associated with depressions on tracks *3c/4a*.

Eastern Mediterranean. The north-westerly gales of the south-east Aegean often continue into the north of the eastern Mediterranean as gales from directions between west-north-west and south-west. Depressions in the Cyprus area are responsible for north or north-easterly gales in the north-east of the eastern Mediterranean. Violent local winds occasionally descend from the mountains round the Gulf of Alexandretta (Iskenderon). In the south of the eastern Mediterranean gales blow mainly from directions between south-west and north-west in association with depressions on track *4b* and with depressions forming in the Cyprus area. Depressions on track *2c* may give south to south-west gales off the coasts of lower Egypt.

STRONG WINDS

The frequency of strong winds (that is, winds of Beaufort force 6 or more) shows the same annual pattern as for gales as may be seen from Figure 1.27, which gives the mean annual percentages of observations with strong winds over the Mediterranean Sea. It will be noticed, however, that the area of maximum in the Gulf of Lions is in this case matched by equal maxima in the Gulf of Trieste and in the Aegean Sea. It will also be noticed that while gales decreased in frequency from north-west to south-east by a factor of more than one tenth, the corresponding decrease in the frequency of strong winds is only about a factor of one quarter; similarly, the relative frequency of strong winds in summer compared with winter is higher than for gales and in one area, the Aegean, the frequency of strong (etesian) winds in July, August and September is notably high. The effects of these winds on the frequency pattern extend to areas south of the Aegean from about 20°E. to 30°E.

As the frequencies of strong winds (Beaufort force 6 or more) are not deducible from the tables of Volume II they are given below in Table 14 for the sea areas of the Mediterranean.

LAND- AND SEA-BREEZES

The diurnal alternation of land- and sea-breezes is very pronounced in the Mediterranean in the warm season and even in the cool season it is sometimes noticeable in fine settled weather. The season of regular sea-breezes is from April to October. In midsummer the sea-breeze begins at about 0700 or 0800 local time, reaches its maximum about 1300 or 1400 and continues till 1800 or 1900. In spring and autumn it begins later- about 1000 local time - and in winter, when it occurs, its time of onset may be delayed till noon. The land-breeze generally sets in at about 2000 or 2100 in summer, reaches a maximum in the early hours of the morning and lasts till about 0500 or 0600.

The extent of land- and sea-breezes is generally between 10 and 20 miles from the coast, the greater distances corresponding on the whole to stronger winds. In some places sea-breezes extend considerable distances inland, for example in summer along the coasts of Libya, Egypt, Palestine, the Lebanon and Syria, where the sea-breeze tends to be strong. The onset of the sea-breeze becomes later for places

Table 14

Percentage frequency of strong winds (Beaufort force $\geqslant$ 6) over the sea areas of the Mediterranean

Marsden Sub-square	180A	180B	179A*	109D	109C	144C	144D	143C	143D	142C†	142D	143B	142A	142B	141A
Coordinates	40°-45°N. 0°-5°E.	40°-45°N. 5°-10°E.	40°-45°N. 10°-15°E.	35°-40°N. 10°-5°W.	35°-40°N. 5°-0°W.	35°-40°N. 0°-5°E.	35°-40°N. 5°-10°E.	35°-40°N. 10°-15°E.	35°-40°N. 15°-20°E.	35°-40°N. 20°-25°E.	35°-40°N. 25°-30°E.	30°-35°N. 15°-20°E.	30°-35°N. 20°-25°E.	30°-35°N. 25°-30°E.	30°-35°N. 30°-35°E.
(a) Monthly percentage frequency of strong winds															
							per cent								
December	27	28	12	11	11	14	20	16	18	17	28	19	14	16	9
January	29	18	12	12	12	11	20	16	20	24	25	17	18	12	10
February	27	20	14	12	16	14	18	18	20	20	12	13	17	14	12
March	21	20	14	13	15	10	14	14	12	17	15	17	15	10	5
April	16	19	7	10	10	6	9	11	9	11	12	8	8	7	5
May	8	9	2.9	8	7	6	7	6	4.3	6	2.3	2.9	6	2.9	1.6
June	7	10	2.2	5	5	3.8	2.5	2.3	1.6	1.1	2.5	0.4	2.1	2.4	1.0
July	6	6	1.5	5	3.5	3.0	1.0	0.8	0.9	3.6	14	0.5	2.7	2.0	0.2
August	5	8	1.6	5	2.1	2.2	1.1	3.3	1.3	4.6	16	0	3.2	1.7	0.6
September	9	9	5	3.2	4.4	3.6	4.3	3.4	2.3	6	14	2.9	3.7	3.1	0.6
October	12	11	7	7	7	7	9	7	5	10	19	4.2	3.6	1.8	0.6
November	20	22	18	11	12	14	13	13	13	19	36	12	7	6	5
Year	16	15	8	9	9	8	10	9	9	12	16	8	8	7	4
(b) Annual percentage frequency according to direction															
							per cent								
N.	4.3	1.2	0.8	1.9	0.3	0.8	1.2	0.9	1.3	1.8	4.0	1.4	1.3	1.1	0.2
NE.	1.4	1.8	1.0	0.5	1.2	0.8	0.4	0.5	0.9	1.8	4.6	0.6	1.1	0.3	0.1
E.	0.8	1.4	0.5	1.9	1.6	0.7	0.4	0.6	0.8	1.1	0.4	1.0	0.8	0.2	0.3
SE.	0.3	0.7	0.6	0.8	0.1	0.1	0.2	0.7	0.9	1.0	1.2	0.5	0.7	0.2	0.1
S.	0.3	0.3	0.7	0.4	0.04	0.2	0.1	0.5	0.8	0.8	2.8	0.4	0.3	0.2	0.1
SW.	0.8	1.2	1.4	0.8	1.4	1.6	0.6	0.7	1.0	1.5	0.8	0.7	0.7	0.6	0.9
W.	1.2	3.7	2.1	1.0	3.4	2.7	3.5	2.4	2.0	1.8	0.1	1.6	1.5	1.5	1.1
NW.	6.7	5.0	1.2	1.2	0.6	1.0	3.5	3.1	1.5	2.4	1.7	2.1	2.0	2.2	1.2
No. of obs.	7,900	10,200	6,700	21,200	26,500	20,600	15,900	23,000	22,200	10,400	1,700	2,700	17,000	23,700	13,900

* Tyrrhenian Sea only

† Ionian Sea only

inland and its duration correspondingly shorter. Thus at Ismailia and Jerusalem the sea-breeze sets in on summer afternoons at about 1600 local time, at Damascus, 45 miles inland, at 1800 or 1900 and at Cairo, over 80 miles inland, by about 1900.

In conditions undisturbed by other factors, such as katabatic effects or the gradient wind, sea-breezes in the Mediterranean usually reach about Beaufort force 4, blowing roughly at right-angles to the coast, while land-breezes are generally weaker, of Beaufort force 2 or 3. Clear weather is more favourable to land- and sea-breezes than cloudy, except that sea-breezes develop more readily in convectively unstable than in subsided air. When the sea-breeze is fully developed its depth extends generally to heights between 2,000 and 5,000 feet, the strength waning as height increases; land-breezes are shallower, of the order of a few hundred feet, and are by nature a drainage pattern conforming to the topography. Other things being equal the land-breeze naturally tends to be emphasized by bays and gulfs while the sea-breeze is more prominent on open coasts. At many places on the North African coast sea-breezes constitute the prevailing winds of the summer and temper greatly the heat of the day, bringing in addition to lower temperatures a welcome increase in the absolute humidity.

Local variations in the behaviour of land- and sea-breezes are considerable but the main disturbing factor is the gradient wind. The sea-breeze and gradient wind may reinforce, counteract or more generally modify each other according to their relative strengths and directions. Thus near Athens, where the etesian winds of summer normally blow from the north or north-east over the open sea with force 4 or 5, the sea-breeze development is often strong enough to produce a southerly or south-westerly wind during the day. From another point of view we may say that the etesians in the summer months July to September are sufficient to produce a secondary minimum in the frequency of sea-breezes at that time of year at Athens, as can be seen from the following table.

Average number of days of uninterrupted sea-breeze at Athens (1921-1940)

Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
2	3	5	7	10	8	6	6	7	9	4	2	69

This effect is general on the north shores of the Saronic Gulf and the sea-breeze usually establishes itself as a force 3 to 4 south-south-westerly wind, sometimes reaching force 5 to 6 when the etesians are weak. In places where the two factors reinforce each other the sea-breeze may reach force 5 to 7 on a relatively quiet day. This occurs in summer on open coasts of Egypt, Palestine and Syria. At Ténès and the Bay of Bône in Algeria the sea-breeze of summer may occasionally reach gale force and cause considerable damage. Such gales are of short duration and are associated with the passage of a depression in the interior.

In places where the gradient wind reinforces the sea-breeze during the day it counteracts the land-breeze at night. Thus on summer nights on the open coasts of Egypt, Palestine and Syria the gradient wind often nullifies the land-breeze, producing either a calm or a light sea-breeze. Similar though less marked effects occur on the North African coast west of Egypt.

The effect of the land- and sea-breeze factor on the diurnal variation of mistral and bora has already been mentioned (see pages 73 and 76).

Sea- and land-breezes are also modified by katabatic effects in mountainous coastal regions. These tend to reinforce land-breezes and counteract sea-breezes and are chiefly noticeable in winter when the mountains inland are snow-covered. In such circumstances the onset of the sea-breeze may be very much delayed. For example on both east and west shores of the Adriatic and on the west coast of Greece, when the coastal mountains are snow-covered, the land-breeze may persist until nearly noon and on such occasions land-breezes of force 4 and sea-breezes of force 3 are normal.

In many parts of the Mediterranean region it is likely that the coastal sea-breezes and anabatic day-time breezes ascending the mountain slopes become linked in a single circulation system.

The sea-breezes on the small island of Malta have been described by Lamb[53] and their behaviour probably gives some guidance to the behaviour of the systems over other islands, large and small. They are noticeable on about 60 days in the year and reach a maximum force of Beaufort 3 to 4 except where they reinforce the gradient wind. On days of little general wind they form a closed cyclonic circulation which first appears at the downwind end of the island; in the middle of the day the centre of the sea-breeze circulation develops back against the gradient wind towards the centre of the island; later in the day - between 1500 and 1800 local time - even the strongest developed sea-breeze circulations weaken and are often carried right off-shore as they decay. On other occasions, when the general wind is stronger, a sharp trough is formed marking the sea-breeze boundary against the general wind. Places near the centre of the circulation may experience as many as four abrupt shifts of wind direction during the day as the sea-breeze develops, passes back towards the centre of the island and later out again. Luqa Airport is commonly affected in this way, the initial and commonest sea-breeze at this point being from north-east, sometimes veering for a time to south-west; the usual gradient wind is light north-westerly. Cumulus clouds build up in air masses of sufficient humidity over the line of convergence in the sea-breeze system over Malta and offshore, in extreme cases producing drizzly showers which yield measurable rainfall. Two or three times a year the sea-breezes of Malta are swamped by the stronger wind system of a thermal low developing over Sicily. The Malta sea-breezes often swamp the weaker system of breezes over the neighbouring island of Gozo.

Fig.1.19(a) Percentage frequency of wind direction and speed for December, January and February

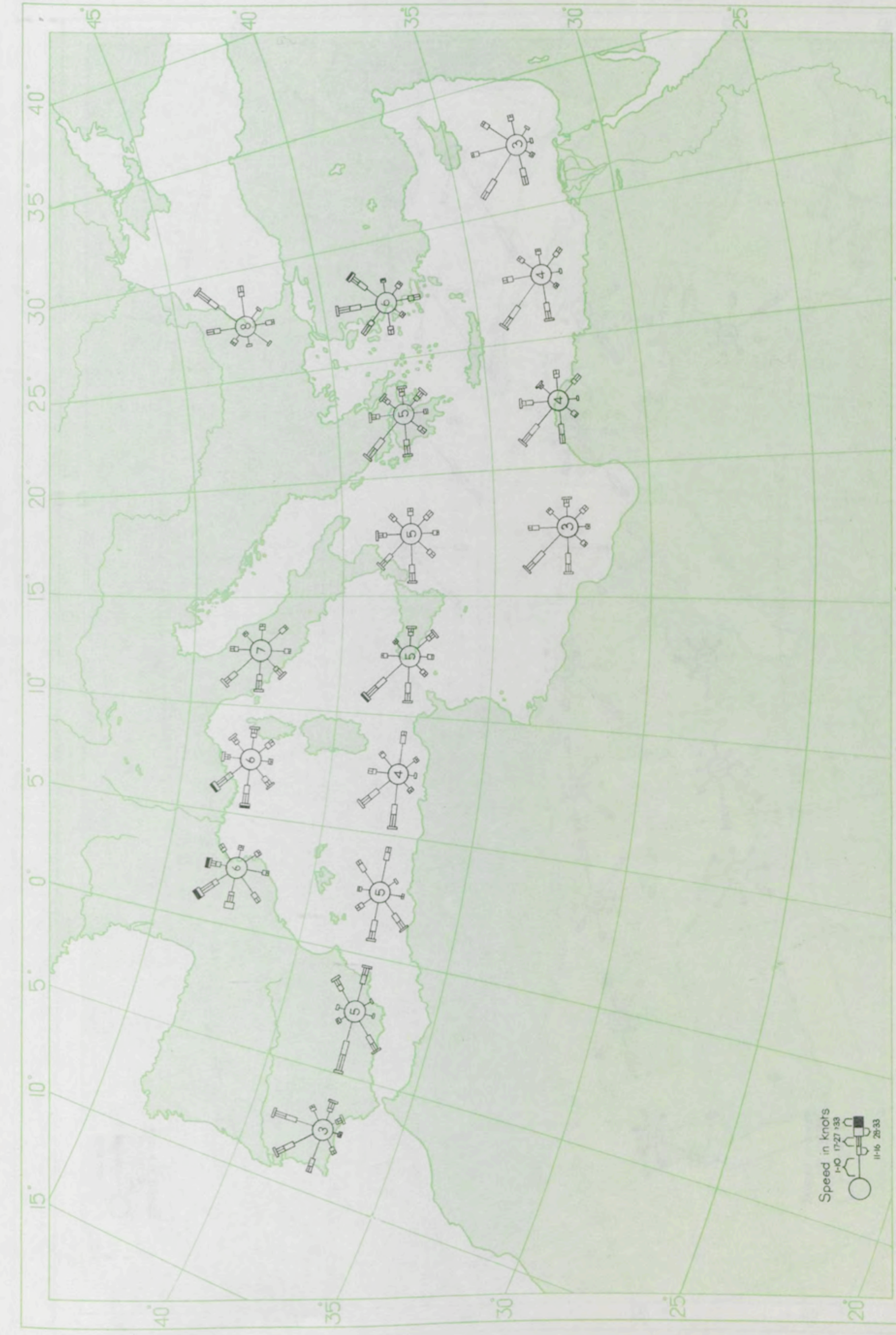


Fig.1.19(b) Percentage frequency of wind direction and speed for March, April and May

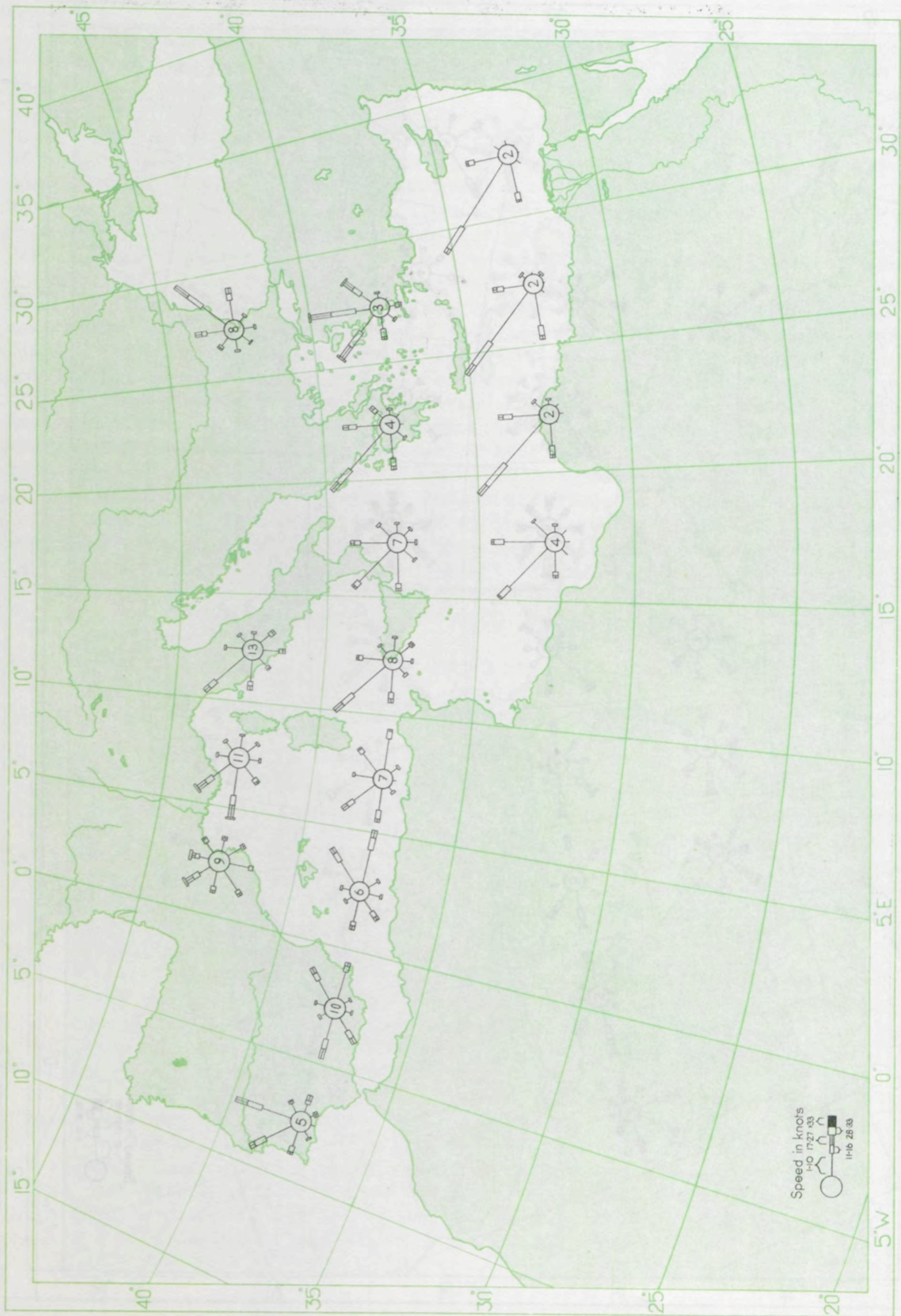


Fig.1.19(c) Percentage frequency of wind direction and speed for June, July and August

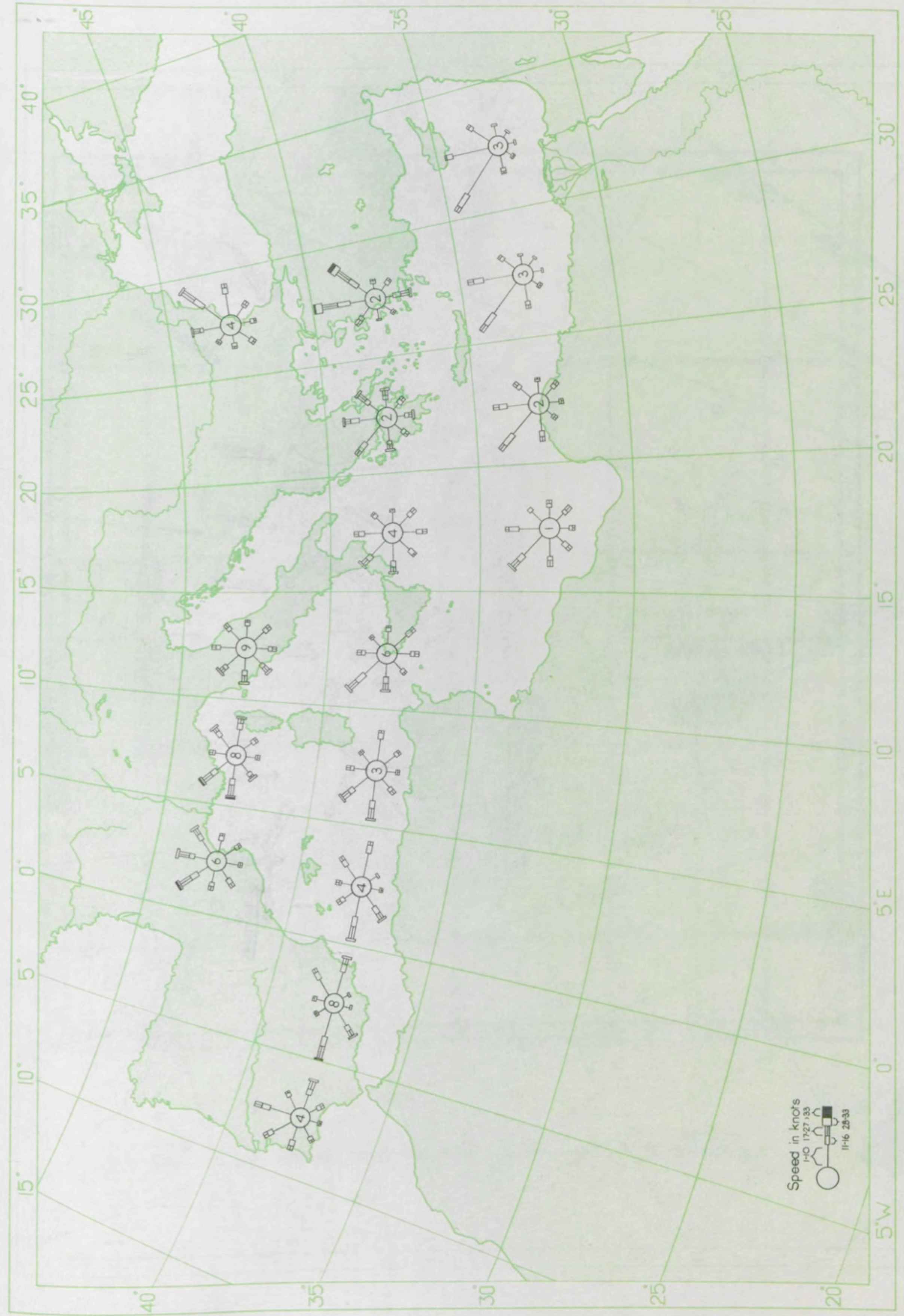


Fig.1.19(d) Percentage frequency of wind direction and speed for September, October and November

Fig.1.20 Main regional winds of the Mediterranean

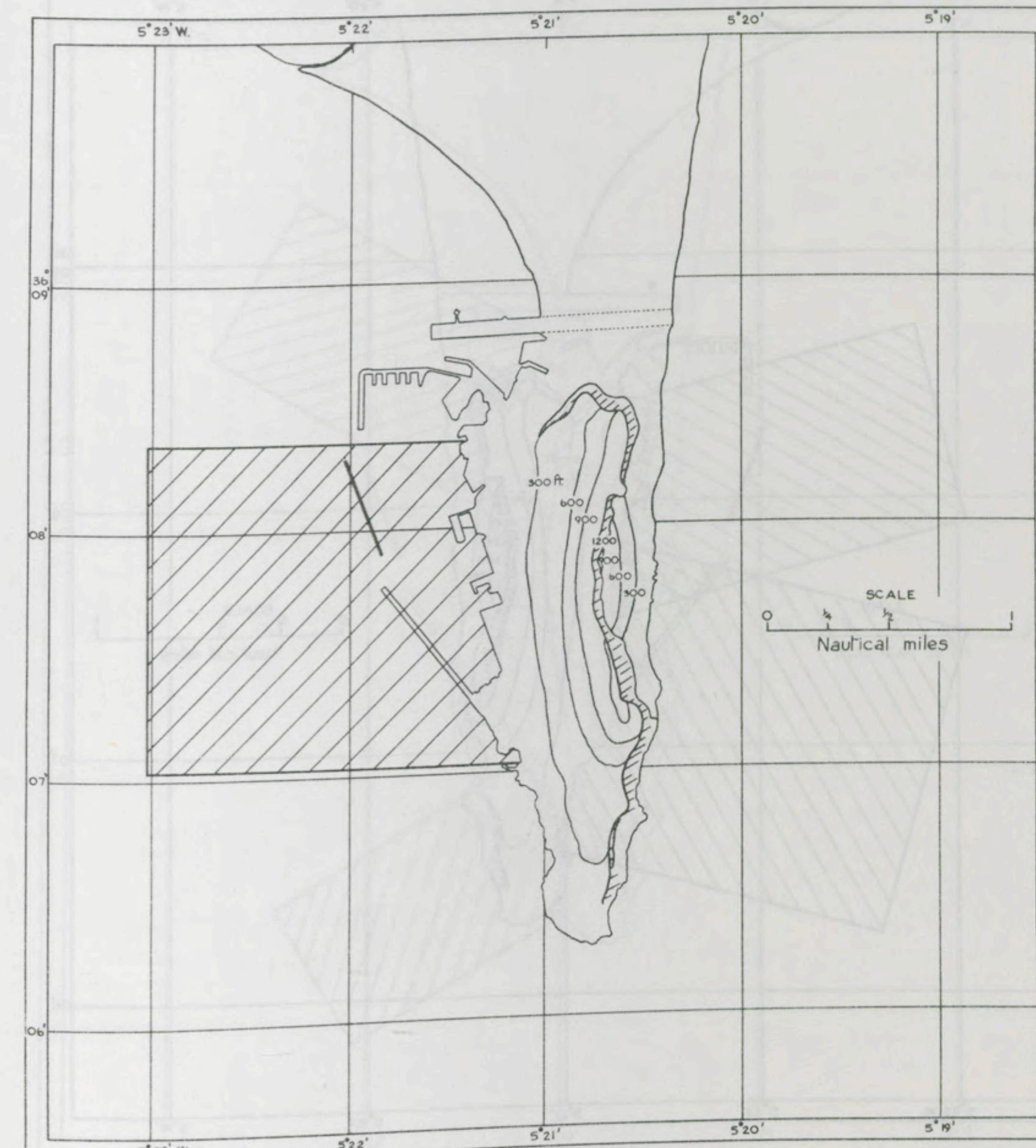


Fig.1.21(*a*) Danger area for wind direction 090^0 at Gibraltar

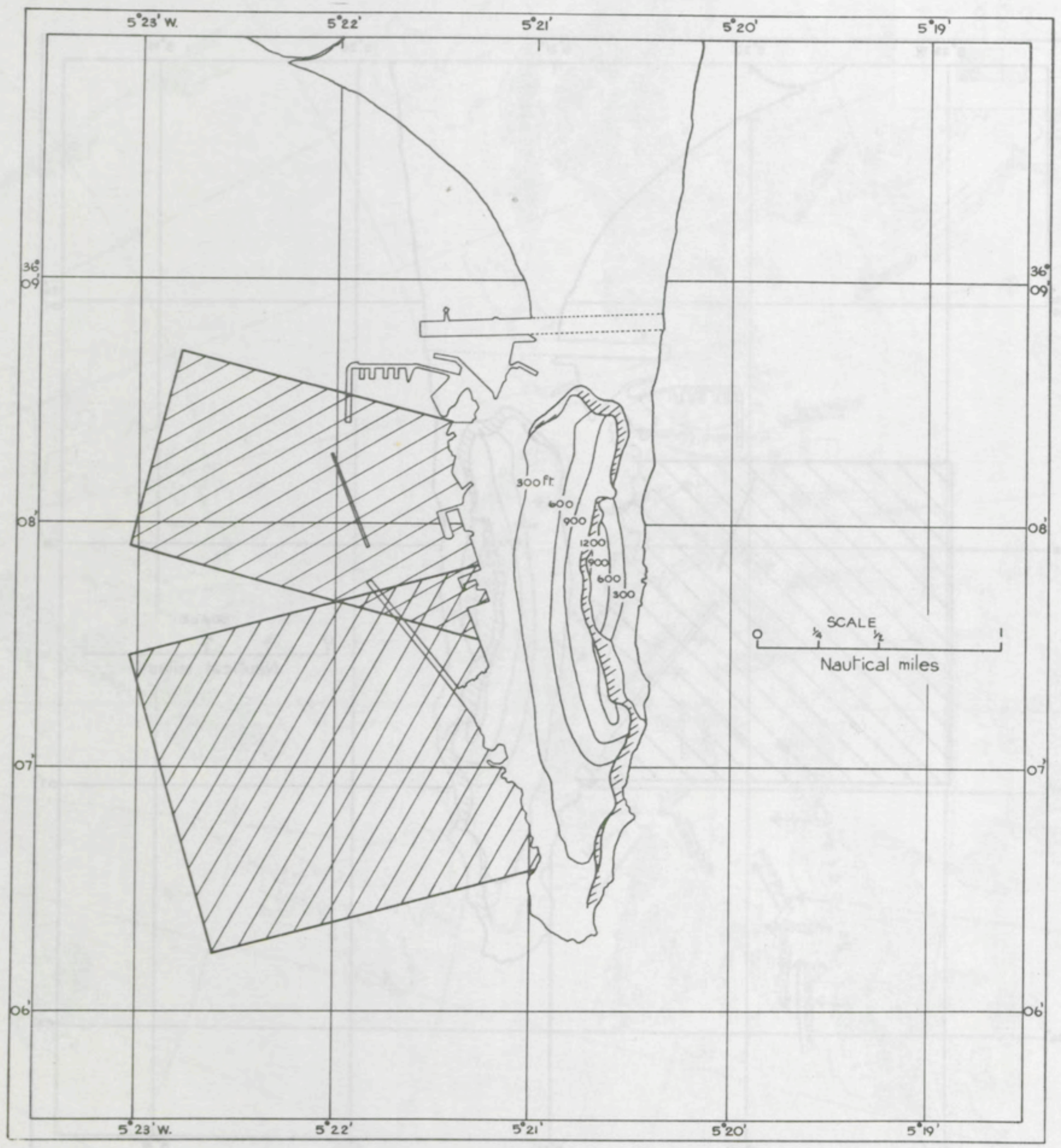


Fig.1.21(*b*) Danger areas for wind directions 075° and 105° at Gibraltar

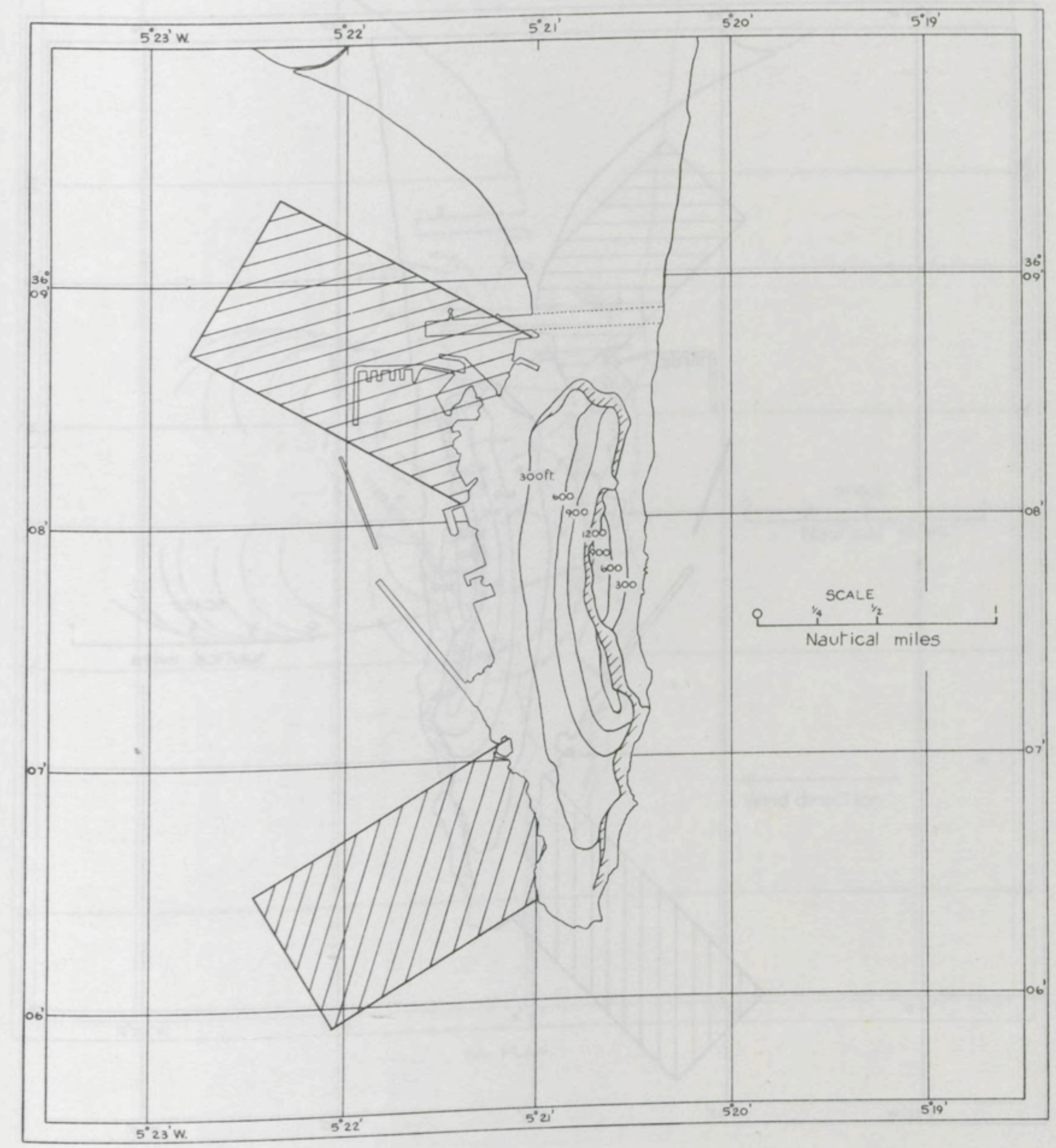


Fig.1.21(*c*) Danger areas for wind directions 060° and 120° at Gibraltar

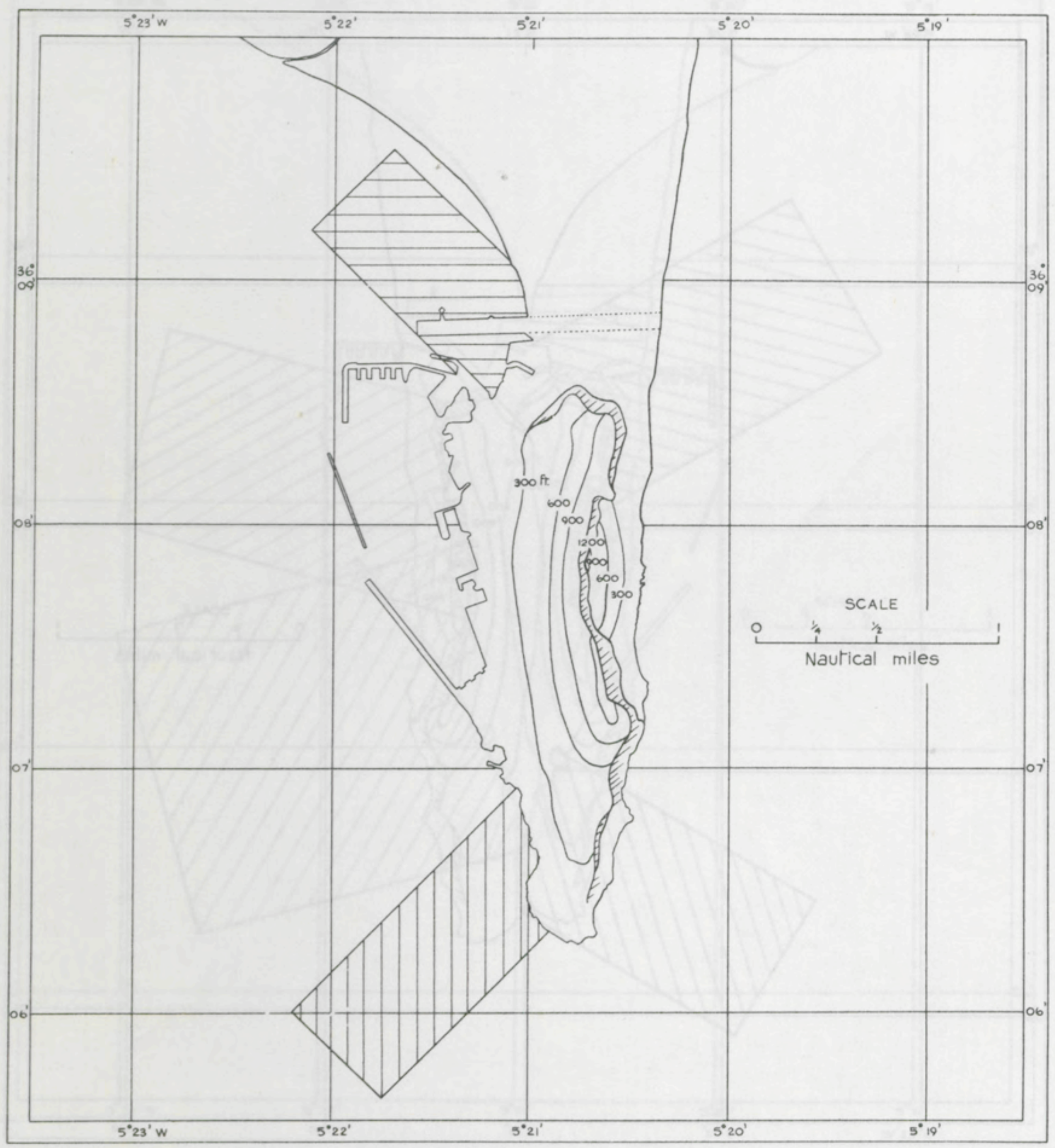


Fig.1.21(*d*) Danger areas for wind directions 045^{0} and 135^{0} at Gibraltar

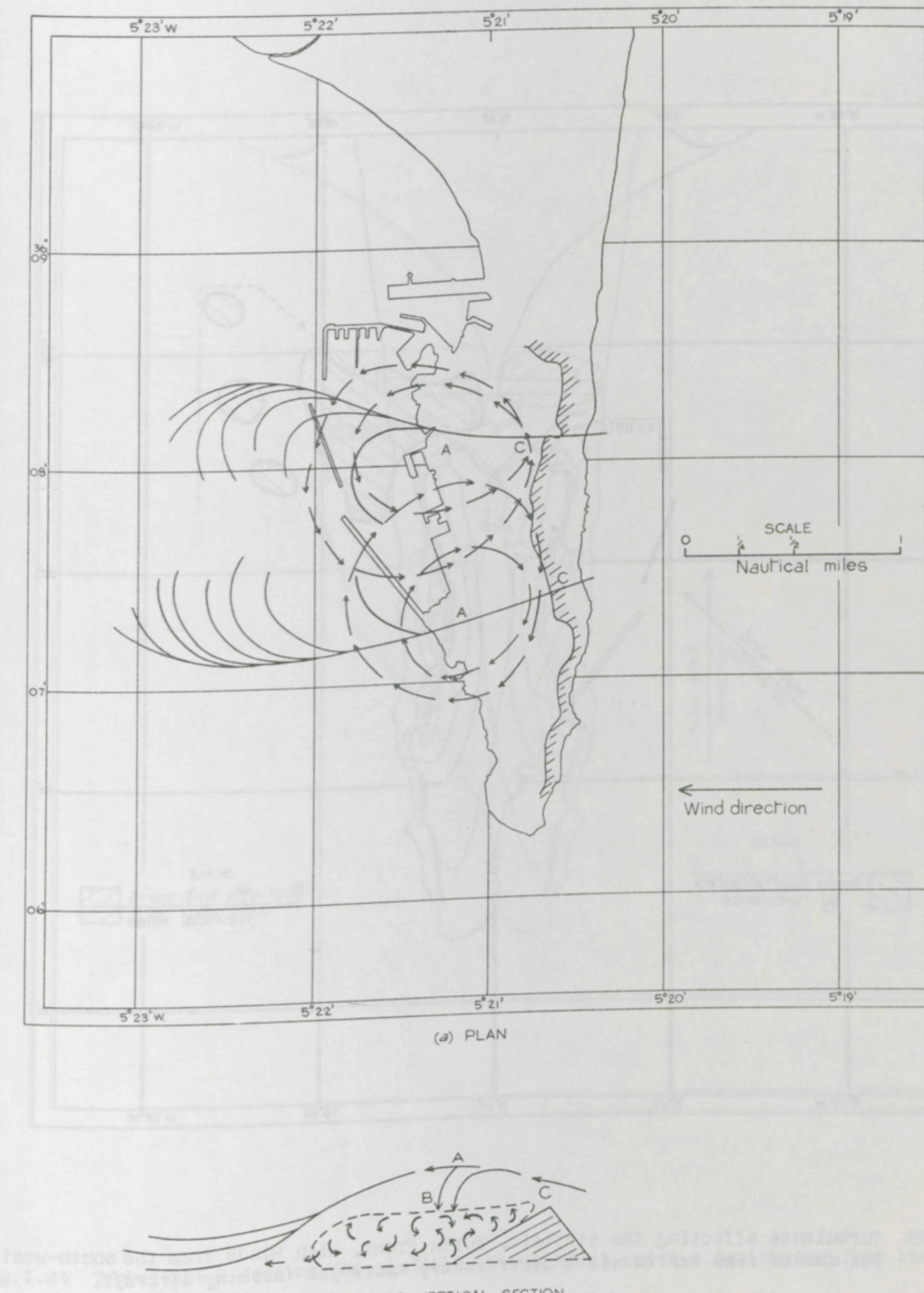


Fig.1.22 Eddies in the lee of the Rock of Gibraltar

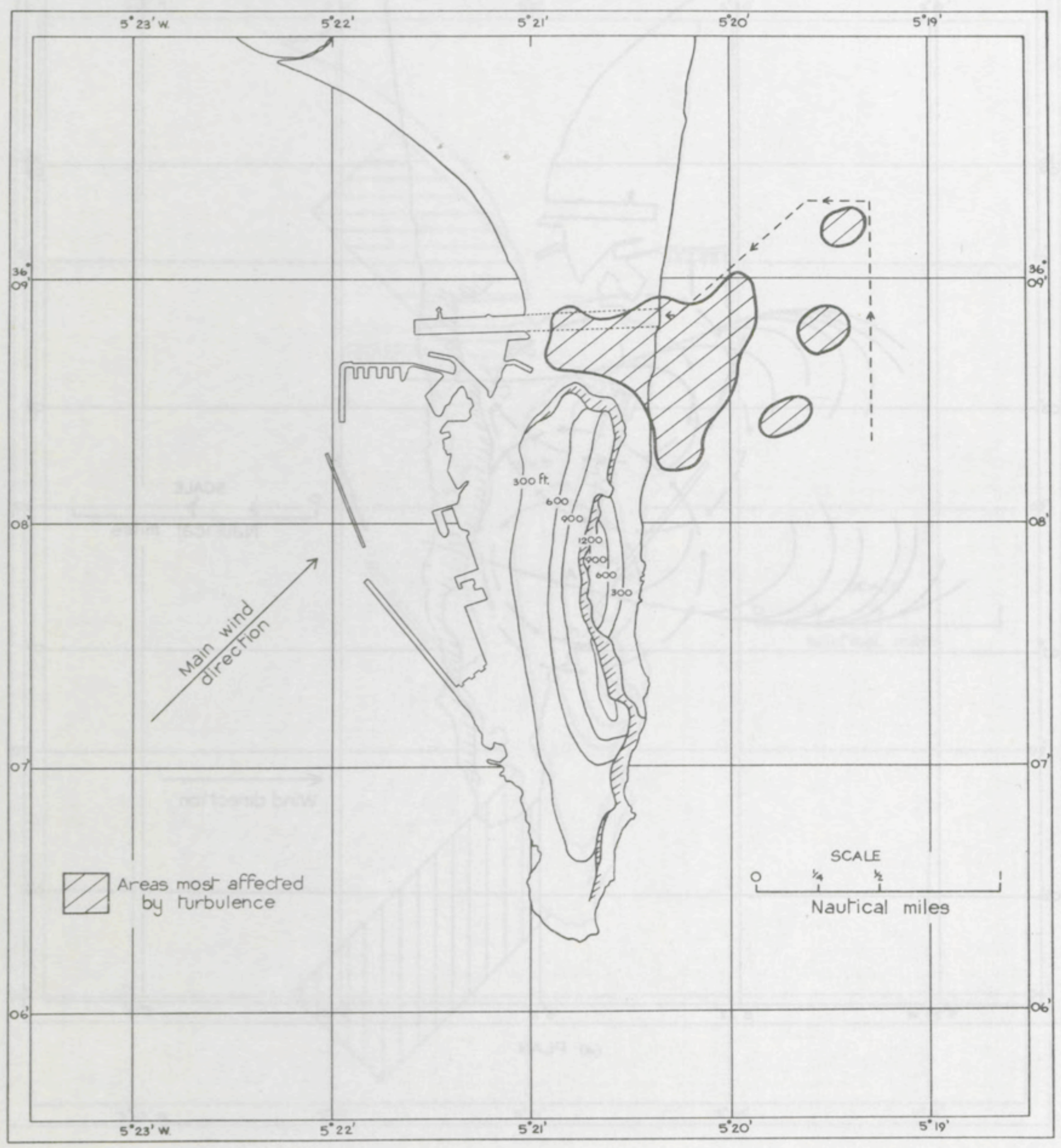


Fig.1.23 Turbulence affecting the airfield, North Front, with winds from the south-west
The dashed line represents a diversionary route for incoming aircraft.

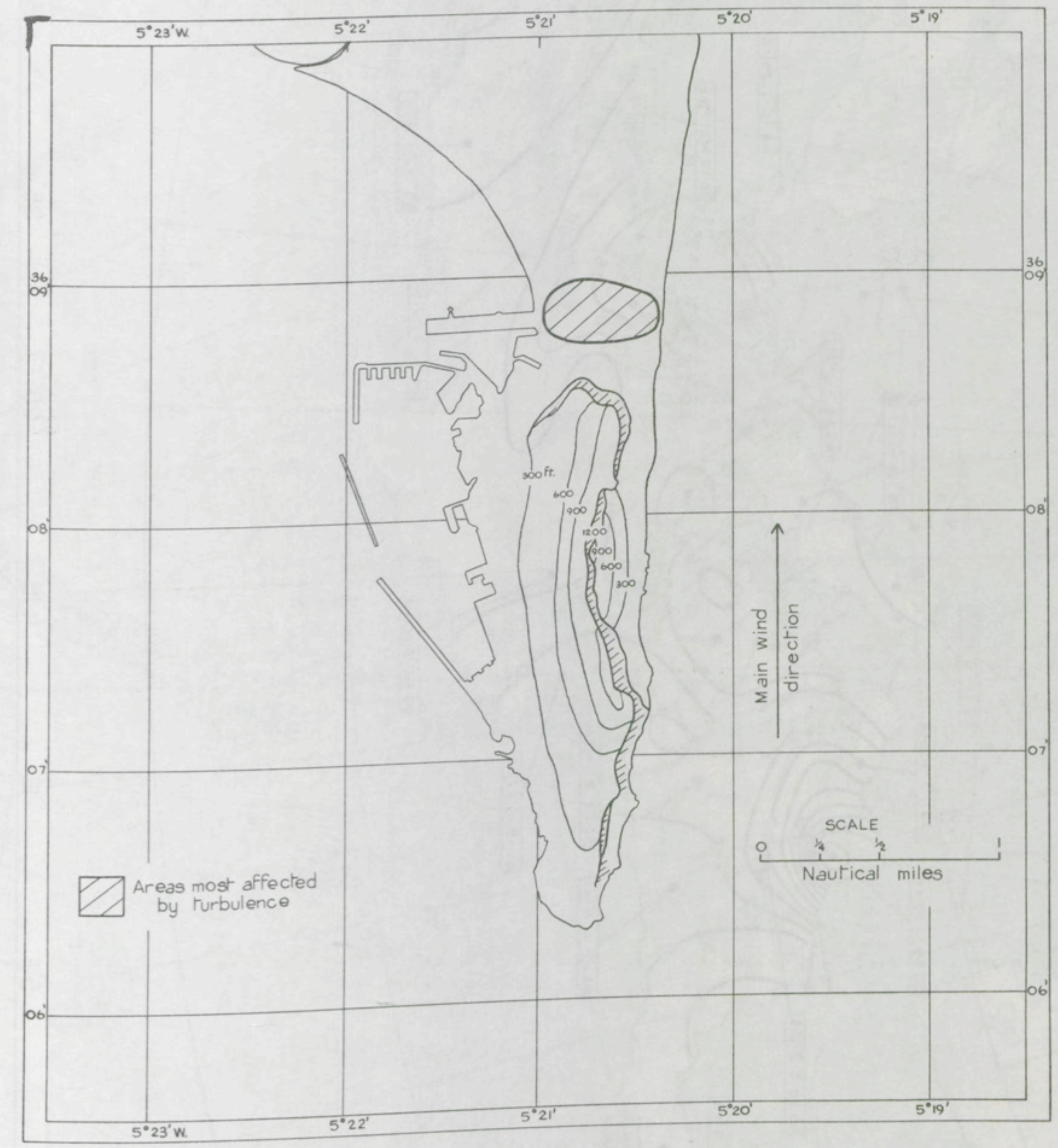


Fig.1.24 Turbulence affecting the airfield, North Front, with a sea-breeze from the south

Fig.1.25 Mean annual percentage frequencies of observations of gales
The "boxed" figures give one value for each season, and an annual mean.

Fig.1.26 Most frequent directions of gales in the Mediterranean
Thicker arrows show the directions of greatest frequency.

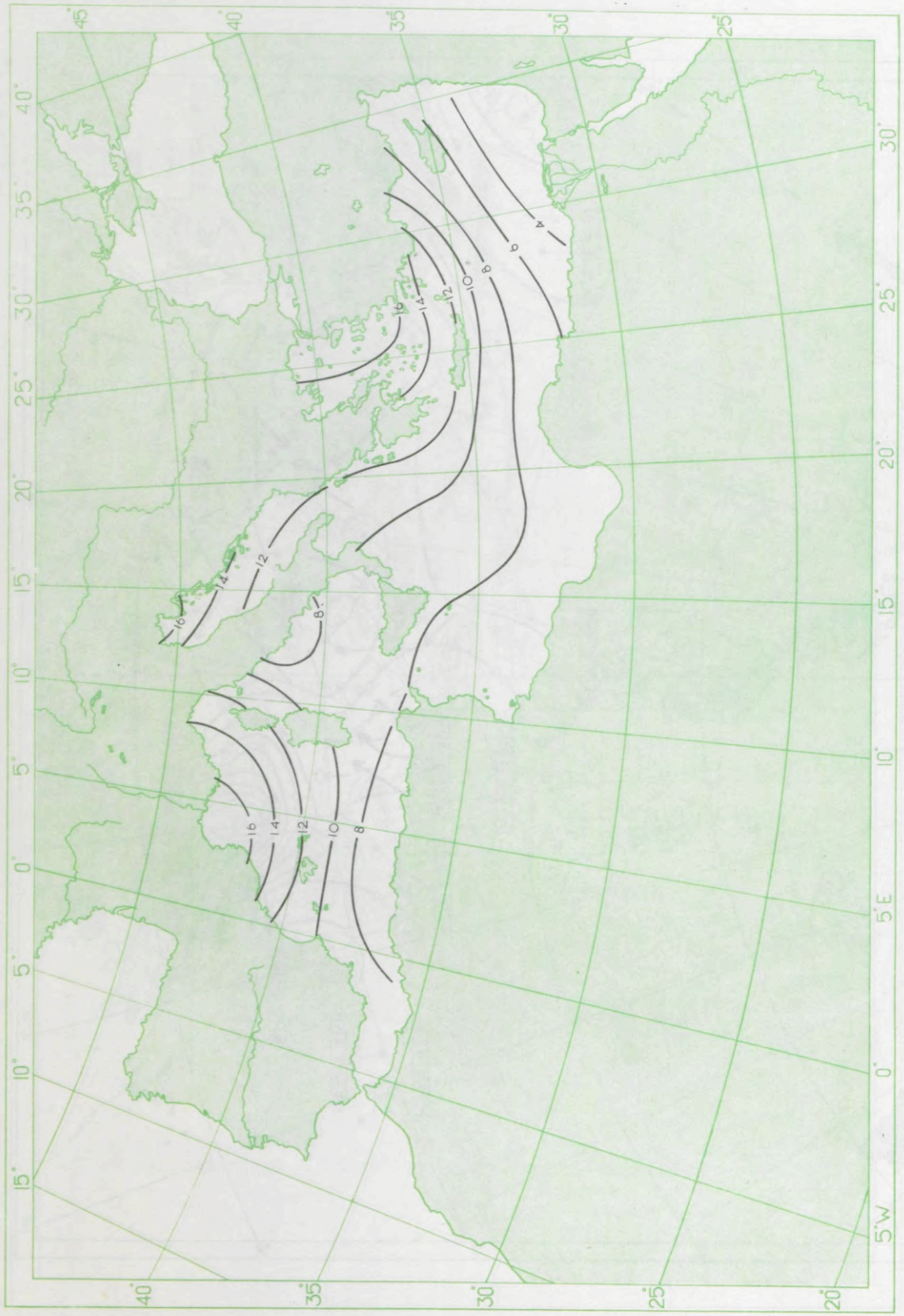


Fig.1.27 Mean annual percentage frequencies of observations of strong winds (Beaufort force ≥ 6)

CHAPTER 7

UPPER WINDS

GENERAL

In Chapter 6 (page 72) it was pointed out that the influence of local surface effects may extend up to about the 850-millibar level in the Mediterranean. This level may therefore be taken as the approximate boundary between the surface wind régime and the régime of upper winds relatively free from local surface effects.

For satisfactory forecasting in the Mediterranean it is important that upper air data should be available and a constant watch must be kept on their analysis. This is particularly vital in connexion with high-flying aircraft, since jet streams over the Mediterranean are frequently orientated with their axes along, or parallel to, the main east-west air routes. This involves a special hazard in that great increases and decreases of wind speed are liable to occur in the upper levels over the whole length of the route. In some cases changes of rather over 100 knots in 12 hours have been reported, as a result of small lateral shifts of the axis of the jet. Very careful and continuous mapping of the upper winds is needed if aircraft are to be warned adequately of these changes.

RELATIONSHIP BETWEEN SURFACE AND UPPER WIND SYSTEMS

If upper air data are scanty it is often possible to make an estimate of the upper wind pattern in a qualitative way from knowledge of the current and earlier surface maps. For example, an estimate of the wind at a given level may be obtained by estimating the temperature distribution in the intervening layer and then making use of the thermal wind relation. The upper structures normally associated with typical surface-pressure distributions are described in modern textbooks (see, for example, "Weather Analysis and Forecasting"[72]) and descriptions need not be repeated here. Jet streams and their association with surface fronts are discussed below (page 113).

Table 15

Classification of upper air charts

Type	Winter	Spring	Summer	Autumn
		Figure number		
A	2.5,2.31(*d*),*2.44(*b*)	2.45(*b*)*,(*e*)† and (*g*)	2.17(*c*),2.15(*b*)	2.47(*d*)*
A_1	...	2.35(*b*),2.45(*d*)*,2.10(*c*)	...	2.48(*c*)
B_1	2.50(*b*)	2.35(*d*)	2.15(*d*)*, and (*e*)†	...
B_2	2.32(*c*)	...	...	2.52(*b*)
B_3	2.51(*c*)	2.33(*c*)	...	2.22(*b*)
C	2.53(*c*)	...	...	...
D	2.54(*b*)	...	2.19(*e*),2.24(*b*)†, and (*d*)†	2.39(*d*), 2.47(*g*) and (*h*)*
E	2.43(*b*)	...	2.56(*b*)	...

* Chart for 300 or 225 millibars. † Thickness chart for the layer 1,000-500 millibars.

Numbers unmarked indicate charts for 500 millibars.

Upper winds associated with weather types

Table 15 lists the upper air charts given in this volume, classified according to the surface weather type (see Chapter 4) and season.

A description is given below of the main upper-wind features which may be expected in association with the various weather types as defined on pages 45 and 46. In this connexion it should be remembered that the positions of depressions in the Mediterranean are not used here as criteria for defining weather types so that one or more depressions may develop and move through the Mediterranean without any change of weather type. In the process of development of such a depression the upper air structure may be considerably modified, so that in this respect there is room for some variation in the upper air pattern.

Type A. The essential feature of this type is the strong northerly current extending from the surface to high levels, between a warm high on the west and a cold low on the east. At the level of maximum wind this current constitutes a jet stream, which also steers the smaller surface pressure systems. The upper northerly current and the jet streams turn to a westerly direction near the main surface front.

Sub-type A_1. The essential features of the surface pressure distribution are repeated on both the thickness and upper-level charts - namely, two warm anticyclones or ridges separated by a narrow cold trough. The cold trough may be the seat of a cold low and/or a cold pool. The upper trough is displaced to the west of its surface position.

Type B. The anticyclone over northern Europe, which is the criterion for type B, may vary a great deal in vertical depth in different cases. If its circulation is shallow little can be said of a general nature about the accompanying upper winds. In considering each sub-type we shall assume, therefore, that the anticyclone extends at least to the level of the winds considered. In all the sub-types we may assume the existence of upper westerlies over the Mediterranean though these may be locally distorted if a sufficiently deep depression is situated there.

Sub-type B_1. In this case a strong north to north-east current is found in the upper levels, flowing between the warm anticyclone and the cold low centre. Before reaching the Mediterranean it is likely to change to a north-westerly direction, becoming westerly near the surface cold front.

Sub-type B_2. With this (mainly winter) type the eastern end of the anticyclone is likely to be shallow even if the western end over northern Europe is deep. The upper air pattern has no well marked characteristics.

Sub-type B_3. The distinguishing feature of this sub-type in the upper air is the warm ridge extending northwards at the eastern end of the Mediterranean, giving upper south-westerly winds in this region.

Type C. There is a general similarity between surface and upper contour charts. Over the Mediterranean one should expect strong west-north-west upper winds in the west, strong westerlies in the central area and strong west-south-west or south-west upper winds in the east.

Type D. The anticyclone over Europe may vary considerably in depth and the value of the surface pressure is no sure guide to its vertical extent. Nothing very useful can be said about upper winds in general. This type is often associated with a diffluent blocking pattern (see page 51).

Type E. Relatively light upper winds may be expected over the Mediterranean and strong westerlies over the middle latitudes of Europe. The distorted patterns of temperature and wind in the upper levels associated with "blocking" have been described in Chapter 4 (page 50).

The continual thermal gradient from south to north in the Mediterranean, especially near the North African coast, results in a pronounced westerly component of thermal wind at almost all times. In this region therefore only rare and extreme situations give rise to easterly winds in the upper troposphere, and these affect a very limited area when they do occur. The occasions when cold pools are centred anywhere over North Africa (chiefly north-west Africa) are commonest between January and March (see also page 116 and Table 17).

THE MAXIMUM WIND LEVEL

At all times of the year the maximum wind level in the Mediterranean is generally at about 200 millibars. On individual days it varies from about 150 millibars in situations with a high tropical tropopause to about 300 millibars or below in situations with a low polar tropopause. The most important phenomenon at this level is the jet stream in which wind speeds of over 100 knots are common and extremes of 200-230 knots not unknown. There are two jet streams which affect the Mediterranean: the polar-front and subtropical jet streams. Their mean positions and intensities (in longitudes near and within the Mediterranean) are shown in Figures 1.28(*a*) to (*l*). These show mean cross-sections, in 10°W., 15°E. and 40°E. longitude, for the months of January, April, July and October 1949-53. In referring to these diagrams it should be remembered that the process of averaging tends to obscure the details of mobile and variable elements, such as the jet-stream maxima, on particular occasions.

The polar-front jet stream. There is no favoured position for the polar-front jet stream in the western Mediterranean and it is often completely absent. Figures 1.28(*a*) and (*b*) show that even in January its mean position is well to the north of this area. It appears as far south as the Mediterranean in association with the vigorous invasions of cold air which occur mainly in winter and it may then be continuous with the main polar jet streams of the North Atlantic. The continuity of the jet is particularly noticeable in winter blocking situations (see page 50 and Figures 2.7(*d*) and 2.47(*j*)) when its direction may be almost from north to south, curving eastwards in the Mediterranean. On other occasions the jet stream associated with an active cold front in the Mediterranean may be quite localized appearing somewhere in the western or central Mediterranean or over North Africa (see, for example, Figure 2.15(*d*)). During the cool season it almost always continues eastwards to merge with and reinforce the subtropical jet stream over the eastern Mediterranean as indicated by the pronounced single maximum at about 30°N. in Figure 1.28(*c*).

The subtropical jet stream. While the jet stream of middle latitudes is normally associated with the main polar front, cases also occur of thermal contrasts in the middle troposphere which are not clearly associated with any surface front. The result may be a jet stream of some importance without any noticeable surface indications. Minor and temporary jet streams of this nature occur, but the most important example is the subtropical jet stream which is found in many longitudes blowing with a strong westerly component. This jet stream appears at about the 200-millibar level over North Africa and the eastern Mediterranean mainly during the six to eight colder months of the year when it extends eastwards across Asia, but it may sometimes appear over the central or western Mediterranean; even in midsummer it is occasionally found over the eastern Mediterranean and, less often, over the western Mediterranean. It is the most prominent feature of the cross-sections for January and April shown in Figures 1.28(*a*) to (*f*), especially those relating to 15° and 40°E.; in July and October it is less prominent, but is certainly present at 15° and 40°E. Winds of 70 to 90 knots at 200 millibars are not unusual in summer over Gibraltar and Malta, though 100 knots is rare at that season; over Nicosia, however, winds of 100 knots and more are quite common in June, less so in July.

The characteristic latitude of the subtropical jet stream is 25°- 35°N. in winter and in weakened form it may be identified in summer at 35°-45°N. over Asia more regularly than over the Mediterranean. The westerly winds in this zone blow with great constancy of direction and in midwinter commonly exceed 150 knots over the Middle East between the Red Sea and Persia, and extreme speeds of 220 to 230 knots have been credibly reported. In the central and eastern Mediterranean this jet stream is often reinforced in winter by association with the polar front though its connexion is not always obvious from the surface weather maps. Its fundamental association is with the marked thermal contrast which occurs in the middle and upper troposphere between air ultimately of temperate or polar origin and air of the tropical zone.

In midwinter the average position of this jet stream lies across northern Libya to lower Egypt. Each cold front from the north-west or north may be associated with an independent wind maximum at about the 300-millibar level which is ultimately absorbed in the main jet stream. As a polar front jet stream moves south and south-east over the central Mediterranean the main subtropical jet may surge northwards to meet it and later move back to its normal position. From time to time the main jet stream may drift well to the south, leaving the central Mediterranean in a slack zone at upper levels.

When an extensive mass of very cold air invades the western Mediterranean in winter (weather type A - often associated with a blocking situation) there may be two important jet streams in the central Mediterranean, one associated with the main polar or arctic front and the other with the subtropical jet stream. These may combine to form a wide belt of strong upper westerly winds with very high maximum velocities - of the order of 200 knots. A case of this kind occurring in January 1954 has been investigated by H. H. Lamb and others.[52] On this occasion it appears that the subtropical jet stream, J_S, moved north out of Africa, passing over Benina on the 3rd, approached Malta on the 4th and then withdrew south-eastwards, recrossing Benina on the afternoon of the 6th. On the 4th a second jet stream, J_A, giving rather more than 80 knots near the 400-millibar level, appeared near Elmas (near Cagliari in southern Sardinia) associated with a cold front, C_A, which swept south over Malta on the 5th (see Figure 2.31(*b*)). This jet stream passed over Malta, where it produced a second wind maximum (about 135 knots at 350 millibars) on the morning of the 5th. Another jet stream, J_B, arriving from the north, accompanying second cold front, C_B, (see Figure 2.31(*c*)) appeared over Elmas on the morning of the 6th with maximum winds at about the 350-millibar level. This jet also continued to move south, though more slowly than J_A. It was responsible for a third maximum of winds aloft over Malta (more than 110 knots near the 300-millibar level) on the morning of the 7th, but may already have become part of the main broad core of strong upper winds near the North African coast. Figure 1.29 is a vertical cross-section on the morning of 6 January 1954, and shows the main broad jet stream (J_S and J_A) to the south with the jet J_B approaching from the north. Figure 2.31(*d*) shows the flow pattern at 225 millibars at the same time. At certain stages of the coalescence of the subtropical jet stream, with the polar front westerlies arriving from the north, the belt of winds exceeding 100 knots at 200 millibars attained a width of 750 nautical miles. Very large wind shears on each side of and below the main belt of strong winds were a notable characteristic and violent turbulence was reported in clear air along the northern flank of the strongest wind.

The upper tropospheric easterlies. In summer, when the intertropical front moves well north of the equator over the African continent there is, north of the front, a corresponding temperature gradient at most levels in the troposphere with warmer air to the north and colder air to the south. This temperature gradient continues in approximately the same sense up to the high tropopause of the equatorial zone where some of the lowest temperatures in the world are observed, (the raised tropopause being associated with vigorous convection in the zone of intertropical convergence). This results in easterly thermal winds which produce easterly winds in the upper levels. In places where the temperature gradient is well marked an easterly jet stream at the level of maximum wind has been spoken of by some writers, though the wind speeds are on the whole less than those associated with westerly jet streams,

and it is not yet certain that the easterly wind maximum is sharp enough to merit the name of "jet".

With the northward movement of the subtropical jet stream between spring and summer in the Middle East sector the easterly stream appears to the south of it. Its mean position in July, as indicated in Figures 1.28(*h*) and (*i*) in longitudes 15° and 40°E., is about latitudes 13° and 15°N. respectively at a level of about 120 millibars, and it has a mean easterly velocity component of 40 knots in 15°E. and 60 knots in 40°E., or a little more. The higher level of this stream is connected with the higher level of the tropical tropopause which accompanies it, and which is at about the 100-millibar level in these latitudes. The easterly stream weakens during the autumn and is not seen again until the approach of summer.

FREQUENCY DISTRIBUTION OF UPPER WINDS

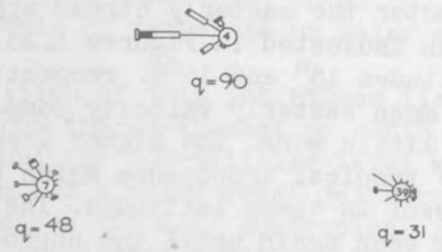
At levels sufficiently remote from the influence of surface features (that is, at or above the 850-millibar level in the Mediterranean), it is possible to obtain a fairly accurate idea of the frequency distribution of winds at a given place in a given month from a knowledge of the vector mean wind and the standard vector deviation of the wind at the place concerned.* If these quantities are known then a frequency distribution for the point in the form of a wind rose can be deduced. A convenient method of presenting climatological charts of upper winds is, therefore, to show the vector mean wind and the standard vector deviation of the wind on charts for various levels and months. This is done in Figures 1.30 to 1.69, which are reproduced from *Upper winds over the world.*[16] Figures 1.30 to 1.49 give the stream-lines (showing the direction) and the isotachs (showing the speed) of the vector mean wind at levels of 700, 500, 300, 200 and 100 millibars for January, April, July and October. Figures 1.50 to 1.69 give the corresponding values of the standard vector deviation.

The most interesting features of the vector mean wind charts are the westerly and easterly streams. It will be seen that in winter (see January charts) the westerly subtropical jet stream is clearly marked over North Africa and corresponds roughly with the January mean position of the Mediterranean front shown in Figure 1.5(*a*). In summer (July) a westerly jet stream is not well marked on the vector mean maps in the Mediterranean-European sector, nor does the polar front appear in this zone in the corresponding chart of prevailing surface winds (Figure 1.5(*b*)). In July, however, the easterly stream lying across Africa in about latitude 18°N. is prominent and corresponds to the mean position of the intertropical front at this season over Africa.

Tabulated data for the stations Gibraltar, Malta, Benina, Nicosia, Habbâniya, Bahrain and Aden are given in Volume II, Table 8. These also give vector mean wind, *R*, and standard vector deviation, σ, as well as the mean (scalar) wind speed, *S*. For all the stations, except Benina, the data are derived from *Upper air data* published by the Meteorological Office.[62] The tables given have been chosen to supply all the most significant information in the concisest possible form for the levels shown. For tables giving frequencies according to speed and direction at these and other levels reference should be made to the original publications concerned with each place. Table 7 of Volume II gives vector mean winds for the seasons at a number of other stations.

* See *Upper winds over the world.*[16] In the free atmosphere, under reasonably homogeneous conditions, deviations of the wind from its vector mean value follow very closely a circular normal probability distribution. A period of the order of a month is found to be sufficiently short for the homogeneity condition to apply.

DEGREE OF STEADINESS OF UPPER WINDS



If V_R represents the magnitude of the vector mean wind and V_S the mean scalar wind speed, then a measure of the constancy of the wind may be obtained from the formula,

$$q = 100 \frac{V_R}{V_S}$$

The vector mean wind V_R will always be less than V_S except when all winds flow from the same direction in which case $q = 100$. When winds blow equally frequently and with the same average speed from all directions then V_R, and consequently the constancy (q) = 0. The value of q can vary between 0 and 100 and is a measure of the constancy or steadiness of the wind[16]. Values of q differing from 0 and 100 are difficult to interpret; wind roses for values of q approximately equal to 30, 60 and 90 are shown in the accompanying small diagram. Fuller details of this are given in *Handbook of statistical methods in meteorology* (page 198).[15]

Figures 1.70(a) to (d) show isopleths of q for various heights throughout the year at Gibraltar, Malta, Benina and Nicosia. It will be seen that on the whole, steadiness increases with height up to about the 150- or 100-millibar level where there is a maximum. There is, however, a great variation from one season to another. From January to mid-April q is about 50 at 250 millibars at Gibraltar and at 200 millibars from mid-September to October, but considerably less than this at lower levels. From May to mid-September and November to December q is about 60 at 700 millibars but greater at higher levels. There is a minimum value of q at 300-200 millibars in January and from May to October.

At Malta, the steadiness is greater at all levels and the seasonal changes are not so great or so sudden as at Gibraltar. The level of maximum steadiness is at about 150 millibars or a little above, and there is a minimum between 500 and 300 millibars which shows in the months February to March, June to July and October to November.

Benina resembles Malta but has a higher steadiness on the whole, especially at the 300-200-millibar levels. The minimum between 500 and 300 millibars appears only in August to September and again in November.

At Nicosia the steadiness is somewhat less than at Malta at the lowest levels but it increases rapidly with height and a little above 500 millibars becomes greater than the corresponding Malta values at all times of the year. The most noticeable feature of the steadiness at Nicosia is that especially in the summer months it has its lowest value at low levels (700 millibars) and its highest at high levels (300-150 millibars).

The commonest deviations of upper winds from their average direction are associated with troughs and ridges in the upper contour patterns, but the most marked

cases occur with cold lows which are associated with relatively light easterly winds on their northern sides and corresponding anomalies in other sectors. A rough estimate of the incidence of cold lows in the Mediterranean area may be obtained from Table 16 which gives the mean number of days in each season when cold lows as shown by the 500-millibar contours may be expected in various regions. These figures are based on the four years 1949-52.[23] The period is too short to give a reliable climatological picture but serves to indicate a rough order of frequency.

Regions 8, 9 and 10 covering North Africa may be assumed to be bounded on the south by the 30°N. parallel as no centres were recorded to the south of it. It will be seen that, in the whole region covered and making due allowances for variations in the areas of the different regions, the most favoured areas for cold lows are

(a) a western area including the Atlantic region from the Azores to the Iberian peninsula, the western Mediterranean, and north-west Africa to 10°E. and

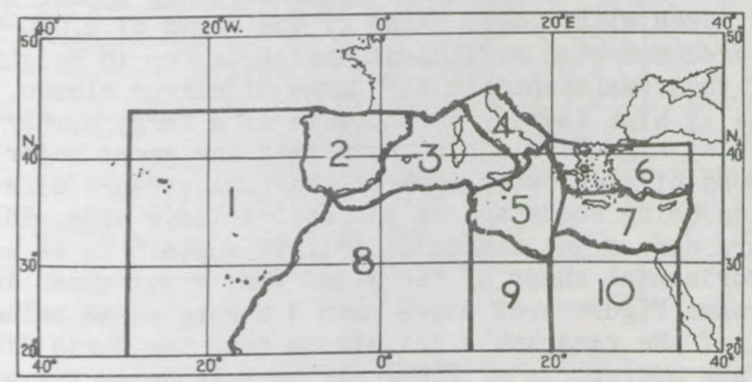
(b) an eastern area including Greece, the Aegean Sea and Asia Minor.

However, the western area is not homogeneous as regards the favoured seasons, for in the Atlantic region the maximum is in summer, over the Iberian peninsula and the western Mediterranean it is in spring, while over the western part of North Africa it is in winter. In the eastern area the maximum is in spring.

Table 16
Frequency of cold lows

	Region 1	2	3	4	5	6	7	8	9	10	Total
	Mean number of days										
Winter	4	2	3	0	1	1	2	7	1	0	21
Spring	8	5	6	1	1	6	2	2	0	1	32
Summer	12	1	0	1	1	3	0	0	1	0	19
Autumn	7	2	3	2	1	2	0	3	1	0	21
Year	31	10	12	4	4	12	4	12	3	1	93

Note. 0 means less than ½.



Key to Table 16.

TURBULENCE IN UPPER WINDS

Orographic turbulence. This is of common occurrence in the Mediterranean region with its sharp relief. Although the question of air flow over mountains has received much attention in recent years, the present state of knowledge is still rather indefinite and qualitative. The effect of mountains on an air stream may be organized or turbulent or a combination of the two depending on such factors as the stability of the air layers and the change of velocity with height. Organized flow is the most amenable to study both in the field and in theory and this has received the most attention. It is known for example that when air flows across a ridge of hills, and approximately at right-angles to it, standing waves of the order of one to ten kilometres in length are sometimes set up over and on the lee side of the hills. The amplitude of these waves generally has a maximum at about the level of the hill-tops and gradually falls off at higher levels and downstream, but may be appreciable up to levels many times the height of the hills. Such standing waves seem to occur most readily when there is a stable layer of air at middle levels (that is, levels comparable with the height of the hills) and a relatively steep lapse rate below. Another requirement appears to be an increase of wind with height at the middle levels, but little or no change of direction with height.

Turbulent flow is experienced under different conditions. This has been found to occur, for example, when the wind decreases with height at the middle levels. If the wind direction is reversed at a level somewhat higher than the mountain top, turbulence occurs both above and below the level of the mountain top. Turbulence and standing waves may occur together when the wind is strong enough, or when intermediate conditions of stability are present.

Orographic turbulence frequently occurs in and around the Mediterranean region in air which is unstable or conditionally unstable. This commonly results in altocumulus castellanus and related cloud forms developing over and downstream from the mountains in an organized or semi-organized pattern over wide areas. Sometimes sheets of castellanus cloud are seen. Turbulence in these clouds may be severe and the skies are often described as chaotic, in spite of the element of orderly arrangement, because of the chaotic turbulence seen in the individual clouds. When the terrain is complicated, standing waves set up by one ridge may interfere with those set up by another and the result is liable to be one of irregular turbulence.

The existence of standing waves is frequently betrayed by the appearance of stationary lenticular clouds, often in parallel succession, on the lee side of a ridge. A similar phenomenon can sometimes be observed when an air stream containing a layer of stratocumulus crosses a mountain area. Organized stationary clearances of the cloud in the form of holes or parallel zones may then appear to the lee of the hills. On occasions, even with modest hills of the order of 2,000 to 3,000 feet, standing waves are produced with sufficient amplitude, up to heights of 20,000 feet, to give evidence of their existence in the forms of cirrus clouds.

Clear-air turbulence at high levels. An analysis of a large number of reports of clear-air turbulence at high levels has shown that the great majority of cases occur near jet streams. Most of such cases were on the low-pressure side of the stream, the other main region being above and on the anticyclonic side. In general, whether the turbulence occurs near a jet stream or not, it appears to be associated with large vertical or horizontal shear of the wind. Very great shear is found near the subtropical jet stream: Figure 1.29 shows such a strong shear below and to the north (low-pressure side) of the remarkable jet stream near the North African coast in January 1954. The lack of reports of clear-air turbulence so far available from the warmer side of the subtropical jet stream is perhaps partly due to the very great height at which the maximum shear probably occurs.

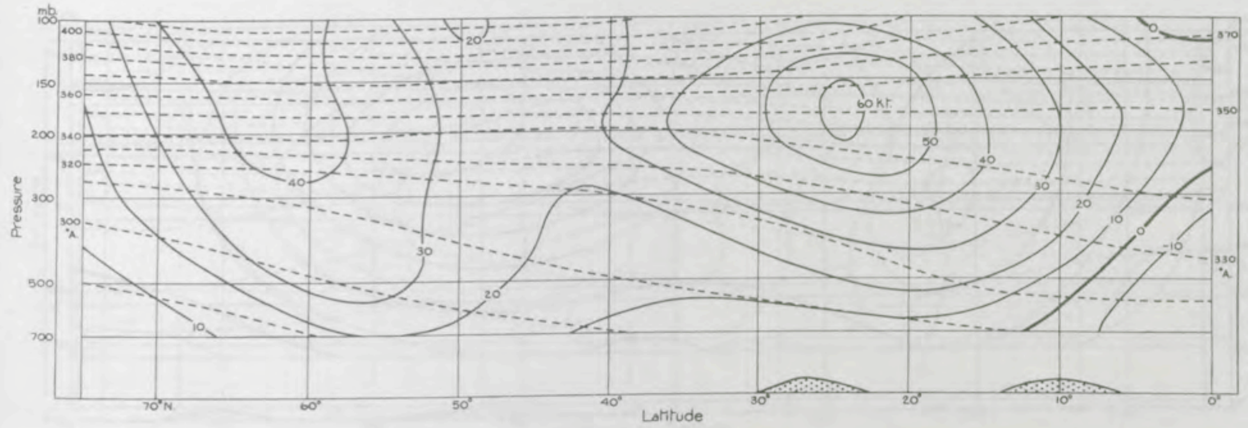


Fig.1.28(*a*) Cross-section at 10°W. showing wind speeds and potential temperature - January
An easterly wind is indicated by a negative value. Pecked lines are isopleths of potential temperature.

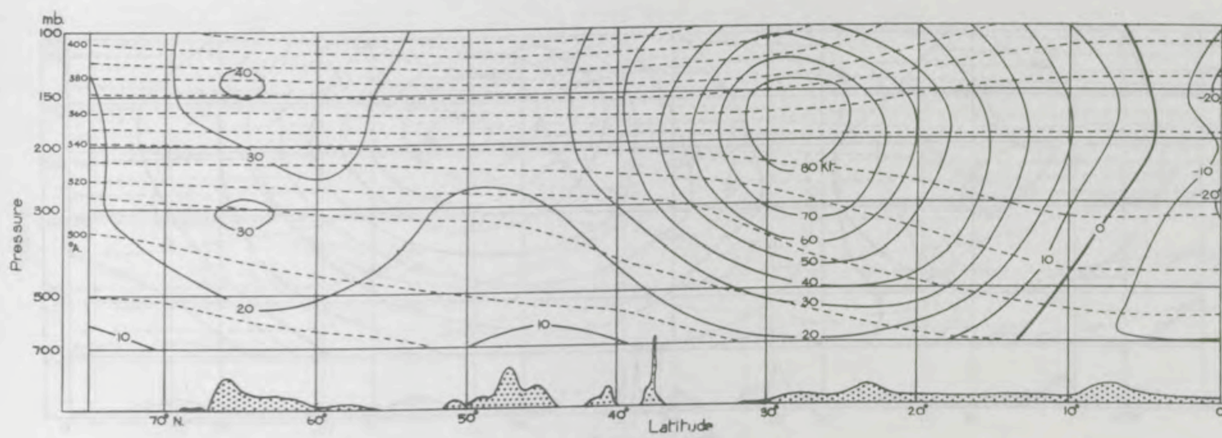


Fig.1.28(*b*) Cross-section at 15°E. showing wind speeds and potential temperature - January
An easterly wind is indicated by a negative value. Pecked lines are isopleths of potential temperature.

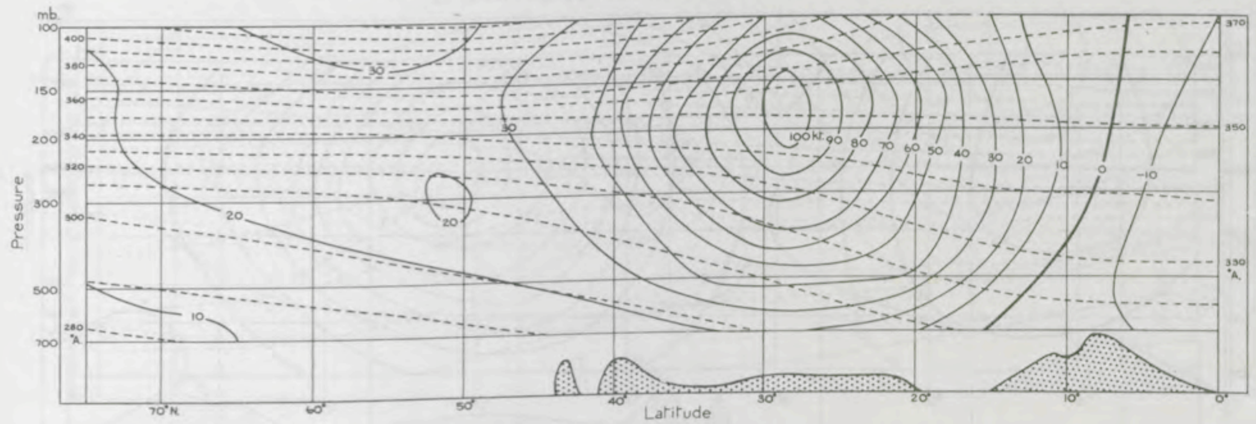


Fig.1.28(*c*) Cross-section at 40°E. showing wind speeds and potential temperature - January
An easterly wind is indicated by a negative value. Pecked lines are isopleths of potential temperature.

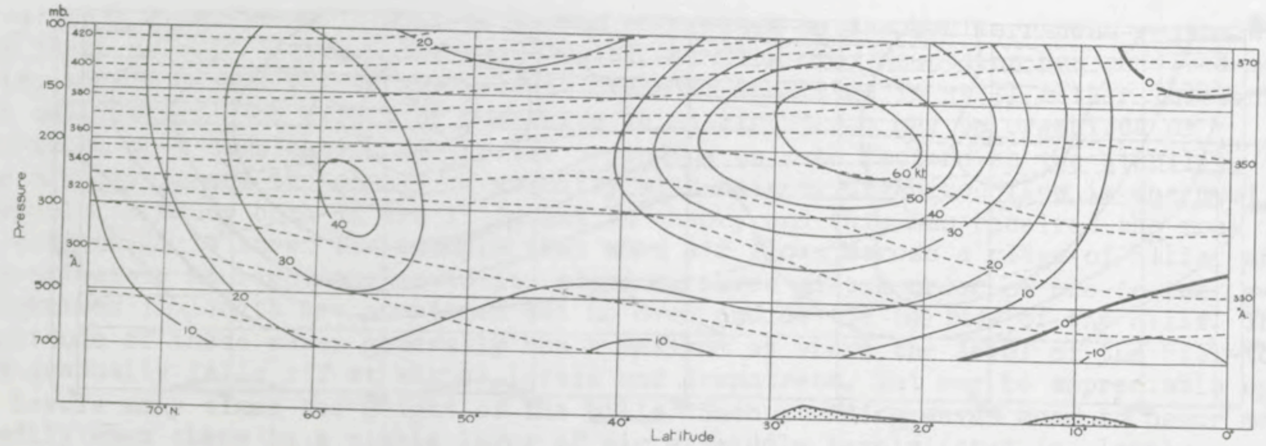


Fig. 1.28(*d*) Cross-section at 10°W. showing wind speeds and potential temperature - April
An easterly wind is indicated by a negative value. Pecked lines are isopleths of potential temperature.

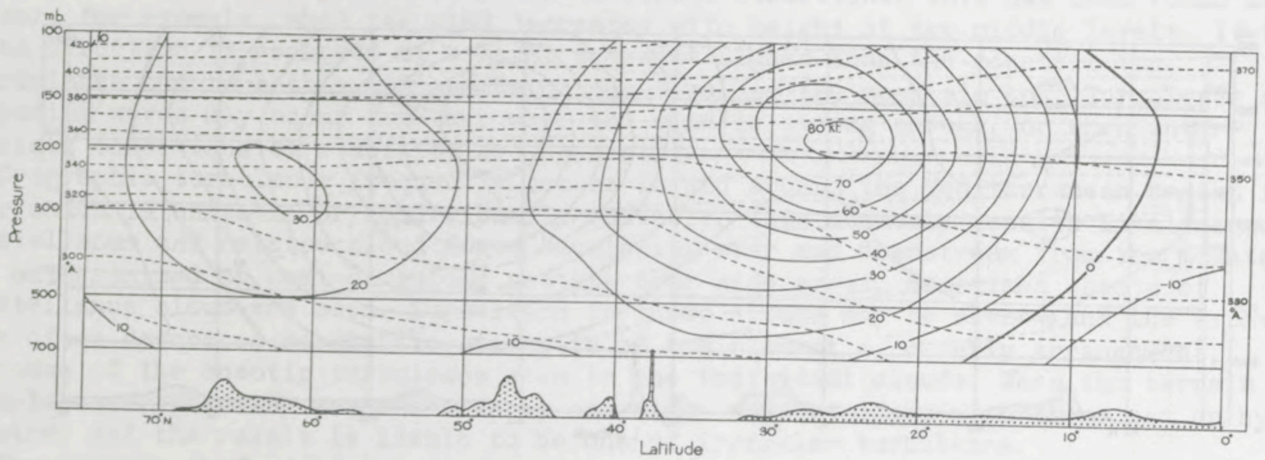


Fig. 1.28(*e*) Cross-section at 15°E. showing wind speeds and potential temperature - April
An easterly wind is indicated by a negative value. Pecked lines are isopleths of potential temperature.

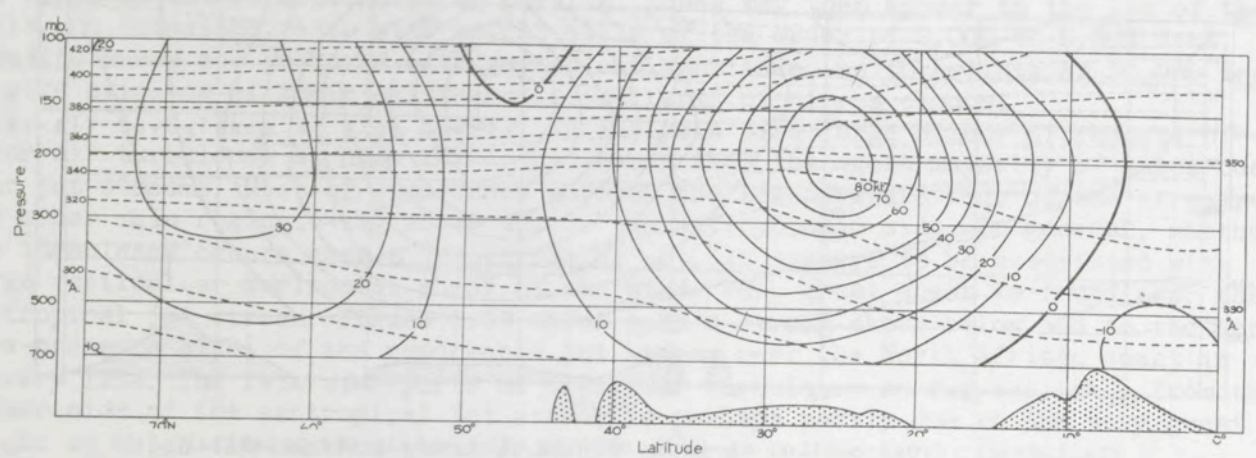


Fig. 1.28(*f*) Cross-section at 40°E. showing wind speeds and potential temperature - April
An easterly wind is indicated by a negative value. Pecked lines are isopleths of potential temperature.

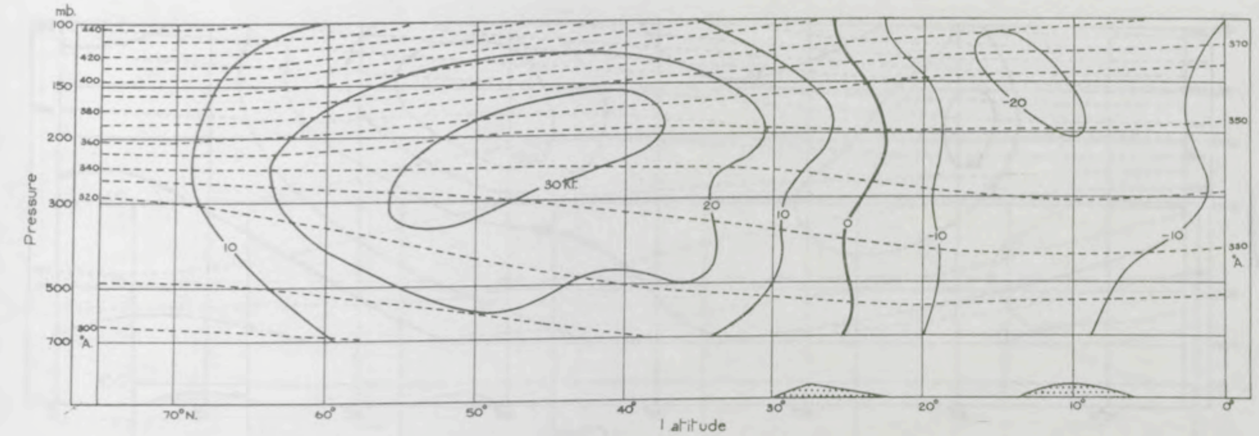


Fig. 1.28(*g*) Cross-section at 10°W. showing wind speeds and potential temperature - July
An easterly wind is indicated by a negative value. Pecked lines are isopleths of potential temperature.

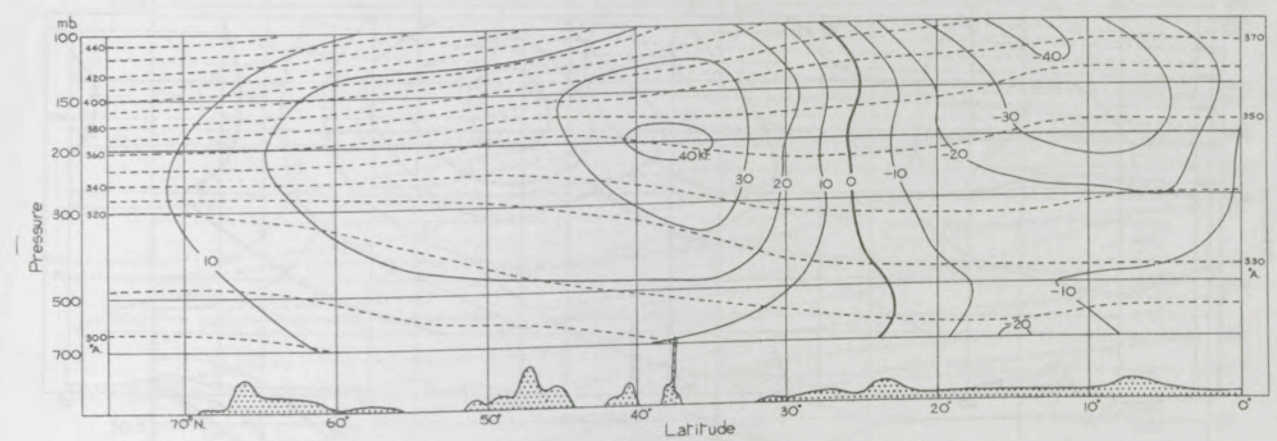


Fig. 1.28(*h*) Cross-section at 15°E. showing wind speeds and potential temperature - July
An easterly wind is indicated by a negative value. Pecked lines are isopleths of potential temperature.

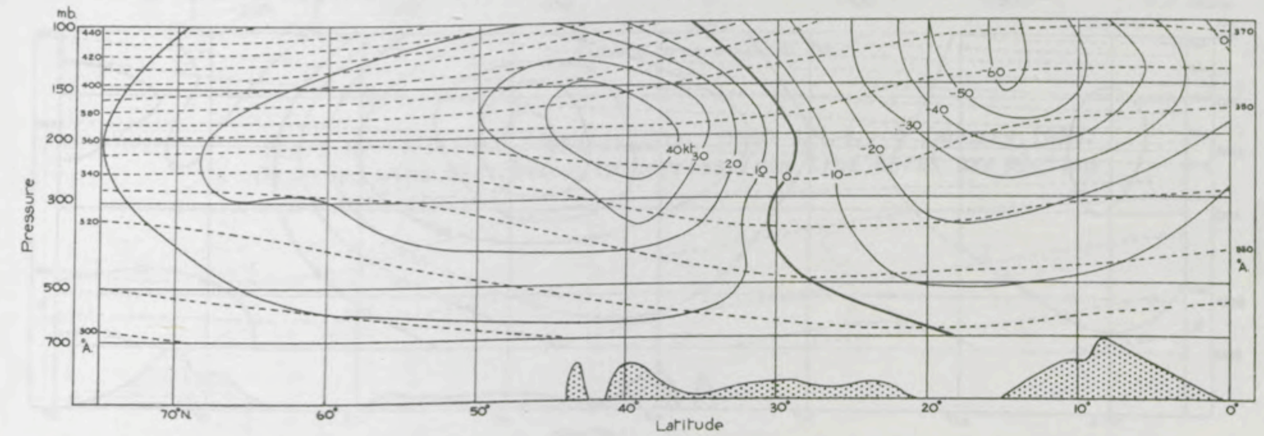


Fig. 1.28(*i*) Cross-section at 40°E. showing wind speeds and potential temperature - July
An easterly wind is indicated by a negative value. Pecked lines are isopleths of potential temperature.

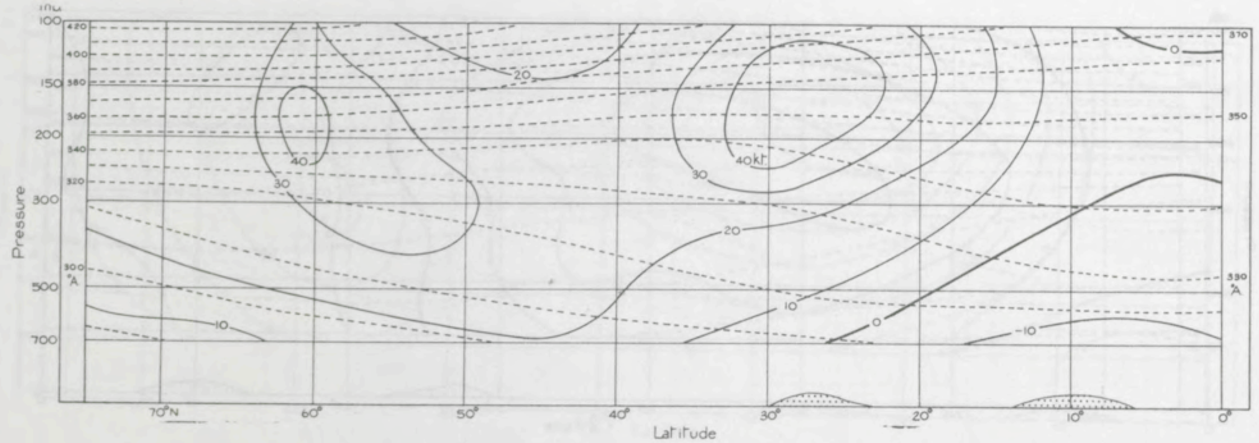


Fig.1.28(*j*) Cross-section at 10^{O}W. showing wind speeds and potential temperature - October
An easterly wind is indicated by a negative value. Pecked lines are isopleths of potential temperature.

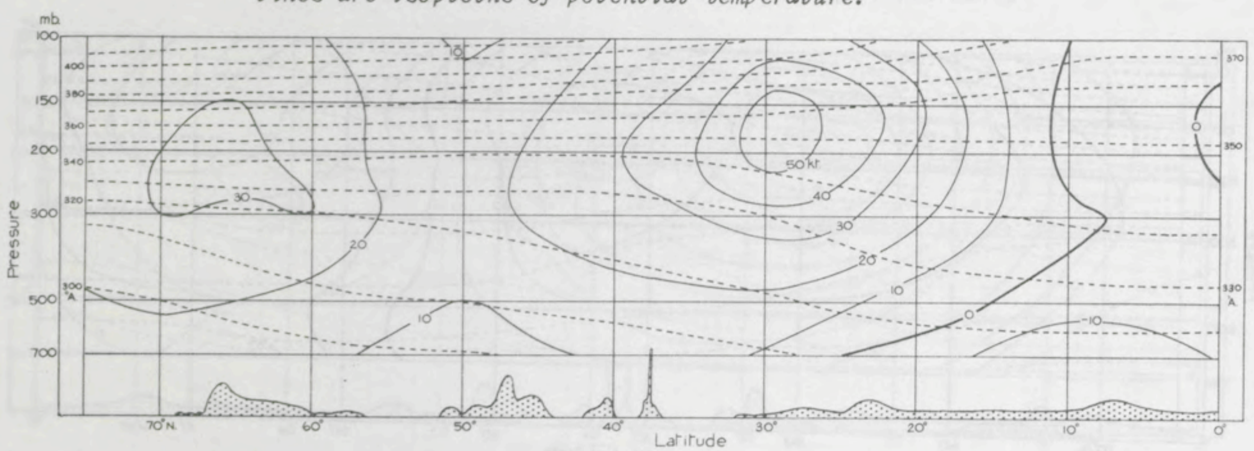


Fig.1.28(*k*) Cross-section at 15^{O}E. showing wind speeds and potential temperature - October
An easterly wind is indicated by a negative value. Pecked lines are isopleths of potential temperature.

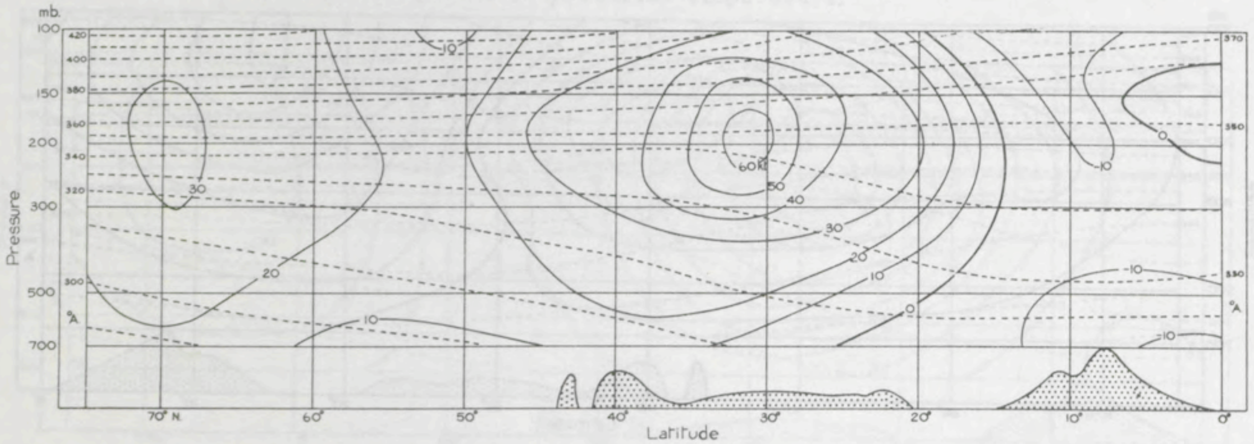


Fig.1.28(*l*) Cross-section at 40^{O}E. showing wind speeds and potential temperature - October
An easterly wind is indicated by a negative value. Pecked lines are isopleths of potential temperature.

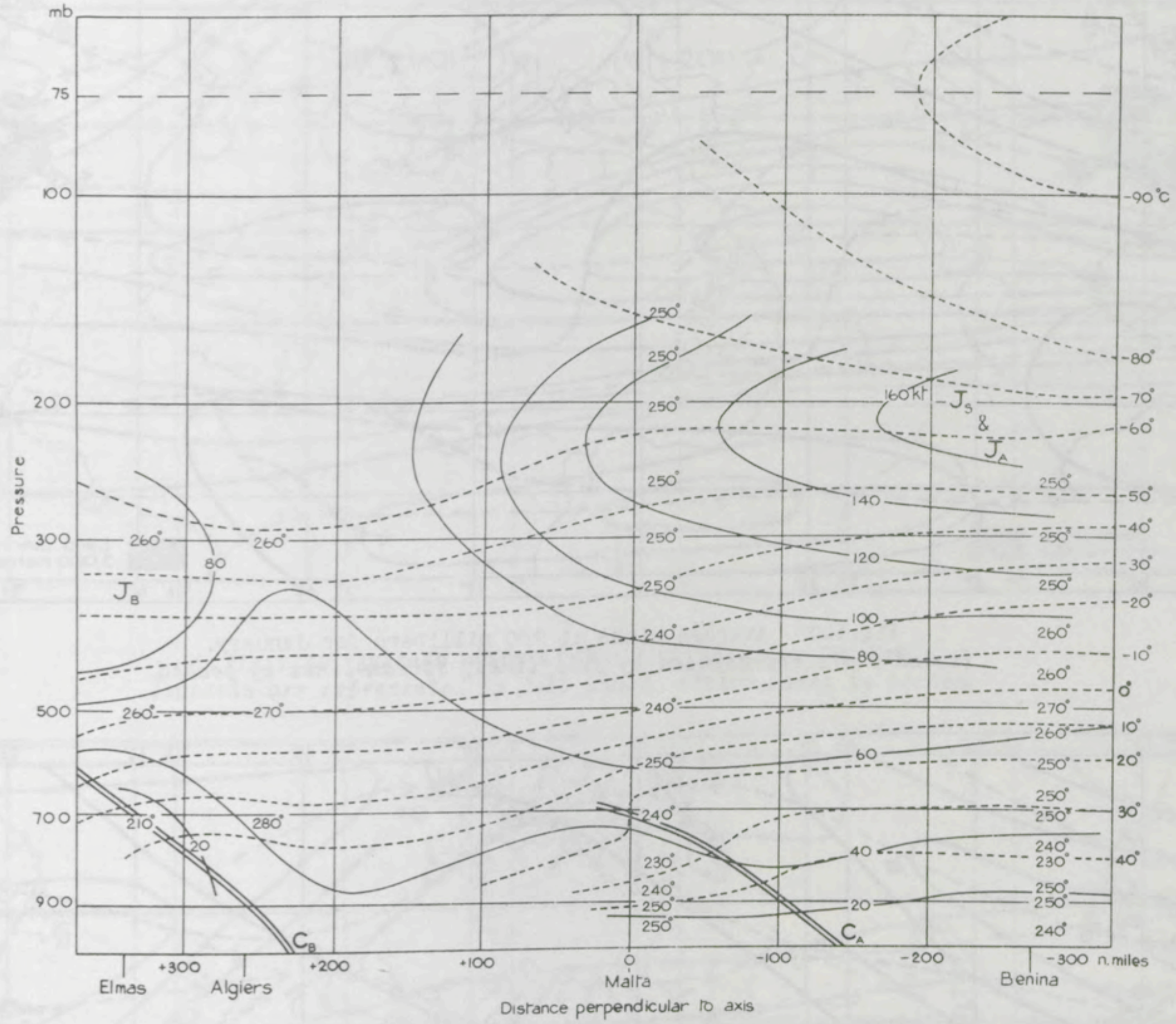


Fig.1.29 Vertical cross-section, 0300 G.M.T., 6 January 1954.
Observed wind directions in degrees from true north are plotted above each station.

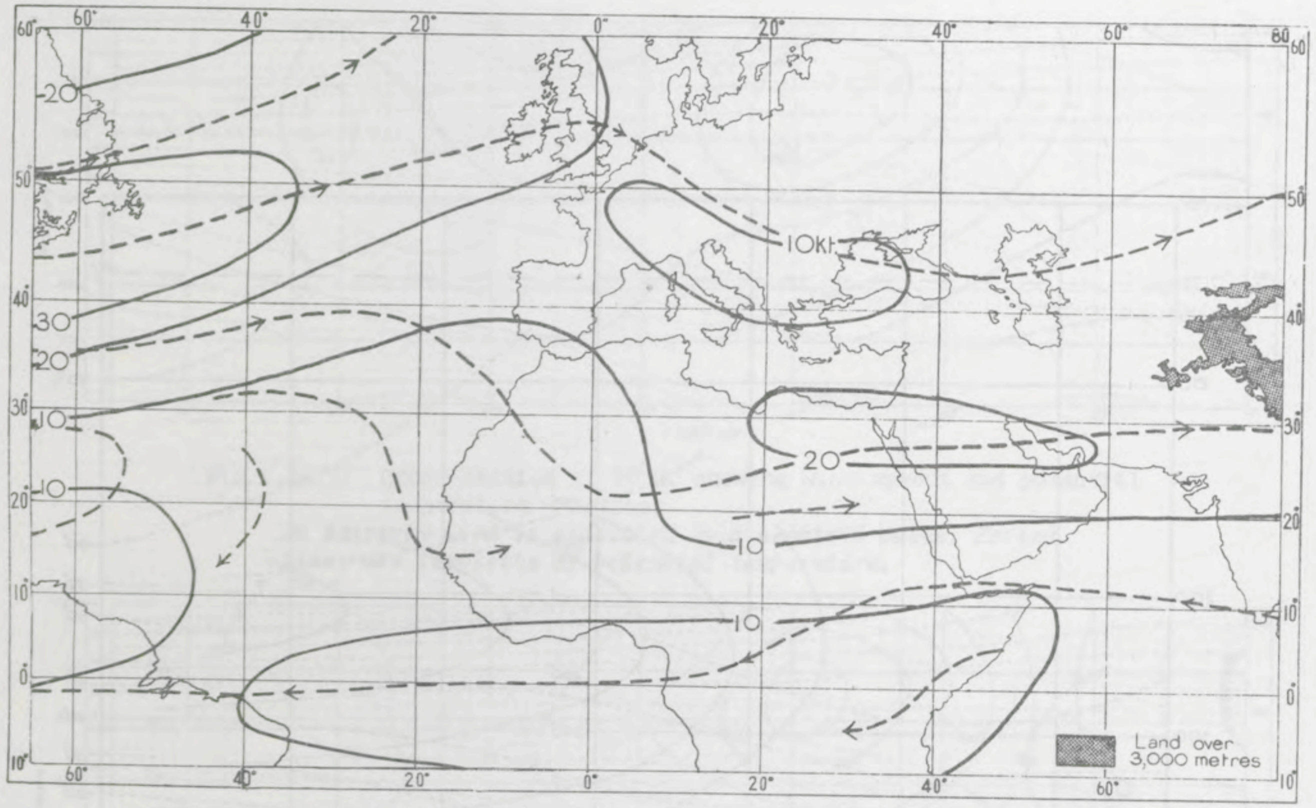


Fig.1.30 Average winds at 700 millibars for January.
Isotachs are represented by full lines, stream-lines by pecked.

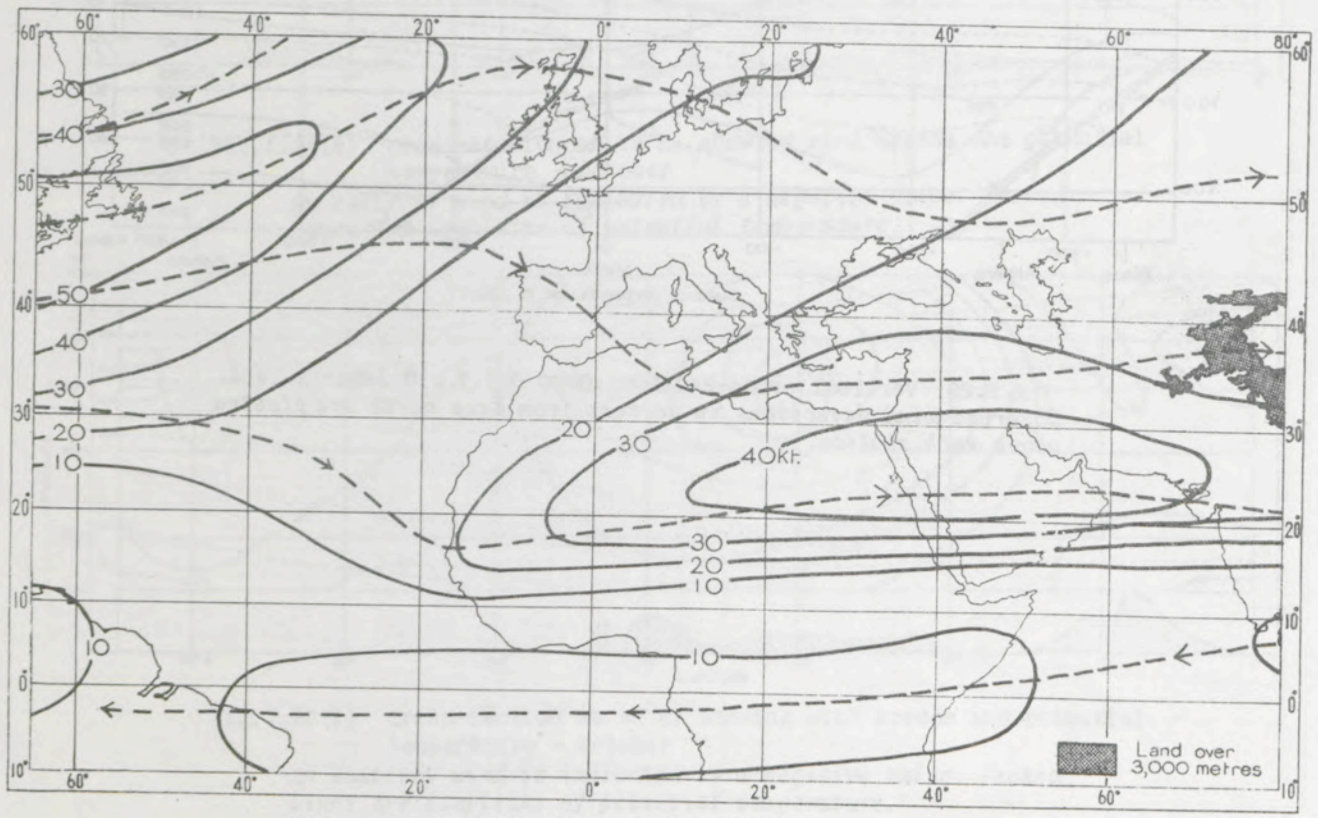


Fig.1.31 Average winds at 500 millibars for January
Isotachs are represented by full lines, stream-lines by pecked.

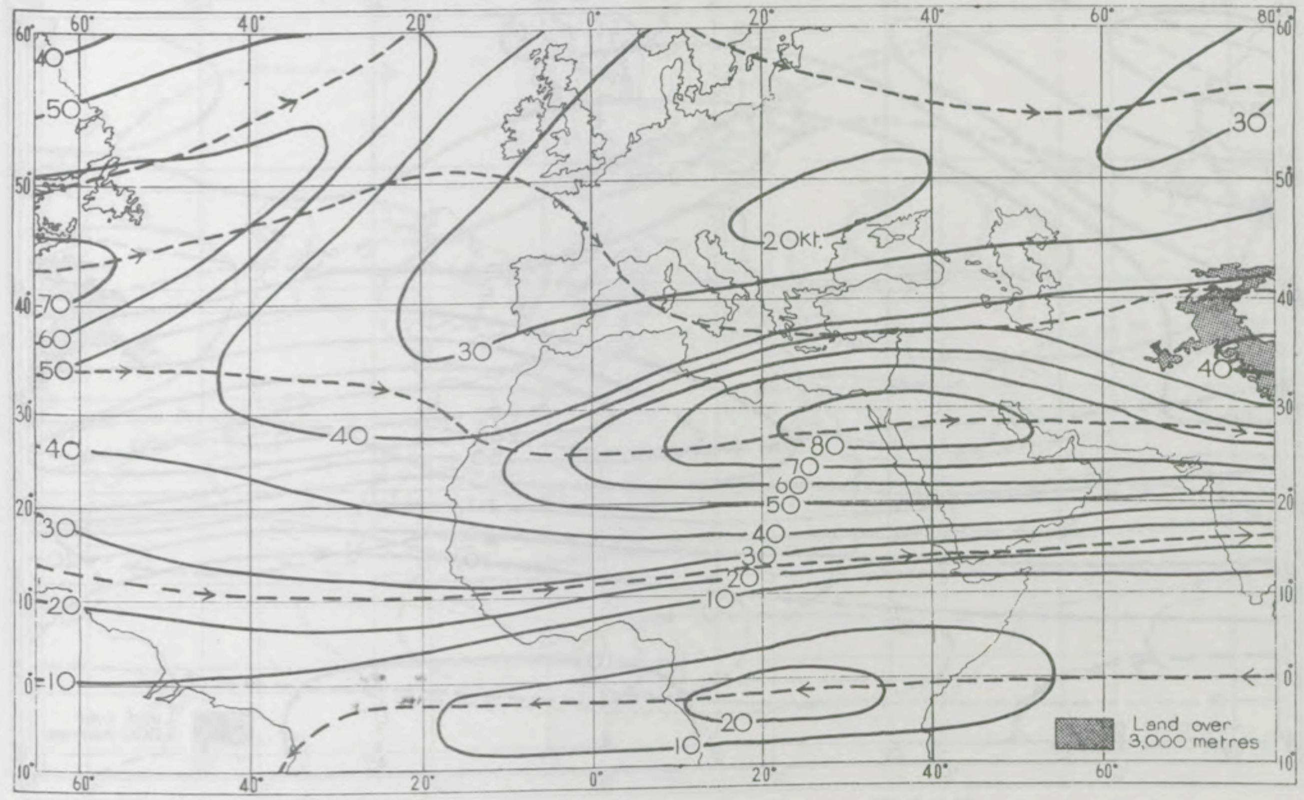


Fig.1.32 Average winds at 300 millibars for January
Isotachs are represented by full lines, stream-lines by pecked.

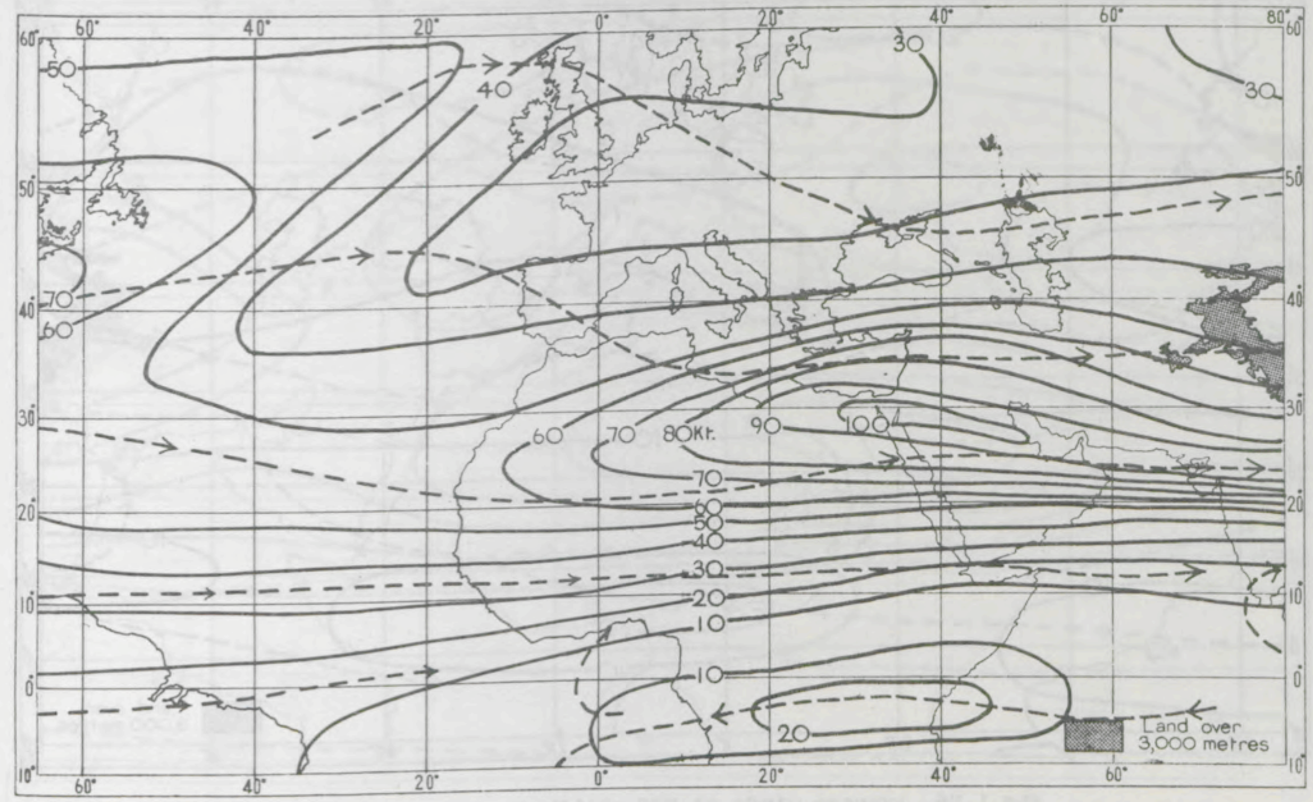


Fig.1.33 Average winds at 200 millibars for January
Isotachs are represented by full lines, stream-lines by pecked.

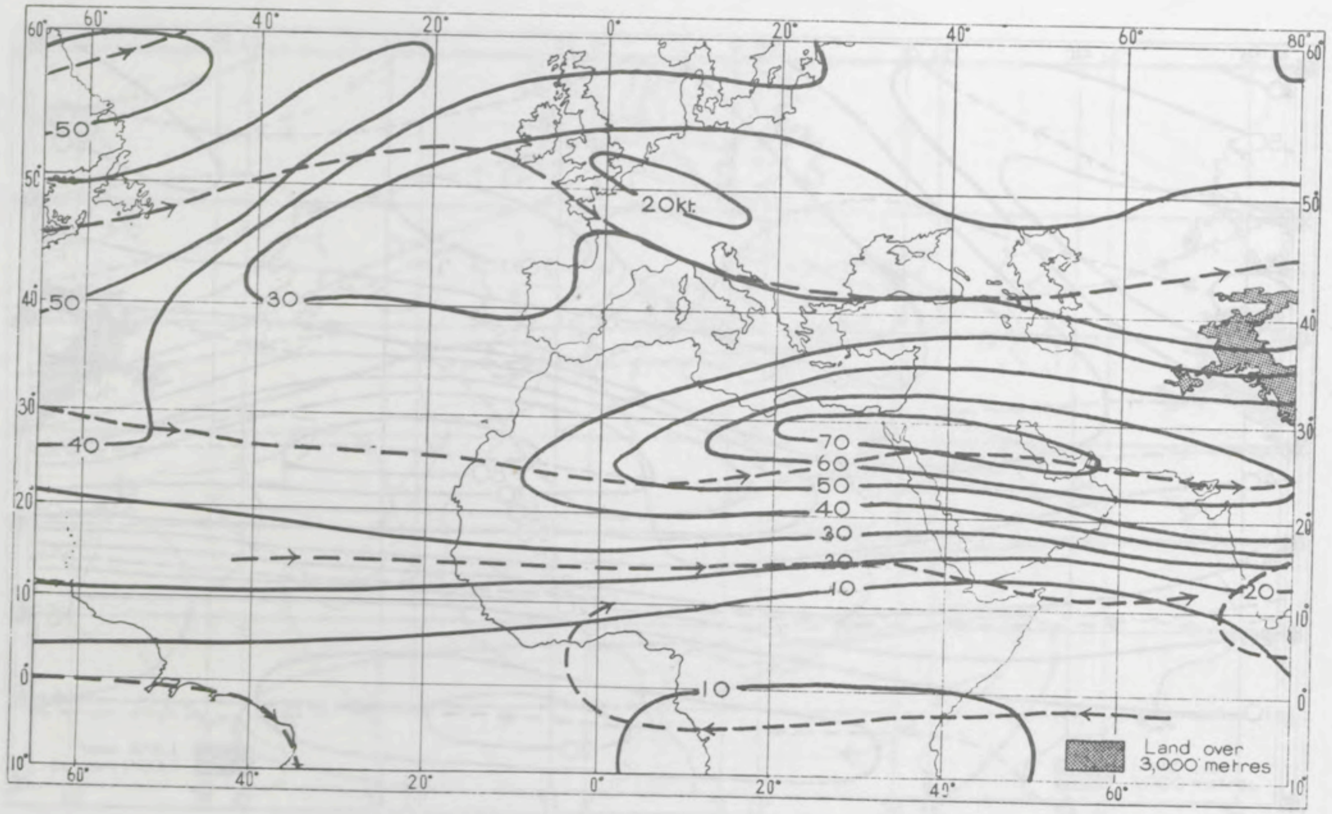


Fig.1.34 Average winds at 100 millibars for January
Isotachs are represented by full lines, stream-lines by pecked.

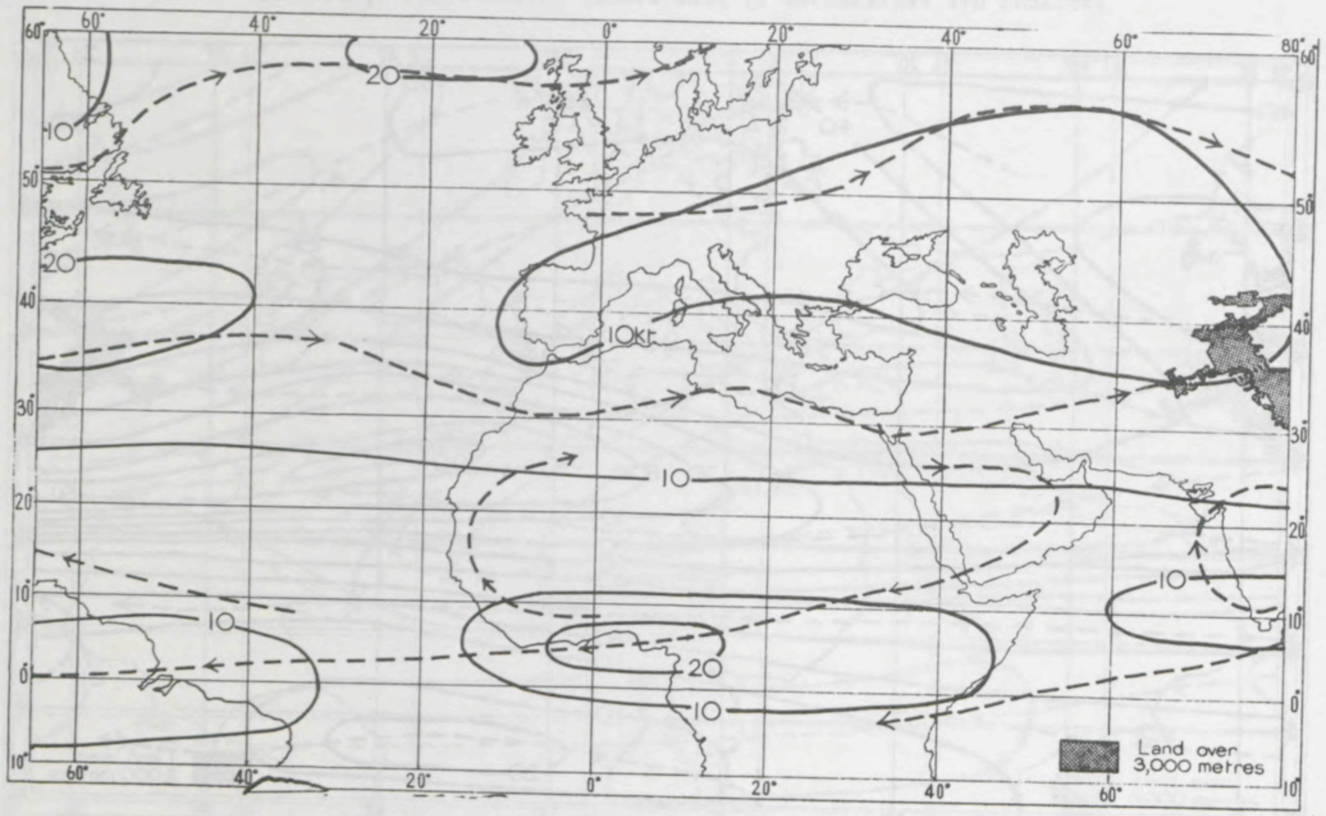


Fig.1.35 Average winds at 700 millibars for April
Isotachs are represented by full lines, stream-lines by pecked.

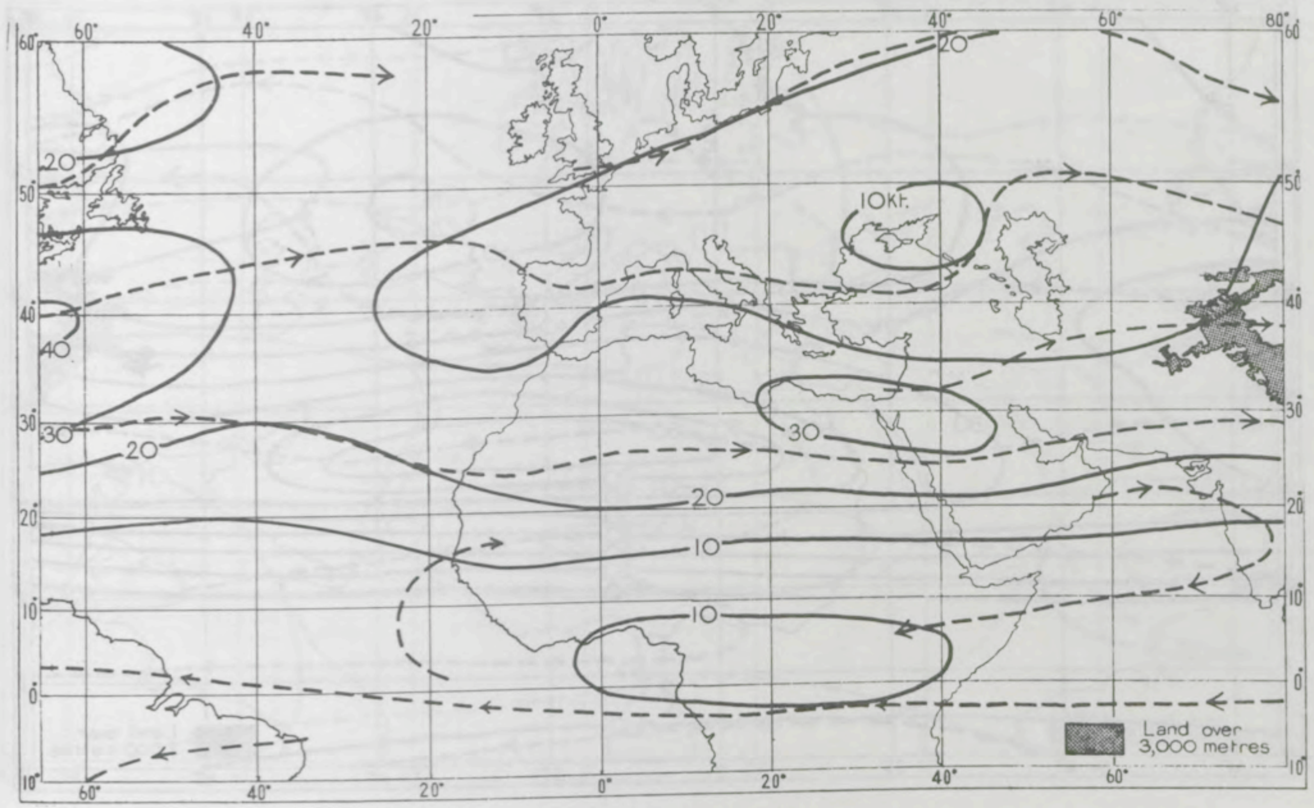


Fig.1.36 Average winds at 500 millibars for April
Isotachs are represented by full lines, stream-lines by pecked.

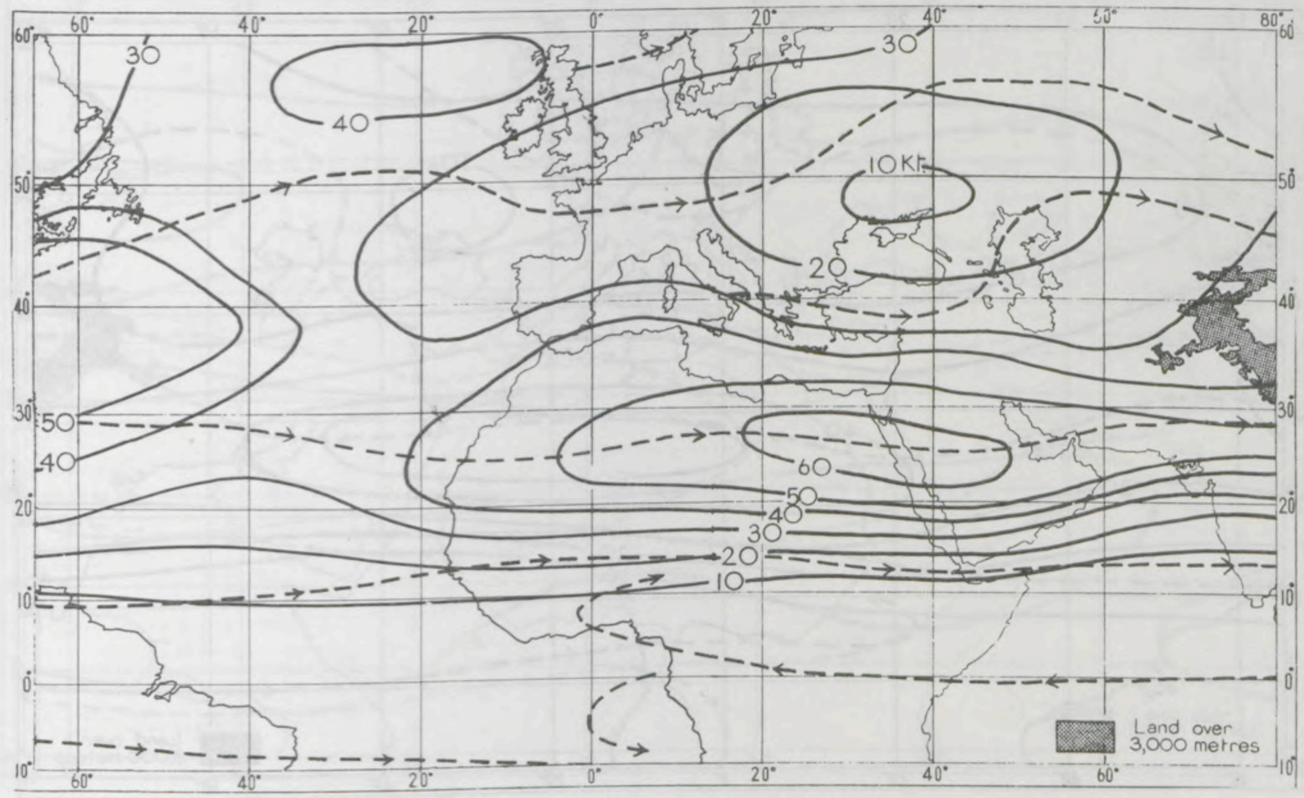


Fig.1.37 Average winds at 300 millibars for April
Isotachs are represented by full lines, stream-lines by pecked.

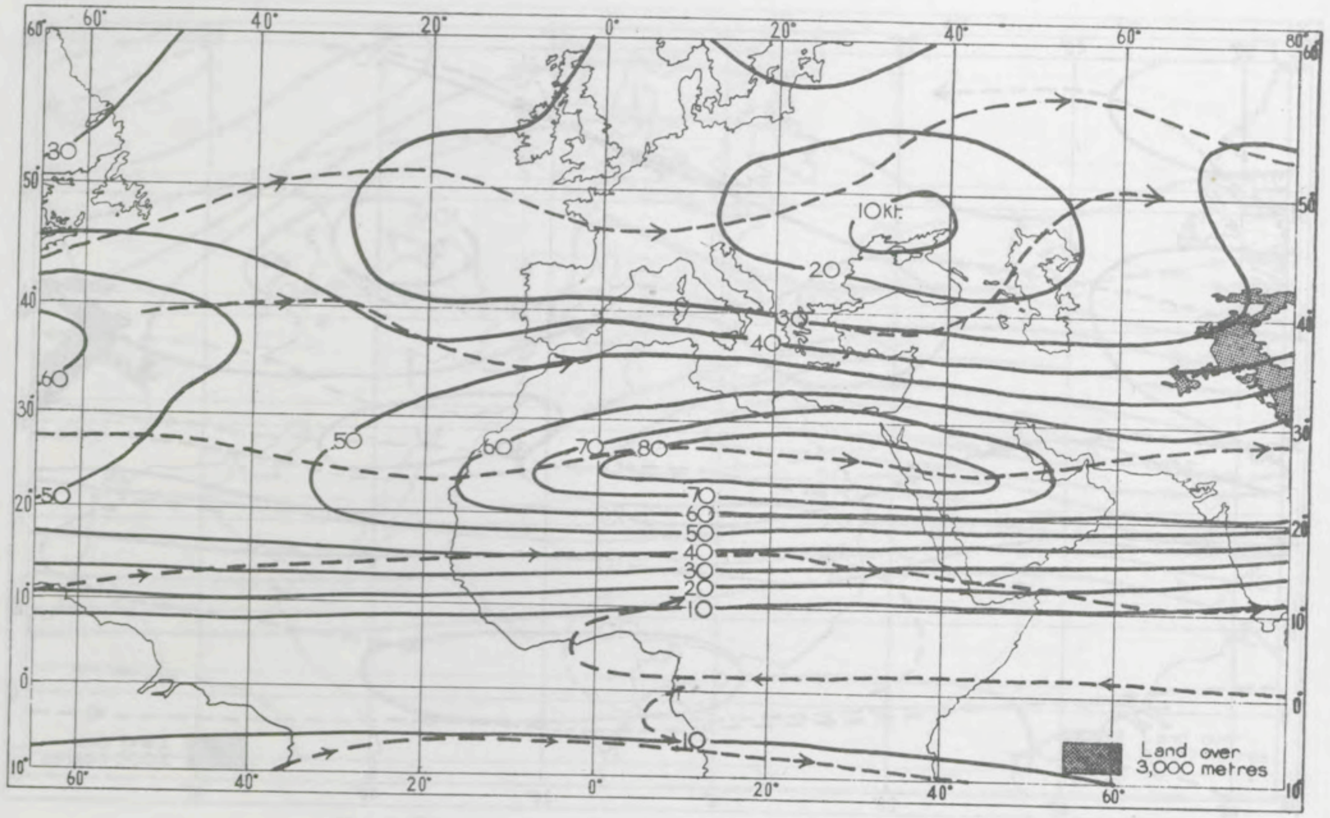


Fig.1.38 Average winds at 200 millibars for April
Isotachs are represented by full lines, stream-lines by pecked.

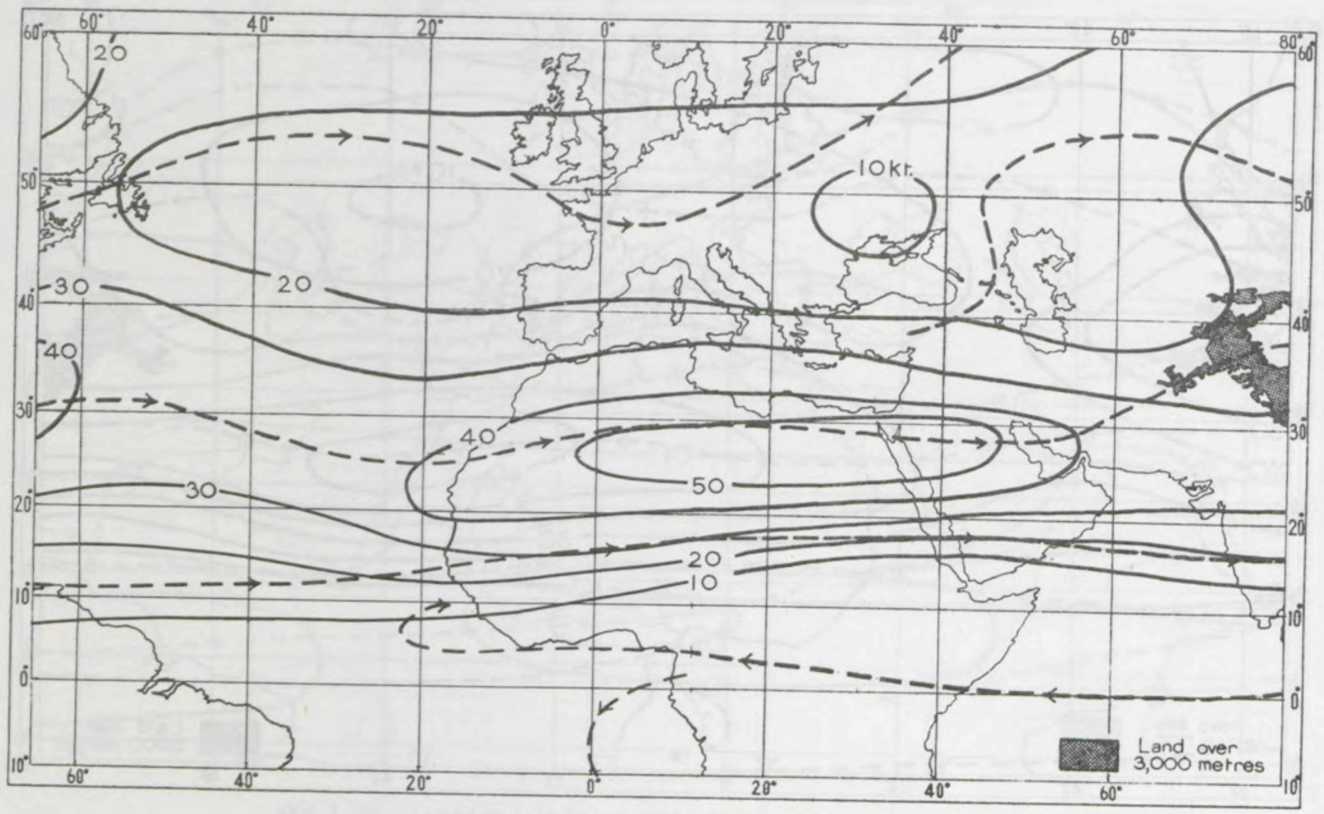


Fig.1.39 Average winds at 100 millibars for April
Isotachs are represented by full lines, stream-lines by pecked.

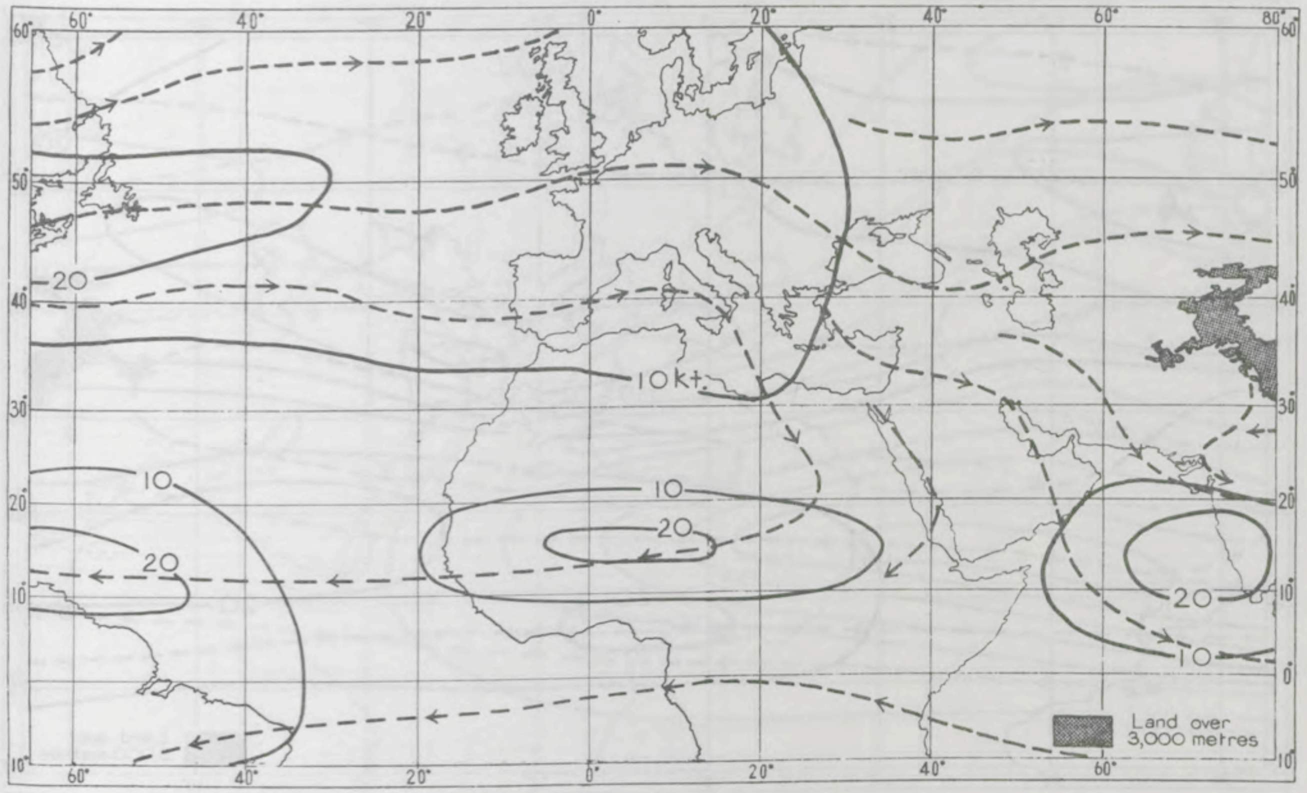


Fig.1.40 Average winds at 700 millibars for July
Isotachs are represented by full lines, stream-lines by pecked.

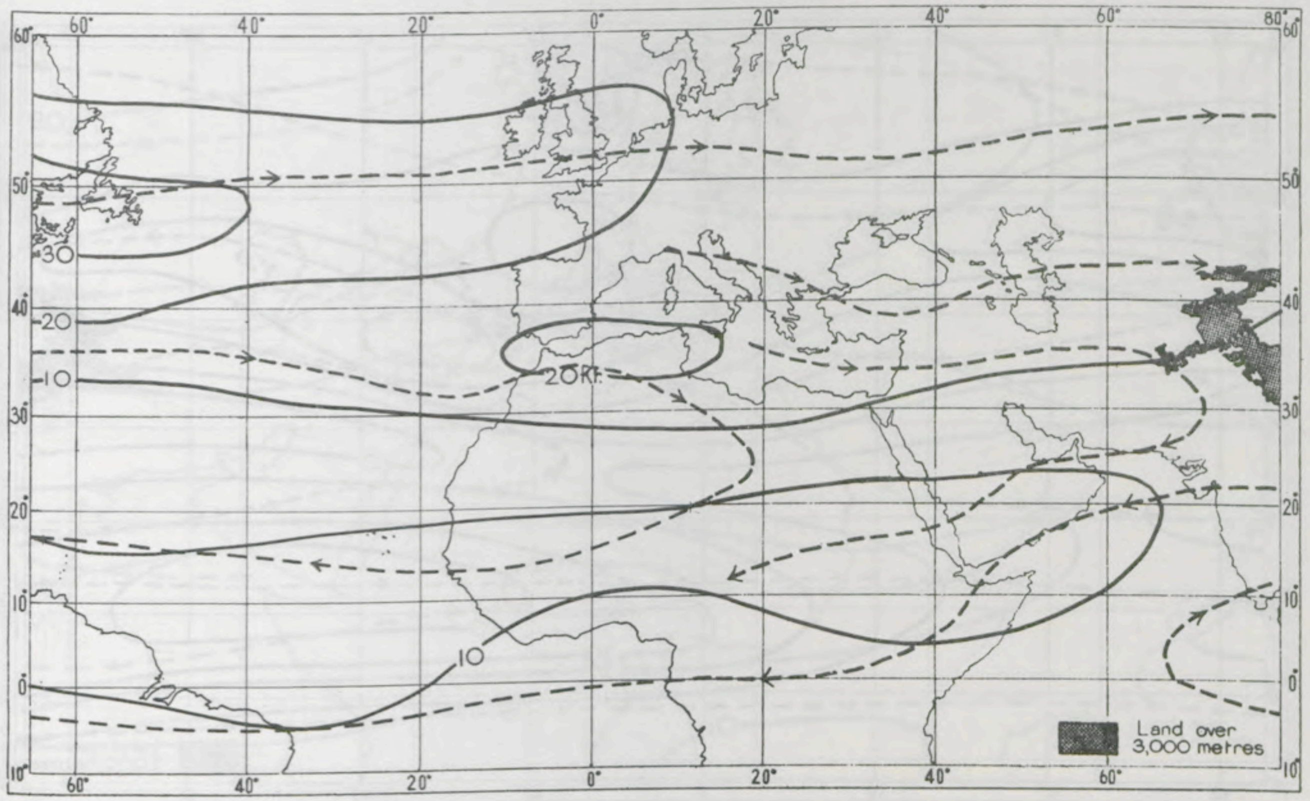


Fig.1.41 Average winds at 500 millibars for July
Isotachs are represented by full lines, stream-lines by pecked.

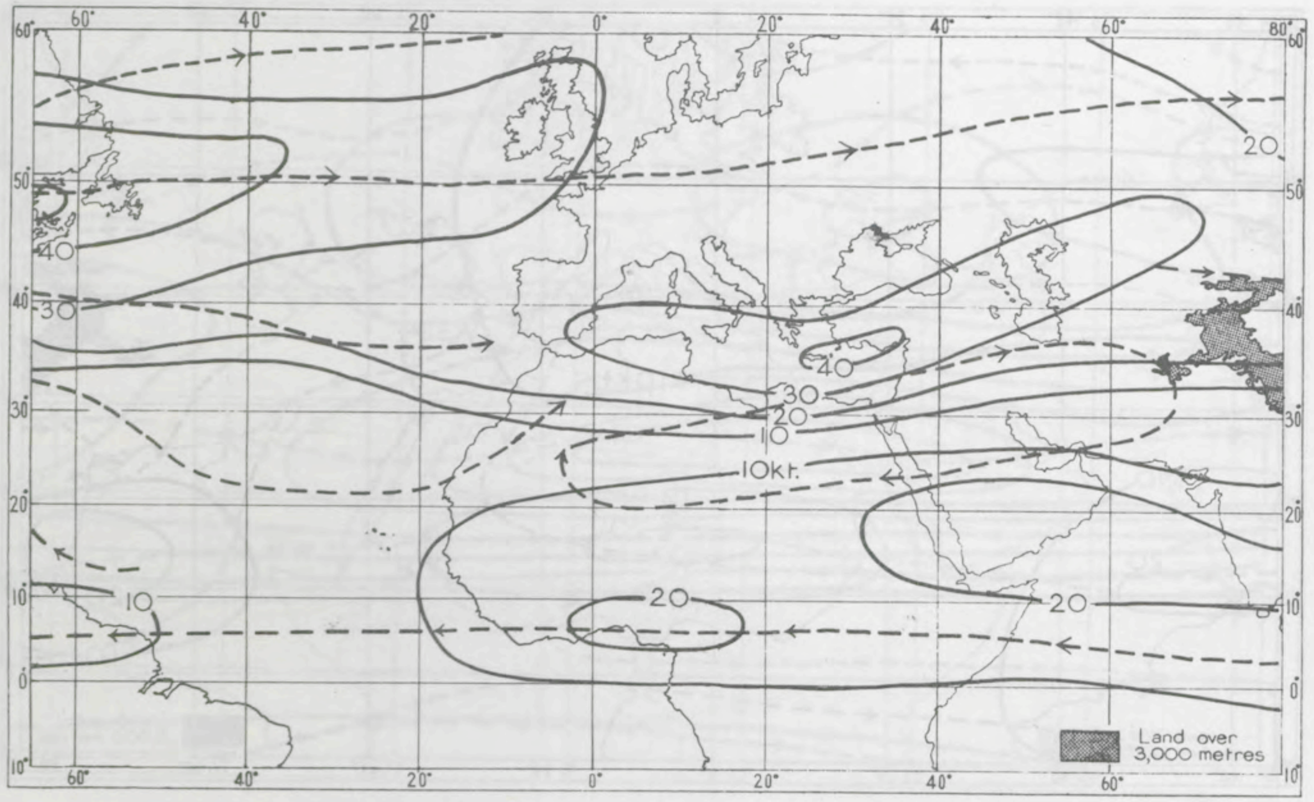


Fig.1.42 Average winds at 300 millibars for July
Isotachs are represented by full lines, stream-lines by pecked.

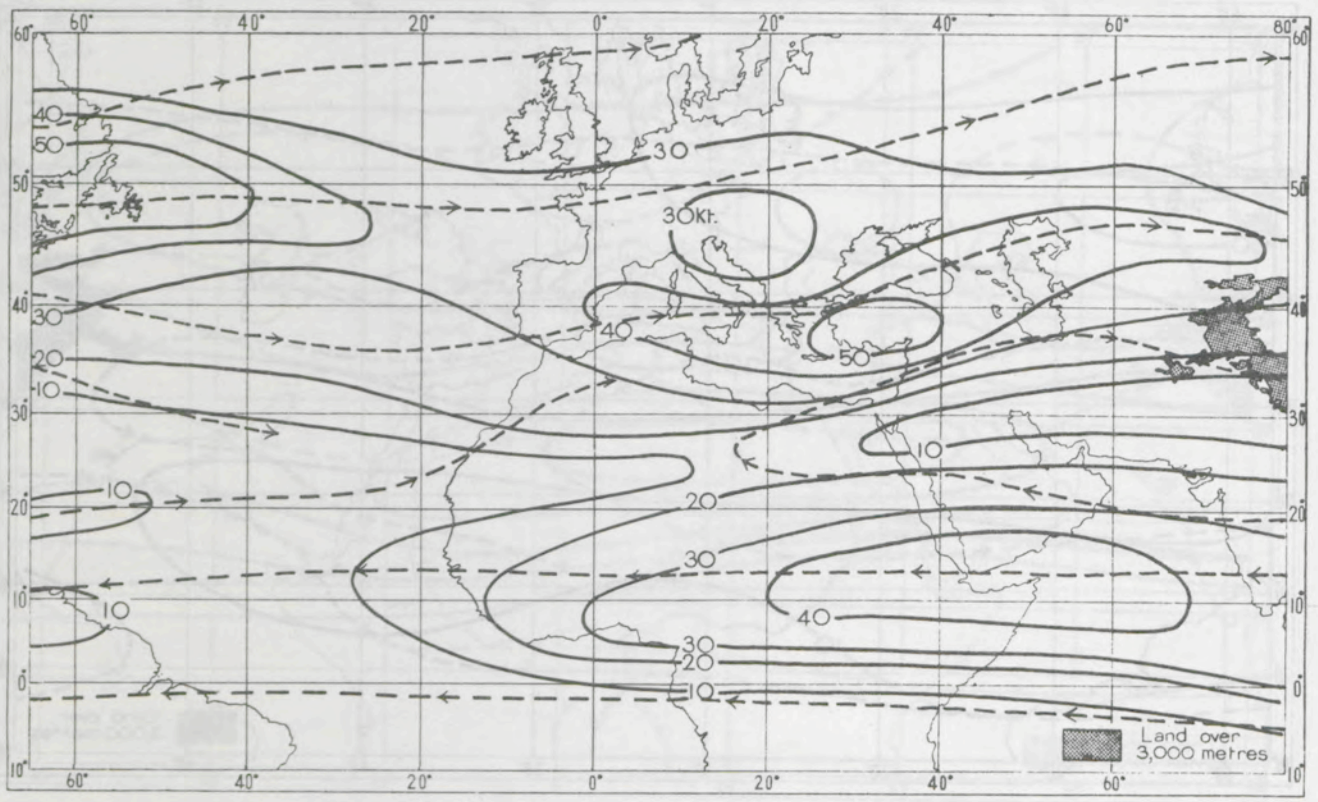


Fig.1.43 Average winds at 200 millibars for July
Isotachs are represented by full lines, stream-lines by pecked.

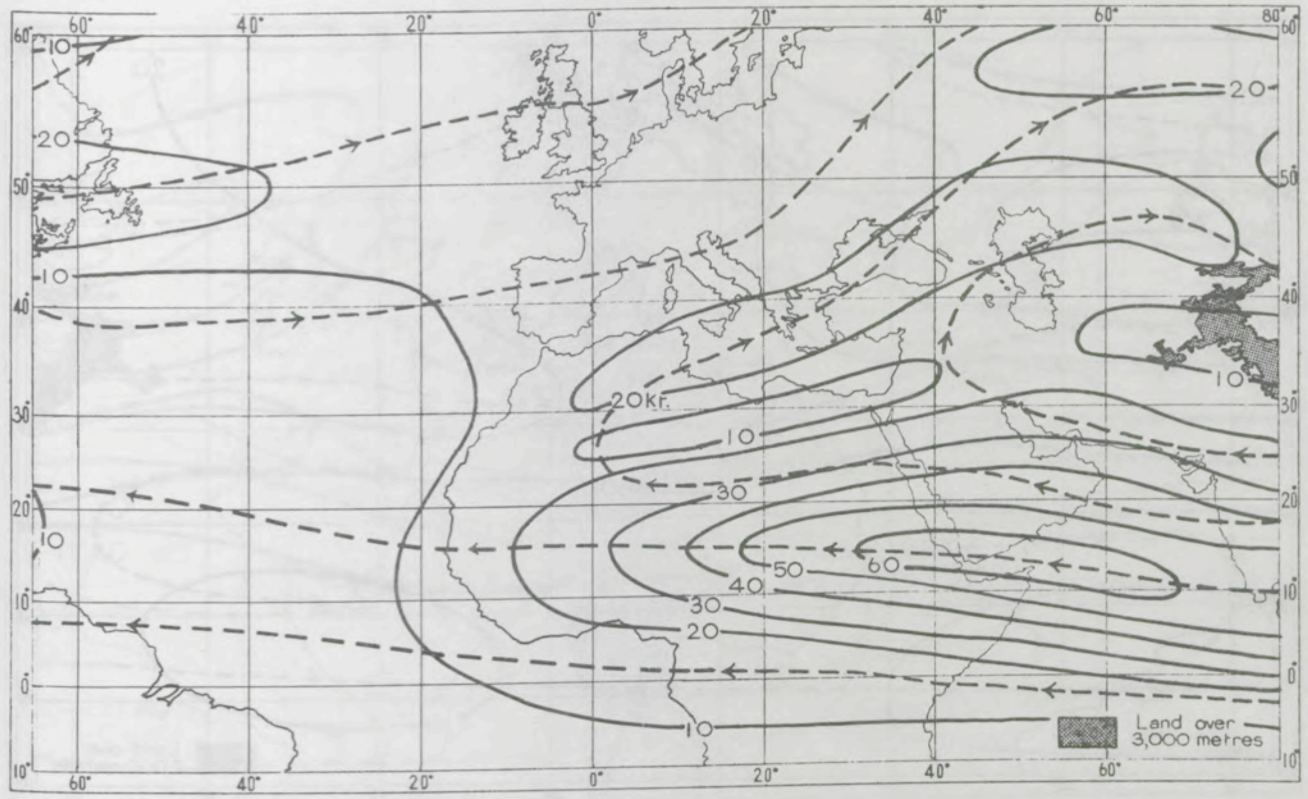


Fig.1.44 Average winds at 100 millibars for July
Isotachs are represented by full lines, stream-lines by pecked.

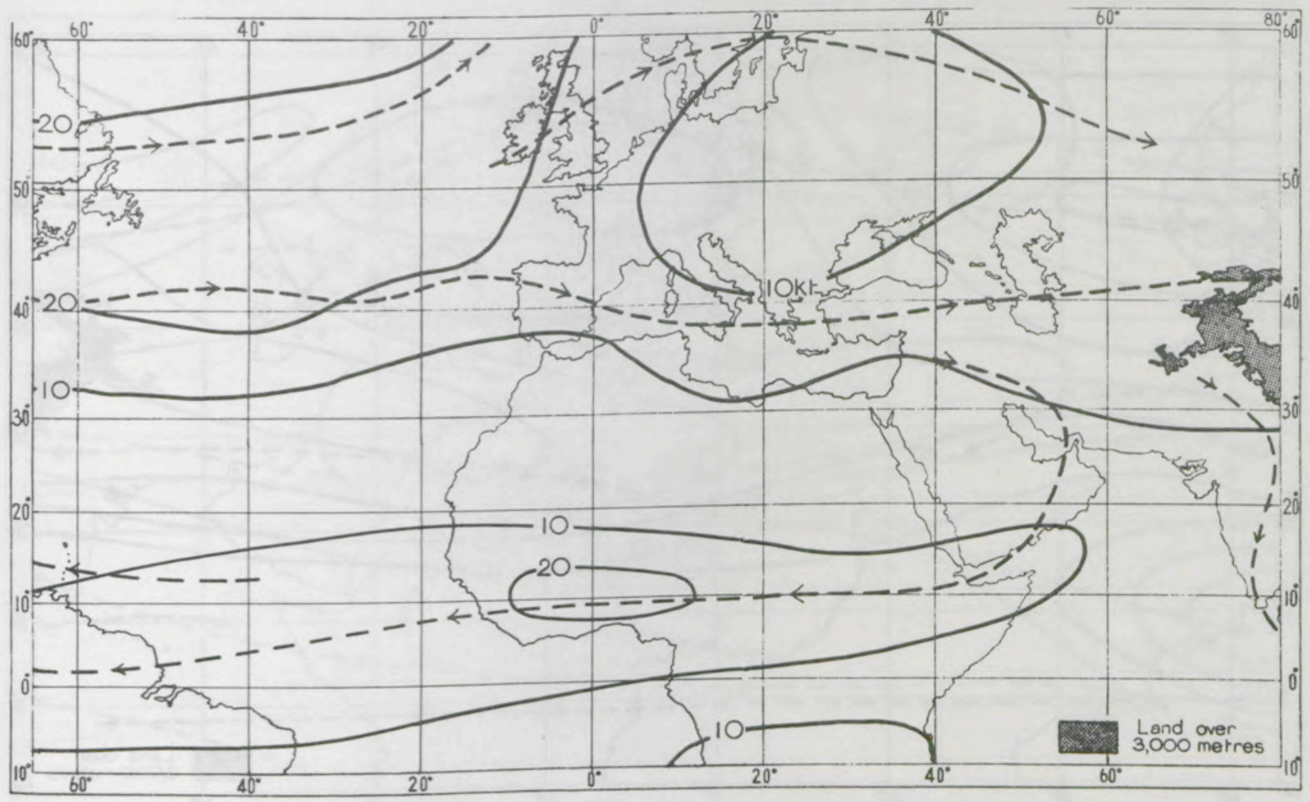


Fig.1.45 Average winds at 700 millibars for October
Isotachs are represented by full lines, stream-lines by pecked.

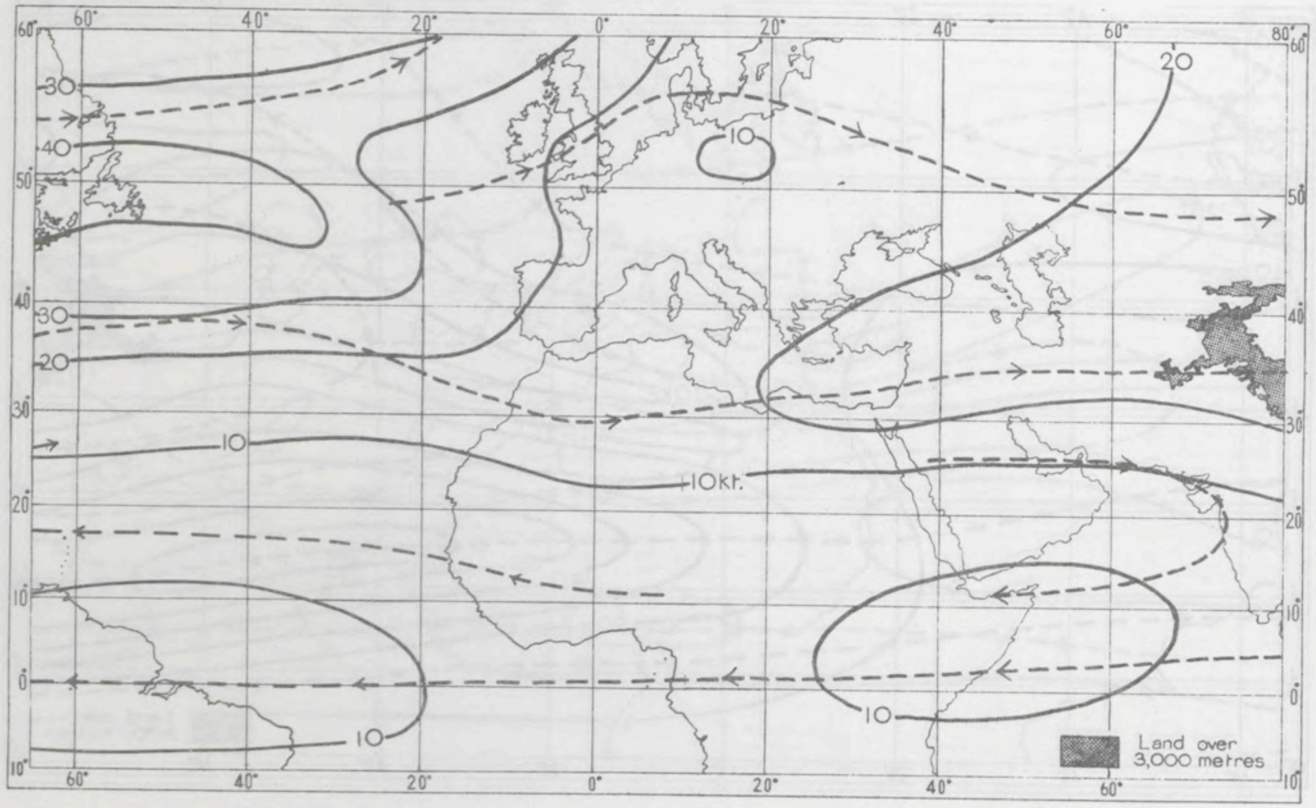


Fig.1.46 Average winds at 500 millibars for October
Isotachs are represented by full lines, stream-lines by pecked.

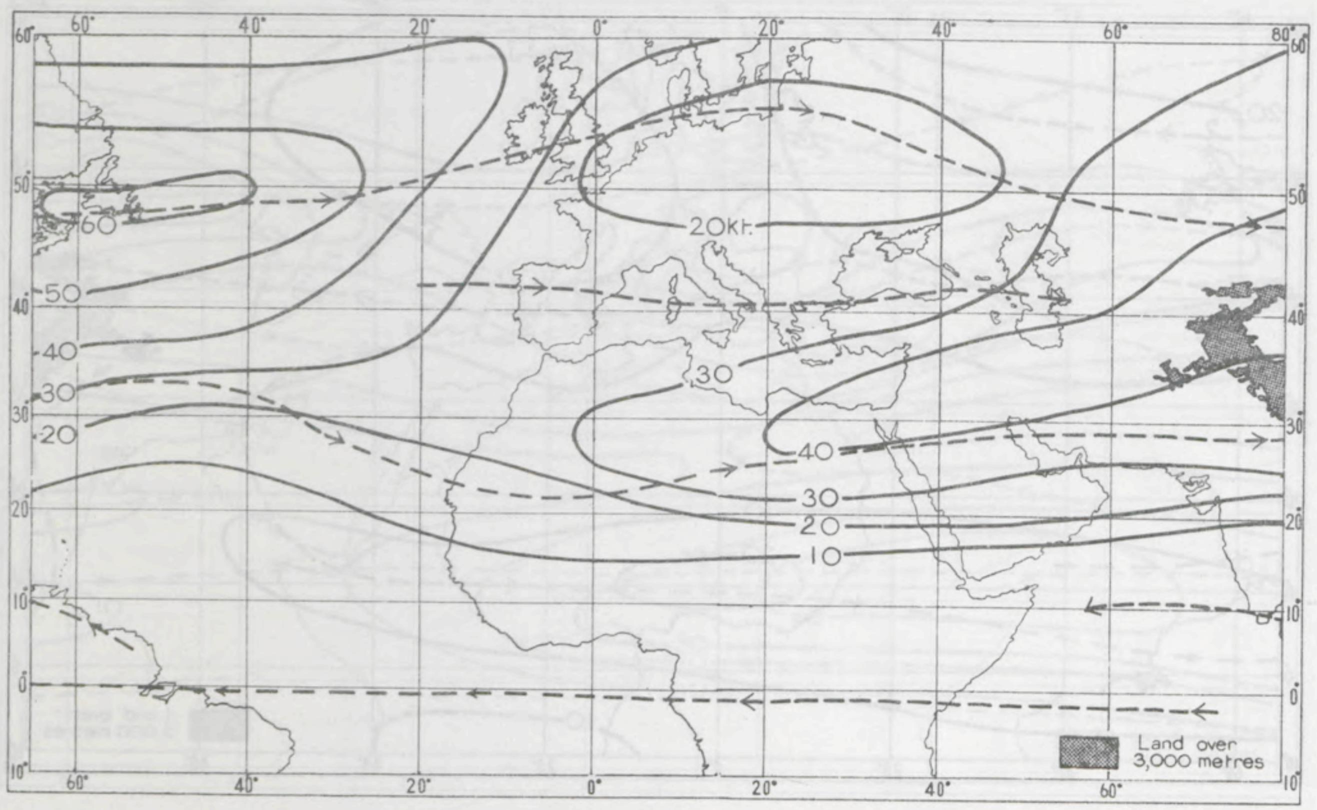


Fig.1.47 Average winds at 300 millibars for October
Isotachs are represented by full lines, stream-lines by pecked.

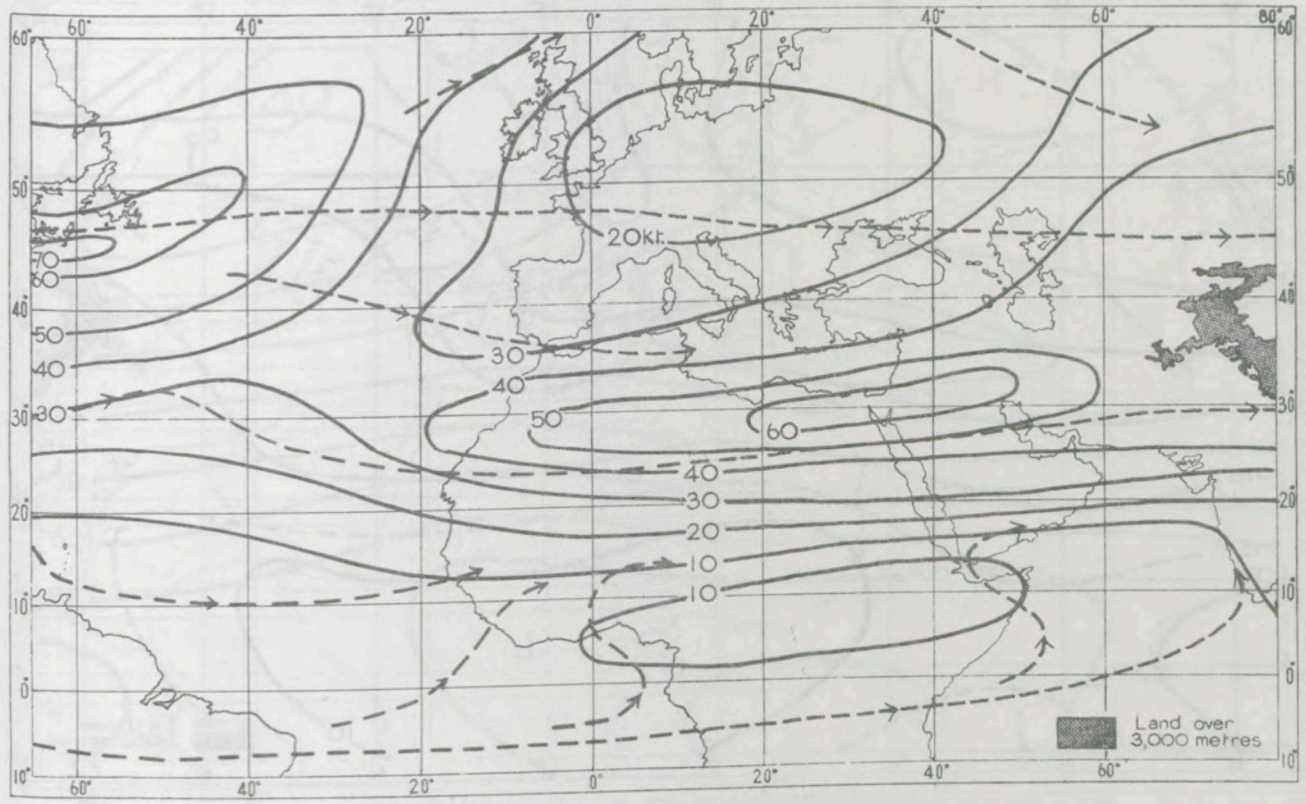


Fig.1.48 Average winds at 200 millibars for October
Isotachs are represented by full lines, stream-lines by pecked.

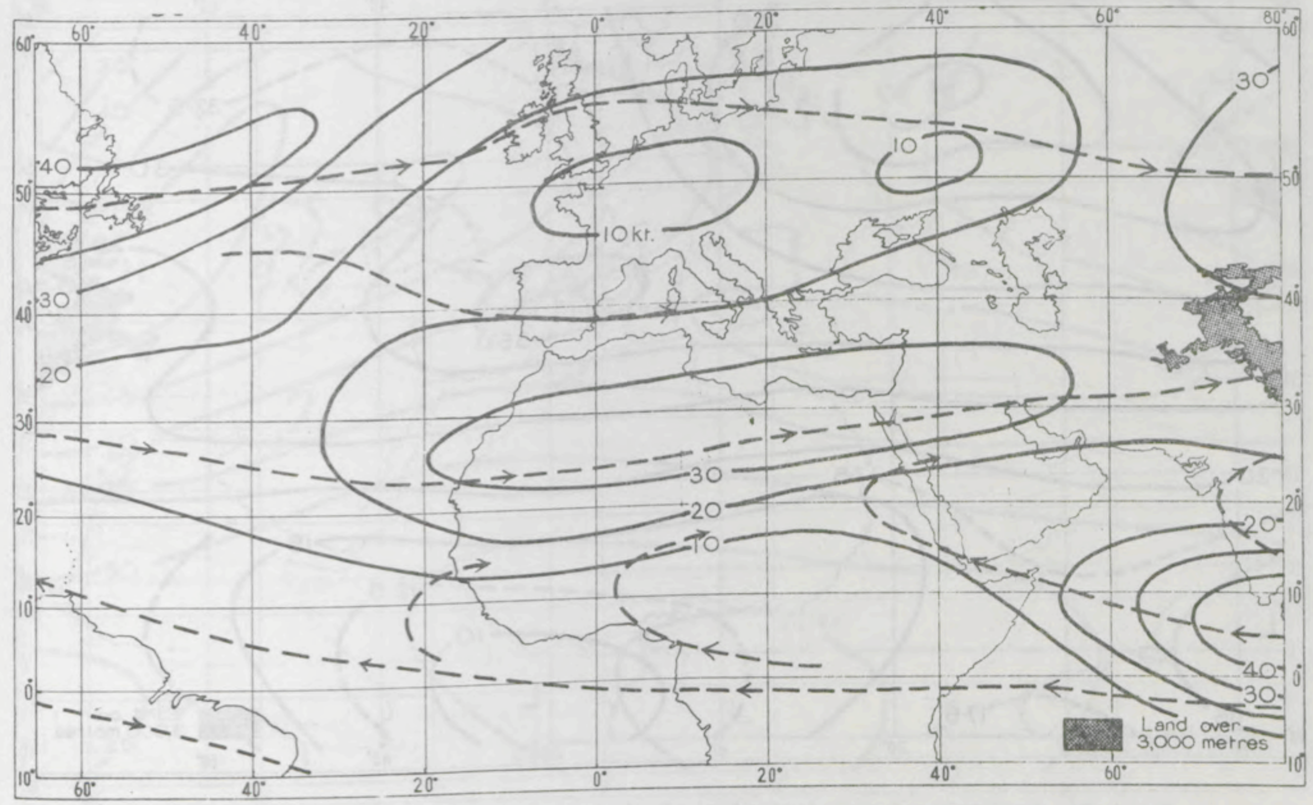


Fig.1.49 Average winds at 100 millibars for October
Isotachs are represented by full lines, stream-lines by pecked.

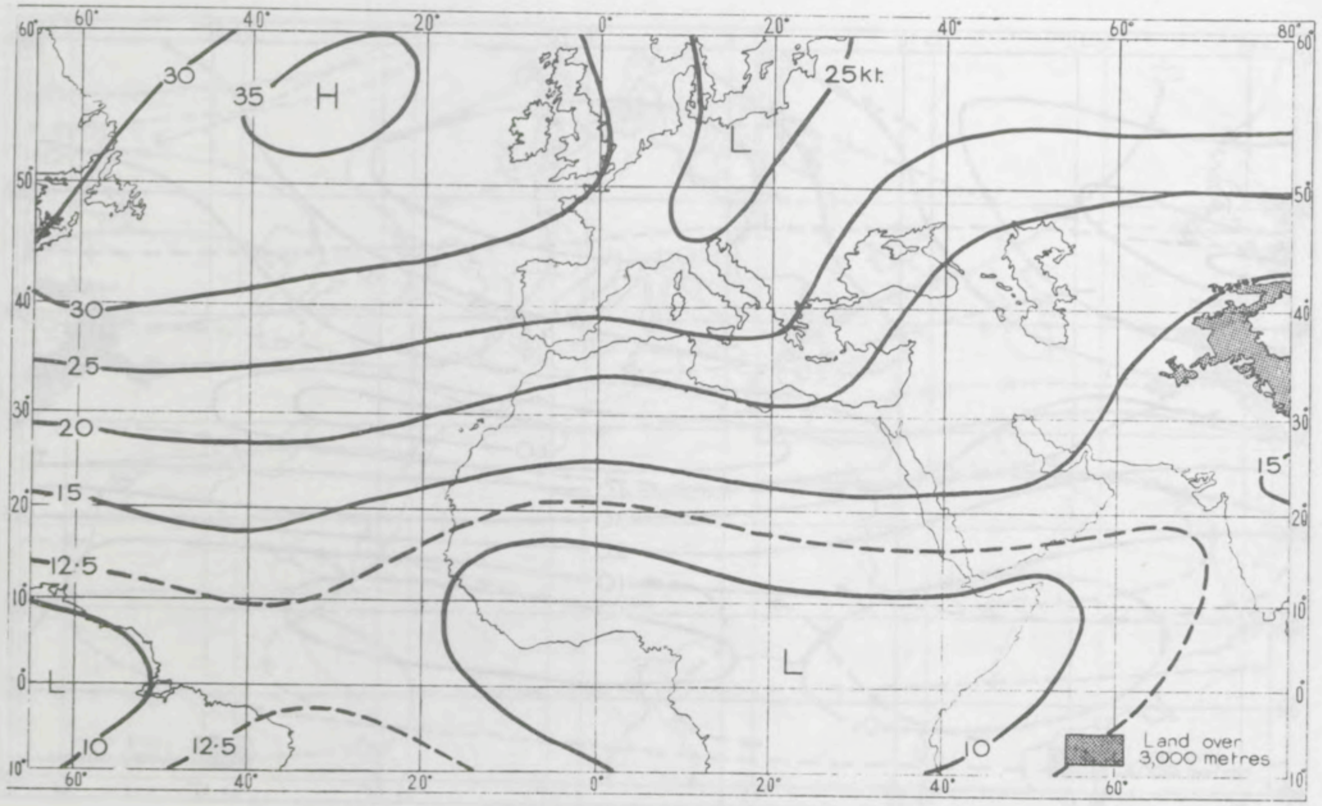


Fig.1.50 Standard vector deviation of wind at 700 millibars in January

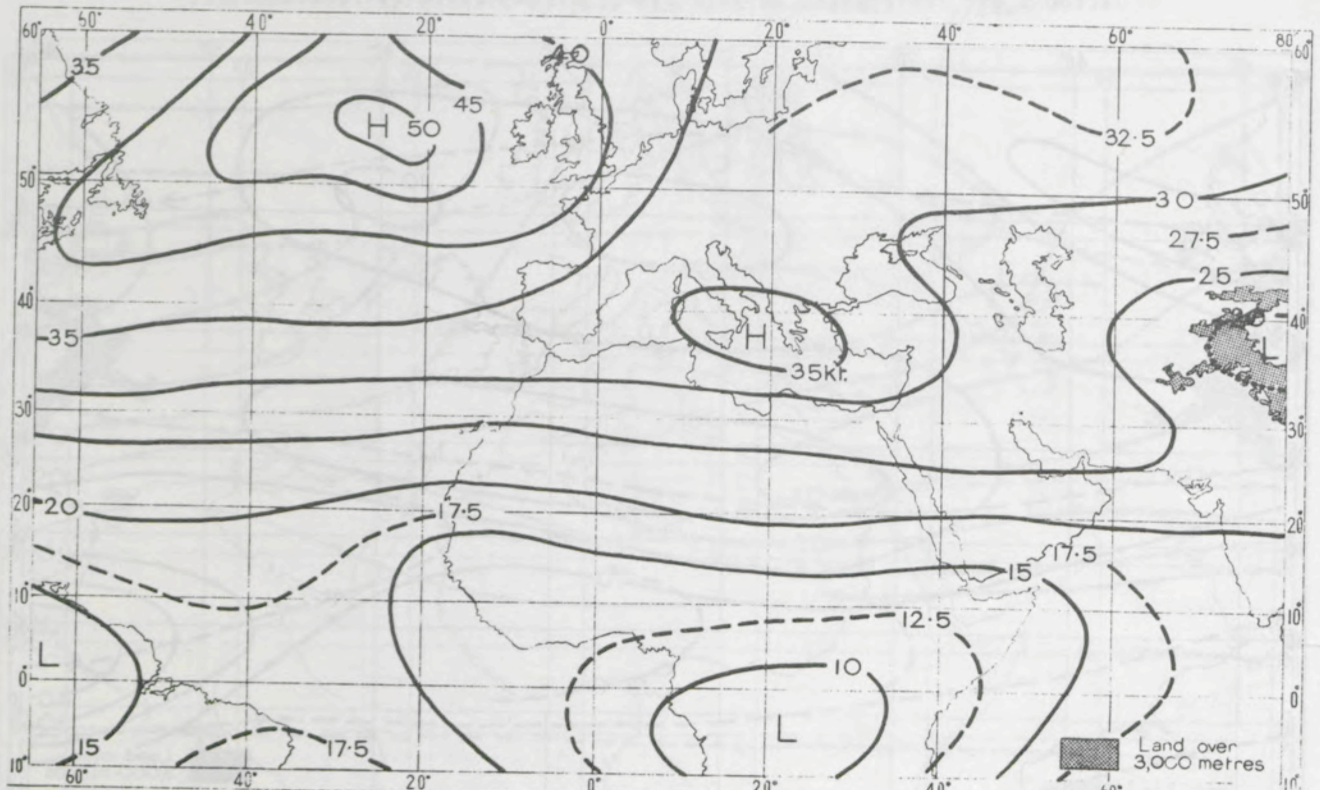


Fig.1.51 Standard vector deviation of wind at 500 millibars in January

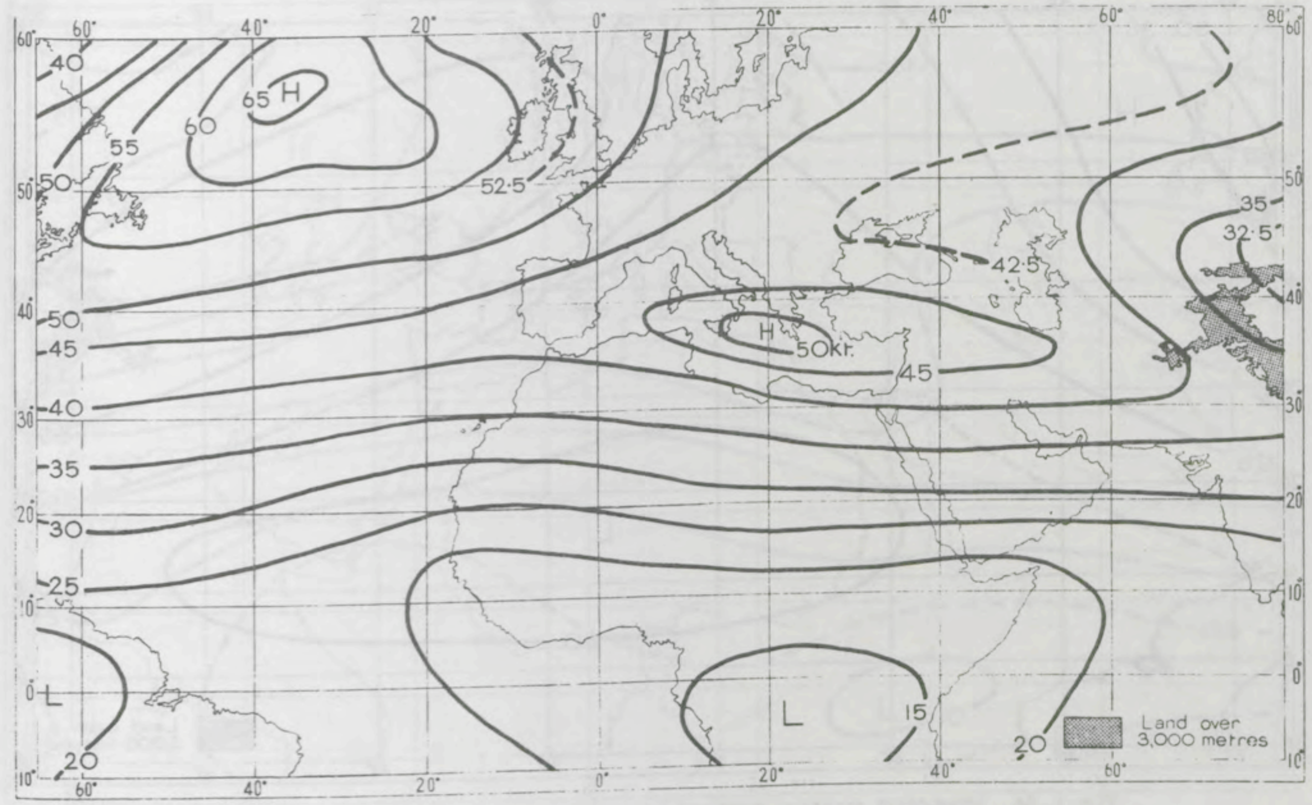


Fig.1.52 Standard vector deviation of wind at 300 millibars in January

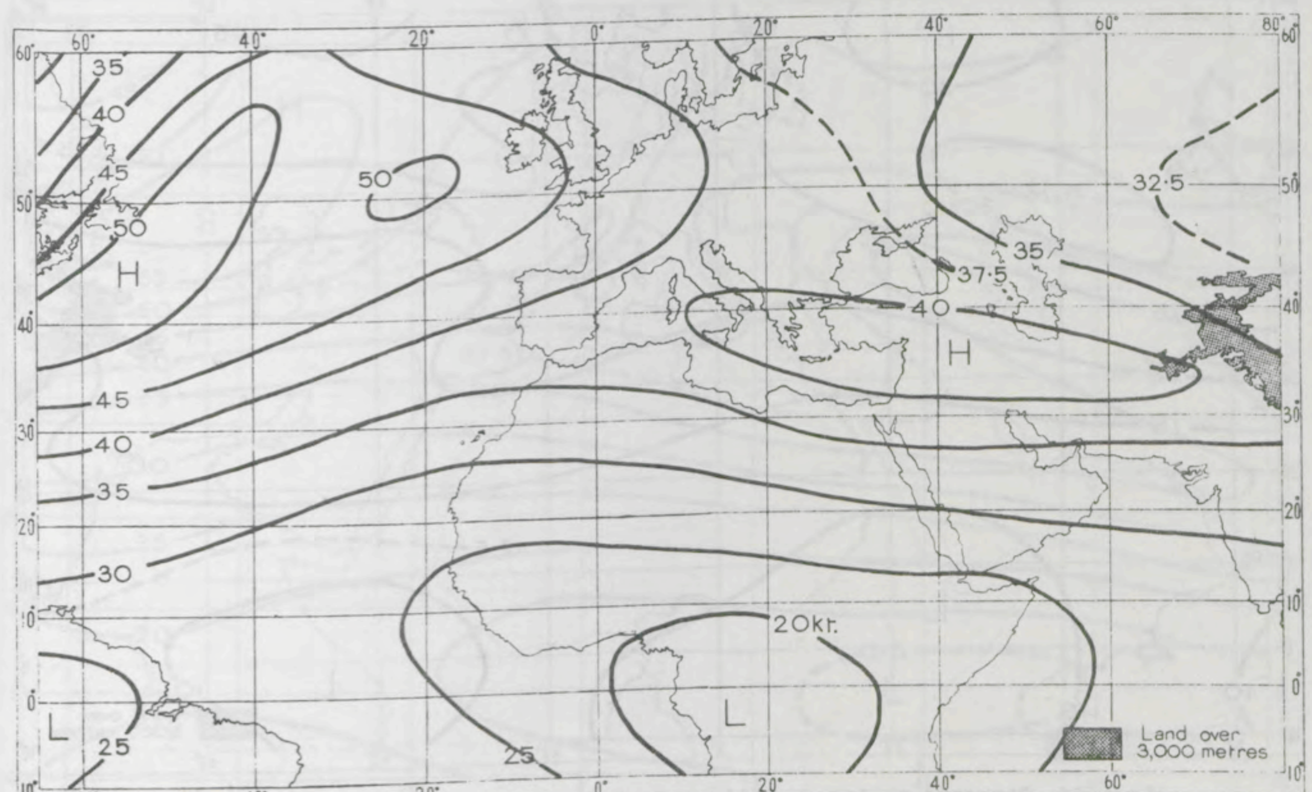


Fig.1.53 Standard vector deviation of wind at 200 millibars in January

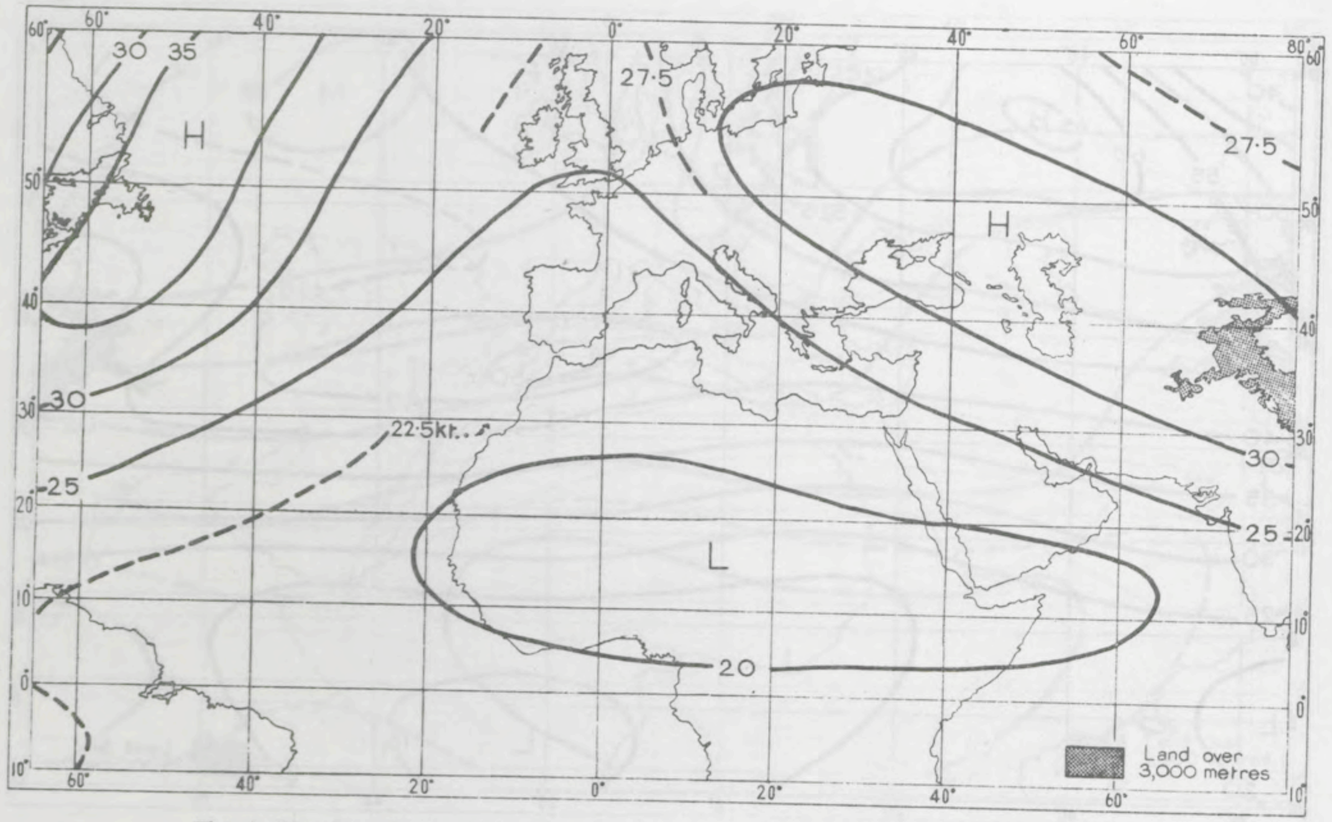


Fig.1.54 Standard vector deviation of wind at 100 millibars in January

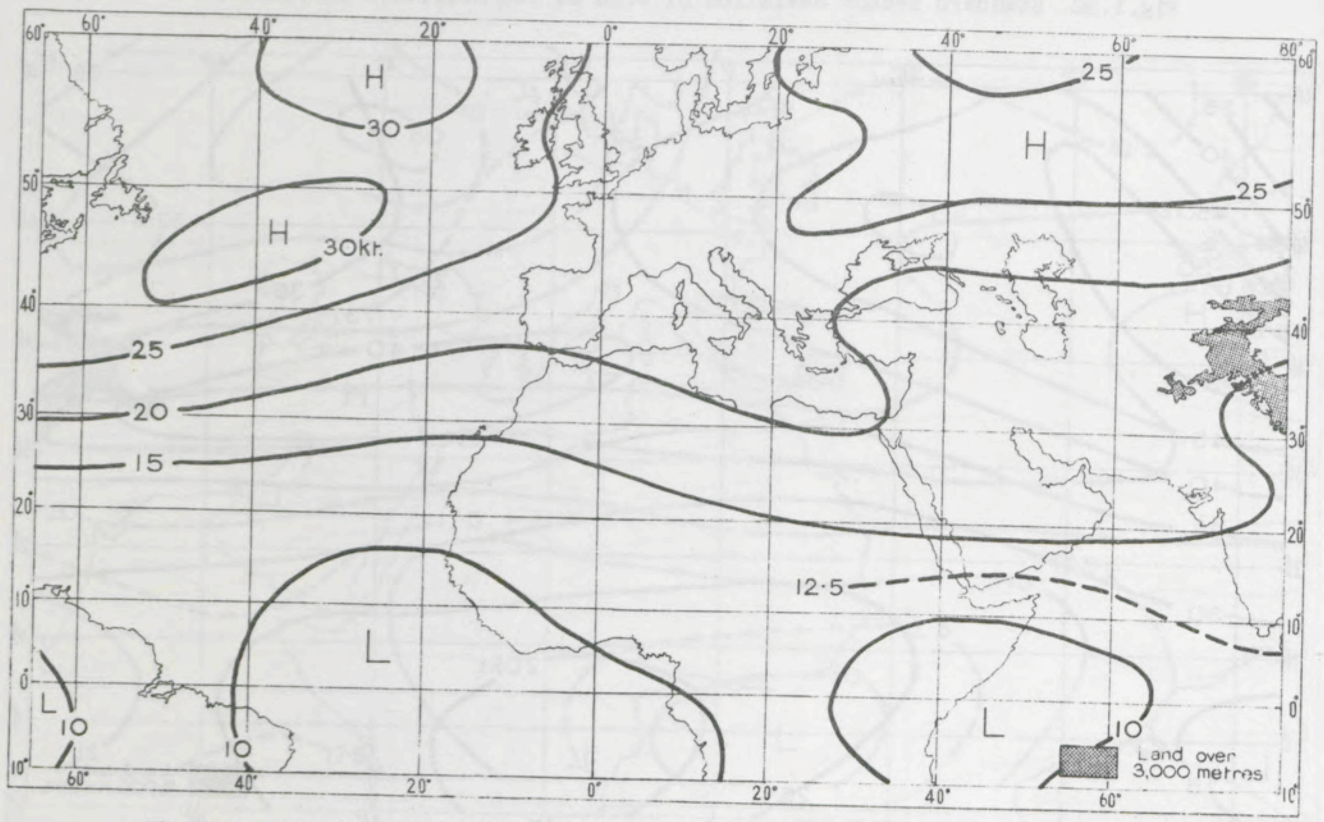


Fig.1.55 Standard vector deviation of wind at 700 millibars in April

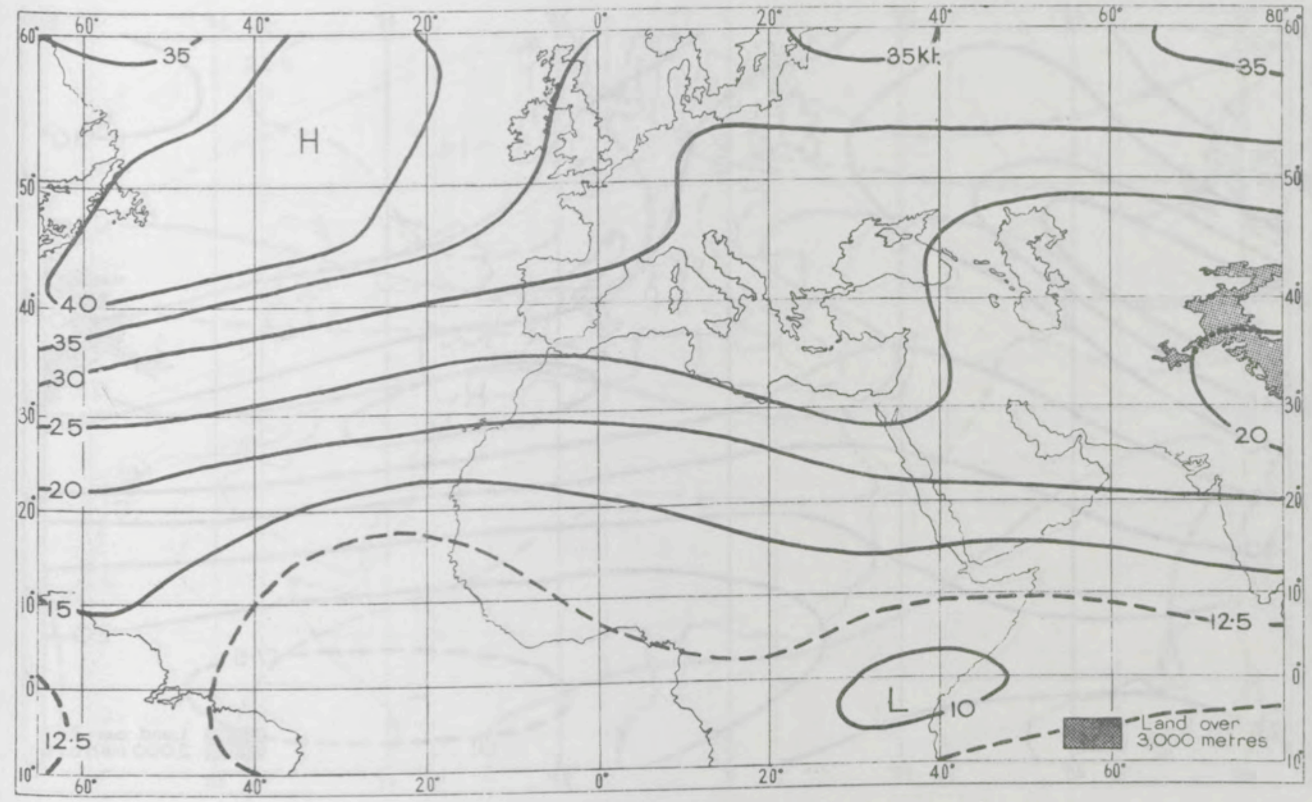


Fig.1.56 Standard vector deviation of wind at 500 millibars in April

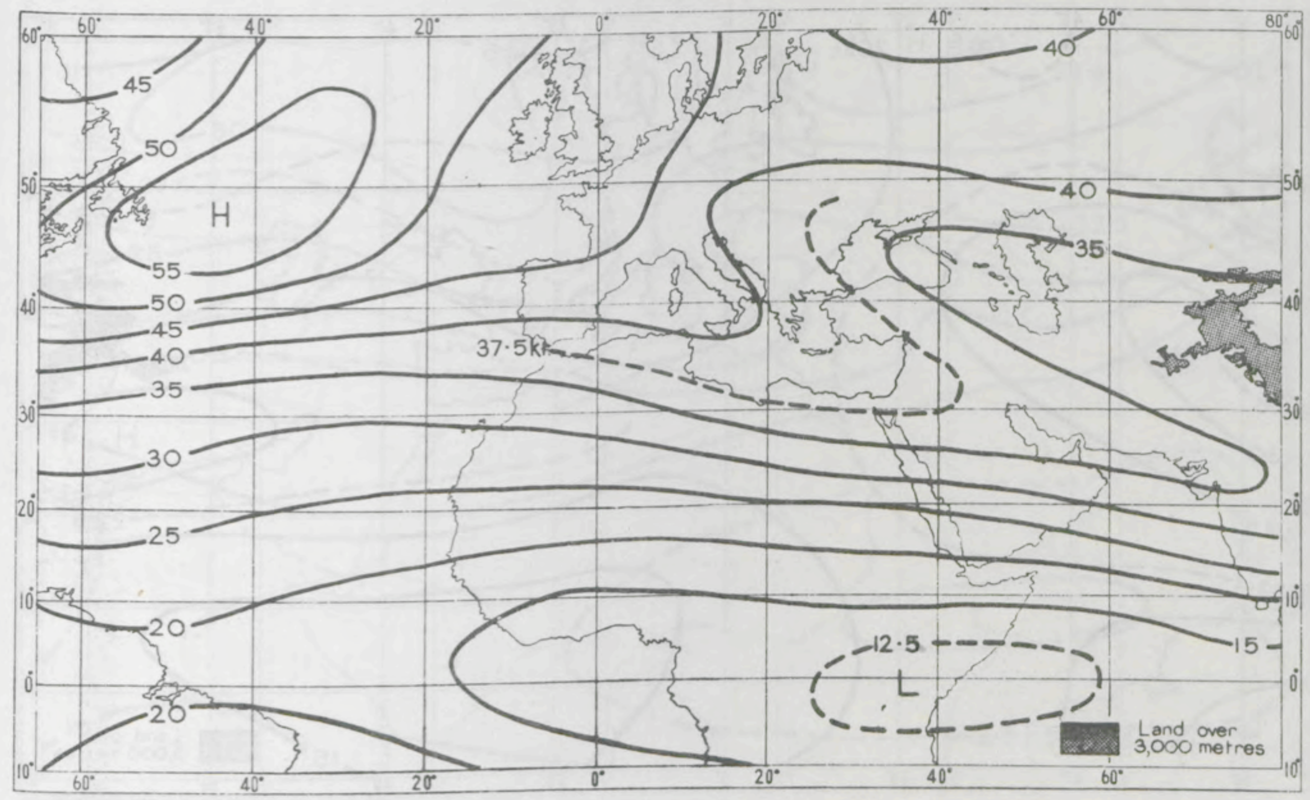


Fig.1.57 Standard vector deviation of wind at 300 millibars in April

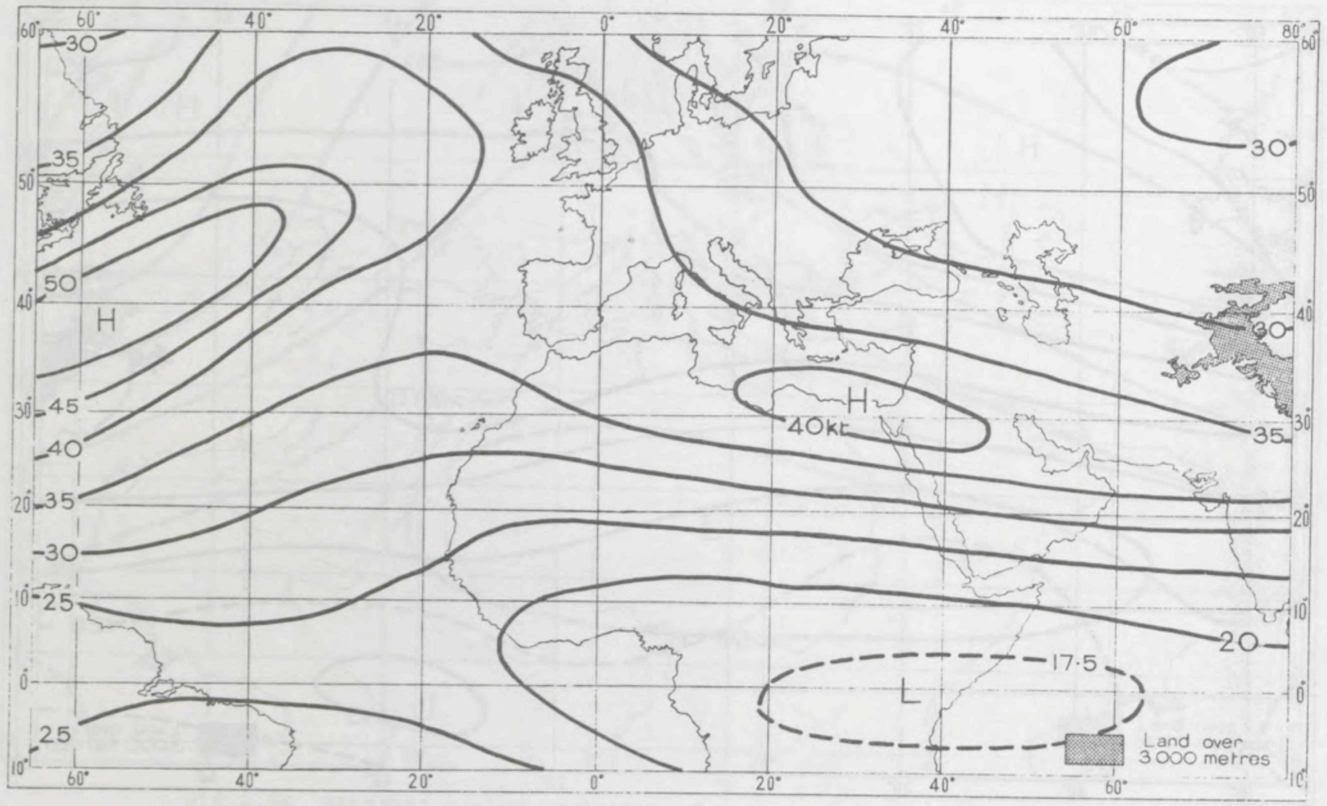


Fig.1.58 Standard vector deviation of wind at 200 millibars in April

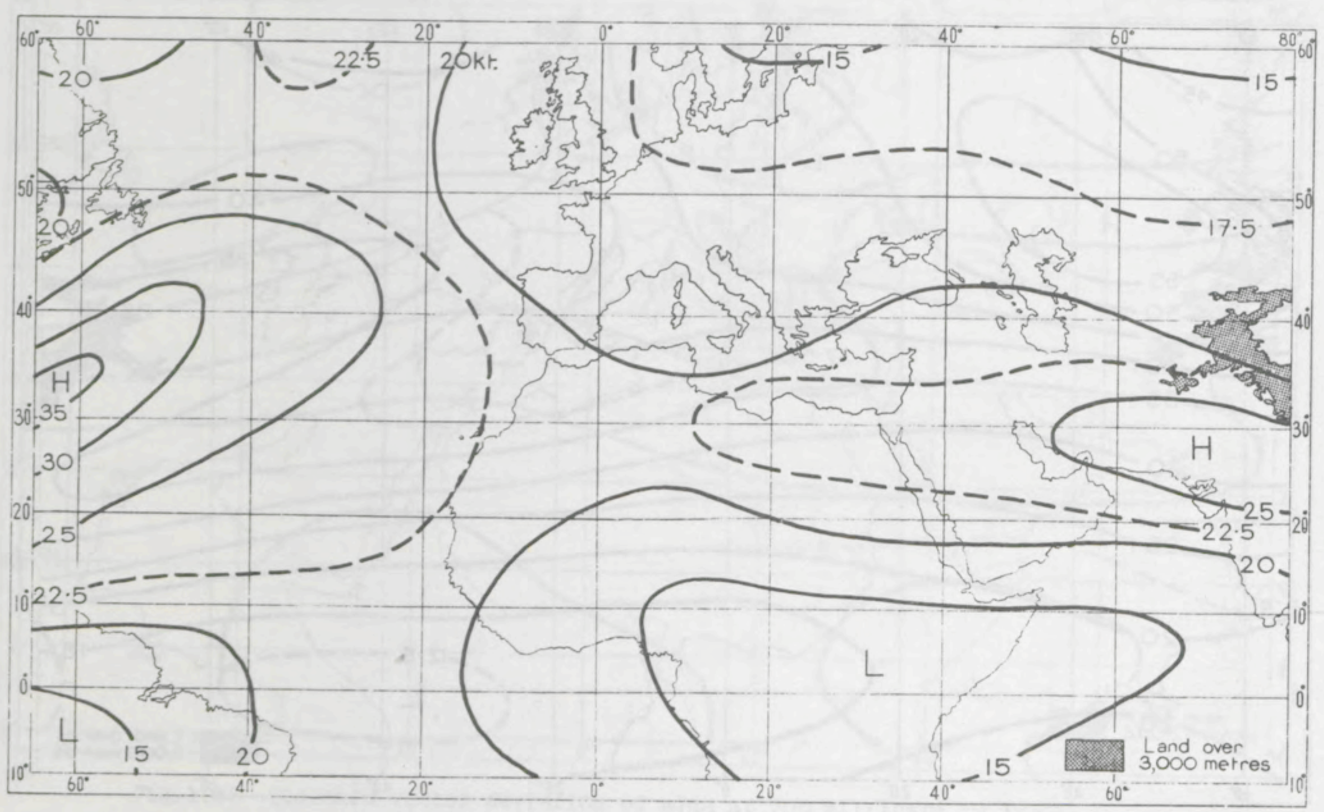


Fig.1.59 Standard vector deviation of wind at 100 millibars in April

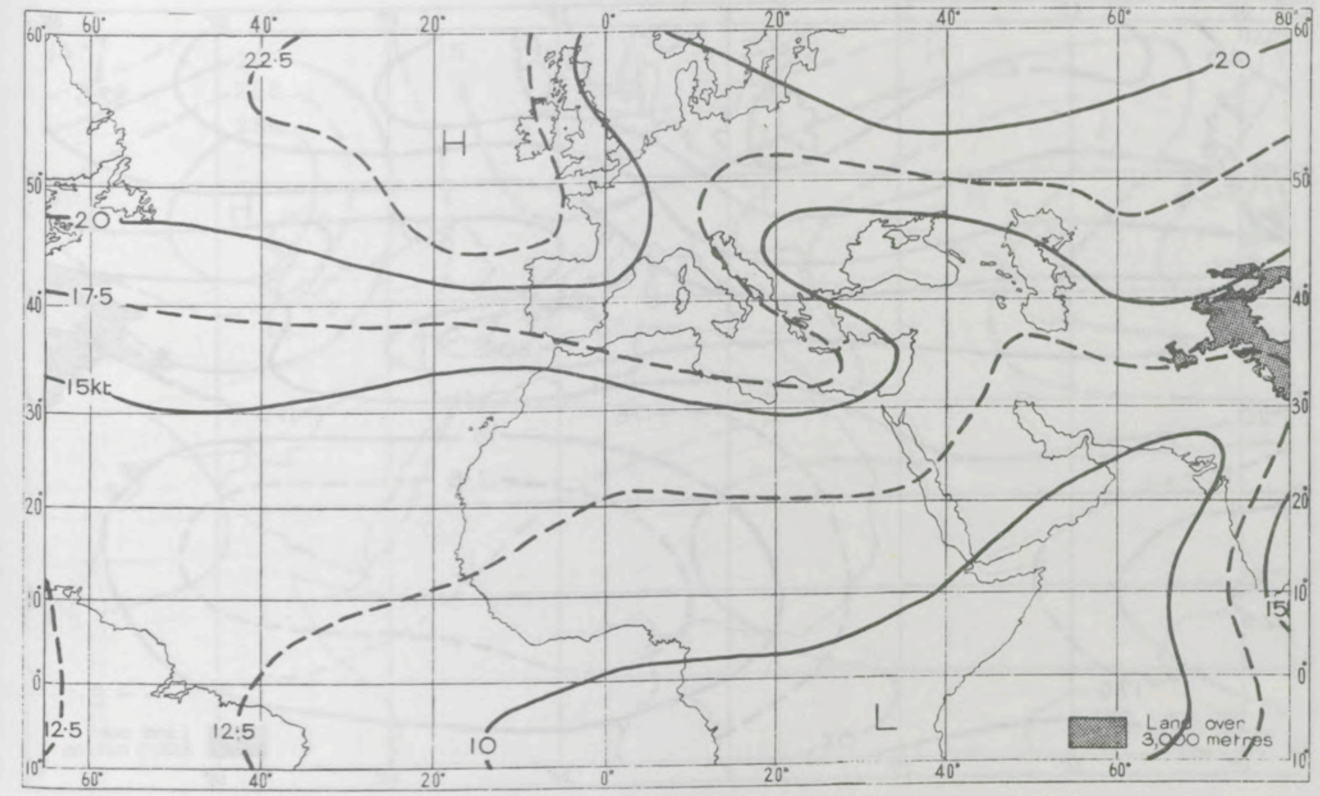


Fig.1.60 Standard vector deviation of wind at 700 millibars in July

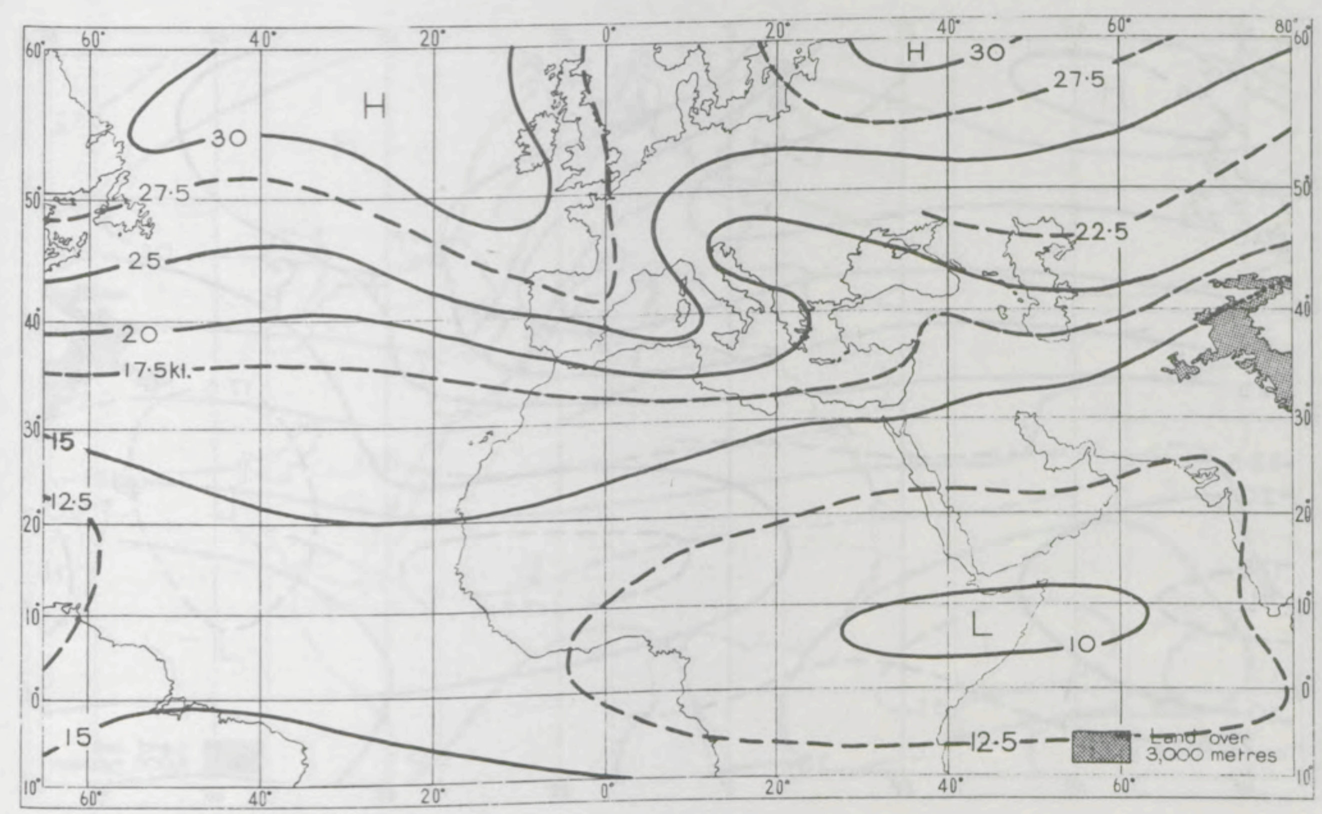


Fig.1.61 Standard vector deviation of wind at 500 millibars in July

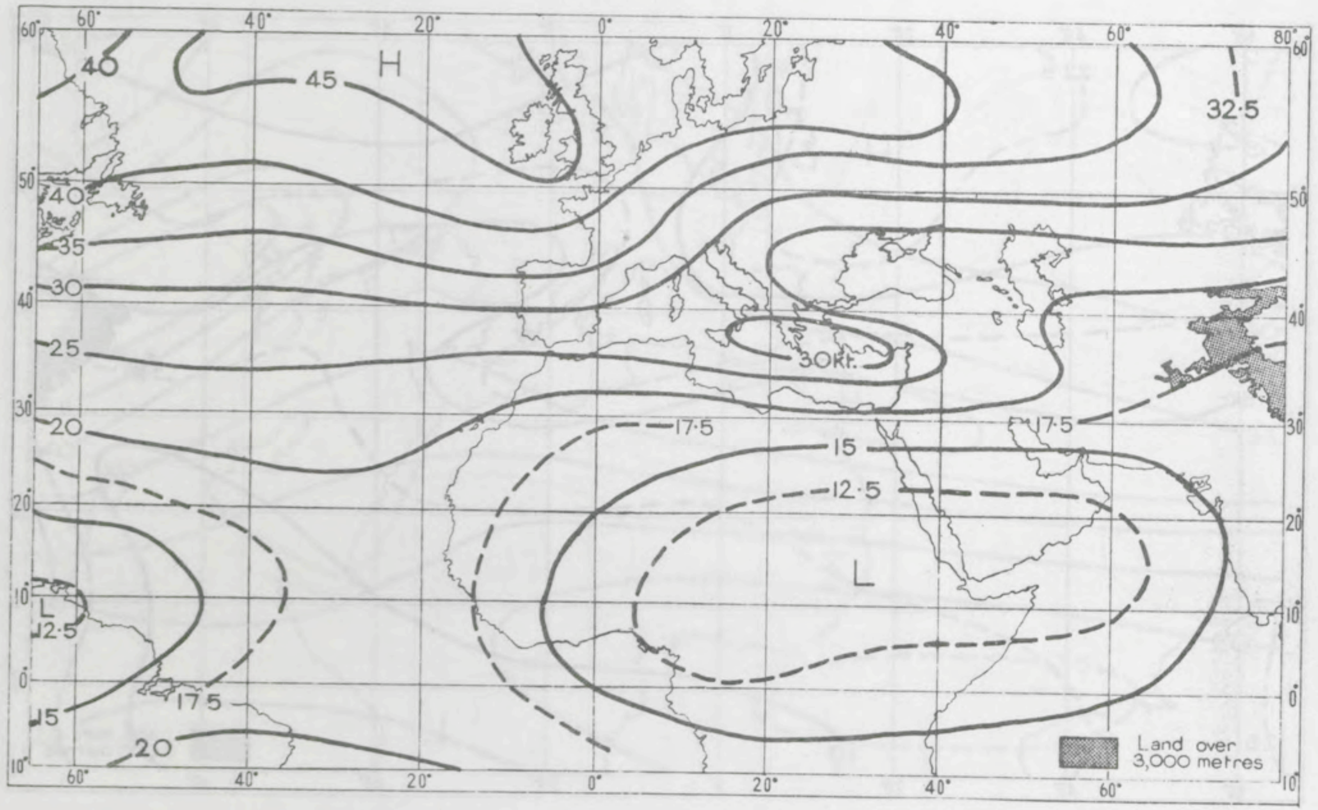


Fig.1.62 Standard vector deviation of wind at 300 millibars in July

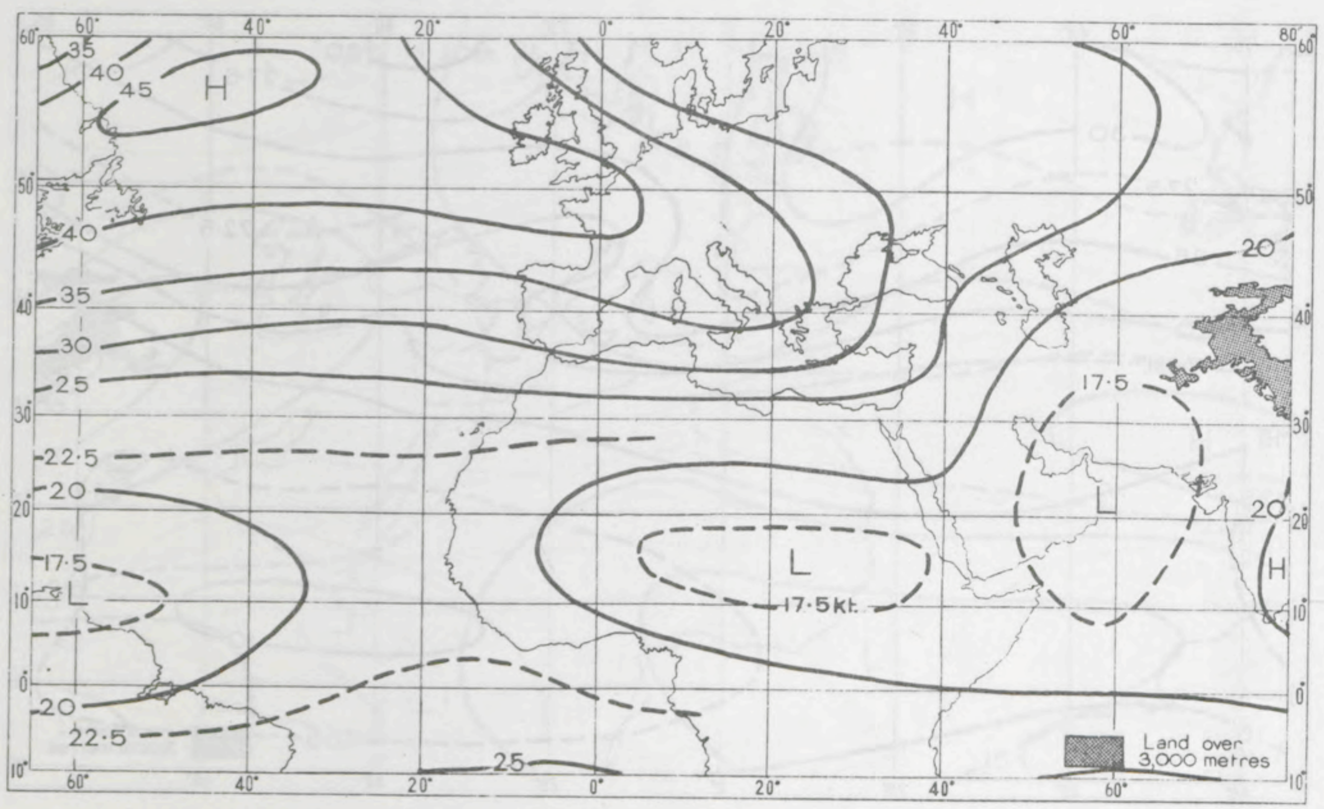


Fig.1.63 Standard vector deviation of wind at 200 millibars in July

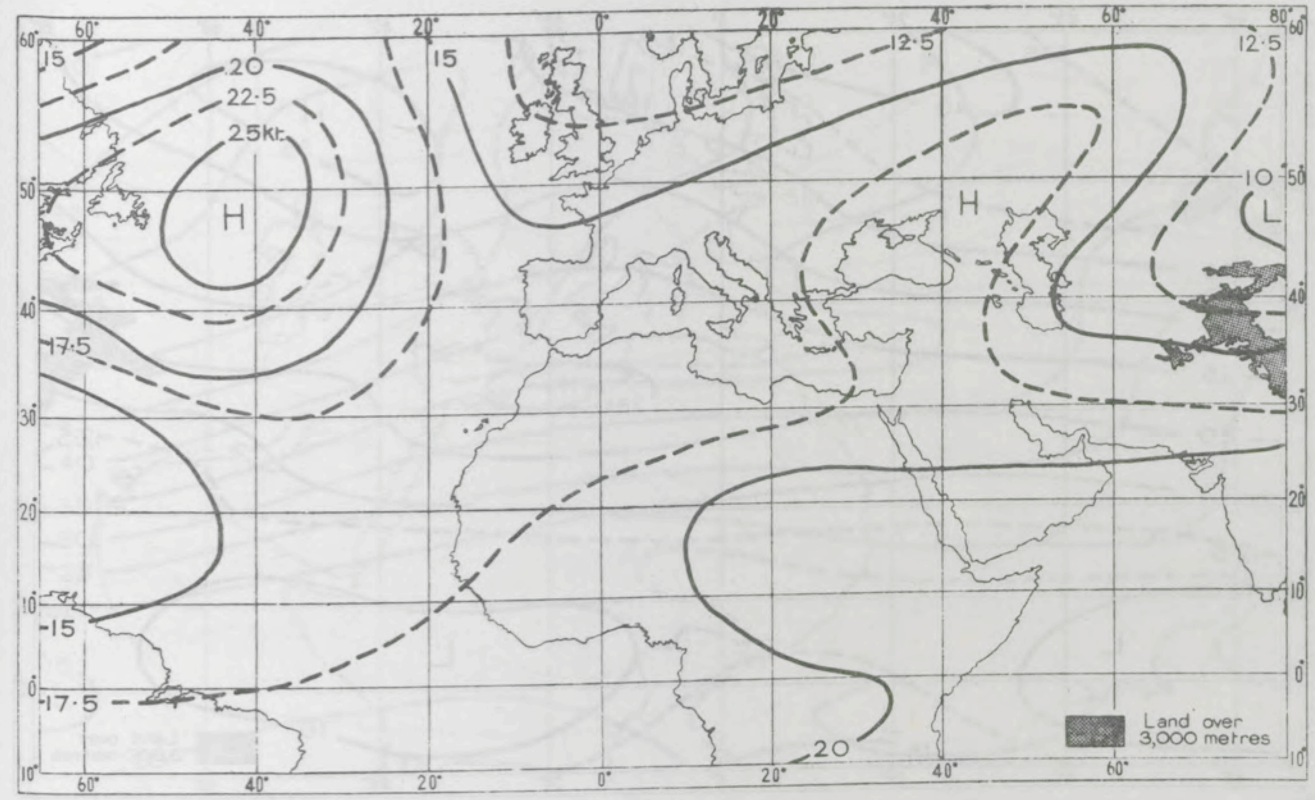


Fig.1.64 Standard vector deviation of wind at 100 millibars in July

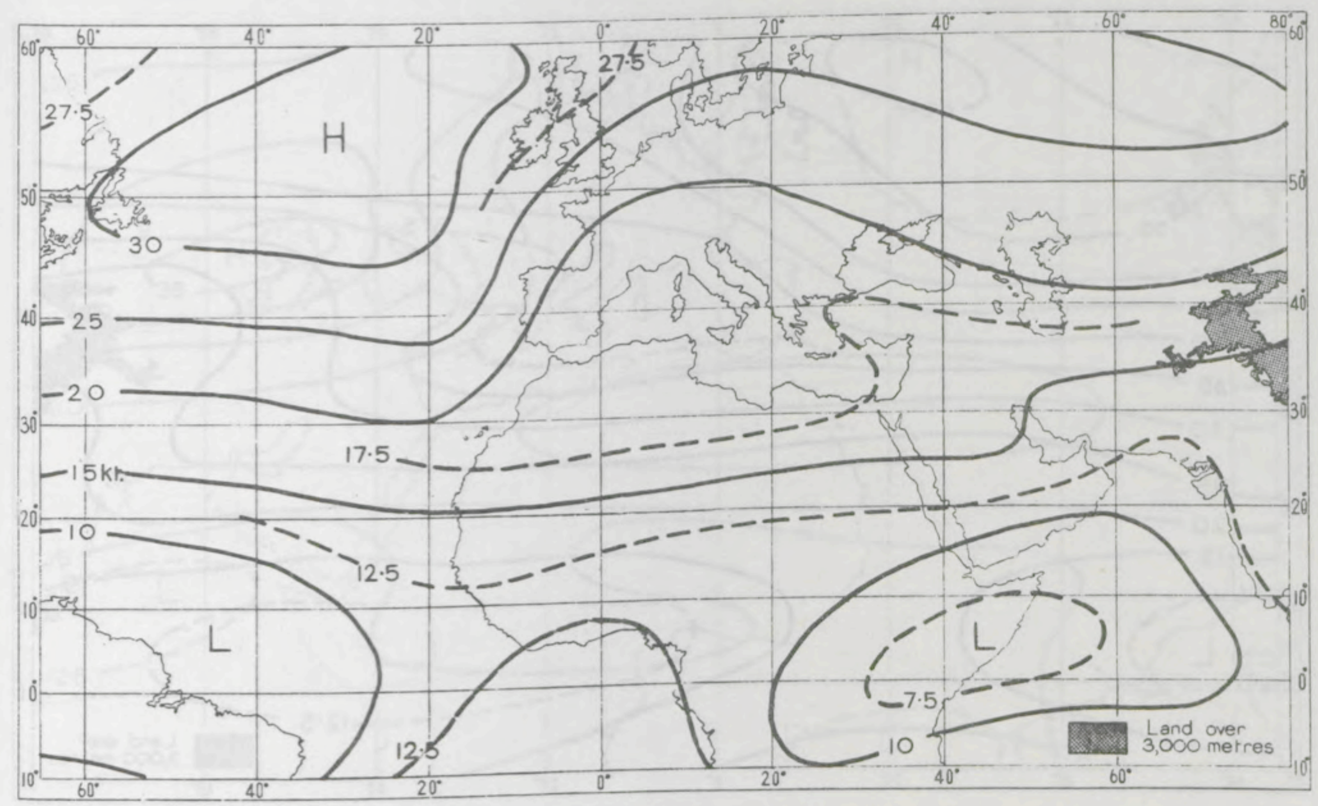


Fig.1.65 Standard vector deviation of wind at 700 millibars in October

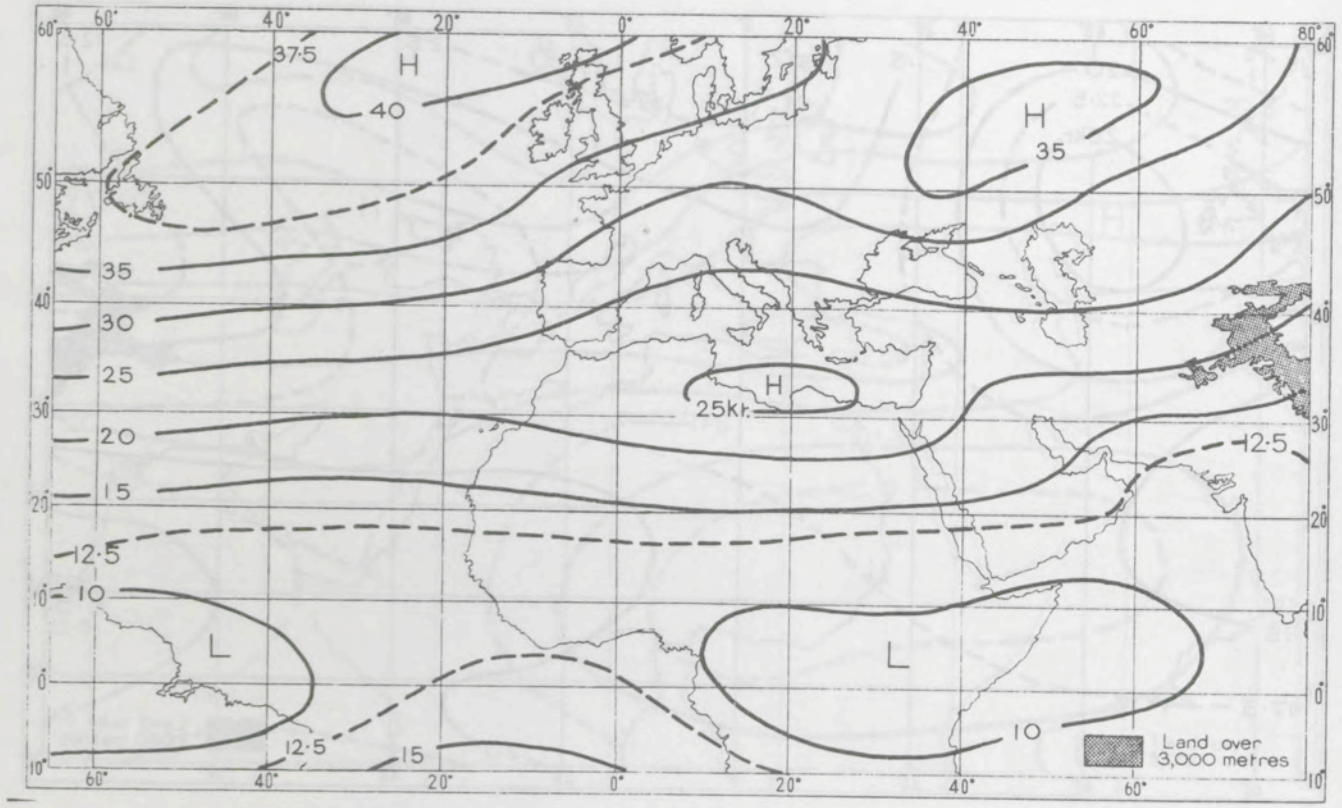


Fig.1.66 Standard vector deviation of wind at 500 millibars in October

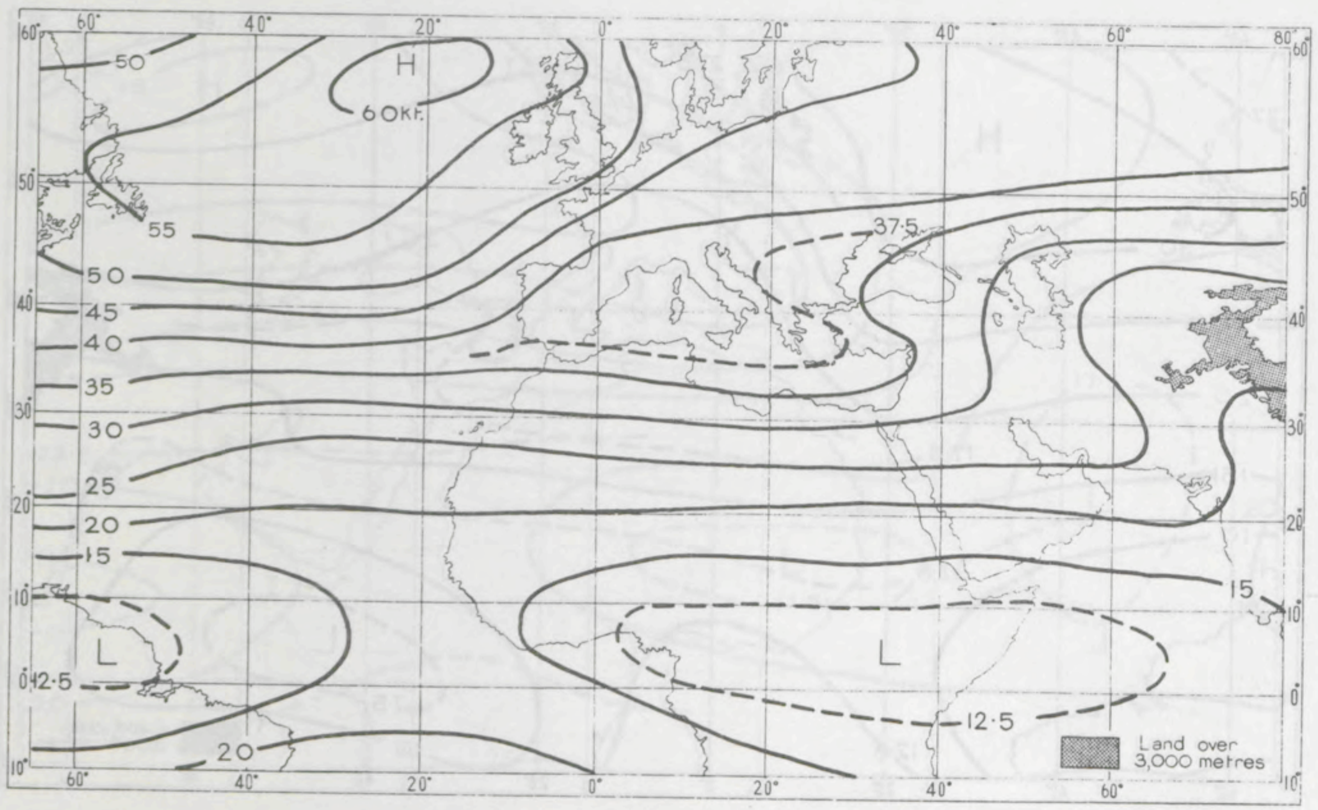


Fig.1.67 Standard vector deviation of wind at 300 millibars in October

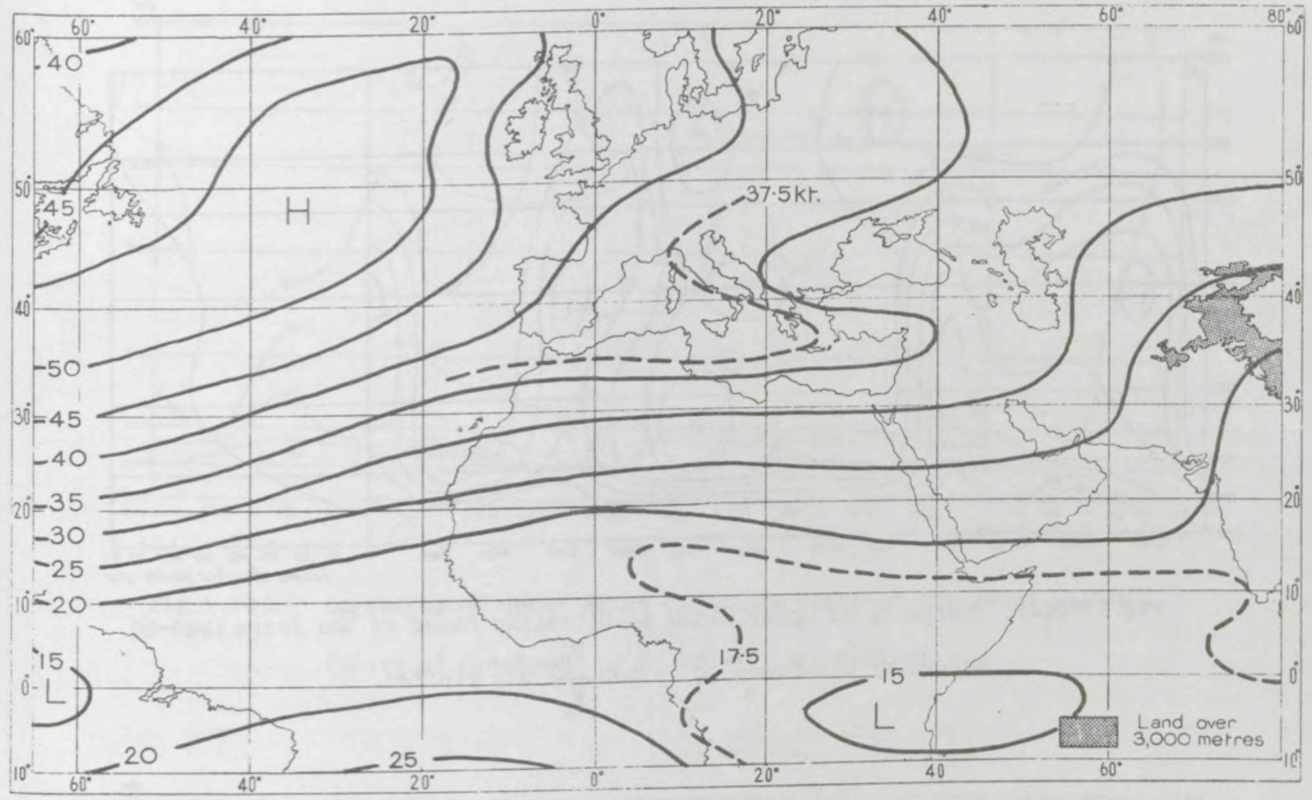


Fig.1.68 Standard vector deviation of wind at 200 millibars in October

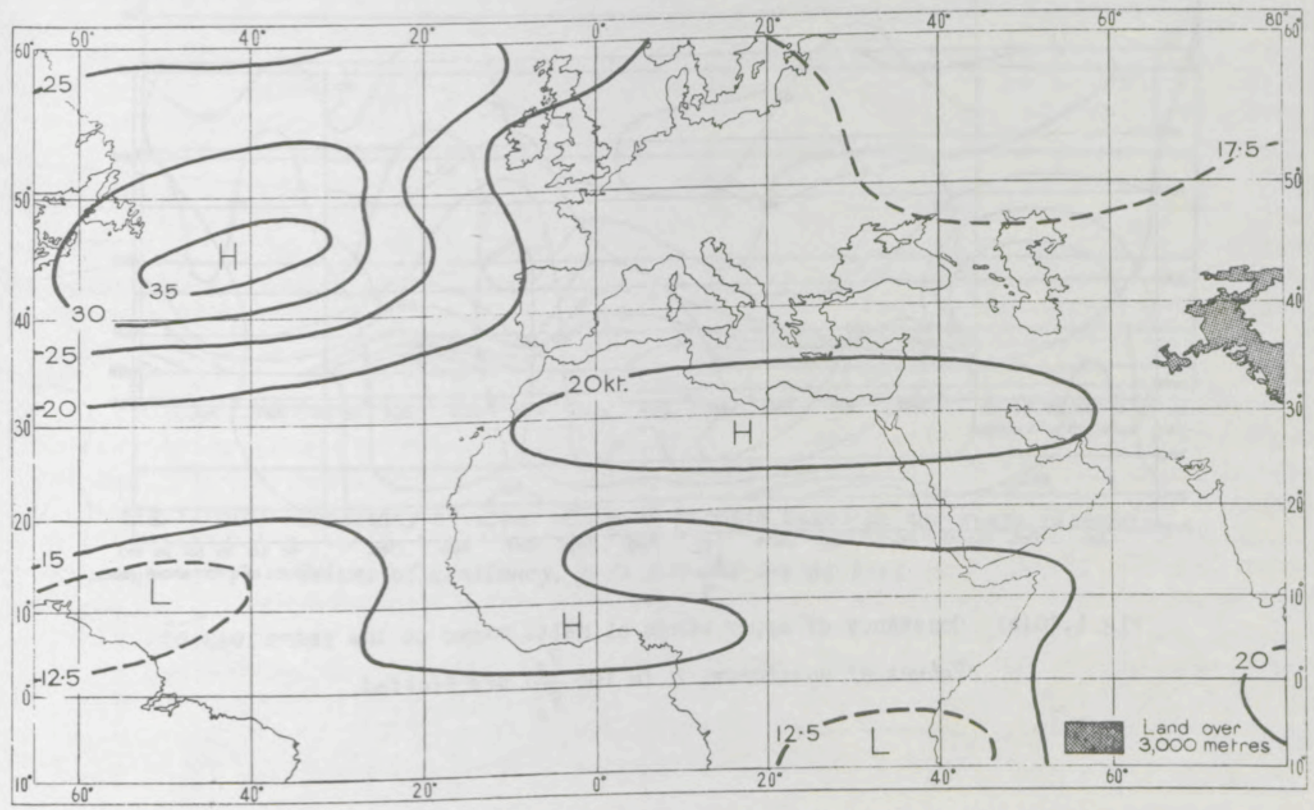


Fig.1.69 Standard vector deviation of wind at 100 millibars in October

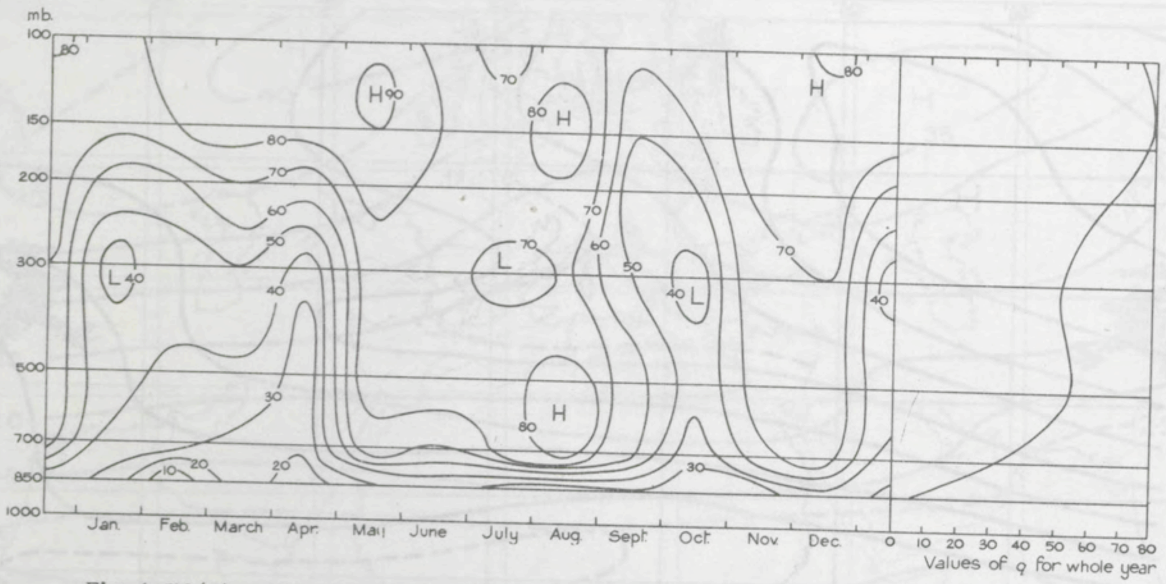


Fig.1.70(*a*) Constancy of upper winds at Gibraltar based on the years 1948-50

Values of constancy, q $(= 100 \frac{V_R}{V_S})$ *are plotted.*

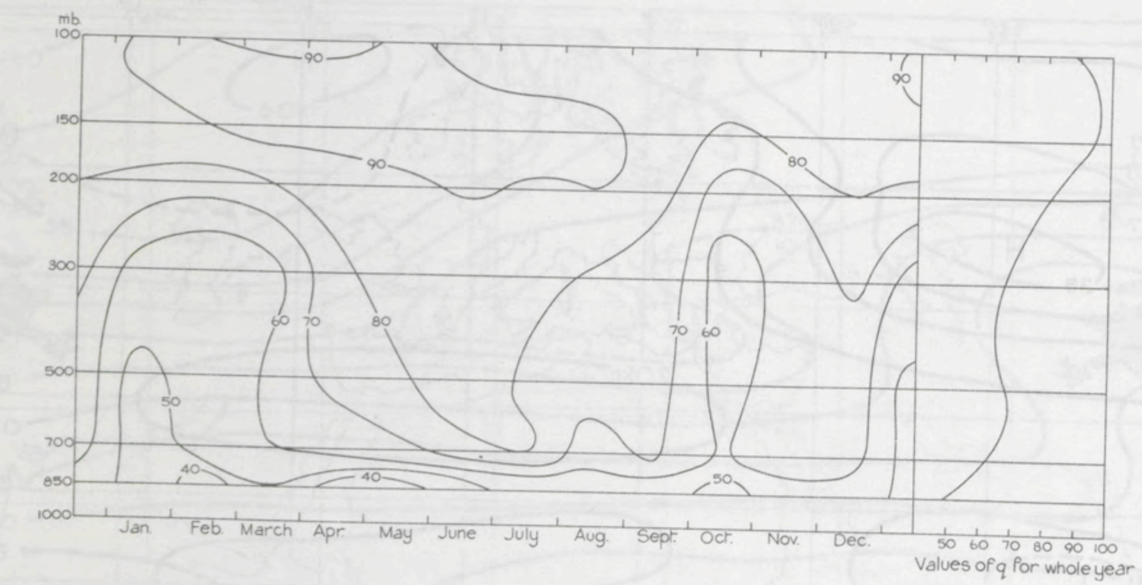


Fig.1.70(*b*) Constancy of upper winds at Malta based on the years 1948-50

Values of constancy, q $(= 100 \frac{V_R}{V_S})$ *are plotted.*

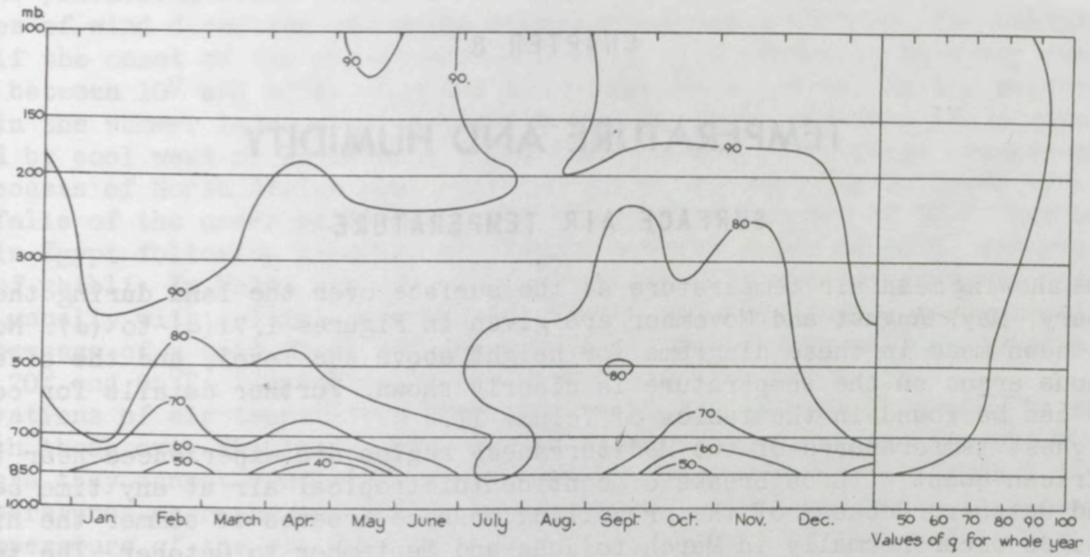


Fig.1.70(*c*) Constancy of upper winds at Benina based on the years 1948-50

Values of constancy, q $(= 100 \frac{V_R}{V_S})$ *are plotted.*

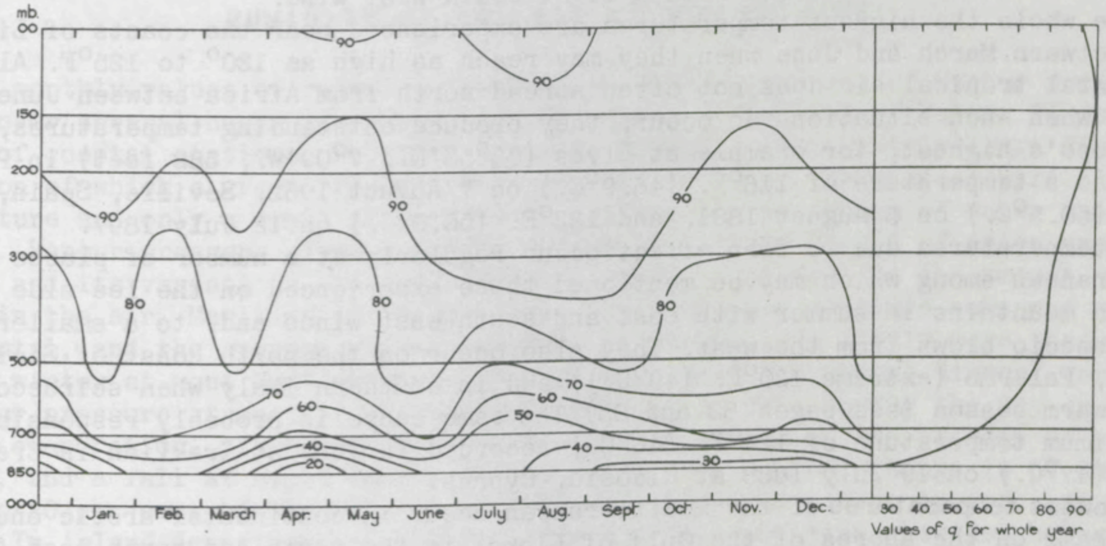


Fig.1.70(*d*) Constancy of upper winds at Nicosia based on the years 1948-50

Values of constancy, q $(= 100 \frac{V_R}{V_S})$ *are plotted.*

CHAPTER 8

TEMPERATURE AND HUMIDITY

SURFACE AIR TEMPERATURE

Isotherms showing mean air temperature at the surface over the land during the months of February, May, August and November are given in Figures 1.71(*a*) to (*d*). No allowance has been made in these diagrams for height above sea level, and the effect of mountainous areas on the temperature is clearly shown. Further details for coastal stations can be found in the tables of Volume II.

The highest temperatures of the Mediterranean region are experienced near the North African coast with outbreaks of continental tropical air at any time between March and October. Because of the prevailing onshore breezes of summer the highest temperatures occur normally in March to June and September to October. The temperature of a continental tropical air stream from the Sahara normally continues to rise as long as it remains over the desert and reaches its maximum rather near the coast. In the most extreme cases the air may have been previously warmed by föhn effect on crossing the mountains between 17° and 23°N. where rainfall may occur. The highest accepted temperature on record at a meteorological station anywhere in the world is 136°F. (57.5°C.) which was observed at Azizzia, 25 miles south-west of Tripoli, on 13 September 1922. It occurred with a light south-west wind.

On the whole the highest temperatures are experienced near the coasts of Libya and Egypt between March and June when they may reach as high as 120° to 125°F. Although continental tropical air does not often spread north from Africa between June and August, when such situations do occur, they produce outstanding temperatures, including Europe's highest, for example at Elvas (38°53'N., 7°09'W., 682 feet) in Portugal which had a temperature of 116°F. (46.9°C.) on 7 August 1932; Seville, Spain, with 123°F. (50.5°C.) on 8 August 1881, and 122°F. (50.0°C.) on 12 July 1897.

High temperatures due to föhn effect occur regularly at a number of places in the Mediterranean among which may be mentioned those experienced on the lee side of the Corsican mountains in summer with east and south-east winds and, to a smaller extent, when Libeccio blows from the west. They also occur on the north coast of Sicily, for example, Palermo (extreme 120°F. (49°C.)) and in southern Italy when scirocco blows in the warm season (see pages 82 and 85). The same cause is probably responsible for the maximum temperature of 114°F. (46°C.) recorded in June at Iraklion in Crete, and 116°F. (47°C.) on 19 July 1888 at Nicosia, Cyprus.

The lowest temperatures of the Mediterranean occur in continental arctic and polar air streams on the shores of the Gulf of Lions, in the north and north-east Adriatic and in the north and north-east of the Aegean Sea. In these areas the minimum temperature may be as low as 10° to 15°F., and near the shores of the Adriatic region it may, exceptionally, fall below 10°F. (-12°C.).

The mean daily range of temperature is least on the small islands, for example, Skiros and Rhodes where it varies from about 6°F. in winter to 10°F. in summer. At coastal stations of the mainland it varies on the whole between 10° and 15°F. in winter and 15° to 20°F. in summer, though these figures are exceeded at such places as Tunis (23°F. in summer), Sirte (23°F. in spring and autumn), Paphos (24°F. in April), Izmir (24°F. in June) and Ramle (26°F. in May).

In places suitably exposed the high afternoon temperatures and the large diurnal

ranges which might be expected in summer are often modified by sea-breezes. This is particularly noticeable along the coast of North Africa, from Tripolitania to Egypt, where the prevailing winds reinforce the sea-breezes of summer.

Changes of wind direction can bring marked temperature changes. For example, in summer if the onset of the sea-breeze is delayed till afternoon this may result in a drop of between 10° and 20°F. when the sea-breeze does arrive. On the west coast of Greece in the summer large changes occur when hot, dry winds from the mountains are replaced by cool west or north-west winds from the sea. Very large changes also occur on the coasts of North Africa when scirocco winds are suddenly followed by a cold front; falls of the order of 20°F. may be experienced and one of 30°F. has been recorded in Egypt following khamsin. At Tripoli a daily range of 50°F. was recorded in a case of ghibli. In Malta periods of great warmth with air temperatures approaching 100°F., usually with a light scirocco air stream and subsidence, are commonly followed by the passage of a cold front and north-westerly winds with maximum temperatures between 70° and 85°F. (depending on the month) a day or two later.

Observations of air temperature over the sea do not compare in number or reliability with those over the land. Owing to the effective discontinuities which occur at the coasts they cannot conveniently be shown by the isotherms in Figure 1.71. Mean air temperatures over the sea are shown by figures underlined which represent the mean temperature of the air over an area roughly centred at that point. The air temperature over the sea is controlled to a large extent by the sea surface temperature. As a result mean air temperatures over the sea are in general warmer than mean air temperatures over the adjacent land from about November to February and cooler from about May to August, being about the same in the intervening months. The diurnal variation of air temperature over the sea is much less than over the land.

HUMIDITY OF THE AIR AT THE SURFACE

Average monthly values of relative humidity at fixed hours and of vapour pressure meaned over several hours of observation are given in Table 1 of Volume II for a number of coastal stations. Relative humidity normally has a fairly large diurnal variation of which a great proportion is generally due to the diurnal variation of temperature and only a small proportion to changes in the amount of water vapour in the air. Vapour pressure gives a better indication of the amount of water vapour present and its variations are due almost entirely to changes in the amount of water vapour in the air. Maritime air masses have a high vapour pressure compared with continental, and the average vapour pressure in summer is a little more than double that in winter at most Mediterranean coastal stations. The normal diurnal variation of vapour pressure at most places consists of a small rise during the day as a result of evaporation, often reinforced at coastal stations by the effects of sea-breezes, and a fall at night due to condensation. The diurnal change is of the order of 15 to 20 per cent of the daily mean value in winter and 10 to 15 per cent in summer. In inland desert areas, however, the diurnal variation, besides being very small, is often reversed, since day-time convection tends to carry away from the surface a certain amount of water vapour.

Since the humidity of the air depends to a large extent on its past history, big changes may occur at a station when there is a change of wind direction or air mass. In addition to the effects of land-and sea-breezes the most marked changes occur with cold fronts

(i) on the North African coast when a dry southerly scirocco is followed by relatively moist air from the sea, and

(ii) in the northern Mediterranean when a moist scirocco is followed by relatively dry polar or arctic air from the continent of Europe.

In the former case the vapour pressure may rise by about 10 millibars (and the dew-point by about 20°F.) with the arrival of colder air from the north or north-west. There are also cases in North Africa when the passage of a warm front brings a great drop in vapour pressure (and dew-point) with the arrival of a dry southerly air mass.

SEA TEMPERATURE

Isotherms of mean sea surface temperature for the four months February, May, August and November are shown in Figures 1.72(*a*) to (*d*). These months are chosen because in most parts of the Mediterranean average sea temperatures are highest in August and lowest in February. Although the isotherms are drawn to the coasts they cannot be relied upon for shallow coastal waters. Local variations must also be allowed for in the Aegean owing to the large number of small islands and the broken nature of the coastline.

A feature which is characteristic of all seasons is the rapid rate of fall of temperature towards the mouth of the Rhône, the northern end of the Adriatic and north-eastwards through the Aegean towards the Dardanelles. On the whole there is a general increase of sea temperature from west to east as well as from north to south. The highest sea temperatures of the Mediterranean occur in the Gulf of Sidra where the mean in August is sometimes as high as 88°F. This is closely followed by the Gulf of Alexandretta (Iskenderon) where the mean sea temperature in August sometimes exceeds 86°F. The lowest sea temperatures are found in the extreme north of the Adriatic, the mean in February falling to 46°F. in the Gulf of Trieste. In this region, where the surface water inshore is fairly fresh off the river mouths, ice forms at times in the depth of winter. This is well known off Trieste and Venice. Similar ice formation occurs from time to time in the shallow waters off Salonika.

Over the greater part of the Mediterranean Sea the mean sea temperature is greater than the mean air temperature from November to February, the difference being about 2° to 4°F. in December and January, while the reverse is the case from May to August, the sea being about 1° to 2°F. cooler than the air on the average during June and July. The mean temperatures of sea and air are about the same in the intervening months.

In narrow or enclosed sea areas and in shallow coastal seas the mean air-sea temperature differences may depart somewhat from these values. This is noticeably so in the northern Adriatic where, at Trieste for example, the sea becomes about 5°F. warmer than the air in December and is coolest relative to the air in May with a difference of about 1½°F. The temperature of the air over the sea is considerably more variable than that of the sea itself, depending greatly on the direction and strength of the wind, so that, on any particular occasion, the actual difference between sea and air temperatures may depart considerably from the mean value. Some of the greatest differences occur along the coast of North Africa in late spring and summer with scirocco winds, when the air may be 10°F. or more hotter than the sea surface. The reverse is the case in winter over the northern Mediterranean when mistral or bora is blowing. Off the mouth of the Gulf of Lions the air temperature may fall to freezing point while that of the sea is almost normal - say 48°F.

UPPER AIR TEMPERATURES AND HUMIDITIES

The mean upper air temperatures in °C. for each of the four mid-season months, January, April, July and October at the levels of 700, 500, 300, 200 and 100 millibars are given by isotherms in Figures 1.73 to 1.76 (reproduced from *Upper air temperature over the world* 36).

Figures 1.77(*a*) to (*d*) show isopleths of mean humidity mixing ratio in grams per kilogram for each of the four mid-season months, at the levels of 850, 700 and 500 millibars. The equivalent dew-point in °C. is given for each isopleth.

More detailed information concerning upper air temperatures and humidities at Gibraltar, Malta, Benina, Nicosia, Habbaniya, Bahrain and Aden is given in Volume II, Table 8. Standard deviations of temperature are also given for all these stations except Benina. Values of all quantities are based on all available hours of observation except where otherwise stated.

Table 17

Freezing levels

Station	Lowest	Average January		Average July		Highest
	mb.	mb.	ft.	mb.	ft.	mb.
Gibraltar	920	730	9,100	590	15,400	520
Malta	900	760	7,900	590	15,000	510
Nicosia	Surface	800	6,400	550	16,700	450
Habbaniya	Surface	780	6,800	530	18,000	460
Bahrain	910	670	11,200	530	17,800	450
Aden	660	560	16,400	560	16,600	500

Figures are based on the year 1950 only: all hours of observation

The freezing level. Approximate values of average and extreme freezing levels for a number of places in and near the Mediterranean are given in Table 17. It will be seen that the range of height of the freezing level is greater in the east of the Mediterranean than in the west, extending both higher and lower at Nicosia than at Gibraltar. The average figures are based on the mean temperatures at the various levels and are therefore not strictly average values of the freezing level, irregularities in individual ascents having been smoothed out. However, the figures give a good approximation to the average freezing level. When the freezing level is at or near the surface the situation is often one where there is a shallow layer of polar or arctic air with an inversion above. In such cases there may be a layer of above-freezing temperature above the inversion and another freezing level above that.

The tropopause. The Mediterranean is a transition region between the higher latitudes where the low "polar" tropopause is almost exclusively present and the tropics where the higher "tropical" tropopause is dominant. In this intervening area there is a zone of discontinuity where one or other tropopause may be present and often both. In Gibraltar a double tropopause occurred during 1950 on 29 per cent of occasions, being most common from January to April. The lower tropopause alone occurred on 47 per cent of occasions, mainly in the cool season, and the upper tropopause occurred alone on 24 per cent of occasions, almost all cases being between July and November. At Nicosia the corresponding percentages in 1950 were: double tropopause, 56 per cent; lower tropopause only, 3 per cent; upper tropopause only, 38 per cent (mainly from July to October); and tropopause not reached, presumed high, 3 per cent. At Bahrain in 1950 there were: double tropopause, 19 per cent (April-June, November-December); upper tropopause only, 72 per cent; tropopause not reached, 9 per cent. The polar tropopause is seldom, if ever, found south of 20°N.

Table 18 gives some data on the pressure and temperature of the tropopause in the four mid-season months during the year 1950. These, and the data for Table 8 in Volume II are based on *Upper air data for stations maintained by the Meteorological Office*[63] where further information may be found.

Table 18

Pressure and temperature at the tropopause

Month	Pressure: Average: Lower tropopause	Pressure: Average: Upper tropopause	Pressure: Lowest pressure	Temperature: Average: Lower tropopause	Temperature: Average: Upper tropopause	Temperature: Lowest temperature
	mb.	mb.	mb.	°C.	°C.	°C.
Gibraltar						
January	202	85	68	-63	-62	-76
April	207	81	55	-59	-60	-67
July	(161)	114	70	(-58)	-65	-71
October	192	117	86	-59	-63	-71
Malta						
January	224	100	79	-57	-61	-69
April	239	96	45	-57	-60	-71
July	...	93	54	...	-67	-72
October	178	100	48	-61	-63	-68
Nicosia						
January	236	96	62	-56	-62	-71
April	217	94	55	-58	-62	-70
July	(351)	93	66	(-27)	-69	-75
October	193	102	50	-59	-64	-71
Habbaniya						
January	222	101	75	-57	-64	-76
April	202	84	46	-60	-63	-72
July	...	88	66	...	-74	-79
October	175	108	76	-62	-68	-76
Bahrain						
January	(198)	93	66	(-57)	-73	-81
April	185	84	60	-61	-71	-78
July	...	81	36	...	-78	-84
October	(146)	93	67	(-64)	-75	-82
Aden						
January	...	78	58	...	-82	-87
April	...	82	60	...	-82	-88
July	...	98	68	...	-79	-88
October	...	101	82	...	-81	-87

Figures are based on the year 1950 only: all hours of observation.
Values in brackets are based on less than 10 observations.

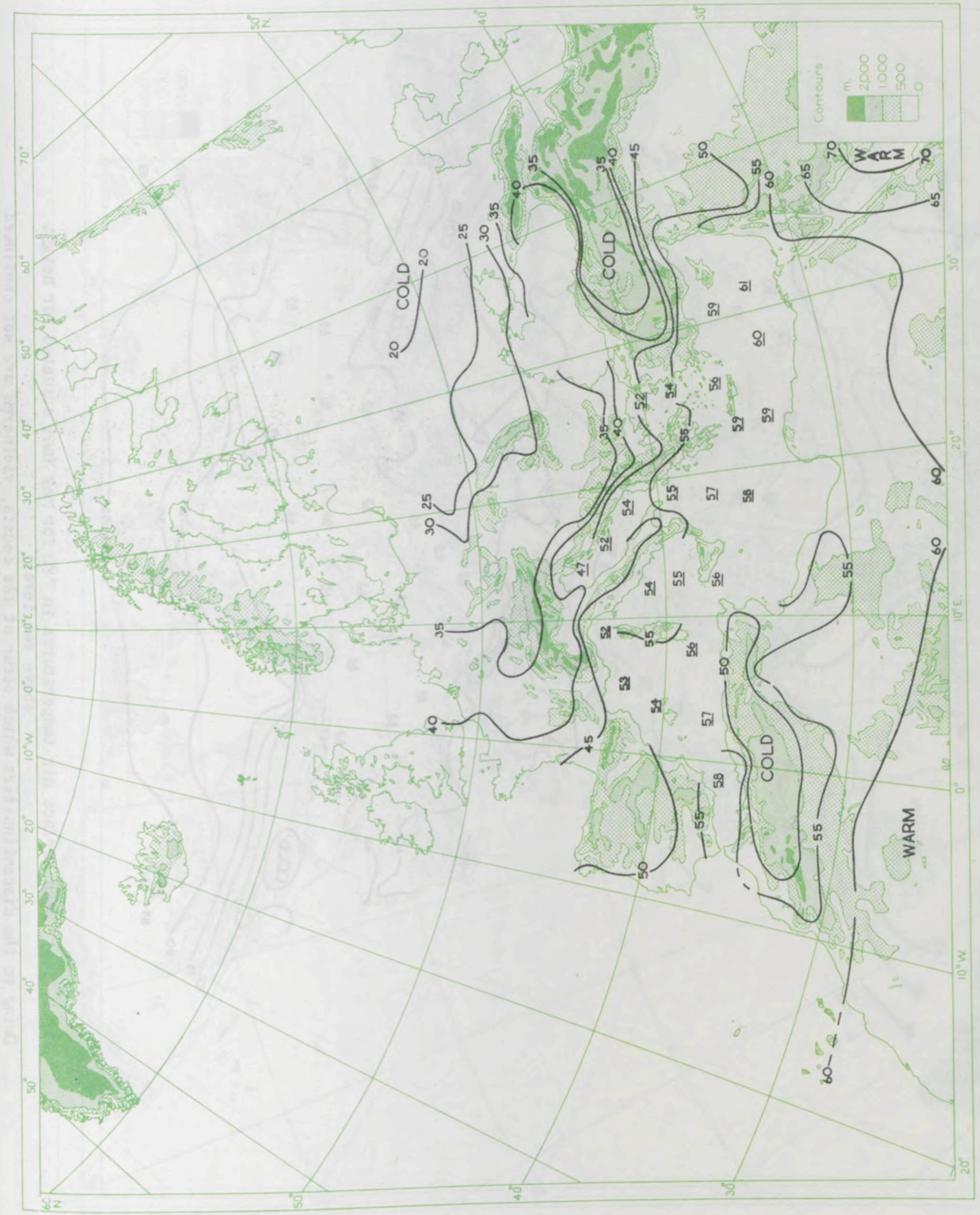


Fig. 1.71(*a*) Mean surface air temperatures in °F. for February (not adjusted for height above sea level)

Owing to the discontinuities which occur at the coasts, isotherms are not continued over the sea. Mean temperature of the air over the sea is shown by figures underlined which represent the mean temperature of the air for an area roughly centred at that point.

Fig.1.71(*b*) Mean surface air temperatures in °F. for May (not adjusted for height above sea level)

Owing to the discontinuities which occur at the coasts, isotherms are not continued over the sea. Mean temperature of the air over the sea is shown by figures underlined which represent the mean temperature of the air for an area roughly centred at that point.

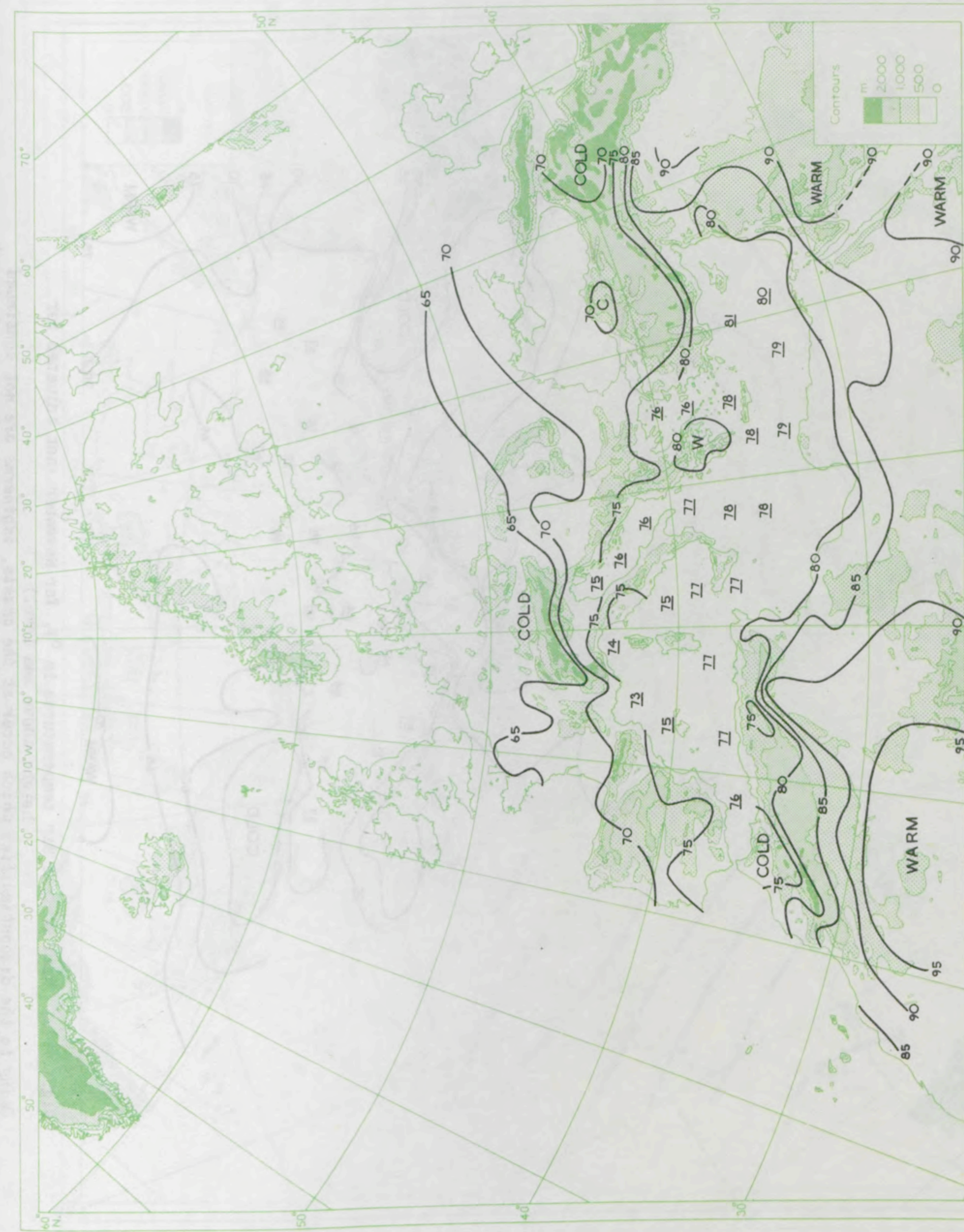


Fig.1.71(*c*) Mean surface air temperatures in °F. for August (not adjusted for height above sea level)

Owing to the discontinuities which occur at the coasts, isotherms are not continued over the sea. Mean temperature of the air over the sea is shown by figures underlined which represent the mean temperature of the air for an area roughly centred at that point.

Fig.1.71(a) Mean surface air temperatures in °F. for November (not adjusted for height above sea level)

Owing to the discontinuities which occur at the coasts, isotherms are not continued over the sea. Mean temperature of the air over the sea is shown by figures underlined which represent the mean temperature of the air for an area roughly centred at that point.

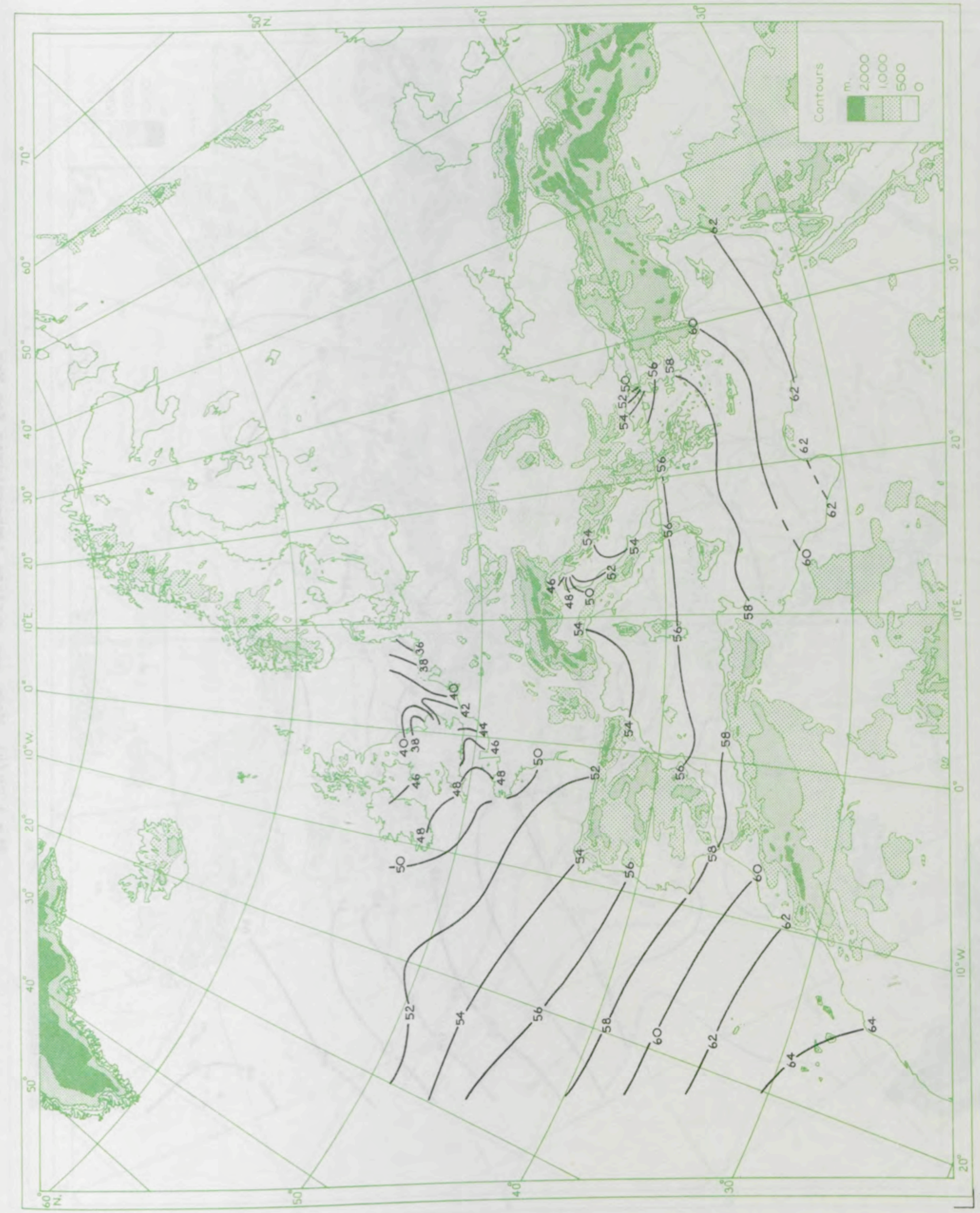


Fig.1.72(*a*) Mean sea surface temperatures for February

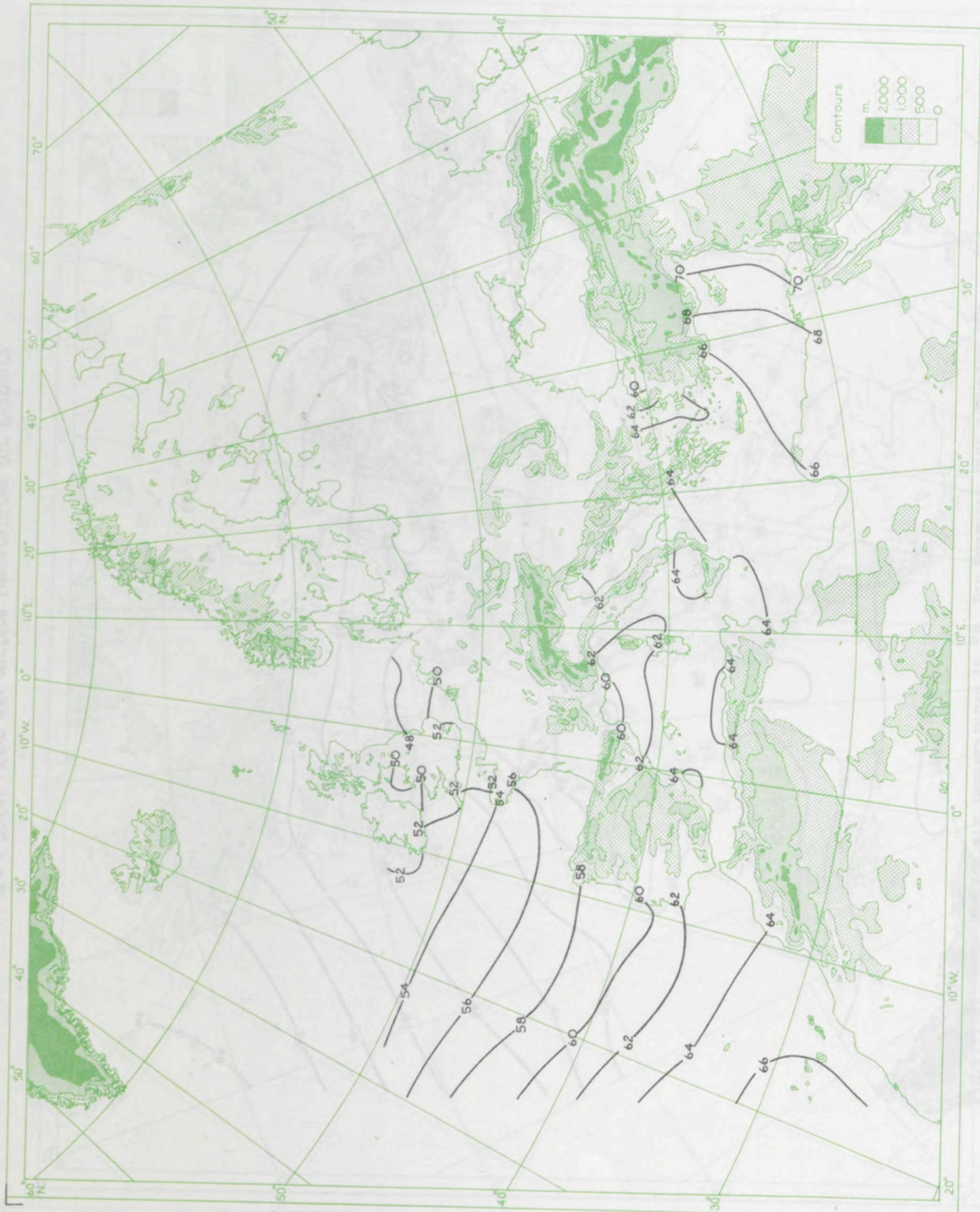


Fig.1.72(b) Mean sea surface temperatures for May

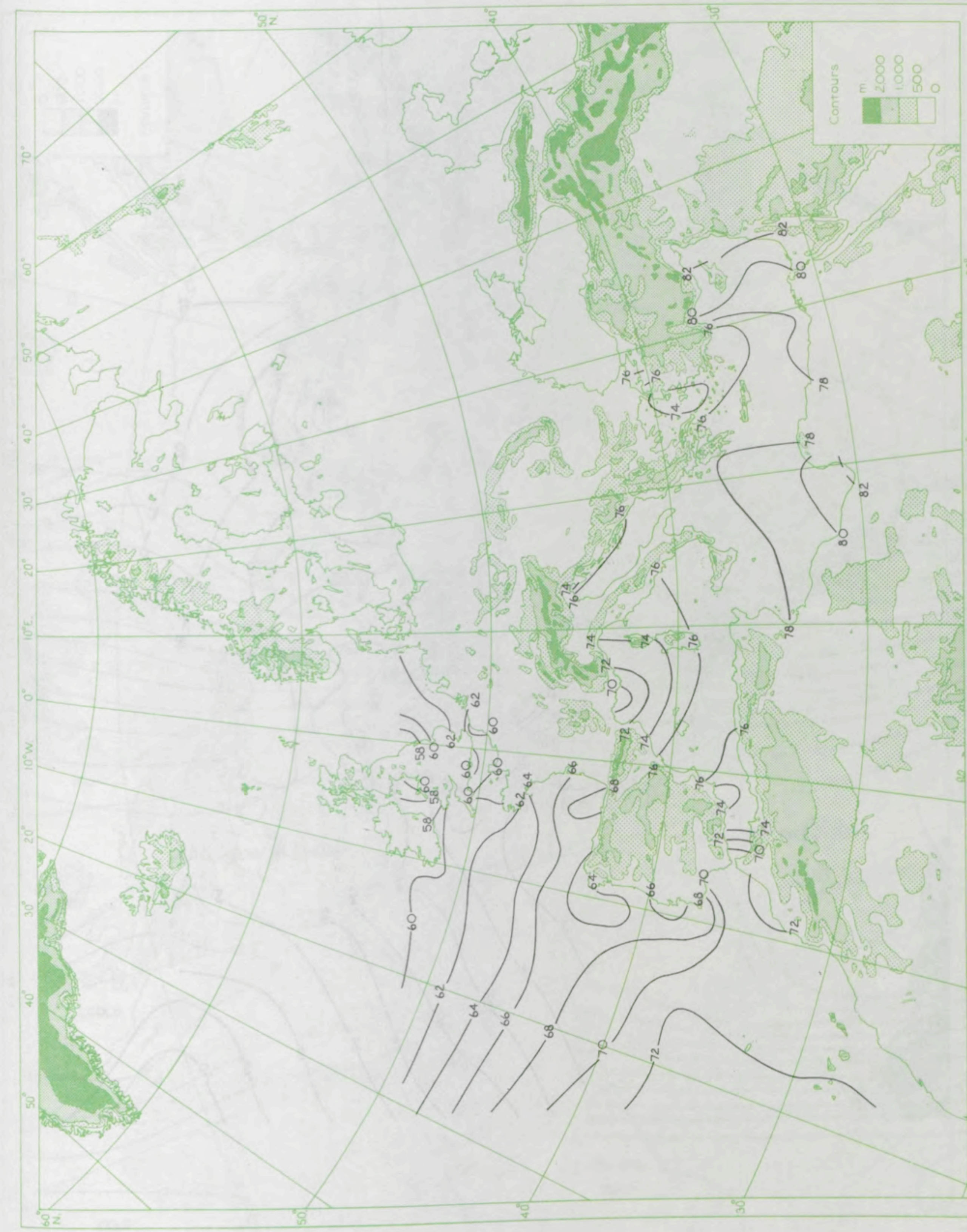


Fig.1.72(c) Mean sea surface temperatures for August

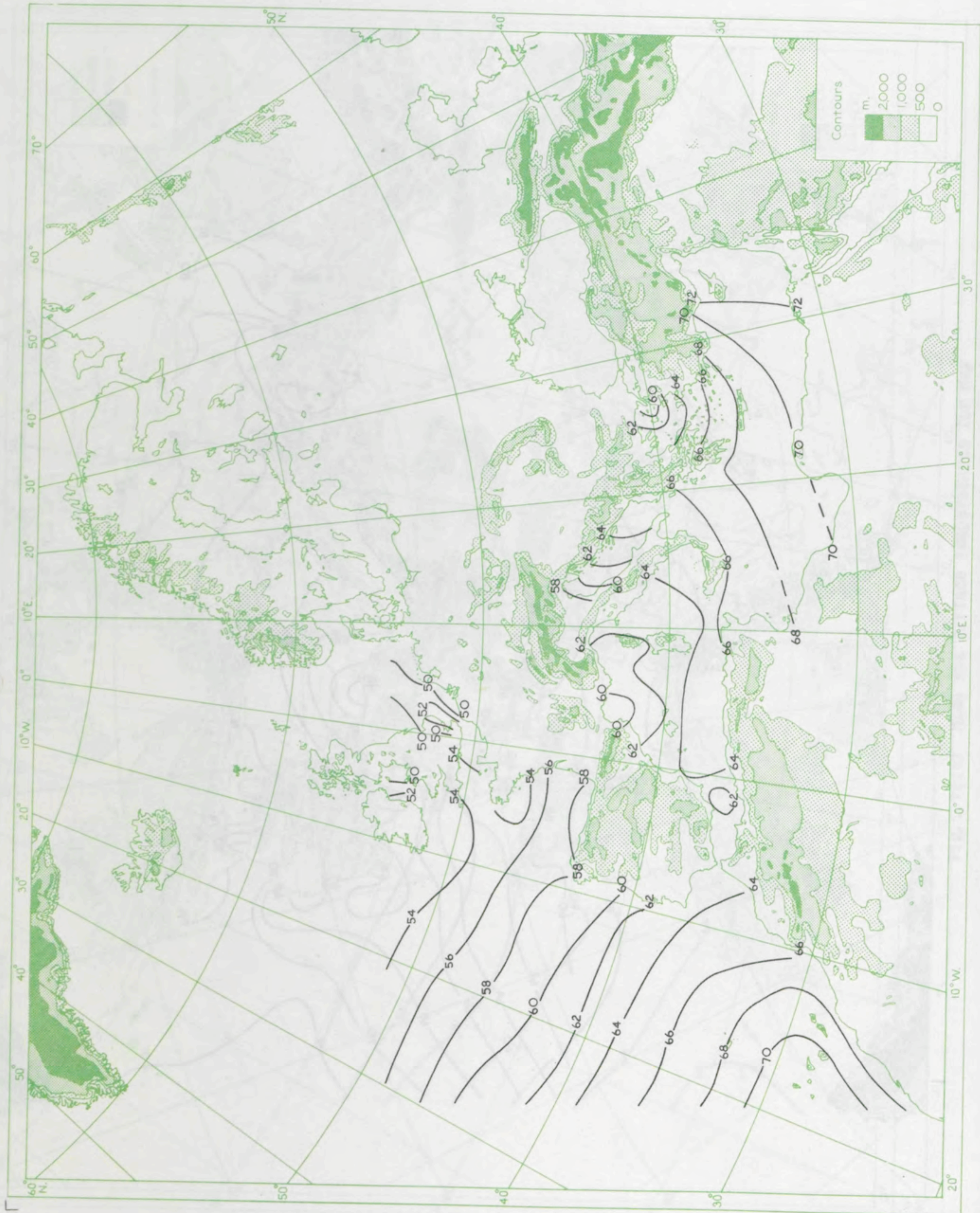
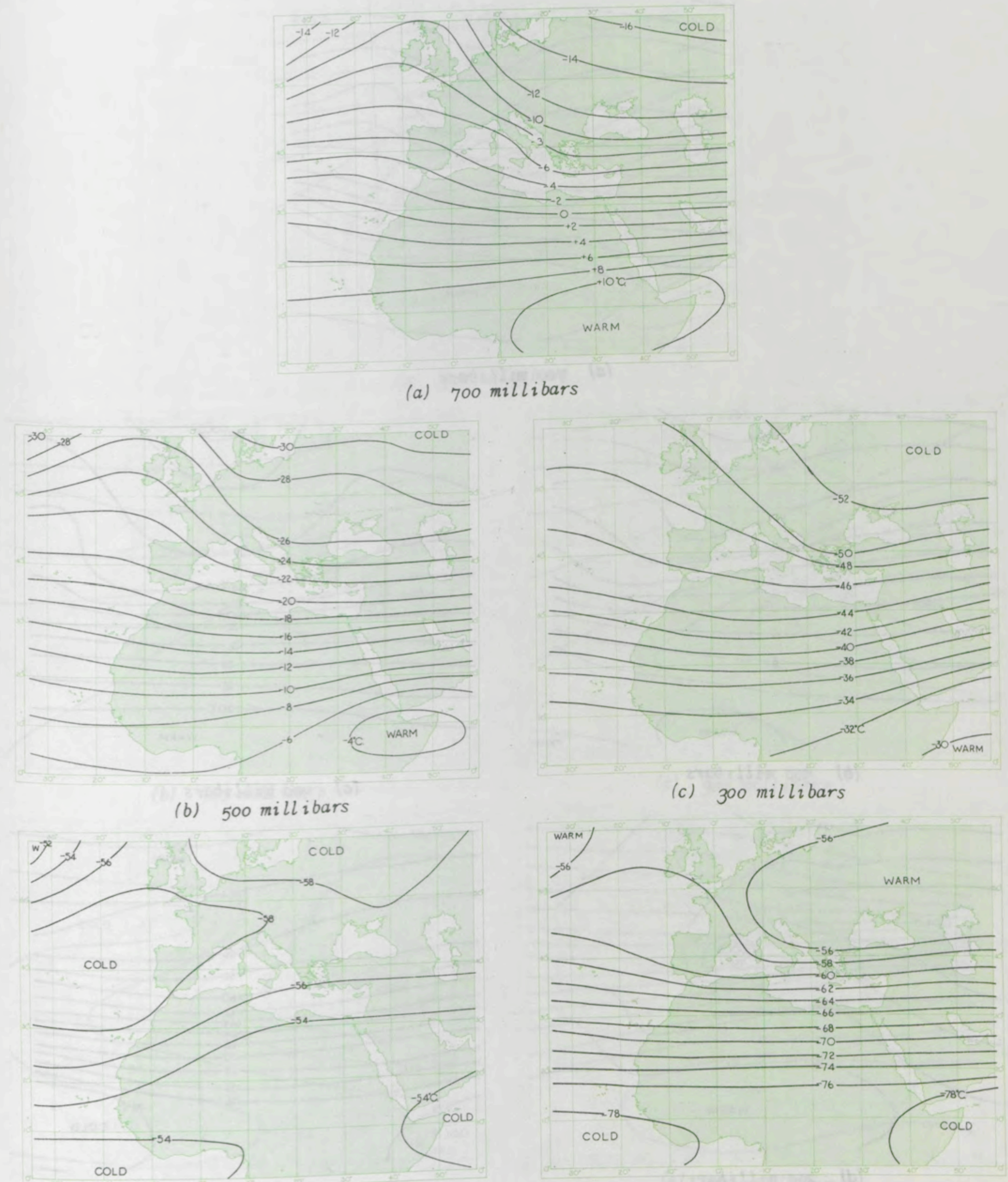


Fig.1.72(d) Mean sea surface temperatures for November



(a) 700 millibars

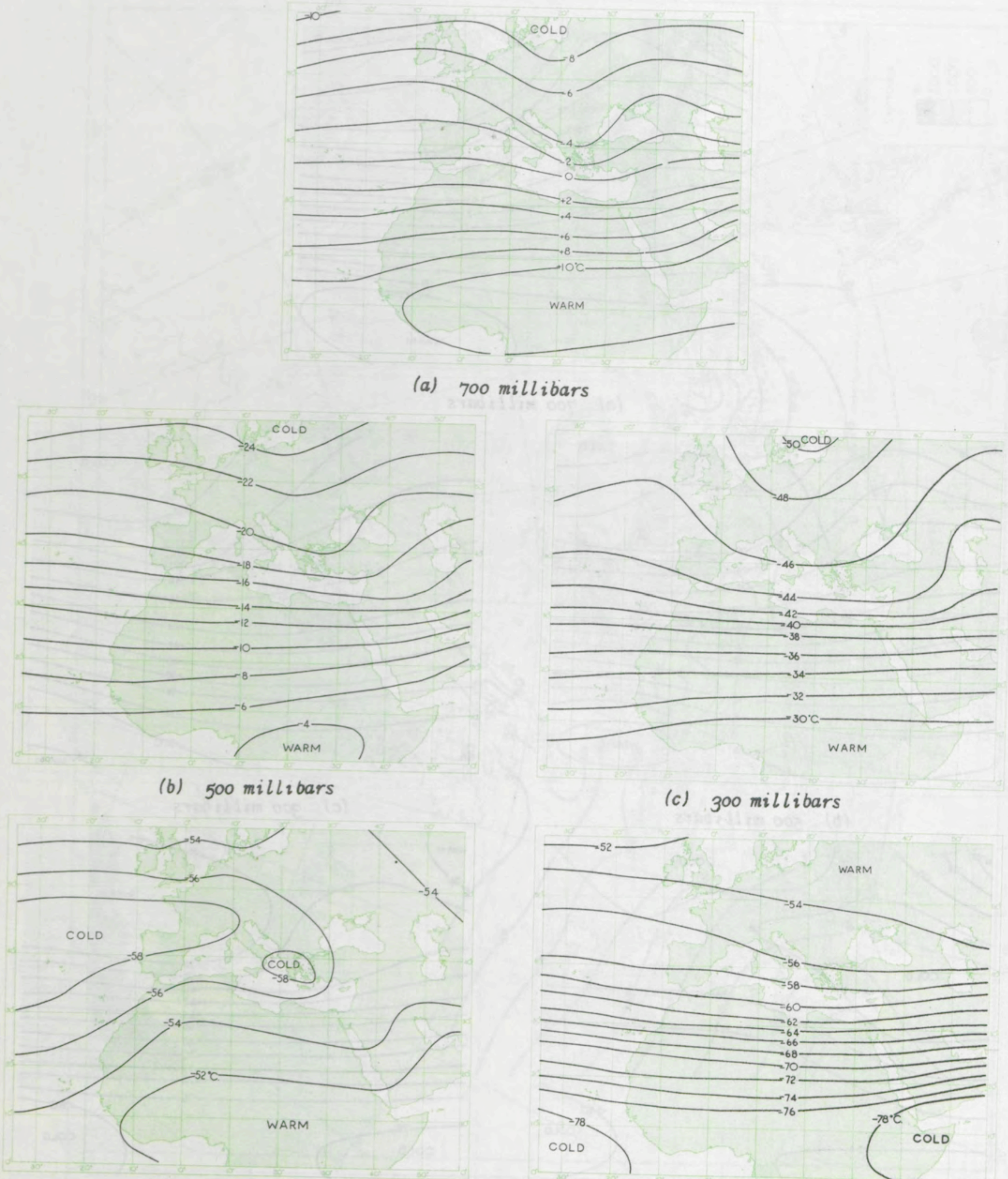
(b) 500 millibars

(c) 300 millibars

(d) 200 millibars

(e) 100 millibars

Fig.1.73 Mean upper air temperature for January



(a) 700 millibars

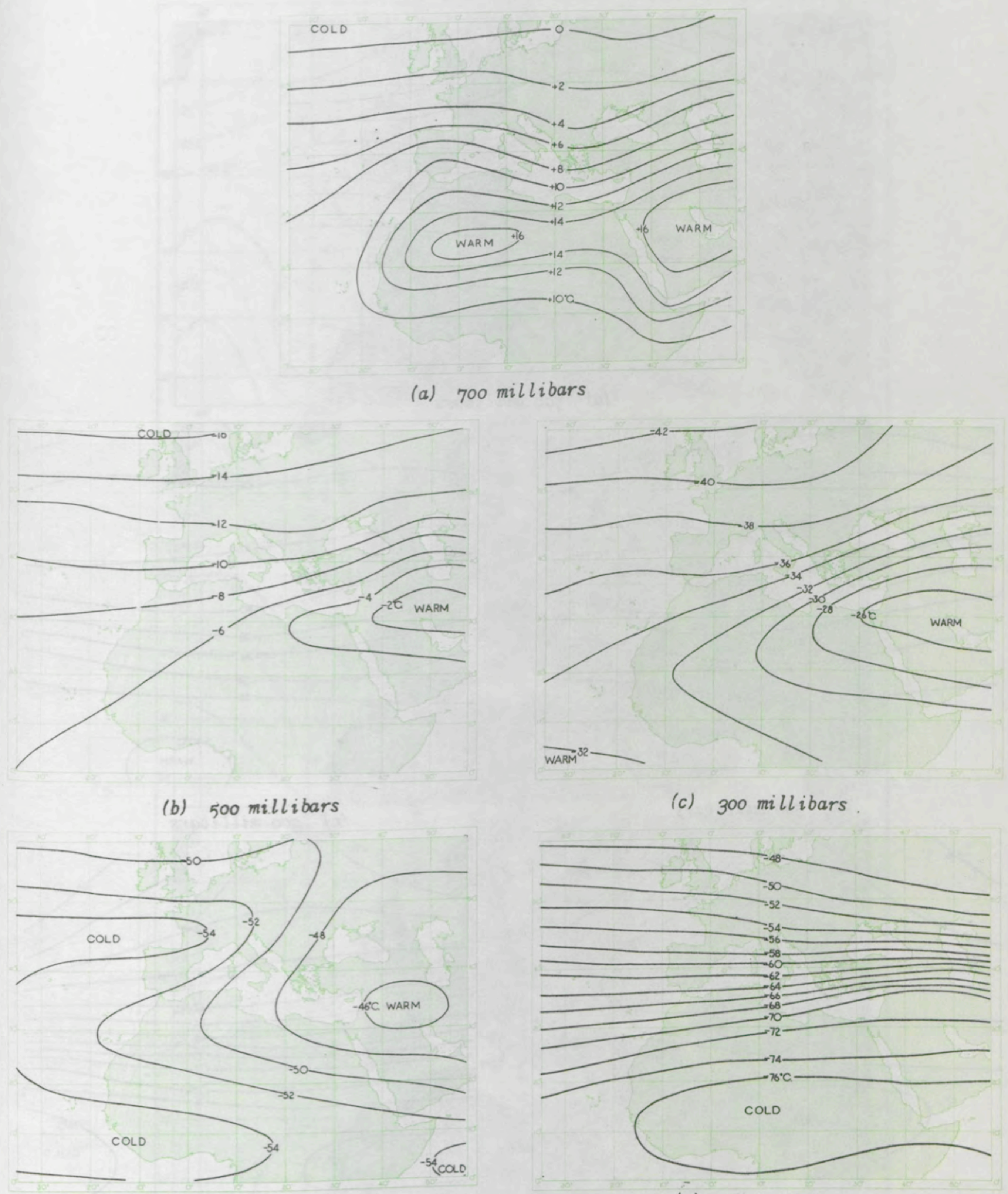
(b) 500 millibars

(c) 300 millibars

(d) 200 millibars

(e) 100 millibars

Fig.1.74 Mean upper air temperature for April



(a) 700 millibars

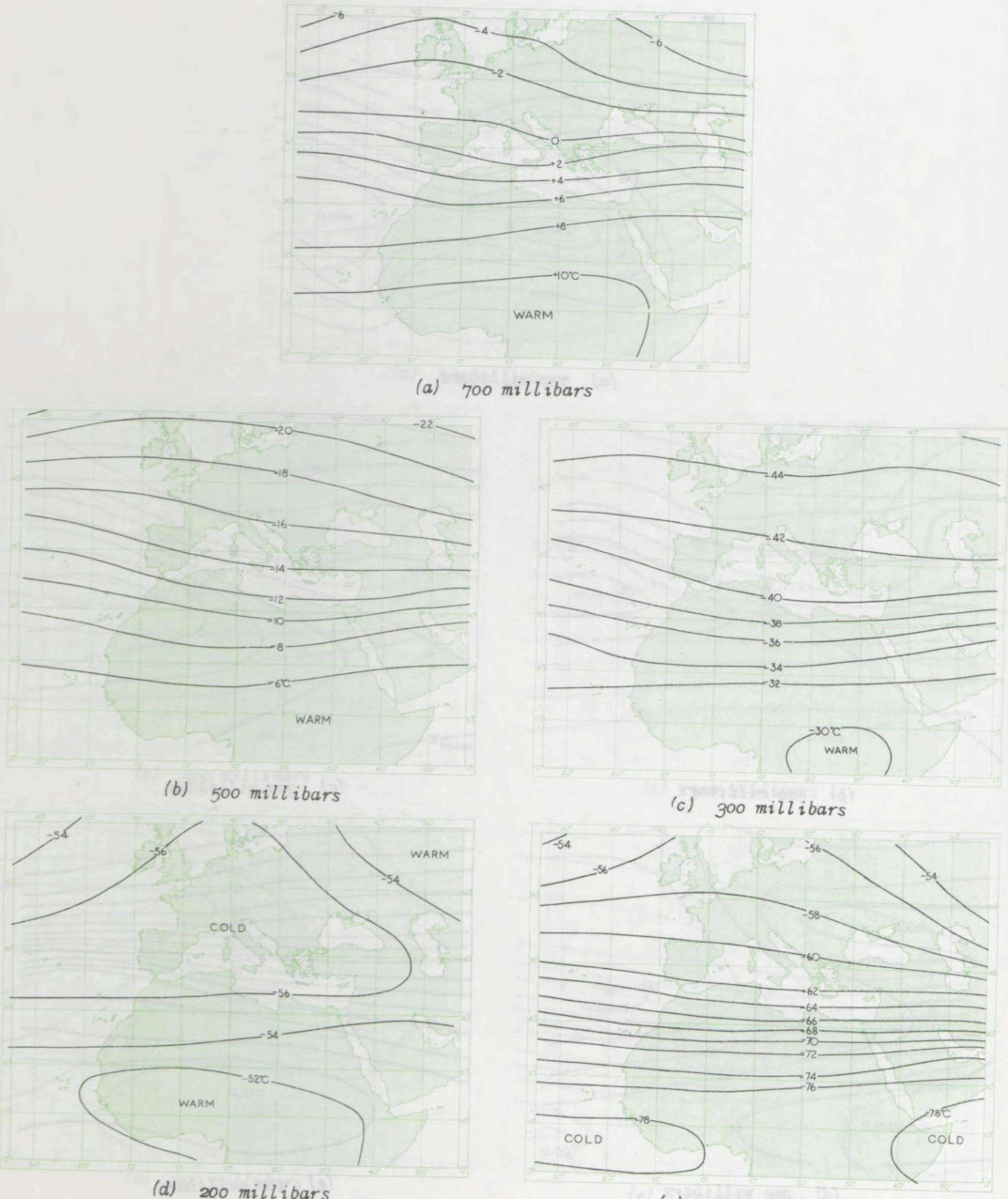
(b) 500 millibars

(c) 300 millibars

(d) 200 millibars

(e) 100 millibars

Fig.1.75 Mean upper air temperature for July



(a) 700 millibars

(b) 500 millibars

(c) 300 millibars

(d) 200 millibars

(e) 100 millibars

Fig.1.76 Mean upper air temperature for October

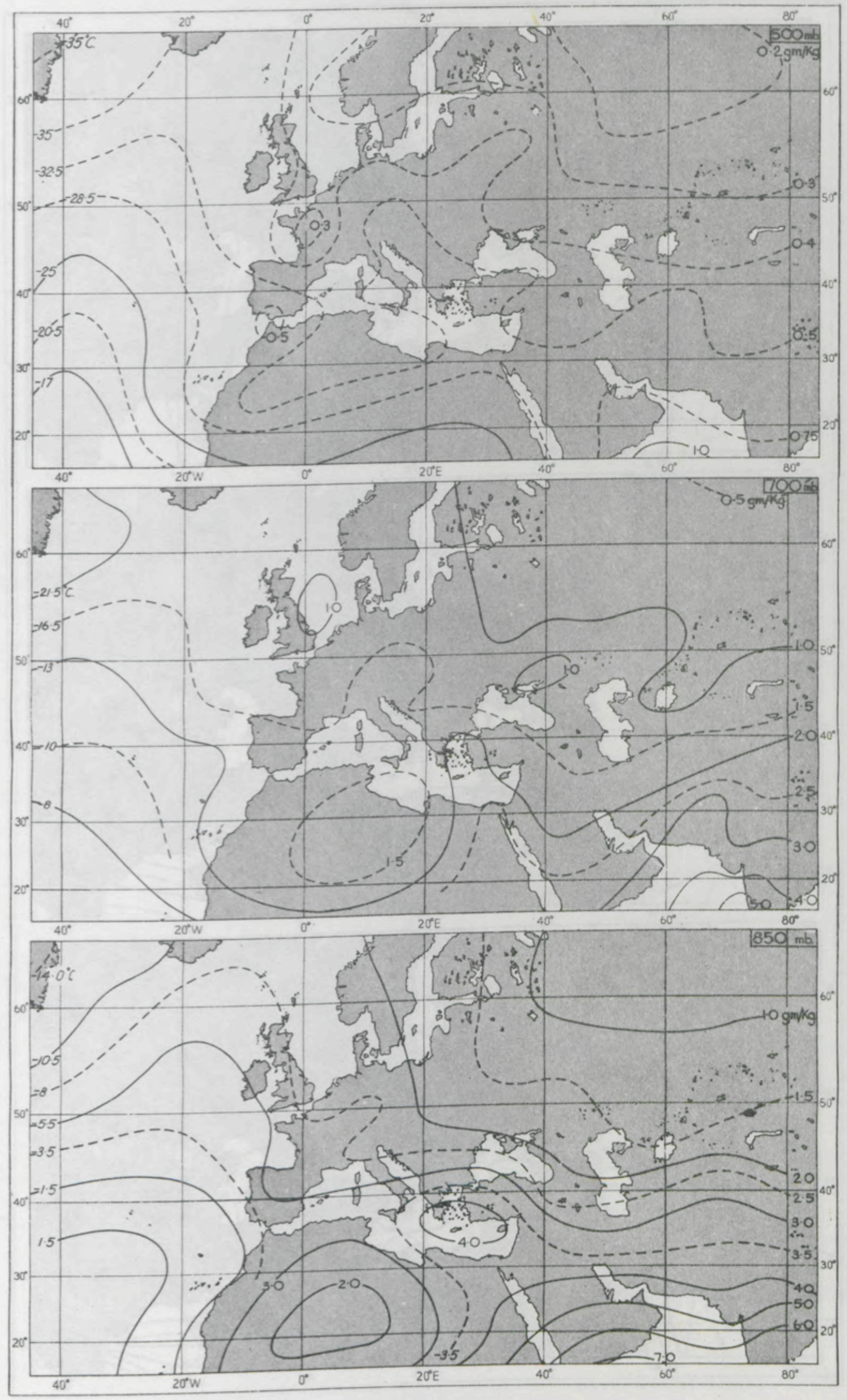


Fig.1.77(a) Humidity mixing ratios and corresponding dew-points for January

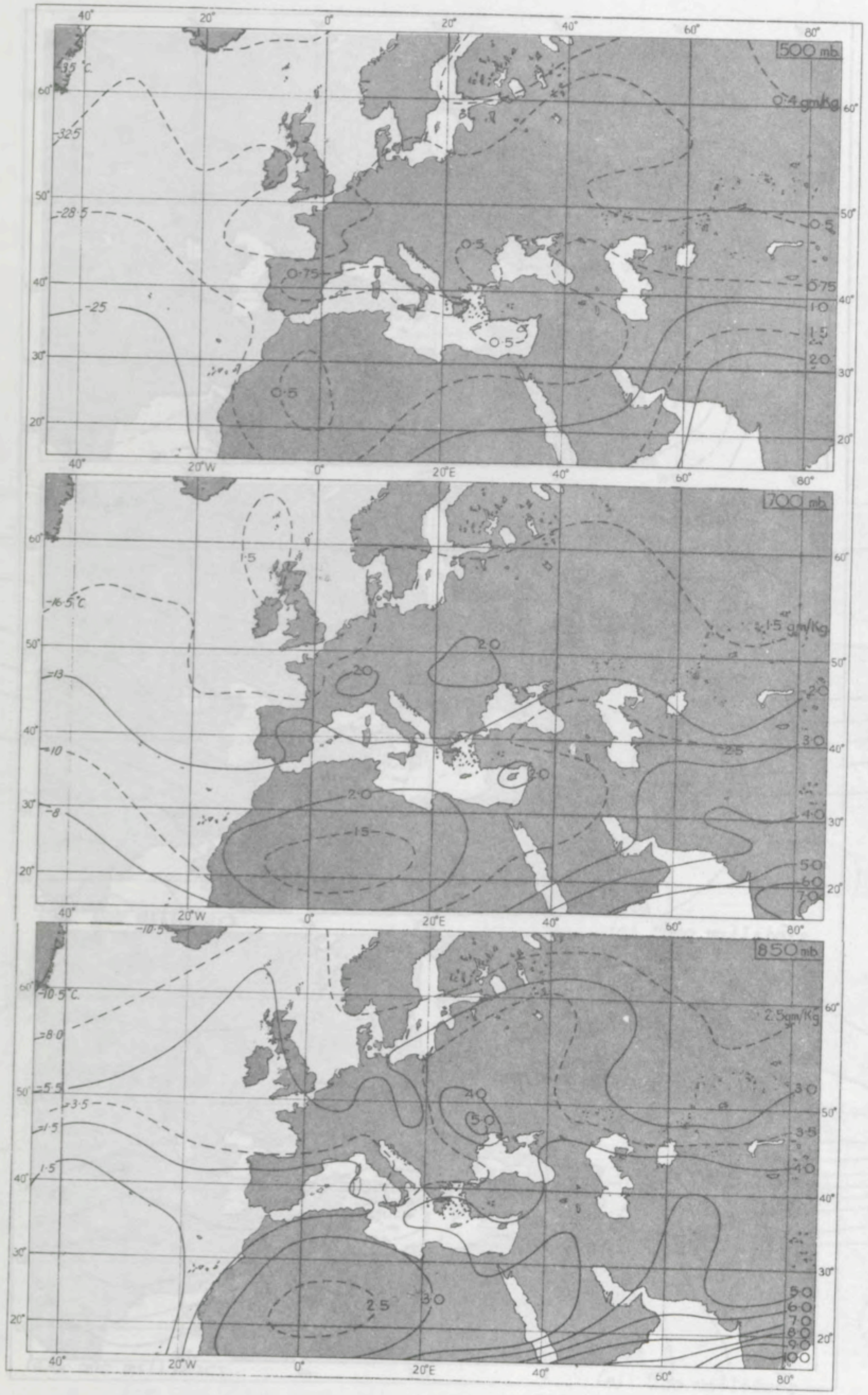


Fig.1.77(*b*) Humidity mixing ratios and corresponding dew-points for April

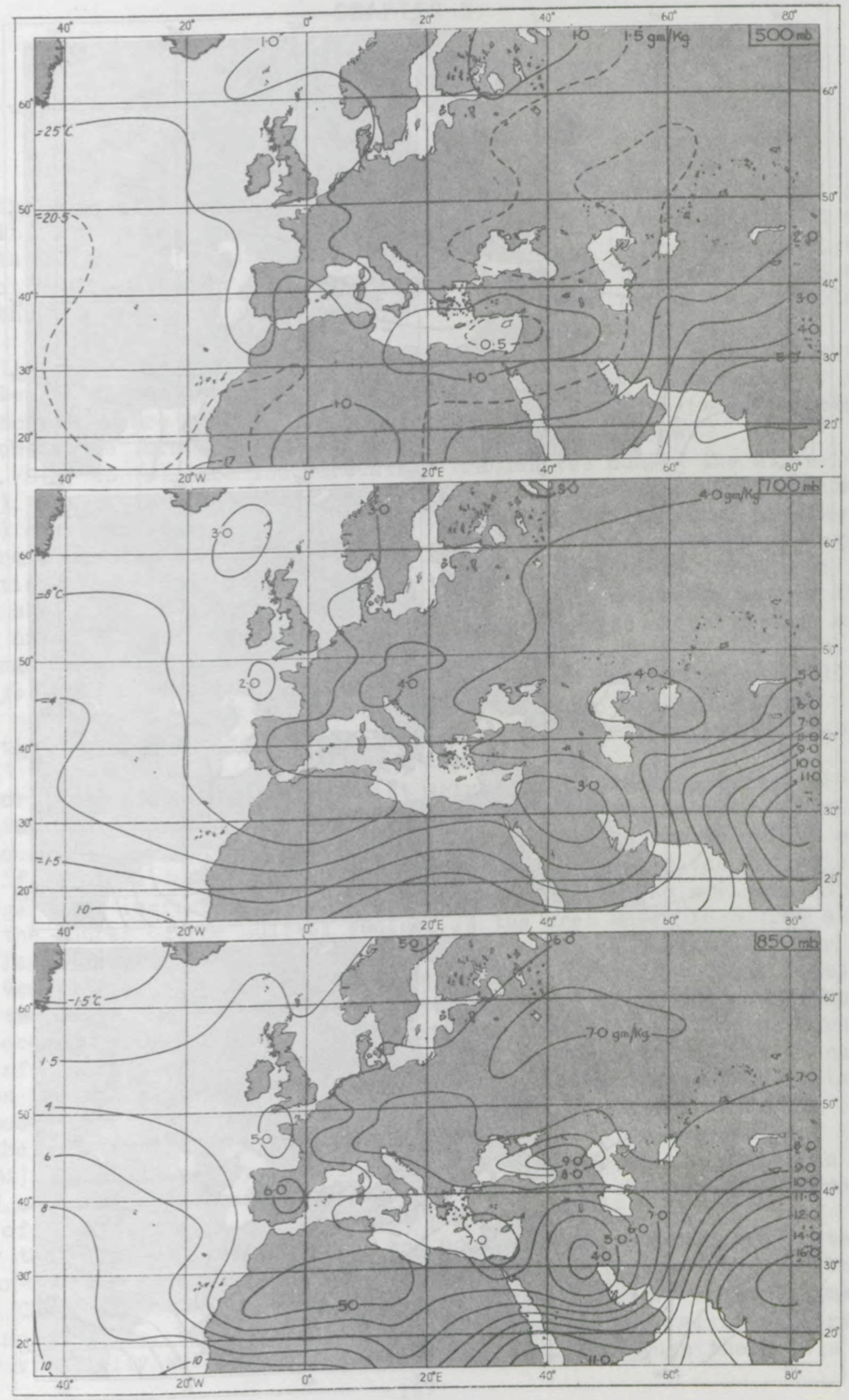


Fig.1.77(*c*) Humidity mixing ratios and corresponding dew-points for July

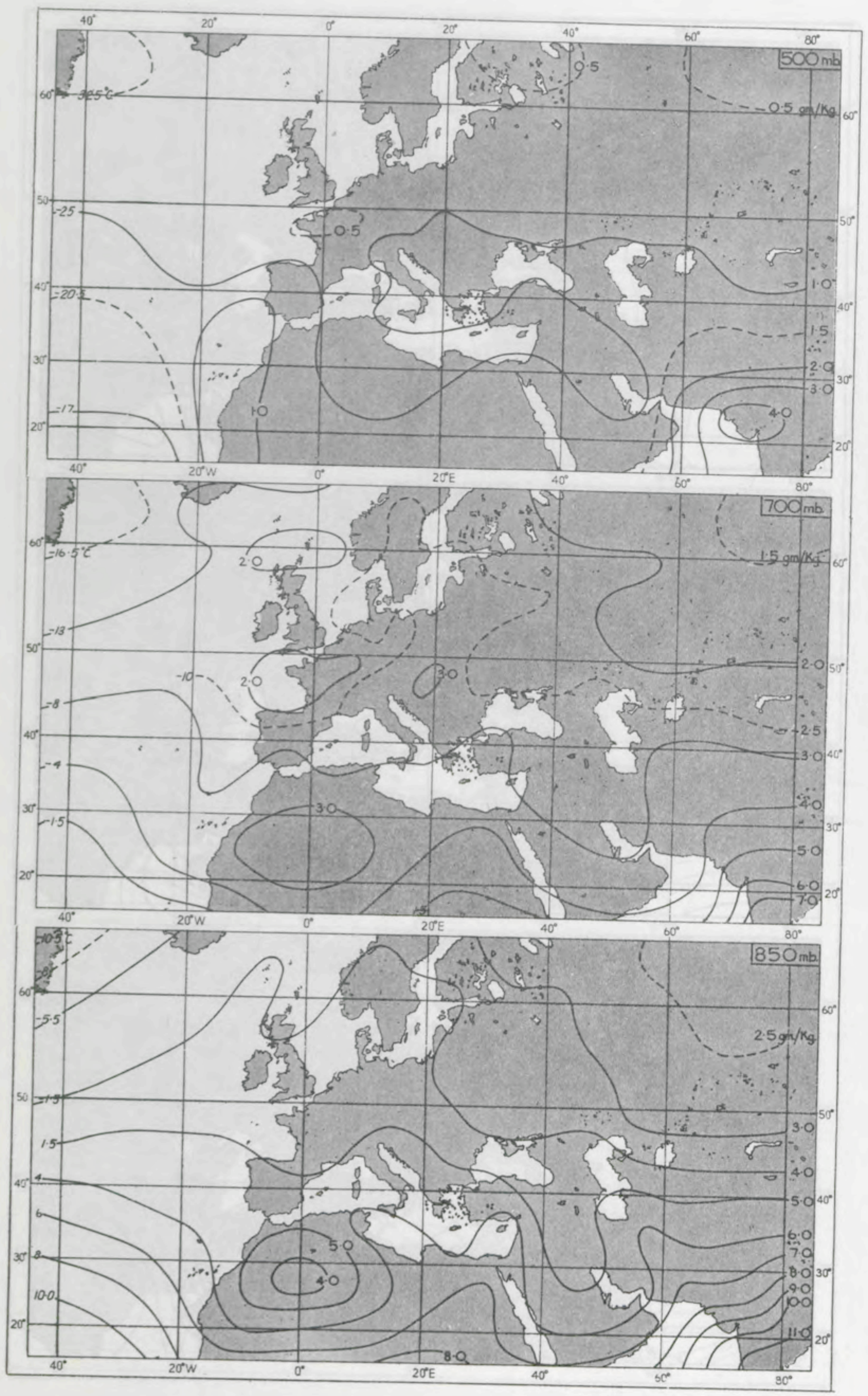


Fig. 1.77(*d*) Humidity mixing ratios and corresponding dew-points for October

CHAPTER 9

VISIBILITY AND CLOUD

VISIBILITY

Compared with industrial Europe and the waters between the English Channel and the Baltic, visibility in the Mediterranean is good. Extreme visibility is not as common as in high latitudes and is almost confined to intervals in the shower activity in polar or arctic air in winter. The percentage frequencies of visibility in various ranges for the sea areas and a number of coastal stations are given in Table 3 of Volume II.

Poor visibility. For the purposes of this chapter poor visibility is defined as visibility less than two nautical miles. The most important causes of poor visibility in the Mediterranean are mist or fog and dust haze. Other less important causes are precipitation in the form of heavy rain, thick drizzle and snow.

Figures 1.78(*a*) to (*d*) show the percentage frequencies during the winter (December to February), spring (March to May), summer (June to August), and autumn (September to November) of visibility less than two nautical miles at morning, afternoon and evening hours (approximately 0700, 1300 and 1900 hours local time) at a number of coastal stations. They represent quite well the main variations throughout the area, but fail to show the incidence of radiation fog at night which frequently disperses before 0700 or 0800 local time. Such fogs probably occur as often as five to ten nights during the winter even in the south.

Mist and fog. During the cool season from November to March poor visibility mainly affects the northern parts of the Mediterranean, and the chief causes are

(i) radiation fog in old stagnant polar air (that is, Mediterranean air, see page 8), and

(ii) the northward movement of warm moist scirocco air over the relatively cool sea.

In the latter case fog or poor visibility is generally accompanied by drizzle and much low cloud, and any of the areas of the northern Mediterranean may be affected from the Gulf of Lions to the Aegean Sea (see pages 82-86). In the Adriatic thick scirocco fogs occur increasingly from Pelagosa northwards. The northern Adriatic, especially the shores of the Gulf of Venice, is the area where fogs from all causes are particularly frequent. On the western shores, north of Ancona, fog may last all day and at Venice it has been known to continue as long as five days. South of Ancona, on the western shore, the frequency of poor visibility decreases and diurnal variation becomes more pronounced. On the eastern shores of the Adriatic poor visibility is infrequent in winter south of the Istrian peninsula and the frequency decreases on the whole southwards. On this shore a common cause of poor visibility is strong south-westerly winds (libeccio) associated with a depression in the Adriatic, the results of which can be specially dangerous on the coast of Istria (see page 82). Poor visibility associated with strong winds, low cloud and precipitation also occurs in the Ionian Sea with gregale and in the western Mediterranean and Strait of Gibraltar with vendaval (see pages 78 and 81).

In summer the chief regions where fog and poor visibility occur are in the Strait of Gibraltar and Alboran Channel and along the coast of North Africa. In the Strait and Alboran Channel the frequency of easterly winds (levanter) is at its maximum and these warm moist winds, blowing over the relatively cool sea, give low stratus and fog or poor visibility which may persist for some days although there is a tendency for fog to disperse or become patchy during the day. While the easterly wind continues the sea surface gradually warms, and the eastern end of the fog area gradually recedes westwards until after three or four days only the Strait itself is affected, with fog patches further west in the Atlantic. This summer levanter fog is cleared by an incursion of fresh polar air giving westerly winds. The westerlies again cool the water of the Strait and Alboran Channel and there is upwelling of cold water in the east of the Strait. For an example of levanter fog at Gibraltar see Figure 2.55(*a*). It has been estimated that the average numbers of days with fog over the Strait of Gibraltar from May to November are as follows:

May	June	July	Aug.	Sept.	Oct.	Nov.
2	5	11	8	4	3	2

At coastal stations the frequency is about half the above values.

Over and inland from the coast of North Africa summer fog and low stratus are due to the warm moist air which moves from the sea across the coast as the prevailing wind of the season. The low stratus and poor visibility or fog occur in the early morning as a result of cooling by nocturnal radiation. The most favourable conditions are when the air mass is continental tropical from Mesopotamia or Asia Minor and has passed over the Mediterranean and picked up moisture (see page 22). As a result the worst affected area is lower Egypt, where low stratus occurs on an average of about ten to fifteen days in each of the months of July and August. At Ismailia fog occurs on an average of one day per month in July and August with a maximum of about four days in each of these months. Invasions of fresh polar air clear away the fog and low stratus after which there is generally a gradual return to the former conditions. The inland areas of Cyprus and Palestine are similarly affected on a few days per month in the summer. An important exception occurs on the western coast of Cyrenaica where night-time conditions are commonly marked by a light katabatic easterly drift from the Cyrenaican hills in the interior. As a result Benghazi (and its airport, Benina) enjoy a remarkable freedom from low stratus and fog.

On the coast of Sardinia mist and fog are said to be most common in June and July, and to be rare in winter. In the Straits of Bonifacio they are frequent in May. The fog is mainly early-morning fog, but mist occasionally lasts all day. There is often thick mist over the coast of Sardinia when the air is quite clear at sea, during the night as well as in the early morning; special precaution is necessary in this vicinity on account of such night fog (see also page 85).

In spring and autumn poor visibility in the form of mist or fog is not common in most areas of the Mediterranean if we except November and March which have been included in the cool season. It has also been noted that the levanter fogs of the Strait of Gibraltar extend outside the summer from May to November. However, spring and autumn are the seasons when scirocco air most frequently spreads northwards over the Mediterranean and, especially in spring and early summer when the sea is still relatively cool, mist or fog is liable to be found wherever the scirocco air spreads, the frequency being greatest during the night and early morning. The places most often affected in this way in spring and early summer are the northern parts of the western Mediterranean, the Tyrrhenian Sea, Malta, the Ionian Sea and the northern parts of the Adriatic.

In spring poor visibility may occur over the North African coast in light north-easterly winds blowing in the rear of Saharan depressions. At Tripoli fog is commonest from March to June, generally being confined to the early morning.

In autumn the northward extension of the Red Sea trough is most prominent and this favours the flow of continental tropical air from Arabia to the eastern Mediterranean where it is stabilized and moistened and then flows southwards into lower Egypt on the west side of the trough. This air brings frequent fog to the Nile delta and Canal

Zone especially in October. Poor visibility also occurs in autumn to the north of the Gulf of Sidra in light southerly or south-easterly scirocco blowing from North Africa.

At Malta scirocco fog and low stratus normally occur only with winds which have moved from the Gulf of Sidra and reach the island from an easterly direction. Such a track gives opportunity for the continental tropical air to pick up sufficient moisture (see page 82). The presence of protective hills along the western side of the island is also a factor which leads to the low frequency, over the greater part of the island, of advection fog and low stratus in any but easterly winds. It is only rarely that the stratus descends low enough to give fog at Luqa (the civil airport, 260 feet above sea level) and even less commonly at Hal Far (the Naval station). But in extreme cases, even as late as 1 June, fog may persist, lifting only between about 0900 and 1600 local time, while stratus remains low most of the day, dropping to the level of the top of the cliffs on the southern coast at about 1600 to 1700 local time. Where there is a suitable onshore component of scirocco wind, fog may envelop the cliffs along the south and south-west facing coasts of Malta and Gozo for most of the 24 hours, especially when the wind is light.

Radiation fog at Malta is rare though it may occur in any season in quiet conditions, and is most frequent in the valley bottoms in the eastern part of the island. At Luqa it is always shallow and usually very patchy. Generally it is a dawn phenomenon but may occur as early as 0200 local time. At Hal Far radiation fog is almost unknown.

At Luqa, on average, visibilities below 2,000 yards occur on about 10 to 15 days in the year, and visibilities below 1,000 yards on about 5 days. Very low stratus (4 eighths or more at less than 500 feet) occurs on about 20 days in the year.

Dust and haze. In spring and autumn the main cause of poor visibility is dust carried northwards from the desert areas of North Africa when depressions move eastwards along or near the North African coast. Duststorms raised by the winds in these depressions give visibilities between 50 and 2,000 yards and the winds carrying the dust may cause reduction of visibility in regions far distant from the originating duststorm. The majority of duststorms occur with depressions on tracks 2*b*, 2*c* and 2*d*, but depressions on tracks 1*b* or 2*a* may give occasional duststorms on the coasts of Algeria and Morocco. Duststorms may also occur in winter with deep depressions on track 3*d*/4*b*, especially if their paths are near to the North African coast (see page 39). There is great variety in the extent and severity of duststorms, depending on the strength of the wind and the state of the ground over which it blows. They reach their worst in the strong winds ahead of the cold front of the depression, generally in a belt 20 to 50 miles wide just ahead of the front. With a passage of the cold front the dust may blow again if the place is not too near the coast, especially when there has been no rain with the front and when the cold air is unstable as is often the case in February and March. In such cases a duststorm may continue for some hours after the passage of the cold front. Under less favourable conditions the storm degenerates into occasional rising sand. Occasionally, strong to gale winds ahead of the warm front of a depression may also raise much dust. With exceptionally deep and extensive Saharan depressions the belt of duststorms may be more than a hundred miles in width, and thick dust may be carried up to 15,000 or even 20,000 feet. Such dust may travel great distances northwards (see page 16). The extent of visibilities under 200 yards is usually limited to a narrow band across the width of the air stream, but visibilities of about 1,000 yards may be quite general on the North African coastland near an approaching cold front and even at Malta may be only two miles. A duststorm at any one place seldom lasts for more than 12 hours although the depression may cause duststorms for three or more days as it moves along its track. Generally the dust clears after the passage of the cold front.

The frequency of duststorms may be gauged from the fact that they occur chiefly with Saharan depressions of which there are, on average, about 14 in a year (see

Table 4) and that severe duststorms may be expected with about 50 per cent of Saharan depressions. They are commonest in May.

Rising dust of a more local character may occur in the south-westerly winds of the less severe depressions, and at times with fresh to strong north-westerly winds inland from the North African coast especially with the well developed sea-breezes of summer (see, for example, page 94). In such cases the dust does not usually rise more than a few hundred feet, and although visibility may be reduced to between 200 and 500 yards this is only for short periods. Severe localized duststorms may occur with cumulonimbus clouds, but they are rare.

The amount of dust raised by the wind and the height to which it is carried both increase during the day, normally reaching their maxima in early afternoon when convection is most vigorous. When the desert surface is wet after rain the raising of dust is inhibited, but in most circumstances, in the absence of further rain, the top layer of sand dries very quickly and if the wind is sufficiently strong the sand will rise. However, in some places the desert surface tends to cake when drying after heavy rain.

The raising of dust in the form of dust devils is another localized phenomenon which may result in a deterioration of visibility. Dust devils occur with calm air or light winds over intensely heated loose sand or soil and are familiar features of the hot months in all coastal regions of the south and east Mediterranean, especially the latter. Dust devils may only grow to ten feet or so in height before dissipating, but in southern Palestine they are known to reach heights of 600 to 700 feet. They drift in the prevailing wind and, like waterspouts, may rotate in either direction. When a well developed dust devil passes over the sea it may become a waterspout, just as a waterspout passing across the coast over suitable loose ground may become a dust devil.

That the ability of a wind of any given force to raise dust depends on the state of the ground is well illustrated by comparing Idris, the airport for Tripoli, with El Adem, an airport about 18 miles inland from Tobruk. Although the immediate vicinity of Idris is cultivated, loose sand is not far distant and a surface wind of force 5 from any direction between north-east through south to west-north-west may reduce the visibility to 1,000 yards, while a wind of force 6 will reduce it to 600 yards. A strong pressure gradient in the desert to the south of the Tripolitanian plateau brings up thick dust haze. El Adem, on the other hand, lies on a stony plain and in this locality there is more loose sand to the north than to the south so that rising sand is far more likely to be associated with a strong wind from the north. Thus visibility at El Adem is likely to remain hardly affected by several hours of strong southerly winds, but may deteriorate seriously as soon as the wind veers to north-west.

Outside North Africa the reduction of visibility caused by dust is most frequently in the form of haze carried northwards by scirocco winds. Generally reduction of visibility to less than two miles occurs only over the sea areas bordering on the North African coast, but may reach southern Spain (for example, Almeria) with leveche (see page 85) the onset of which is said to be sometimes marked by a cloud of dust. Further north the presence of desert dust is mainly noticeable through the darkening of the sky, or in less severe cases by the characteristic white haze and yellow sunsets, on account of the sand particles suspended at high altitudes or finely distributed through a deep layer.

The dust is eventually washed out of the air, commonly in orographic drizzle and rain where the air stream is lifted over a mountain barrier, but when this does not occur or is not complete Saharan dust may reach as far afield as England.

A few other places besides North Africa are noted for the raising of dust by the wind. For example, at Salonika in the summer northerly gales occasionally sweep down the Vardar valley with clouds of dust, spreading haze over a wide area. At Athens,

when the etesians are strong, similar conditions are said to occur from time to time.

Upper haze. Dust in suspension in the air may cause a noticeable reduction in visibility aloft. After a duststorm large quantities of dust may be raised to considerable heights and visibility aloft may be reduced over large areas. While most of this dust settles after a day or two, the finer particles may continue in suspension for long periods as a result of convection. In summer there is commonly a very persistent layer of haze or mist which may exist up to 12,000 feet and is possibly to be attributed to high humidity and the effect of hygroscopic salt particles. It has been suggested that these effects are to some extent cumulative during the summer season owing to relative lack of air-mass exchange. Within the haze layer itself horizontal visibility is said to be affected more than slant visibility. The upper surface of the haze sometimes appears as a distinct boundary and, to an observer flying above this boundary, slant visibility may be seriously reduced by reflection of sunlight from the particles of the boundary layer.

Mirage. Abnormal refraction in the atmosphere leading to mirage is common in many parts of the Mediterranean both at sea and on land. "Inferior" mirage occurs chiefly in summer and in deserts, shoals, shallow waters and flat coasts when the surface air is at a higher temperature than the air immediately above it. The horizon is depressed, distant low-lying objects are not seen at all, and objects which are seen appear to be nearer and clearer. This mirage occurs mostly in the morning when surface temperature is rising rapidly but before large-scale convection has begun.

When, on the other hand, the surface layers of a relatively warm current are cooled sufficiently, "superior" mirage is observed with elevation of the horizon. Objects appear raised above their usual positions and may be seen even when their distance exceeds that of the normal horizon. As a result, visibility is judged to be exceptionally good. These conditions are sometimes the precursors of fog. The condition occurs in light hot winds blowing offshore, the surface layer being cooled by the sea while the air above remains hot. Turbulence prevents these effects in stronger winds. The phenomenon also occurs in calm evenings in coastal waters when the surface temperature is falling rapidly.

The regions where mirages occur most frequently are on the coast of North Africa (where they are called "sarab" by the Arabs), in the Gulf of Lions and the French Riviera, in the Strait of Messina, where very striking and complicated examples of "superior" mirage (fata morgana) occur, in the Ionian and Aegean Seas, and in the eastern Mediterranean, especially near coasts. At Malta "superior" mirage sometimes enables buildings in Sicily, 70 miles away, to be seen clearly. Remarkable instances of mirage have been recorded in Cyprus on calm summer mornings.

CLOUD

A number of tables giving cloud data for coastal stations and sea areas are included in Volume II. The mean amount of cloud at morning and afternoon hours of observation is given in Table 1. Tables 4(*a*), 4(*b*) and 4(*c*) give the percentage frequencies of occasions when the base of cloud was below certain levels; Table 5 gives the mean number of clear and cloudy days, and Table 6 gives the percentage frequencies of various degrees of cloudiness.

The average numbers of clear and cloudy days in February and August are also given in Figures 1.79(*a*) and (*b*) which show the relative clearness of the skies throughout the Mediterranean in summer as compared with winter. It should be noted that the criteria for clear and cloudy days vary slightly from station to station, but this does not seriously affect the comparability of the figures. The definitions appropriate to each station are given in the tables. The Ionian Sea in particular is noted for clear skies in summer.

In many places ashore the diurnal variation of cloud in winter gives a maximum in the early morning due to low stratus. This cloud normally dissolves after sunrise and there is a second maximum in the afternoon due to the development of cumulus. In summer there is in most places only the afternoon maximum. The clearest time of day is the evening, but clear mornings or mornings with only shallow mist or fog which soon clears occur under the same conditions of light wind and subsidence as in higher latitudes. The tables do not show the frequency of early morning low stratus owing to the fact that this has generally dispersed by the time of the morning hour of observation (0700-0800 local time).

Coastal waters are commonly affected by the diurnal changes of cloud over the neighbouring land; convection however is commonly suppressed, and the sky clears completely over the offshore waters up to about 10-15 miles from the coast, when cumulus development grows over the land.

Cloud with base below 1,000 feet. The incidence of cloud with base below 1,000 feet has a space distribution very similar to that of fog. Its diurnal and seasonal variations are also similar to those of fog, the reason being that fog and low stratus are both essentially due to the same causes. Thus low stratus occurs in winter in old stagnant polar air (Mediterranean type), especially on the north and north-western shores of the Adriatic, to a lesser extent also on other northern shores of the Mediterranean, and at times during the night and early morning in other parts of the Mediterranean.

In summer low stratus is frequent during the night and early morning with levanter winds in the Strait of Gibraltar and Alboran Channel, and inland of the shores of North Africa, especially in the Nile delta. In all these areas the cloud as a rule only lasts for a few hours in the early morning, and here again the conditions for formation and clearance are similar to those for mist and fog. The freedom of Benghazi and its airport, Benina, from low stratus has already been noted (see page 168).

Low stratus, like fog, occurs in the rear of Saharan depressions in light north-easterly winds and its is widespread over the Mediterranean in light to moderate scirocco winds especially at seasons when the sea surface is relatively cool and where the air stream approaches cliffs or a mountainous coast. Other occasions of low cloud are in rain, especially where moist scirocco winds meet continental polar air, in frontal conditions generally, in squally showers, thunderstorms, snow and in hailstorms.

Over the greater part of the Mediterranean the frequency of cloud with base below 1,000 feet is less than two per cent at any time of day throughout the year. The north and north-western Adriatic is the only area of the Mediterranean where its seasonal variation is well marked, having a winter maximum which reaches as high as 15 to 20 per cent with little or no diurnal variation.

Fig.1.78(a) Percentage frequency of visibility less than 2 nautical miles at morning, afternoon and evening hours of observations in winter
Zero is written for frequency less than ½ per cent.
A dash is written where no figure is available.

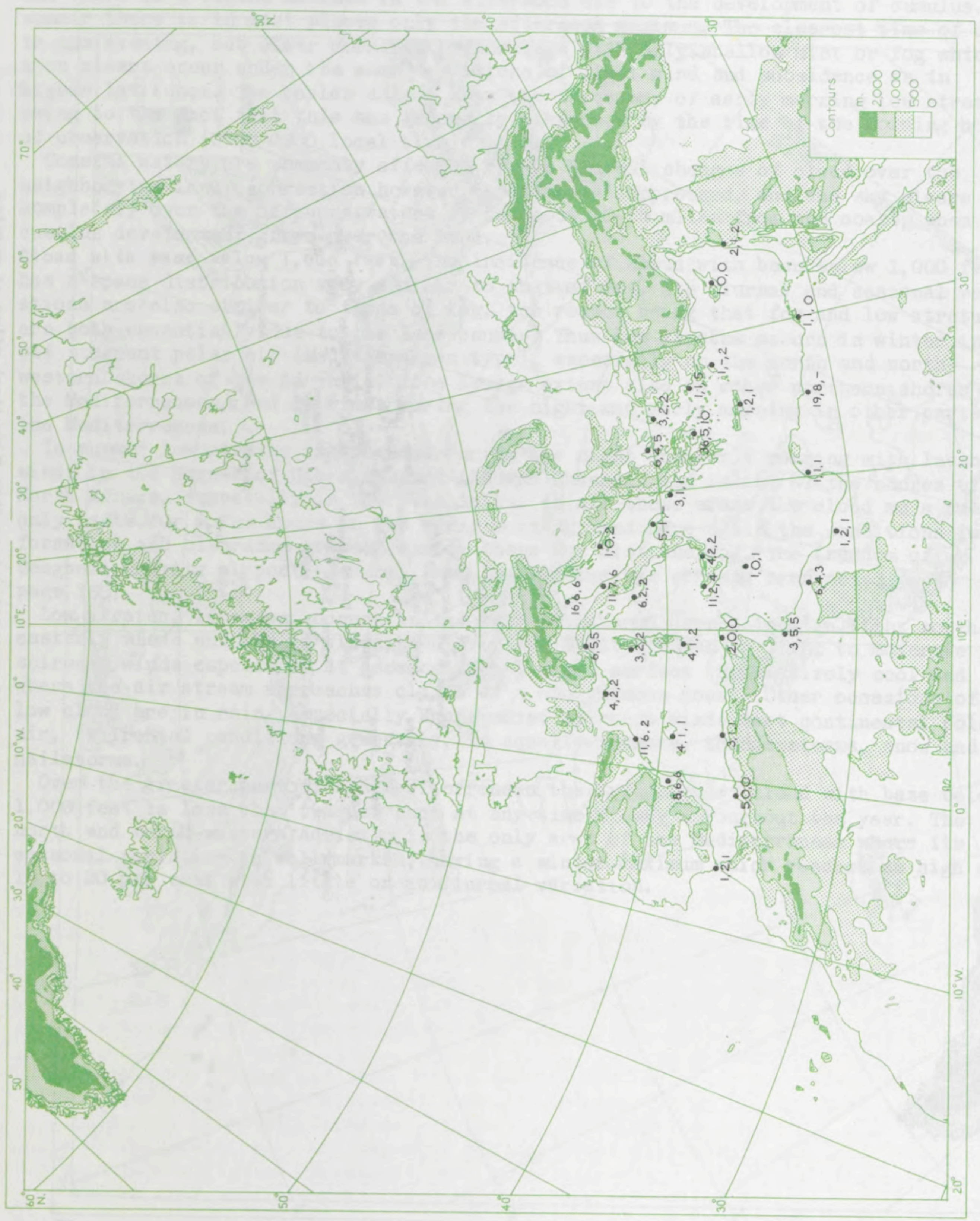


Fig.1.78(b) Percentage frequency of visibility less than 2 nautical miles at morning, afternoon and evening hours of observations in spring
Zero is written for frequency less than ½ per cent.
A dash is written where no figure is available.

Fig.1.78(c) Percentage frequency of visibility less than 2 nautical miles at morning, afternoon and evening hours of observations in summer
Zero is written for frequency less than ½ per cent.
A dash is written where no figure is available.

Fig.1.78(d) Percentage frequency of visibility less than 2 nautical miles at morning, afternoon and evening hours of observations in autumn
Zero is written for frequency less than ½ per cent.
A dash is written where no figure is available.

Fig.1.79(a) Average numbers of days with clear or cloudy skies in February
The figures at each station are for clear and cloudy skies respectively.

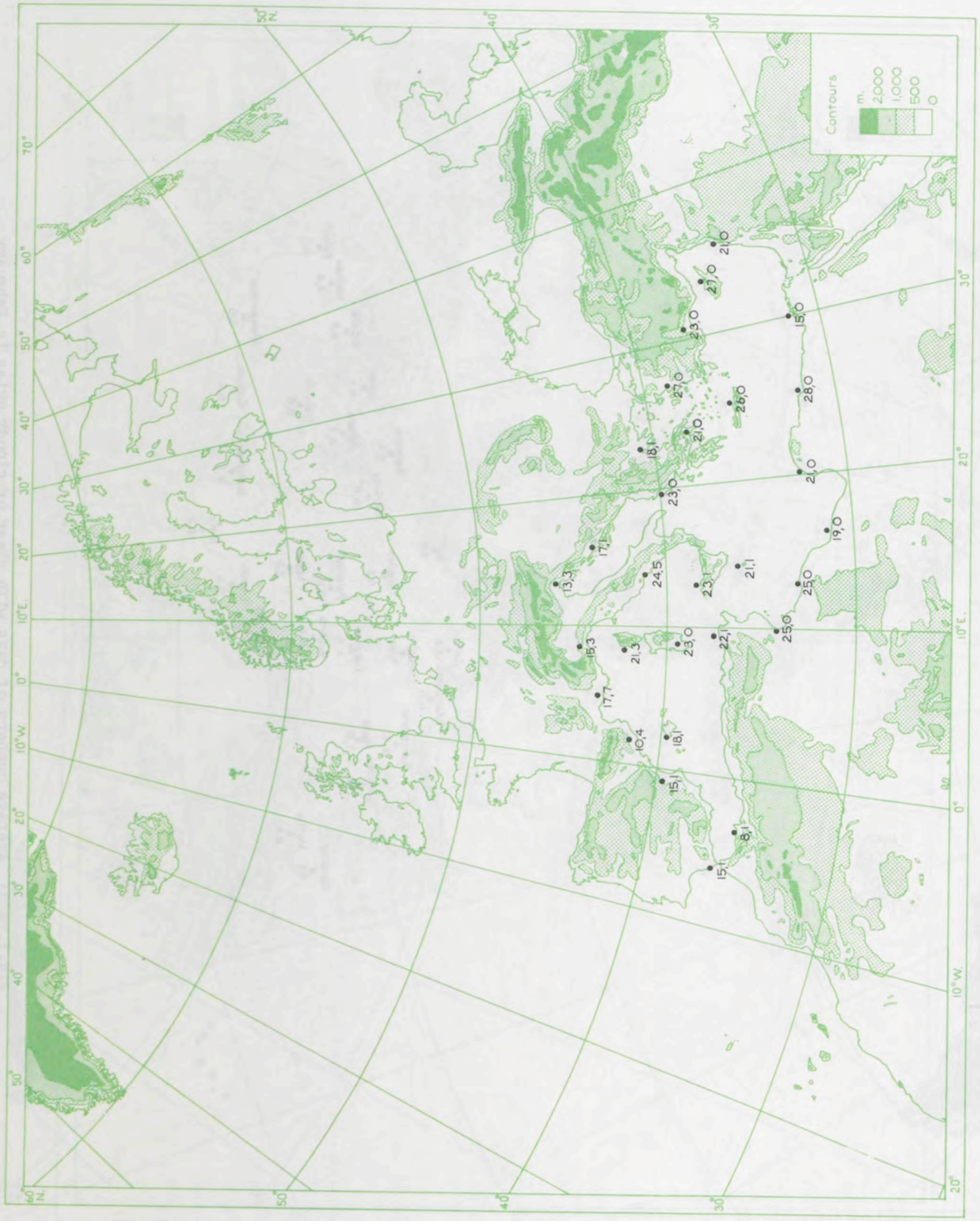


Fig.1.79(*b*) Average numbers of days with clear or cloudy skies in August
The figures at each station are for clear and cloudy skies respectively.

CHAPTER 10

PRECIPITATION AND THUNDER

RAIN

Rainfall occurs in association with depressions, especially those on tracks 1*a*, 3*c* and 4*a* in the northern parts and 2*a*, 2*b*, 2*c*, 3*d* and 4*b* in the southern parts of the Mediterranean. Much of the heavier rain is of the showery type, occurring at the cold fronts of depressions or in instability showers in the cold air mass (see Chapter 2). Particularly heavy rain is liable to occur at cold fronts when the air ahead is specially warm and humid (for example, moist scirocco - see page 75) while instability showers and thunderstorms are specially active in autumn when the sea is still very warm (see page 11). There is often heavy rain and occasionally thunder at warm fronts (see pages 16 and 24). Old polar air in the Mediterranean (Mediterranean-type air) is convectively unstable (see pages 8 and 17) and when lifted by convergence at fronts, or orographically, very heavy cloud and rain may occur. Much of the heavy rain of the northern Mediterranean, especially orographic rain, is due to this cause. Thundery rain from medium cloud also occurs in scirocco air streams when they reach the northern parts of the Mediterranean and are lifted orographically or by convergence (see pages 16 and 22). This occurs particularly with weather type A_1 when a meridional trough between two anticyclones extends into the Mediterranean. Frontal rain, with or without depressions in the Mediterranean, also occurs with weather type C (westerly type). In the warm season rain is largely due to cold fronts with weather types A and E giving thundery rain, especially in the Po valley, in northern Italy generally and the Balkans. Weather type D (easterly type) also gives thundery rain in the Balkans.

The dry season in summer and the relatively low rainfall in spring are associated with subsidence over the sea and almost constant flow of the surface air into, rather than out of, North Africa and with the relatively low temperature of the sea surface compared with the surrounding lands producing rather stable lapse rates even in air from Europe. If it happens that these conditions are absent, for instance when exceptionally cold air arrives from a northern quarter after producing unseasonable cooling in Europe or when very warm air comes out of Africa and is involved in frontal processes, a break in the dry season may result.

DRIZZLE

The main occurrences of drizzle are at the less active warm fronts, such as those ahead of maritime tropical air (page 15), in moist scirocco air streams in the northern Mediterranean - particularly over the sea and coastal areas where there is not much lifting (page 16) and in polar air blowing from the north-east when there is a depression not far to the south (page 75). Drizzle also occurs in the Strait of Gibraltar with summer levanter (page 80). Drizzle is much less common than in higher latitudes.

SNOW

Snow in the Mediterranean is usually associated with the cold fronts of vigorous streams of invading polar or arctic air, or with showers behind the cold fronts. In various regions, especially the eastern Adriatic, the Ionian Sea and the eastern Aegean, snow often occurs with the onset of cold north-east (bora-type) winds after spells of moist southerly winds. December to March are the months when snow is mainly to be expected, with heaviest falls in January and February.

Snow may occasionally be heavy on the mountains in and surrounding the Mediterranean basin. The fall is sometimes sufficient to block the main roads in the higher parts of central and southern Italy and Sicily, and can also be serious in the Spanish uplands and in Algeria on the north side of the Atlas mountains. In Greece, north of the Peloponnesus, snow may lie for many days above 3,000 feet. Snow may also lie for several days on the higher slopes of the mountains of Corsica, Sardinia, Crete, Cyprus and the Lebanon. It is fairly common on the hills of Sicily, northern Tunisia, and Tripolitania, but seldom lies there for more than 24 hours. On the hills of Palestine (for example, at Jerusalem, 2,700 feet) snow falls two or three times a year, chiefly in January but sometimes as late as April; here again it seldom lies for more than 24 hours.

At sea level, however, snow is relatively rare, the most affected areas being the north-east of the Adriatic and the northern parts of the Aegean where it falls on an average of about six days in a year. It falls on an average of about two or three days per year in the Gulf of Lions, the French and Italian Rivieras, the Yugoslav coast, and the islands of the southern Aegean, and about one day in one or two years in Valencia, the Balearics, the north coast of Algeria, the Tyrrhenian Sea, Sicily, the southern Adriatic, north Ionian Sea and the north Coast of Cyprus. It is almost unknown in Malta, along the north coast of Africa (except Algeria), Egypt and Palestine and never lies on the low ground in these areas. Except on the northern shores of the Mediterranean snow seldom lies for more than 24 hours at sea level.

HAIL

In the northern Mediterranean hail may occur at any time of year but in general is most frequent in the winter and spring. Further south it is practically confined to winter and early spring. It occurs mainly at cold fronts, in instability showers in cold air masses and in thunderstorms. In regions where the rainfall consists mainly of heavy showers the highest frequencies of hail are in the seasons of maximum rainfall, and not necessarily in the seasons of maximum thunderstorm activity. This is noticeable in the northern Adriatic, for example at Venice where hail occurs most often in late spring or early summer but thunderstorms most often in the middle or late summer. In the Aegean, hail is said to be more common in the south than in the north. In the south-east Mediterranean, including Egypt and Palestine, hail occurs mainly, perhaps only, with winter thunderstorms.

Reliable and comparable data on the frequency of hail are available for only a few stations in the Mediterranean. Table 19 gives frequencies for three British stations, based on the years 1949 to 1956.

Table 19

Mean number of days with hail

	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Gibraltar	0.4	0.4	0.3	0.1	0	0	0	0	0	0	0	0.1	1.3
Malta	3.9	3.4	1.5	0.5	0.1	0.1	0	0	0.3	0.6	1.4	2.0	13.8
Nicosia	0.5	0.6	1.4	0.5	0	0	0	0	0.3	0	0.3	0.3	3.9

THUNDERSTORMS

General. The conditions for the formation of thunderstorms are similar to those required for showers and heavy rain, but a greater degree of instability is necessary before thunderstorms are produced. In the Mediterranean the majority of thunderstorms are the result of invasions of polar or arctic air and many of the conditions favourable for thunderstorms have already been mentioned. Thus thunderstorms occur at cold fronts and in the cold air streams behind cold fronts especially when the sea is warmest, that is, in early autumn. They also occur at active warm fronts and in regions of convergence in moist tropical air streams (for example, moist scirocco); these are of particular importance because of their danger to aircraft: cumulonimbus develops in medium-level layered clouds and it is only at a later stage that development to lower levels may take place (see Chapter 2). Such cases are commonest in the western Mediterranean in autumn with weather type A_1 (page 46) and in the eastern Mediterranean with slow-moving depressions on track *2c*.

Warm-front instability is commonly associated with a marked warm "ridge" on the 1,000-500 -millibar thickness chart. The crest of such a ridge is frequently a line of thunder development even in the summer months. Thunderstorms also tend to break out near the tips of the warm sectors of depressions, even at the very early stage of development when a wave is forming on a trailing front (see pages 24 and 42): these cases depend upon developing horizontal convergence in the unstable warm air mass.

Orography plays a particularly important part in the production of thunderstorms in the Mediterranean, commonly providing the necessary lift in convectively unstable air masses. Besides the mountain ranges to the north of the Mediterranean basin the Atlas ranges in Morocco, Algeria and Tunisia are noteworthy thunderstorm "factories" even in the warm season, and the Tuareg (Ahaggar) highlands near Tamanrasset in the central Sahara produce the same effect.

Thunderstorm activity may be expected in the vicinity of cold pools and cold lows (see page 36). They are said to be more common in the outer sectors than near the centres of cold lows and are specially liable to occur over rough terrain.

The tops of the highest cumulonimbus clouds in thunderstorms extend to 40,000 feet in winter and to between 40,000 and 45,000 feet in other seasons. Storms which form over the mountains may have their bases at quite high levels (for example 8,000 to 10,000 feet). They drift with the upper winds at cloud level (12,000 to 15,000 feet) and the winds at 700 millibars are often a useful guide to the direction and speed of movement of such storms. When they move over the sea in summer (or whenever the sea is cooler than the land) they slowly decay, while in autumn and winter they tend to maintain their vigour and may develop downwards to lower levels.

Thunderstorms are sometimes responsible for clear-air squalls some distance away from the centre of activity. Thus at Luqa Airport in Malta quiet conditions in the middle of the night have been abruptly interrupted by the arrival of such squalls. These are believed to originate in the late afternoon in association with thundery activity in Sicily or Tunisia.

Seasonal and geographical distribution. The parts of the Mediterranean region in which thunderstorms are most frequent are northern Italy and the Balkans, where summer is the season of chief liability (see Figure 1.83(*a*)). Many of these are heat thunderstorms and others are particularly associated with depressions on tracks *3a* and *3b* (page 39). Summer thunderstorms occur in the northern Mediterranean and especially in northern Italy (where the Po valley is the main centre) and the Balkans with weather type E (anticyclonic) when the cold fronts from the depressions over Europe just penetrate the area. On these and some other occasions maritime polar air crosses the mountains and overruns stagnant warm air on the lee side (sometimes marked by a thermal low) and the result is violent overturning and heavy thunderstorms (see pages 18, 29 and 50). Summer thunderstorms also occur in the Balkans with weather type D (easterly) (see page 49).

In other parts of the Mediterranean, autumn and winter are the main seasons for thunderstorms (see Figure 1.83(*c*)). The sea is at its warmest when the thunderstorm season begins about August-September but from then on until about January the sea-air temperature difference tends to increase in cold air masses blowing over the sea. Autumn thunderstorms are commonest in the western and central Mediterranean (including the coast of North Africa from Algeria to Libya), the southern Adriatic and the western Aegean, but in the eastern Aegean and the eastern Mediterranean thunderstorms are commonest in winter. There are many local exceptions, however, to this general picture and frequencies are often a little different from October to January. Thunderstorms are least frequent on the north coast of Africa from Libya to Egypt. More precise details can be found in the tables of Volume II.

GEOGRAPHICAL AND SEASONAL DISTRIBUTION OF PRECIPITATION

The dry season of summer and wet season from late autumn to early spring are noticeable features nearly everywhere in the Mediterranean, the chief exception being northern Italy where summer thunderstorms give considerable rainfall, amounting to between 20 to 25 per cent of the annual total. Elsewhere in the northern Mediterranean summer rainfall is by no means negligible, being about 10 to 15 per cent of the annual total. But south of about 40°N. the proportion of the annual total that falls in summer is 5 per cent or less, and in the south-east and south-central Mediterranean it is less than one per cent. These latter regions experience in most years an absolute drought lasting from three to five, or even six, months.

The month of greatest normal precipitation is later on the whole as one goes southwards, showing the progressive penetration of polar air masses southwards over the Mediterranean. Thus north of a line from north-east Spain through the centre of the western basin, the centre of Italy, northern Greece and the north Aegean the month of greatest rainfall is October. Between this and a line from the Strait of Gibraltar through Sardinia, the south of Italy and the central Aegean, the month of greatest rainfall is November. South of this line December, and sometimes January, is on the whole the month of greatest rainfall, but often the differences between October and January are not great. There are, of course, many local exceptions to this general pattern and in individual years wide variations may occur. In Malta every month from October to March has been the wettest in one year or another; October, November and January are, in fact, the wettest months there almost as often as December. Similar variations occur in other parts of the Mediterranean.

WATERSPOUTS

Waterspouts generally occur in thundery weather but often when instability is not quite sufficient to cause thunderstorms. They are commonest in the Mediterranean in spring and autumn, especially the latter season. The winds in the vicinity of a well developed waterspout may be dangerous to aircraft as well as to small sailing vessels and it may cause sufficient disturbance of the sea to upset small rowing boats. Waterspouts are reputed to be notably common in the Strait of Gibraltar and Alboran Channel and are said to occur in particular with the onset of vendavales. They also occur fairly frequently in the western and central Mediterranean, but are not often reported in the Aegean or the eastern Mediterranean.

CHAPTER 11

SEA AND SWELL

The roughness of the sea depends on the strength of the wind, the length of the wind's fetch over the sea and the depth of the sea. Waves raised by a strong wind travel out of the area where they are generated and are then known as swell. Thus swell derives its energy from wind blowing elsewhere and has no direct connexion with the winds blowing over it, although it may be modified in height and length by the local winds.

Gales and strong winds raise heavy seas if their fetch is long, and they may cause damage on windward shores. Some harbours are liable to rough seas when a strong wind blows from a critical direction, and they may also be susceptible to swell from the same direction even though no strong wind is blowing in the neighbourhood.

Strong winds near a front often cause swell which travels ahead of the front and may give warning of the approach of strong winds. Such premonitory swell may set in as much as 24 hours before the arrival of the strong winds. However, the setting in of swell in this manner does not always portend strong winds from the same direction because an area of strong winds does not necessarily travel in the direction of the wind itself, so that the strong winds may never actually reach the area affected by the swell. When an area has been affected by strong winds and high seas, swell may continue up to 24 hours after the strong winds have died down. Such conditions are probably most often associated with easterly winds blowing on the north side of an eastward-moving depression, the continuing swell being caused by easterly winds whose area of activity is itself moving eastwards. Apart from these special occasions the sea generally subsides quickly after the strong wind has died down.

The speed of swell decreases in shallow water. This causes it to change direction in the vicinity of coasts and islands; hence the tendency for swell to break nearly parallel to a shore-line. Swell may also be reflected in the neighbourhood of broken coasts. Partly for these reasons swell may affect places sheltered from the direct force of gales blowing at the time in the vicinity.

Observations of sea and swell in the Mediterranean are limited in number and quality. At coastal stations and even island stations such observations often have little relevance beyond the immediate vicinity of the observing points. This is specially so in the case of offshore winds. A picture of sea and swell conditions can, on the whole, be best assessed from a knowledge of the winds affecting the region and of the conditions of exposure of the place of interest. However, some general information on sea and swell, mostly for coastal areas, is given below.

The western Mediterranean. Along the northern part of the east coast of Spain north-easterly gales give the heaviest seas, though southerly gales also cause much damage through rough seas from time to time at places exposed to them. Further south, easterly gales bear more directly on the coast. The north-westerly gales of Spain raise high seas at some distance east of the coast but not on the coast itself. Strong mistral, blowing from the north or north-west, raises a heavy sea in the Gulf of Lions outside coastal waters. At Minorca the roughest seas accompany gales from between north-west and north-east and during these spray is said to be carried completely across the island. The rough seas off Corsica from Sanguinaires Island southwards, off the Straits of Bonifacio, and off Sardinia are similar to those of Minorca. Heavy seas are also experienced in this area with libeccio (see page 82). Along the coast of France the southerly marin raises a high sea, especially between

Sète and Aigues Mortes (page 85). Scirocco winds may cause heavy swell in the Gulf of Genoa and produce a rise in the water level which may precede the setting in of the wind by 24 hours (page 85).

Ionian Sea. On the coasts of the Ionian Sea during strong winds in the cool season, and also even in the summer, violent squalls give rough seas off the mouths of valleys running down the leeward side of mountainous coasts. There are numerous examples along the west coast of Greece, among the islands, and along the south coast of Italy. At some places these squalls are specially strong in the evening.

Adriatic Sea. In the Adriatic bora gives heavy seas on the shelterless western shore, among the islands, and in those channels and harbours along the eastern shore which are exposed to its full force. With scirocco, which blows more or less axially along the Adriatic, rough seas, increasing in violence northwards, are experienced on the eastern, western and northern shores. Premonitory swell from the east is said to occur often on the western shore before scirocco, and to continue after the wind has dropped (see page 86). The north-westerly gales of summer cause rough seas mostly in the south-east, while westerly and south-westerly gales are specially felt at the southerly entrance of the sea, and on the eastern and northern shores. Squalls, especially the south-east squalls known as "furiani" off the mouth of the Po, are said to be accompanied by very rough seas at times (see page 82).

Aegean Sea. In the Aegean Sea the strong northerly winds of both winter and summer raise a short, heavy, troublesome sea among the islands, and this is aggravated by violent squalls in their lee near the land. In the south, at Kíthira, westerly winds give turbulent seas all along the coast, and Kithira is often cut off from local shipping even in summer. In Kapsáli Bay and Roads and in Agios Nikolaos Bay south and south-east winds send in a dangerous sea, and squalls from the hills are often violent. At Fana Kopiá Bay the backwash from swell striking the cliffs to the north gives a confused sea. The vicinity of Cape Maléa is much disturbed in strong north winds during which violent squalls descend from the land. The west to south-west winds of the Gulf of Laconia (Lakonikos Kolpos) raise a considerable sea along its eastern shore in summer, and in Vátika Bay southerly winds give a heavy sea. At Salonika the south-west wind is noteworthy for the rapidity with which it raises a considerable sea, and at Bashika Bay (Besike Limani) gales from south-south-west give a more unpleasant sea than the stronger gales from north or north-east.

North African coast. Along the coasts of Algeria and Tunisia and on the west coast of Sardinia heavy seas are raised by the west or north-west winds prevailing from October to April which are often fresh and gusty. Gales from north-north-west are often preceded by a heavy northerly swell. The roadstead of Ténès is particularly liable to rough seas with strong winds from the north.

In the vicinity of Tripoli the occasional strong north and north-east winds which occur from May to September raise heavy seas. The Gulf of Sidra may be affected by heavy swell when north-westerly gales blow in the offing, though such gales seldom extend to the head of the Gulf. Rough seas occur there, especially along the south-western shore, with the violent squalls known as "gharra" which are experienced from January to March. From Benghazi to the Bay of Bomba ($32^{\circ}15'$N., $23^{\circ}15'$E.) there is often a premonitory heavy swell the day before the arrival of a cold-front gale, but the rough sea subsides quickly when the wind drops.

The eastern Mediterranean. In the eastern Mediterranean the relative infrequency of gales and strong winds results in a correspondingly low frequency of rough seas and heavy swell. However there is a long fetch for westerly winds, extending from the east coast of Tunisia to Palestine, and at times when there is a predominantly westerly component in the winds over this region, moderate swell may be expected in the eastern Mediterranean. The situations which produce this are commonest in winter and the swell can cause inconvenience to small vessels lying alongside at such places as Beirut. Northerly gales in the Aegean may produce wave trains travelling south-

eastwards which reach the Egyptian coast as a north-westerly swell.

Around Cyprus the greatest swell is produced with south-westerly winds when these have a long fetch. At Larnaca the bay is open to south-east winds, and gales from this direction give a short sea, but they never last for long. However, gales from south-west and north-east give rise to swell at Larnaca, that associated with south-west gales being specially disagreeable. At Famagusta east-north-east winds, which are common in winter, are accompanied by a heavy sea while northerly winds in winter raise a short, choppy sea. South-east gales are said to give considerable swell at Port Paphos and north-west gales cause a heavy sea at Morphou town.

CHAPTER 12

SEASONAL PROGRESSION OF MEDITERRANEAN WEATHER

GENERAL

The progressive seasonal changes in the variability of atmospheric pressure, in the temperature level, liability to rainfall and incidence of thunder are by no means fully represented by monthly mean and extreme values. The Mediterranean region is characterized by particularly strongly marked seasons. Understanding of the nature and timing of the seasonal structure of the year is furthered by the study of daily values and frequencies of various phenomena.

The data here presented relate to particular places, chosen to illustrate the main regimes and enable us to pick out the finer detail of the march of the seasons. Mean values of atmospheric pressure at sea level at a fixed hour on each day of the years 1919-1938 are illustrated in Figure 1.80, showing curves for Perpignan, Genoa, Rome, Athens, Algiers, Malta, Limassol, Gibraltar and Cairo. Variability of the mean pressure decreases southwards, but appears in all cases significantly less between early June and mid-September than during the rest of the year. At the northern stations there appear to be one or two significant variations or discontinuities associated with known singularities in higher latitudes; these will be referred to later. At the southernmost stations, Gibraltar and Cairo, these effects are only faintly registered in the curves in Figure 1.80, and the day-to-day variations of mean pressure at these places appear random.

THE NORMAL SEASONAL PROGRESSION: GENERAL CHARACTER OF THE WEATHER

The autumn break. In terms of pressure pattern the most striking feature is the autumn break, which shows up prominently about 20 October on all the pressure curves (Figure 1.80) from Perpignan and Gibraltar to Malta and more faintly at Athens, Limassol and Cairo as a drop of mean pressure with greater variability from then on. This break ushers in the most regularly rainy, unsettled period of the whole year in the western and central Mediterranean. The regularity of getting at least one rain day in a given pentad (five-day period) rises abruptly from only 50-70 per cent in early October to about 90 per cent from late October to past mid-November in most places in the area (Figure 1.82). Even at Cairo the frequency rises to near 20 per cent although there the main season of rain liability (25-35 per cent in most pentads) is from mid-December to mid-March. The abrupt increase of raininess at Gibraltar comes a little later than in the western and central Mediterranean; Figure 1.82(*e*) shows pentadal frequency of rain days rising to about 80 per cent around 10 November.

The first rains after the dry season commonly take the form of occasional thunderstorms, attributable to increasing moisture content and air-mass instability over the Mediterranean in late summer, particularly after the beginning of autumn in Europe. These cause rising frequency of rain days (10-50 per cent) in the western and central Mediterranean from mid-August onwards (Figures 1.82(*a*), (*b*), (*e*), (*f*) and (*g*)). The drop of mean pressure and increased variability in late October, however, marks the normal invasion of much of the Mediterranean by fairly vigorous cyclonic activity, a change which is decisive and generally irreversible at this

time. After it, cyclonic spells alternate with periods of several days of pronounced high pressure. The pressure curves for Perpignan and Genoa (Figure 1.80) show traces of cyclonic penetration of the Gulf of Lions and the northern Adriatic about 20 September, but places farther south are less commonly affected and it is clear that normally the régime of slack atmospheric circulation remains established over the Mediterranean in general for about another month.

In the twenty years 1919-38 the break at Malta, as indicated by the first fall of pressure of 10 millibars or more within 48 hours, came between 18 and 25 October in eight years (and slightly less abruptly between the same dates in two other years). In three years it occurred between 18 and 23 September. In the remaining years the first similarly abrupt fall occurred at widely scattered dates between 24 August and 11 November.

The breakdown is often spectacular and characteristically accompanies the first cold front followed by deep cold air: ahead of the front notably warm, scirocco air is swept northward and so the trend of mean temperature, averaged over a number of years in which the date of the break varies somewhat, does not show the seasonal break as sharply as the pressure curve.

Figure 2.25 for 23 October 1950 and Figures 2.48(*a*) to (*d*) and 2.52(*a*) for 22-24 October 1951 and 19 October 1953 illustrate the type of situation which accompanies and follows the breakdown of the summer régime.

Characteristics of the pressure pattern during the European winter. The curves of daily mean pressure (Figure 1.80), especially between October and March, show larger amplitude and longer-period fluctuations than in summer. In character these fluctuations resemble those which are well known in Europe, although only the peak of high average pressure between 20 and 24 January (a few days later at Limassol and Cairo) appears to coincide in date with one of the quasi-regular periods of high average pressure in central and northern Europe and even in this case the effect may not be prominent in the Mediterranean in more than about half the years.

What seems to happen is that throughout a normal Mediterranean winter periods of one to three weeks of cyclonic sequences are each followed by a week or so of quiet, fine weather with high pressure. The high pressure over the Mediterranean is most commonly caused by anticyclones moving south-east from Europe or east from the Atlantic. Quiet, anticyclonic conditions are therefore inclined to affect the Mediterranean some days later than Europe and with increasing randomness of date as the systems travel south-east and east.

The transition through spring to the summer dry season. Raininess and rain liability continue close to their winter maximum everywhere until March, and at Gibraltar, Algiers and Rome the decline of frequency is not a marked feature until May or early June. The variability shown by the pressure curves bears witness to continued alternations of cyclonic activity with quieter spells - without any obvious regularity of date from year to year - especially from April onwards. The decrease of rainfall from late March onwards farther south and in the eastern Mediterranean has more to do with increasing stability of the air masses over the sea than to any pronounced decline of cyclonic activity. In fact the spring months, including May, are liable to be windy even though the weather is increasingly sunny.

Over northern Italy there is no pronounced seasonal decline of rainfall frequency, because the region becomes involved in the summer thunderstorm régime over Europe and especially the Alps. Indeed, Milan and Trieste show their maximum frequency of rainfall in summer. In Spain too summer thunderstorms are no rarity, though the Mediterranean littoral becomes involved in the usual dry season and the maximum incidence of thunder in most parts of Spain is in May or June.

The summer regime of anticyclonic subsidence and light winds over the Mediterranean becomes established unspectacularly over most of the region some time after the rains have effectively ceased. The establishment of the real summer régime is signalled by changes in the Azores anticyclone, which develops an extension eastwards or north-eastwards, usually about mid-June (see page 43). In a minority of years when the highest pressure is displaced well to the north-east, deep cold air may occasionally penetrate far enough south in the Mediterranean to give breaks in the dry season even in North Africa. In all cases, however, the intrusion of active cold fronts south of 40°N. becomes rare, and barometric changes characteristically slight. Subsidence prevails over the sea and coastlines, as long as the sea is appreciably colder than the land. The winds are generally light. These conditions are favourable for more rapid heating of the sea surface and its temperature rises steeply from the onset of the quiet summer régime until the seasonal maximum is attained.

THE NORMAL SEASONAL PROGRESSION: TEMPERATURE

Figures 1.81(*a*) to (*h*) show the incidence of various maximum and minimum temperatures on each day of the years 1919-38 at Genoa, Malta, Gibraltar and Cairo.

Genoa. This station is quoted as an example for the northern Mediterranean and places whose climate is strongly influenced by the main mass of the European continent.

The temperatures appear more or less normally distributed about a mean value which rises steadily from about 20 March to a flat maximum between mid-July and the end of August, then falls steadily to the beginning of December. Between December and March the mean value remains nearly constant, and at this time the extreme coldest days and nights depart more from the normal than do the highest temperatures observed.

Malta. This station is chosen to represent the central Mediterranean and the most maritime climates.

The scatter of temperatures is markedly less than at the other stations illustrated: this is no doubt primarily due to the extreme maritime influence on the climate of this very small island. There is a clear departure from normal distribution in that the highest maxima between June and mid-September depart far more from the average value than do the values for the coolest days occurring. The prevailing level of winter temperatures shows little change from mid-December till almost the end of March. This gives a delayed spring, in that there is less disparity between the temperatures of the central Mediterranean and temperate Europe in March and April than at any other time of the year. Moreover, owing to the maritime climate of Malta, the highest recorded temperatures in March and April are lower than the corresponding extremes near 50°N. in Europe. In the period March to May Malta and Italy lag notably behind points in the eastern Mediterranean in the seasonal warming.

The central Mediterranean sector of the African coast only experiences a similar delayed spring in certain years when prevalence of northerly wind components maintains the maritime influence. Southerly winds at Tripoli from March onwards can bring extreme temperatures in the region of 40°-45°C. (104°-113°F.). The temperature of such air streams in March and April falls abruptly over the sea, and the effects at Malta are more liable to be seen in fog and low stratus than in any remarkable temperature.

In one respect, revealed by Figure 1.81(*b*), the climate of Malta is markedly unlike that of oceanic islands. The seasonal range of temperature is large, being of the same order as that of France and parts of central Europe.

Gibraltar. The seasonal range of temperature at Gibraltar is slightly less than that at Malta, perhaps owing to Atlantic influence, and the maximum temperatures are more evenly scattered about the average. The difference is not great, but is most noticeable in summer in the temperatures of the nights and of the coolest days.

Cairo. This station has been chosen to illustrate characteristics of the eastern and southern Mediterranean, particularly of places whose climate is influenced by the continents of Africa or south-west Asia.

Variability of temperature is very great, especially between January and early June. There is a sharp decrease of variability, especially of night temperatures during the summer régime with its northerly (etesian) winds. There is also a clearly marked period in October when the autumn cooling trend is interrupted and the variability of temperature is for a while increased: this is undoubtedly associated with the prevalence of southerly winds ahead of the cold fronts invading the Mediterranean with the break-up of the settled régime (page 84).

THE NORMAL SEASONAL PROGRESSION: RAINFALL AND THUNDERSTORMS

Figures 1.82(*a*) to (*h*) reproduce the frequency of rain days during each pentad at the following stations: Genoa, Gibraltar, Algiers, Malta and Cairo (1919-38); Trieste and Oštri point (1890-1909); Rome (1880-1929). Note should be taken of certain differences of definition in the various figures.

Figures 1.83(*a*) to (*c*) show similarly the frequency of days with thunderstorms at Milan (1919-38), Rome (1929-38) and Malta (1919-38). The salient features of these diagrams have been pointed out in the section on general characteristics of the seasonal progression. The occurrence of thunder at Rome (Figure 1.83(*b*)) displays a mixed régime intermediate between that of the Alps with a summer maximum and that of the Mediterranean itself with greatest frequency of thunderstorms in autumn and winter. The incidence of hail at Malta (see page 180) is closely linked with the incidence of thunderstorms in the winter months.

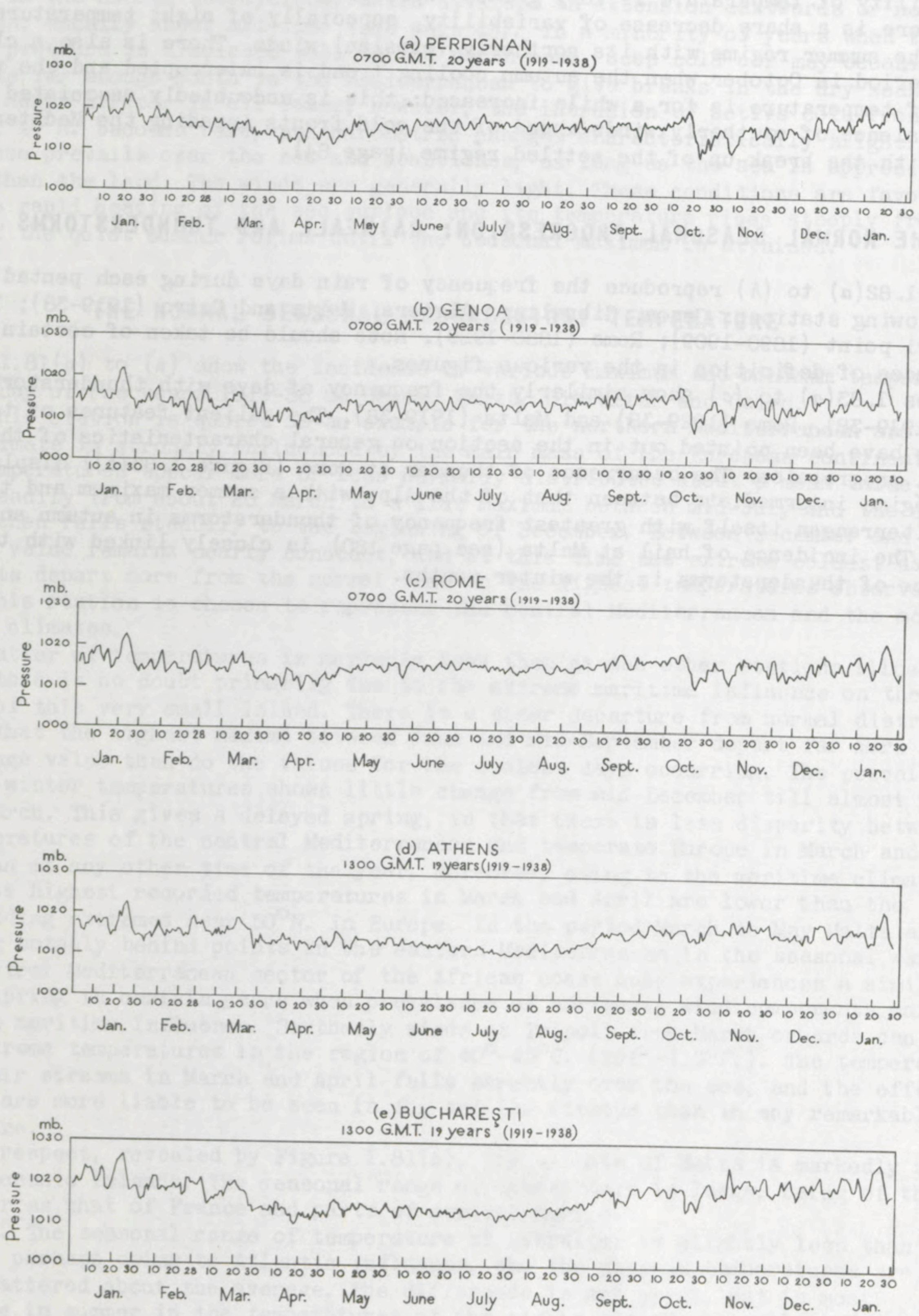


Fig.1.80 Daily mean pressures

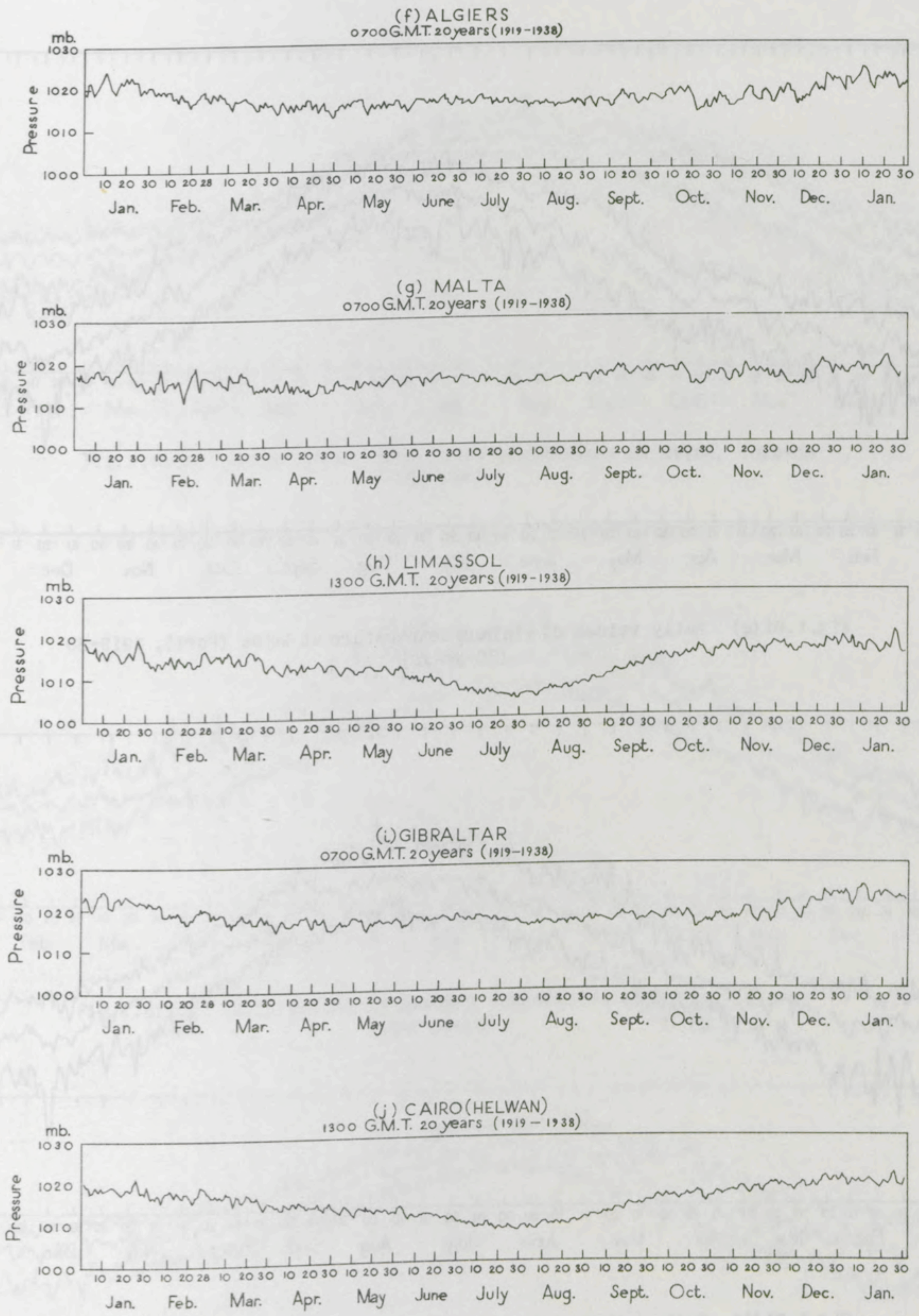


Fig.1.80 *(cont.)* Daily mean pressures

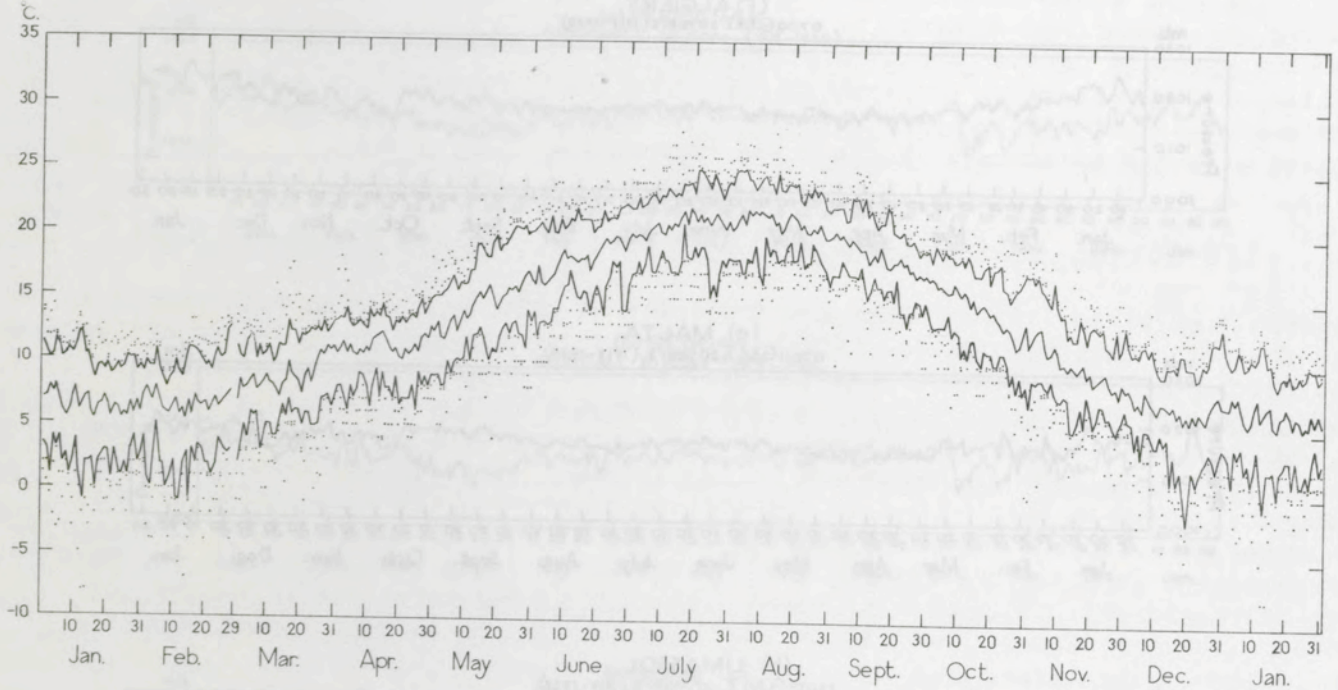


Fig.1.81(*a*) Daily values of minimum temperature at Genoa (Port), 1919-38 (20 years)

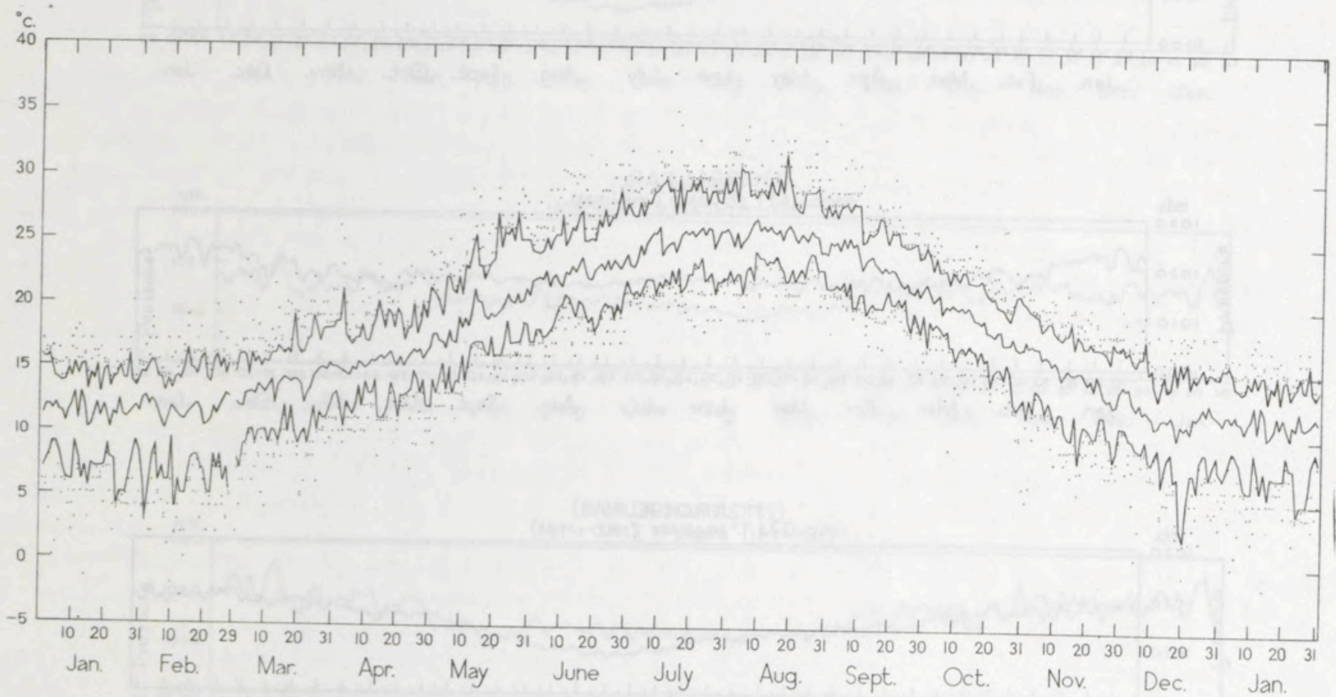


Fig.1.81(*b*) Daily values of maximum temperature at Genoa (Port), 1919-38 (20 years)

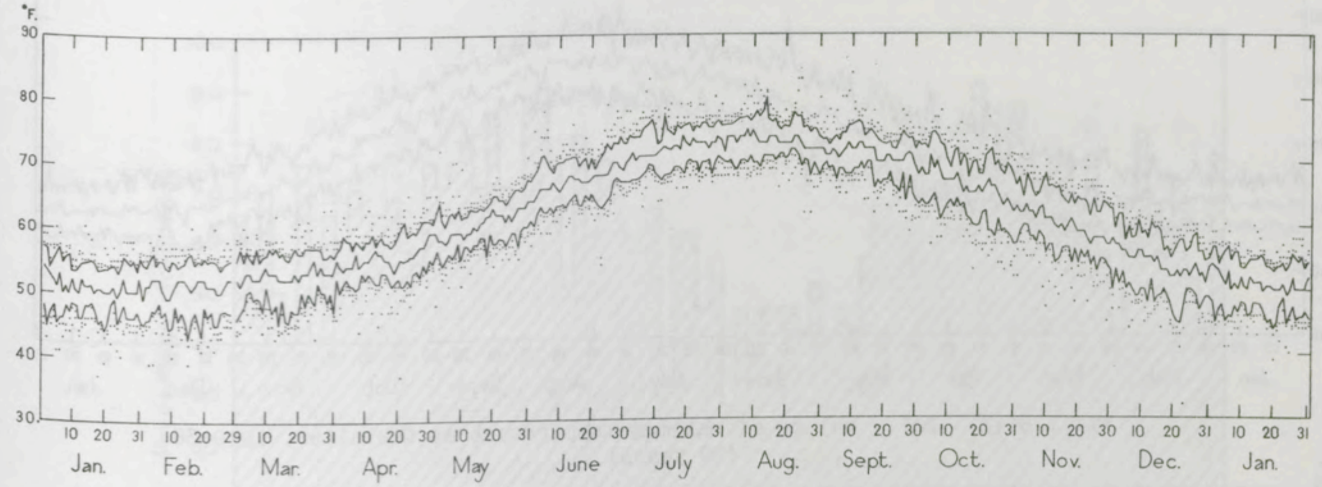


Fig.1.81(*c*) Daily values of minimum temperature at Malta, 1919-38 (20 years)

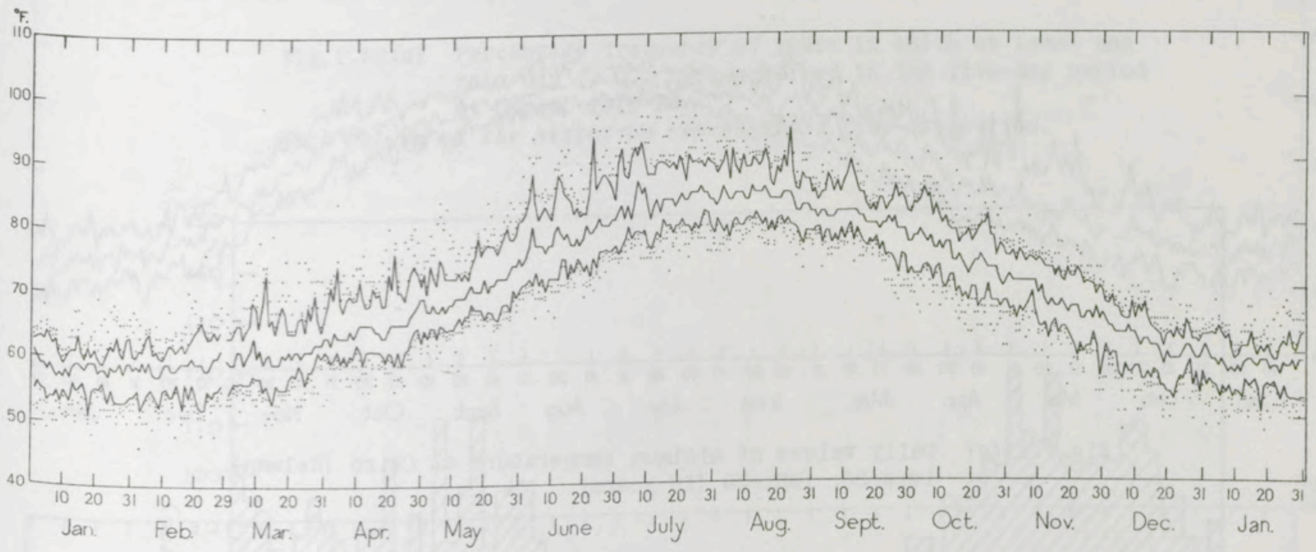


Fig.1.81(*d*) Daily values of maximum temperature at Malta, 1919-38 (20 years)

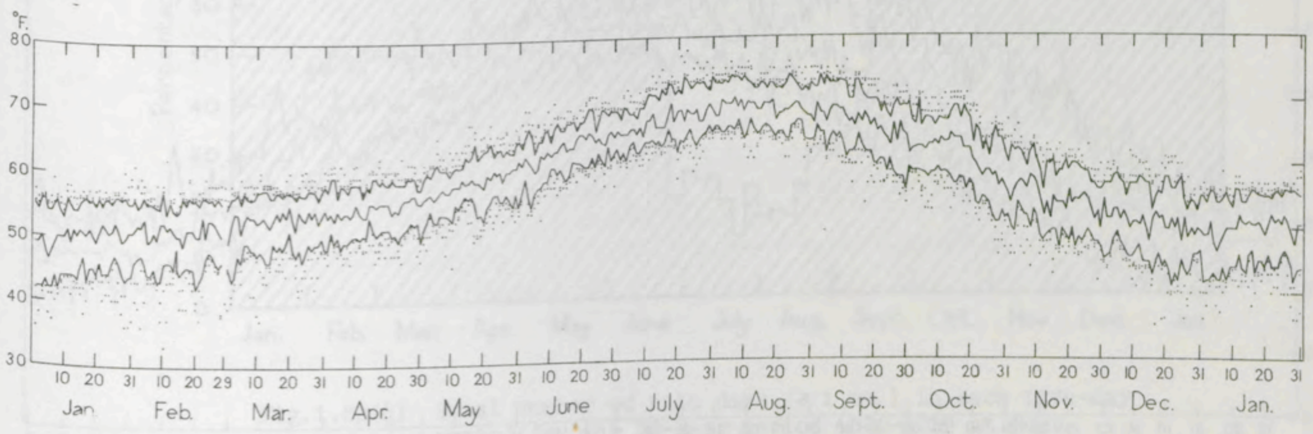


Fig.1.81(*e*) Daily values of minimum temperature at Gibraltar, 1919-38 (20 years)

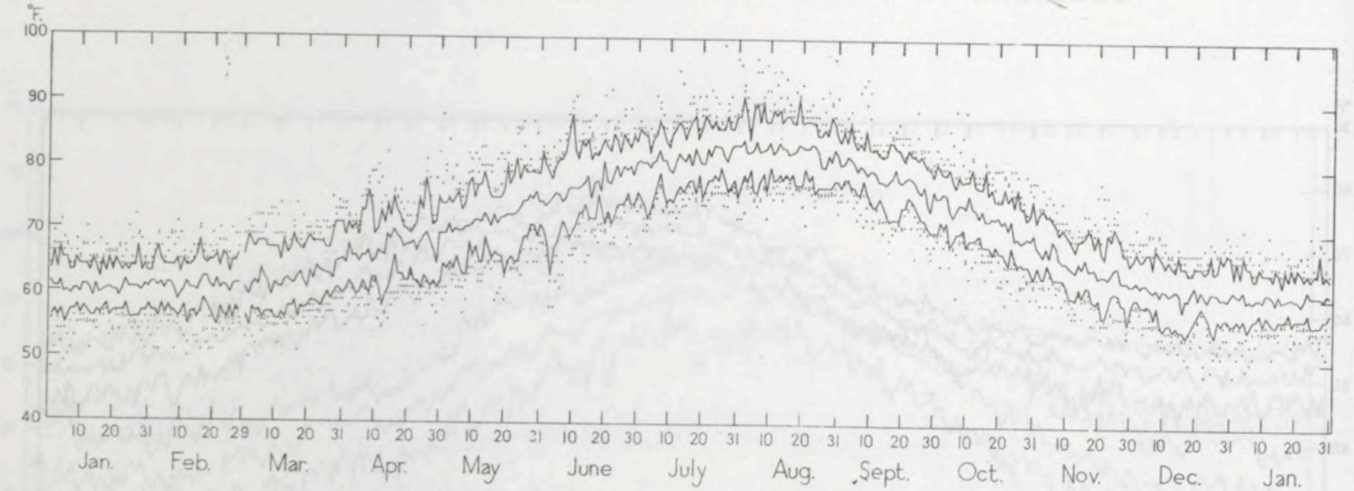


Fig.1.81(*f*) Daily values of maximum temperature at Gibraltar, 1919-38 (20 years)

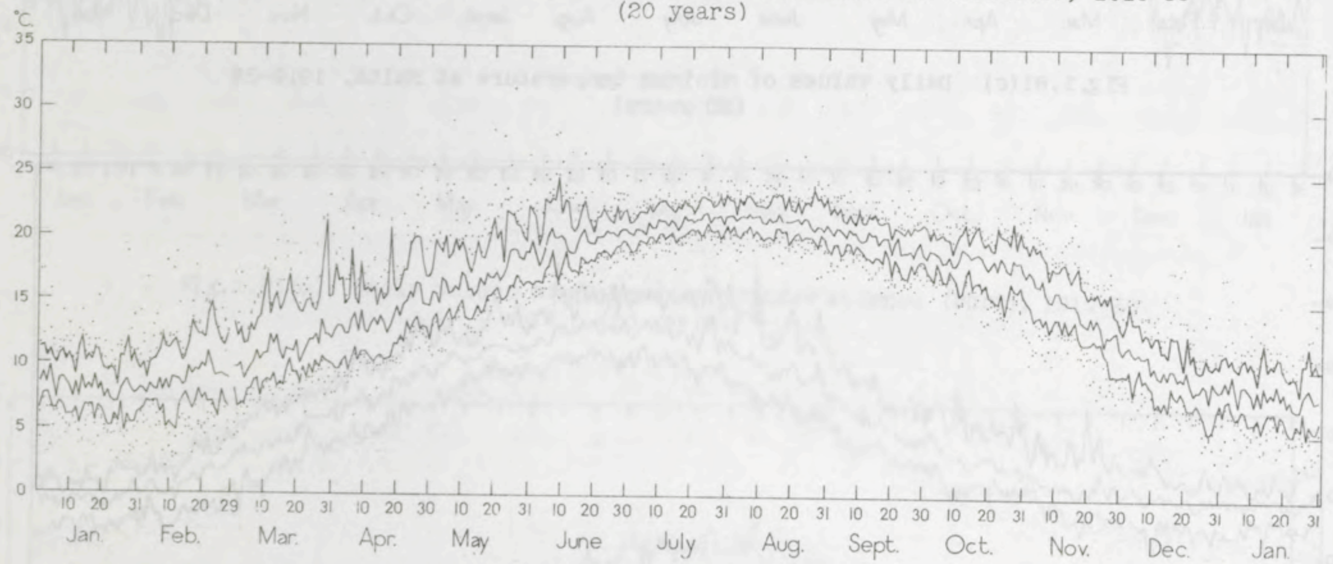


Fig.1.81(*g*) Daily values of minimum temperature at Cairo (Helwan), 1919-26, 1931-38 (16 years)

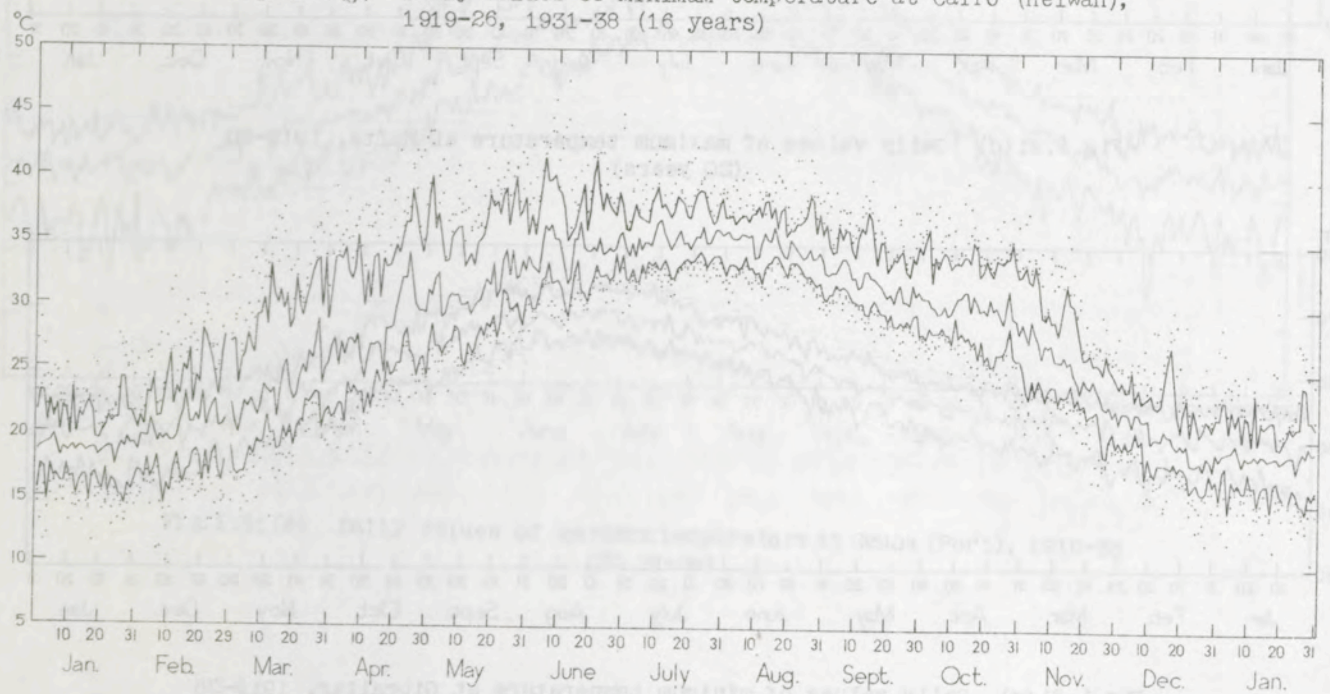


Fig.1.81(*h*) Daily values of maximum temperature at Cairo (Helwan), 1919-26, 1931-38 (16 years)

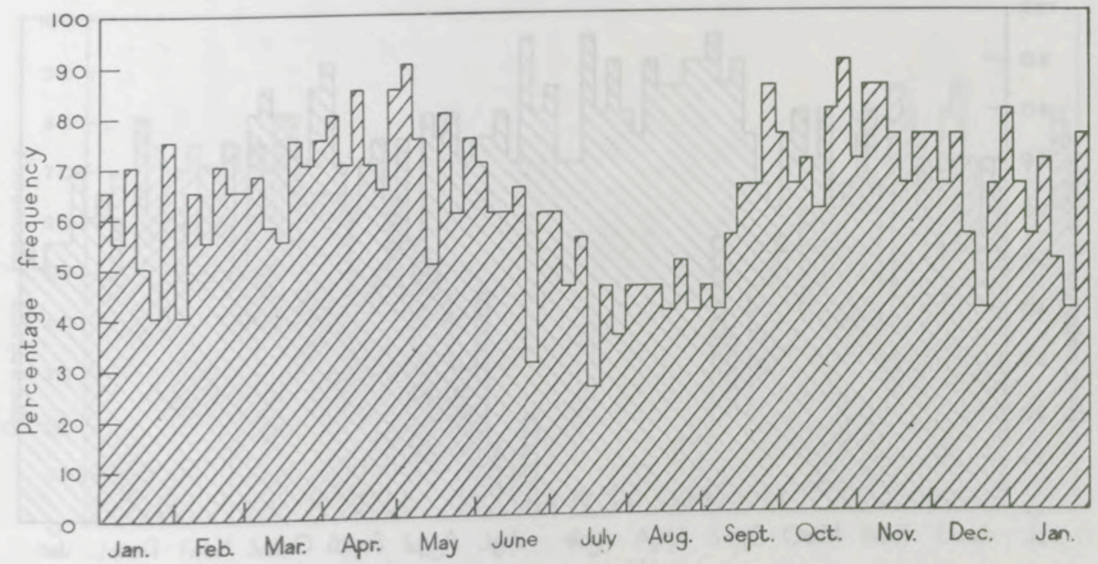


Fig.1.82(*a*) Percentage frequency of years in which at least one rain day (⩾ 0.1 mm.) occurred in the five-day period at Genoa, 1919-38.

Each column of the histogram represents a five-day period.

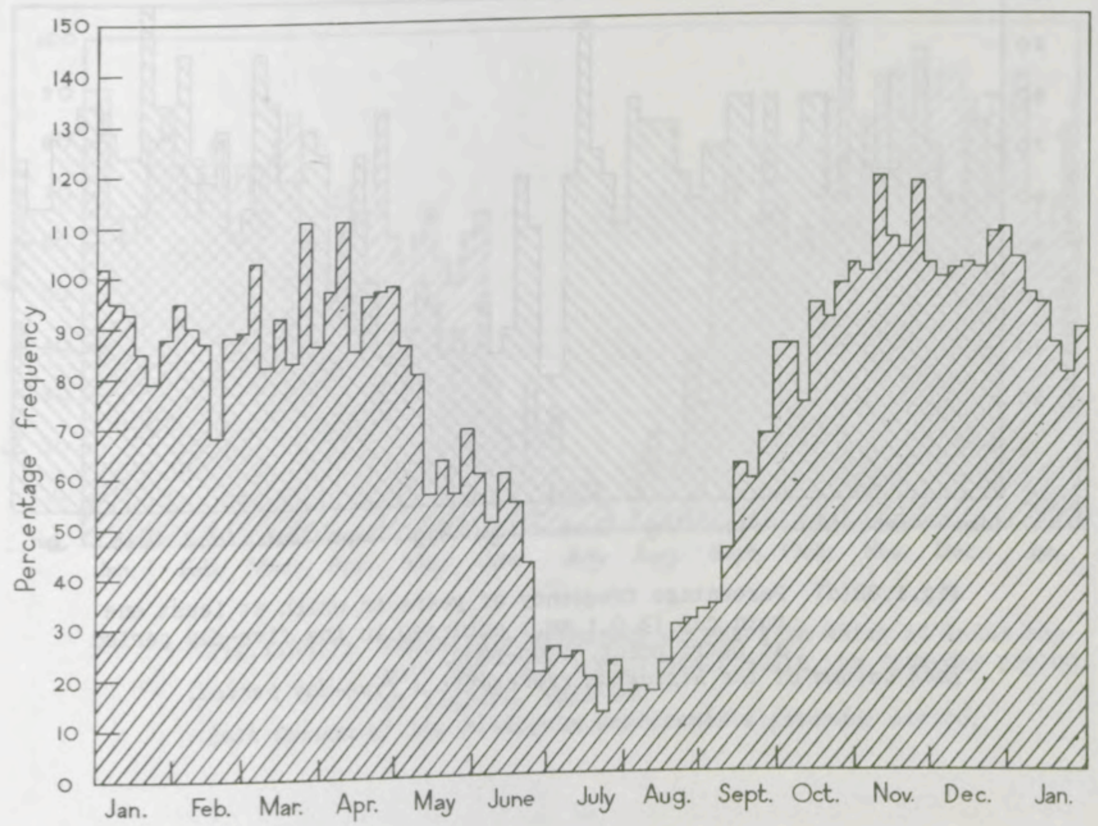


Fig.1.82(*b*) Total number of rain days (⩾ 1 mm.) in each five-day period for the 50-year period 1880-1929 at Rome
Extraction: Bibliography No. 28.

Each column of the histogram represents a five-day period.

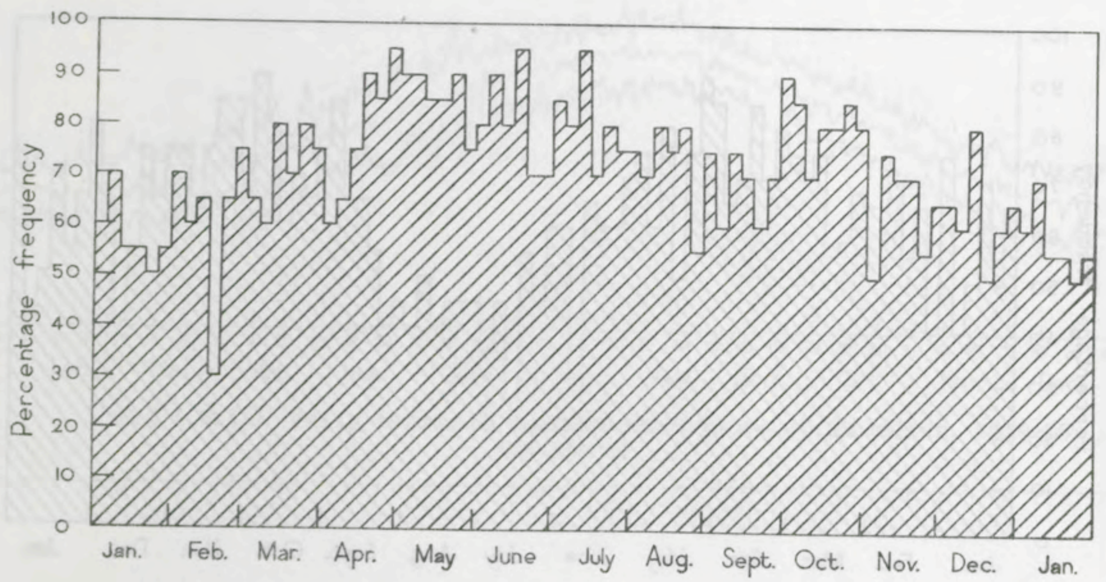


Fig.1.82(*c*) Percentage frequency of years in which at least one rain day (⩾ 0.1 mm.) occurred in the five-day period at Trieste, 1890-1909.
Each column of the histogram represents a five-day period.

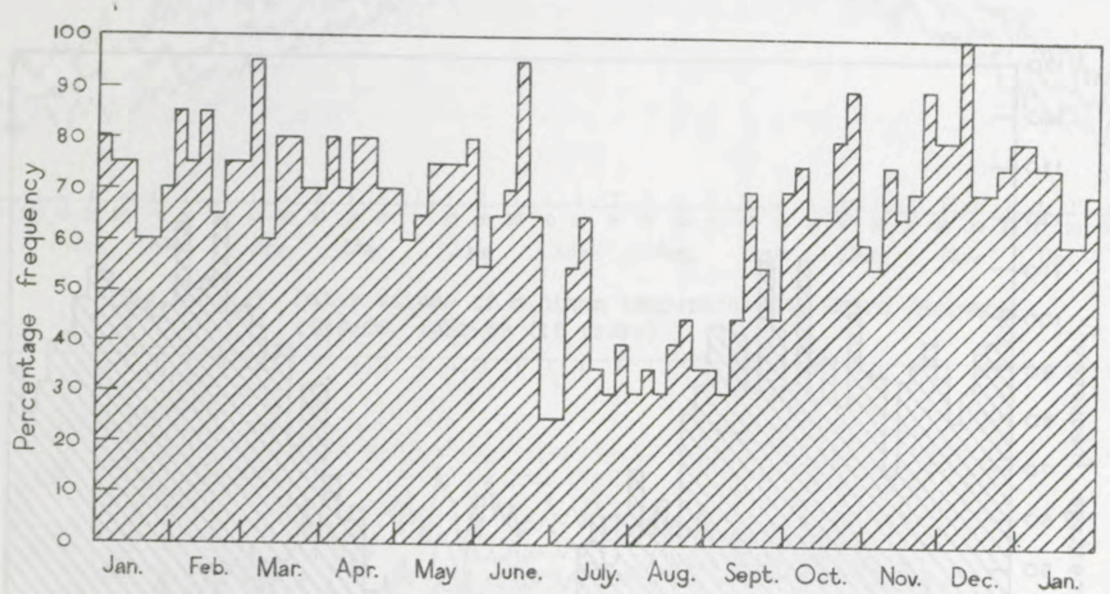


Fig.1.82(*d*) Percentage frequency of years in which at least one rain day (⩾ 0.1 mm.) occurred in the five-day period at Östri point, 1890-1909.
Each column of the histogram represents a five-day period.

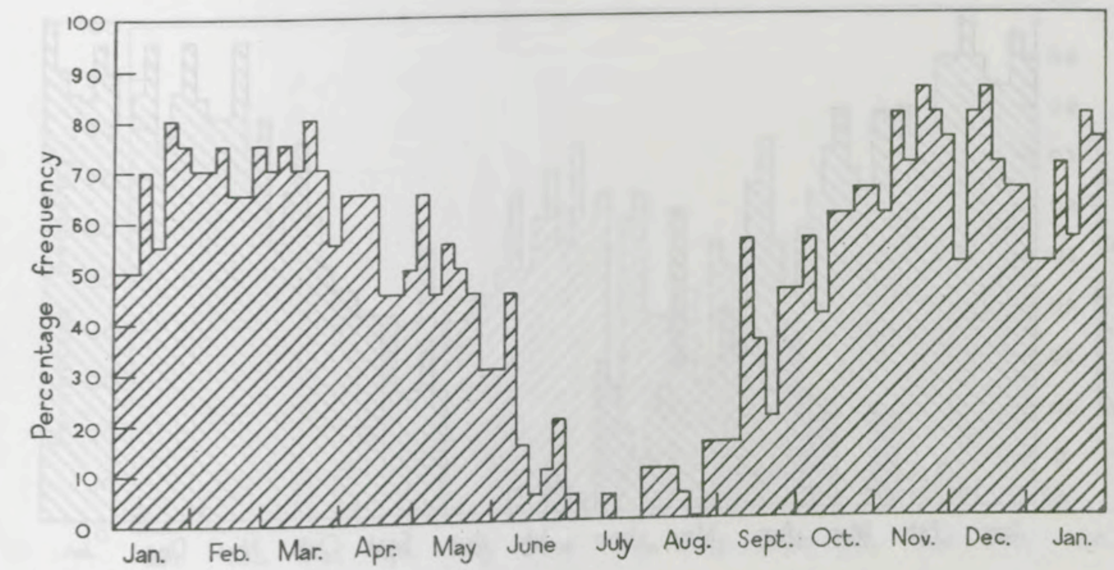


Fig.1.82(*e*) Percentage frequency of years in which at least one rain day (⩾ 0.1 mm.) occurred in the five-day period at Gibraltar, 1919-38.
Each column of the histogram represents a five-day period.

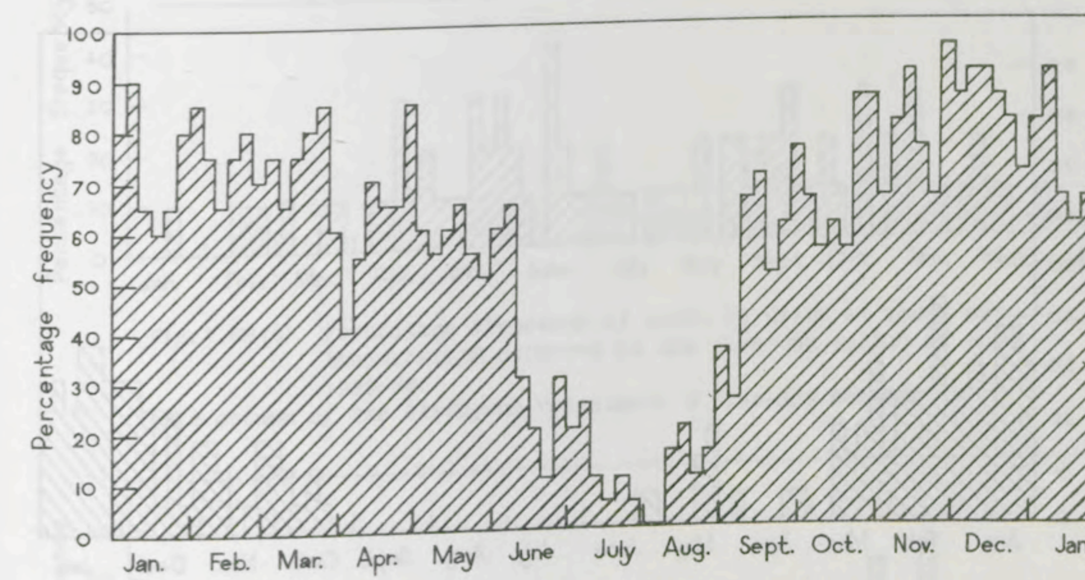


Fig.1.82(*f*) Percentage frequency of years in which at least one rain day (⩾ 0.1 mm.) occurred in the five-day period at Algiers, 1919-38.
Each column of the histogram represents a five-day period.

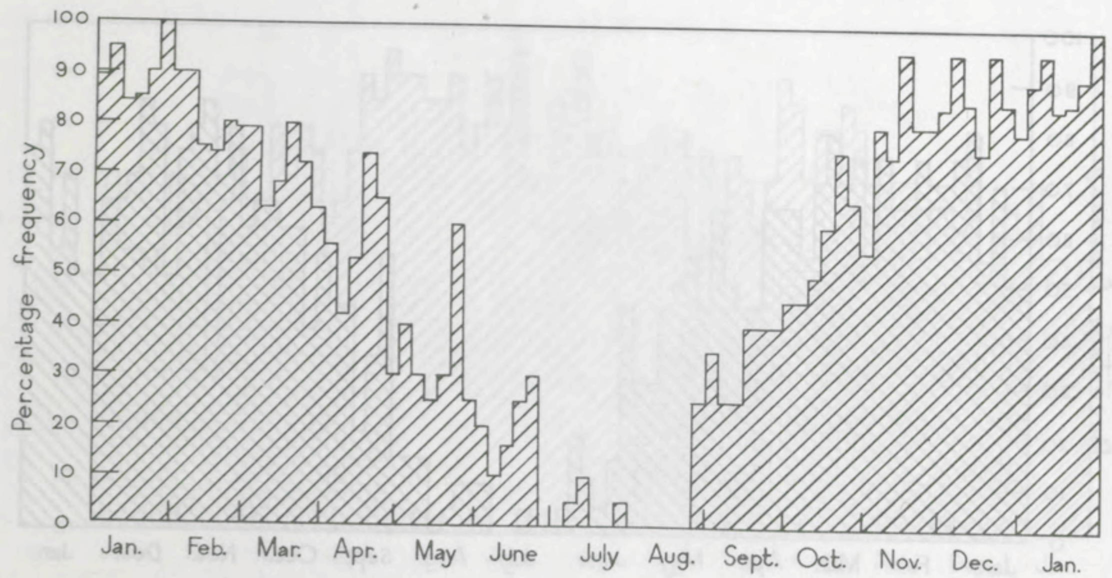


Fig.1.82(g) Percentage frequency of years in which at least one rain day (≥ 0.1 mm.) occurred in the five-day period at Malta, 1919-38.
Each column of the histogram represents a five-day period.

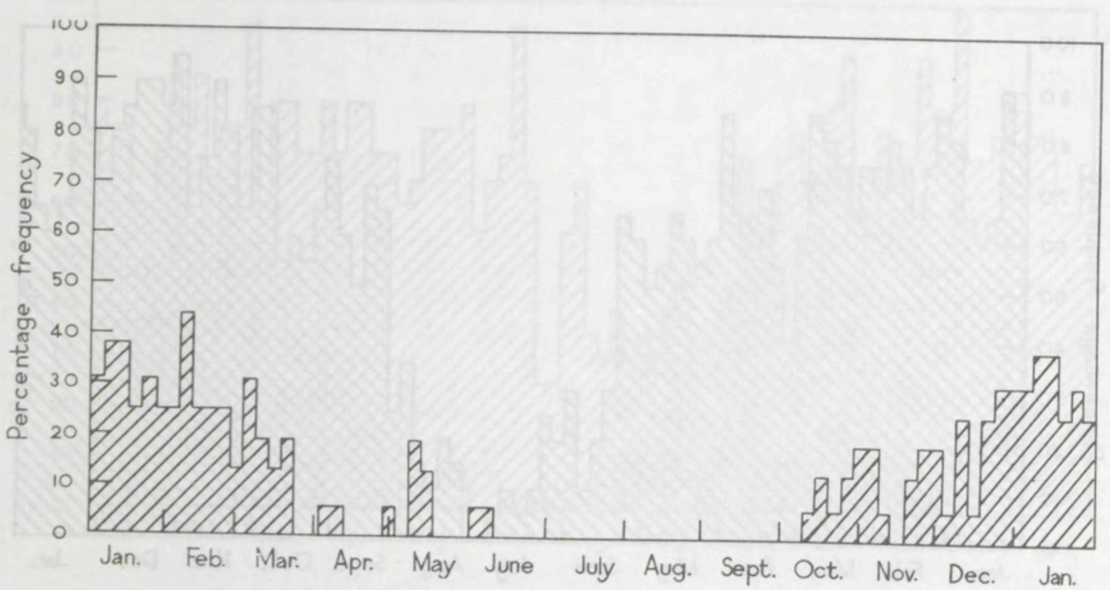


Fig.1.82(h) Percentage frequency of years in which at least one rain day (≥ 0.1 mm.) occurred in the five-day period at Cairo (Helwan), 1919-26, 1931-38.
Each column of the histogram represents a five-day period.

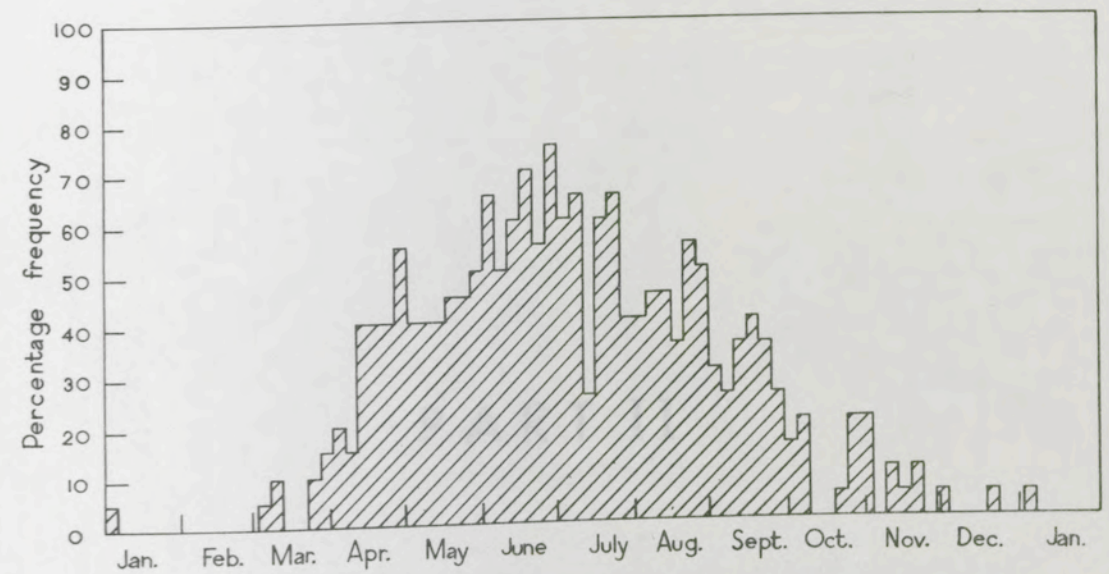


Fig.1.83(a) Percentage frequency of years in which at least one thunderstorm occurred in the five-day period at Milan, 1919-38.
Each column of the histogram represents a five-day period.

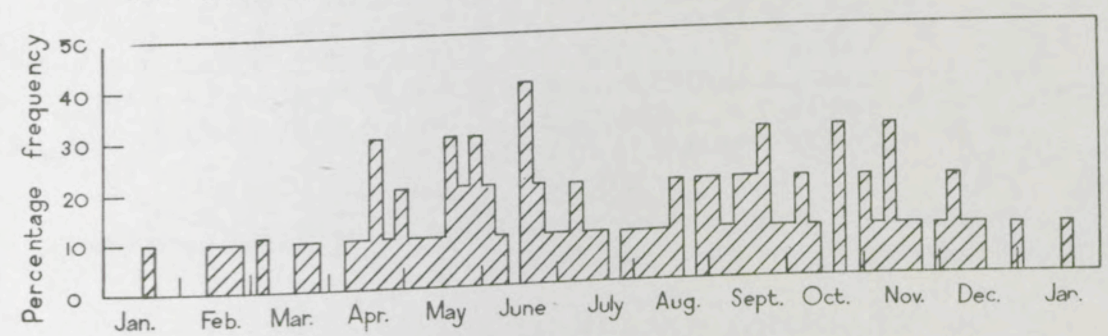


Fig.1.83(b) Percentage frequency of years in which at least one thunderstorm occurred in the five-day period at Rome, 1929-38.
Each column of the histogram represents a five-day period.

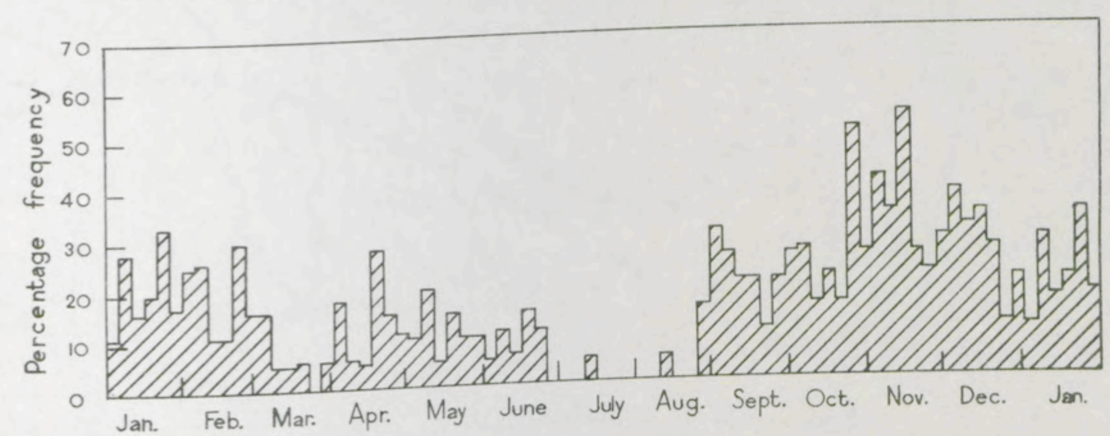


Fig.1.83(c) Percentage frequency of years with at least one thunderstorm in the five-day period at Malta, 1919-38.
Each column of the histogram represents a five-day period.

PART II

ACKNOWLEDGEMENTS

The following diagrams are based on *Täglicher Wetterbericht des Deutschen Wetterdienstes* (Bibl.No.40):

Figs.2.1, 2.2(*a*), 2.3(*a*), 2.4(*a*), 2.5(*a*), 2.8(*a*), 2.9(*a*), 2.10(*a*), 2.11(*b*), 2.13, 2.14, 2.15(*b*), 2.15(*d*), 2.15(*e*), 2.16(*a*), 2.17(*a*), 2.18(*a*), 2.19(*a*), 2.20(*a*), 2.22(*a*), 2.24(*a*), 2.25, 2.26, 2.28, 2.29, 2.31(*c*), 2.31(*d*), 2.32(*a*), 2.33(*a*), 2.35(*b*), 2.35(*d*), 2.39(*a*), 2.42, 2.43(*a*), 2.44(*a*), 2.45(*a*), 2.46, 2.47(*a*), 2.48(*a*), 2.48(*c*), 2.50(*a*), 2.51(*a*), 2.52(*a*), 2.53(*a*), 2.54(*a*), 2.56(*a*).

The following diagrams are based on the United States Weather Bureau *Daily Series Synoptic Weather Maps* (Bibl.No.92):

Figs.2.21(*a*), 2.27, 2.34(*a*), 2.36(*a*)

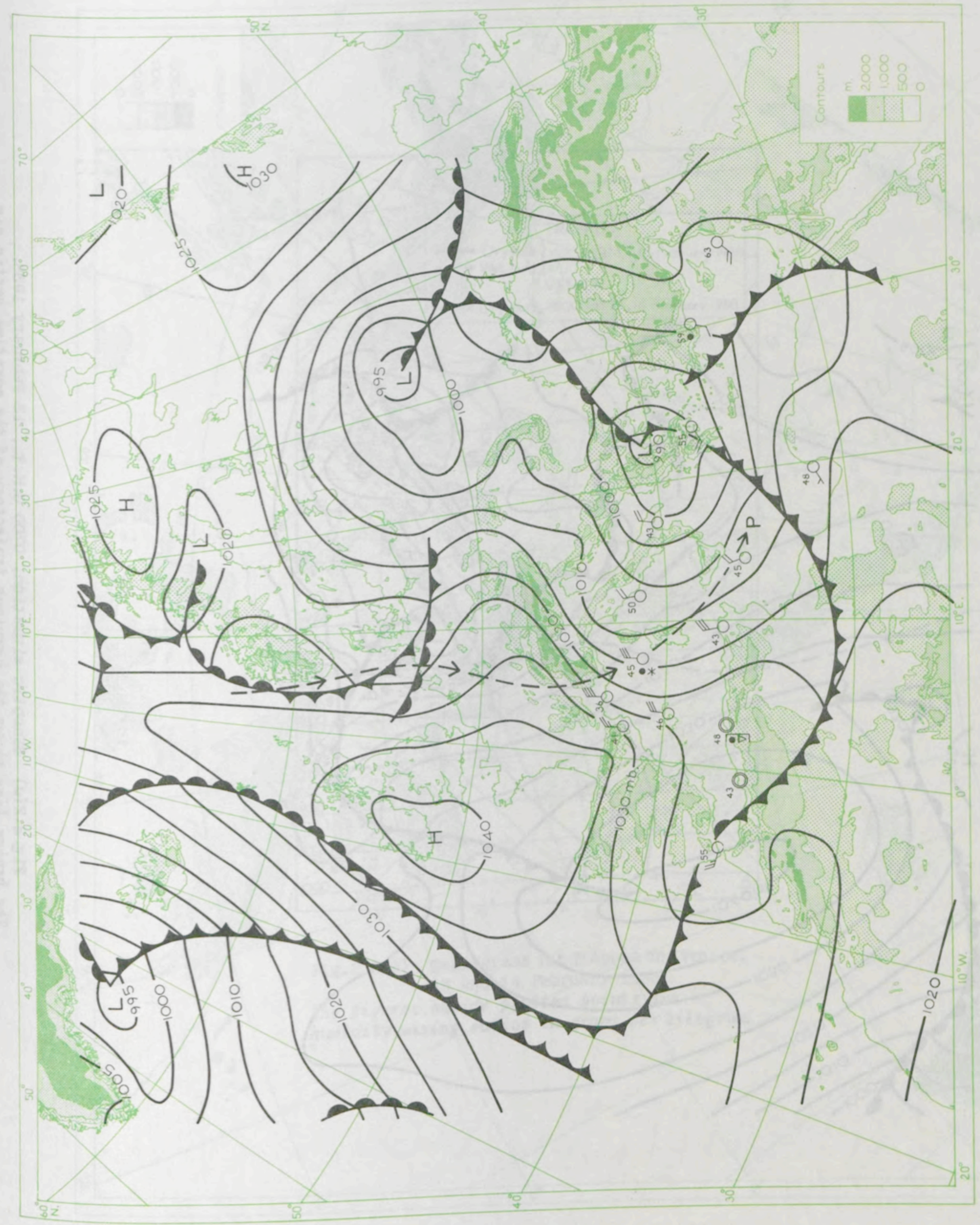


Fig.2.1 Synoptic situation, 0000 G.M.T., 3 March 1949.
The broken line shows the previous trajectory of the maritime arctic air at P.

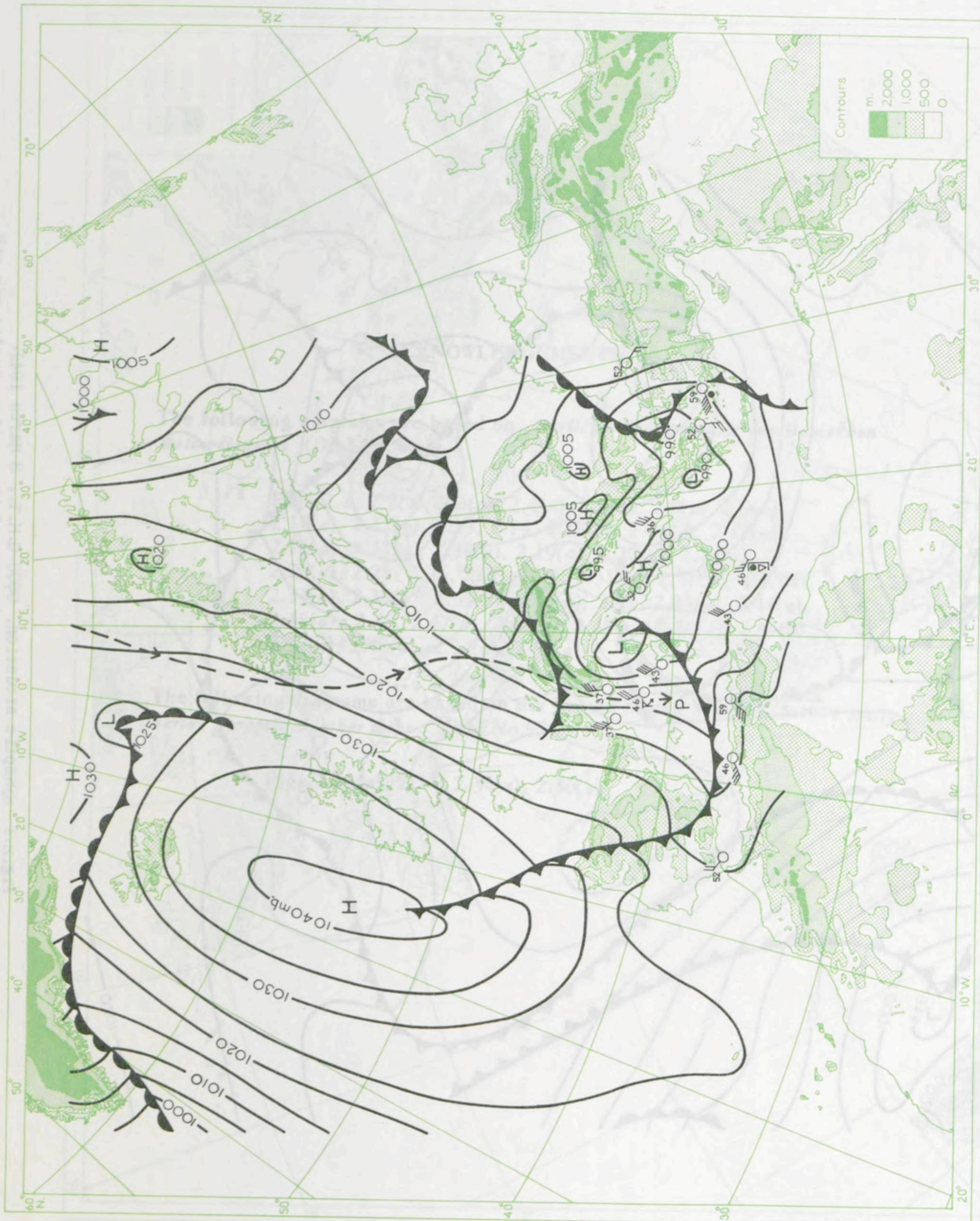


Fig.2.2(*a*) Synoptic situation, 0700 G.M.T., 13 February 1938.
The broken line shows the previous trajectory of the maritime arctic air at P.

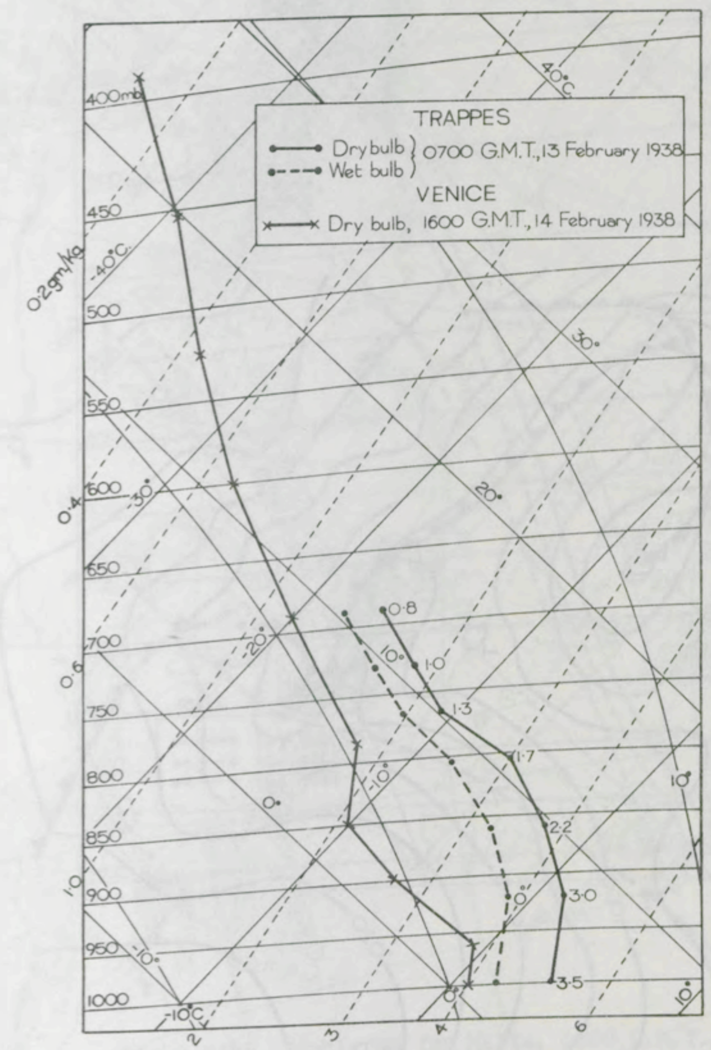


Fig.2.2(*b*) Tephigrams for Trappes and Venice, 13 and 14 February 1938.
The figures beside plotted points are humidity mixing ratios in grams per kilogram.

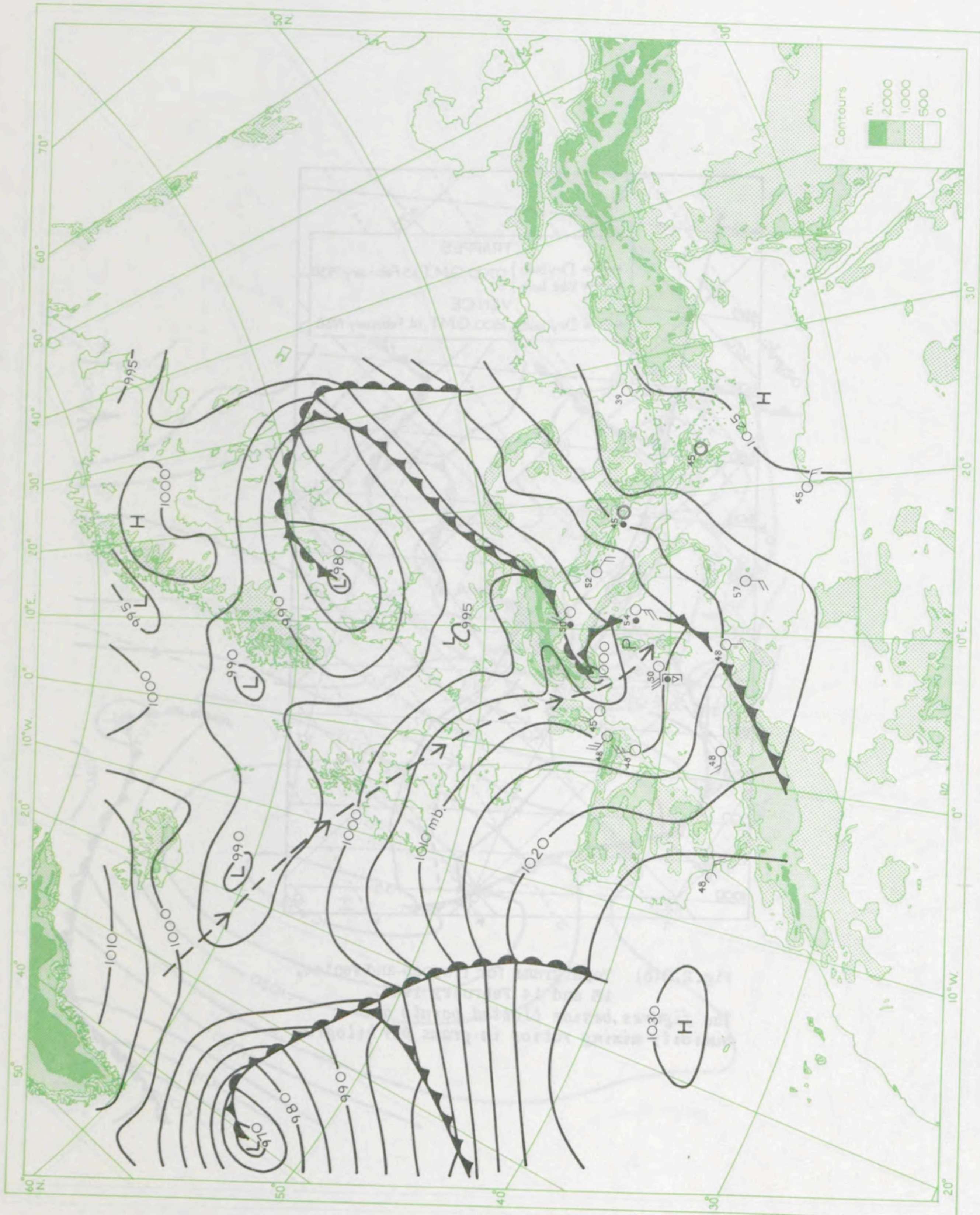


Fig.2.3(a) Synoptic situation, 0600 G.M.T., 14 February 1950.
The broken line shows the previous trajectory of the maritime polar air at P.

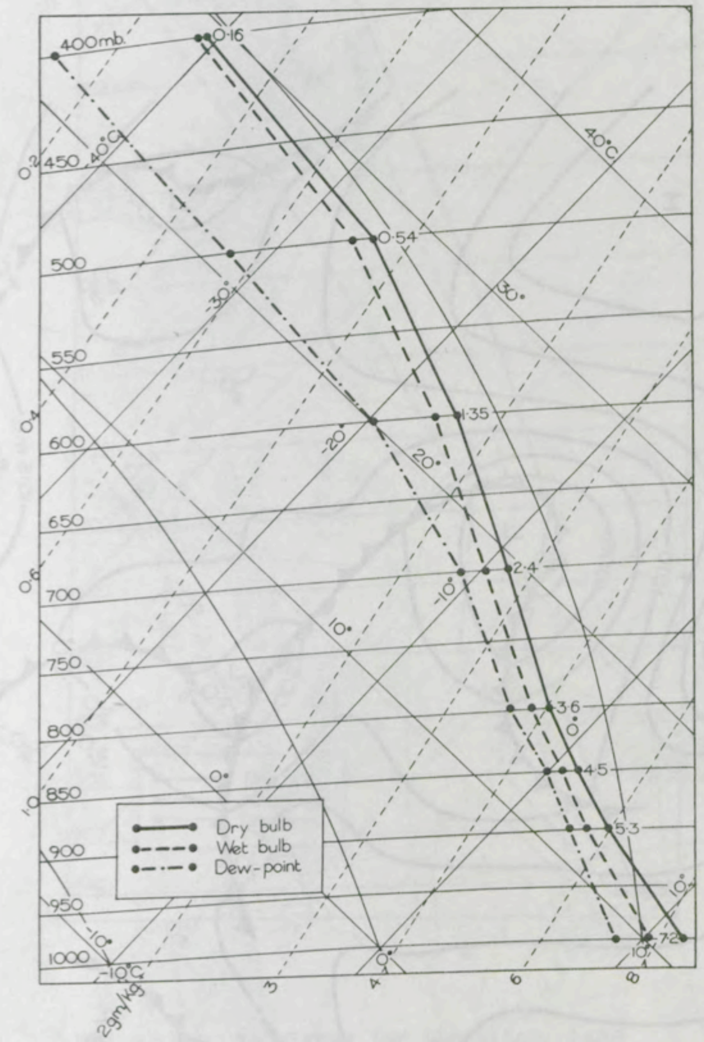


Fig.2.3(*b*) Tephigram for Malta, 1500 G.M.T., 15 February 1950.
The figures beside plotted points are humidity mixing ratios in grams per kilogram.

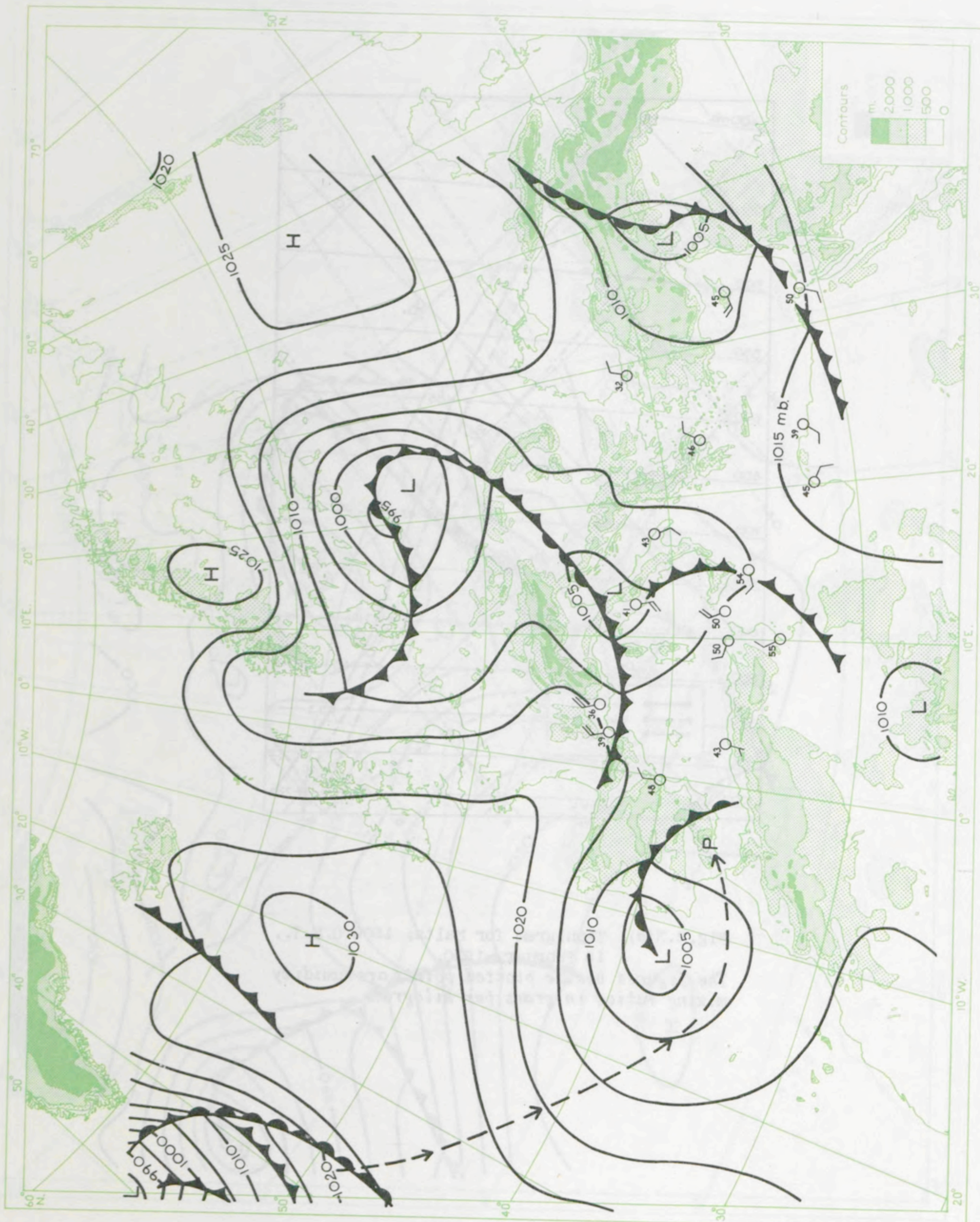


Fig. 2.4(*a*) Synoptic situation, 0000 G.M.T., 6 February 1953.
The broken line shows the previous trajectory of the transitional maritime polar air at P.

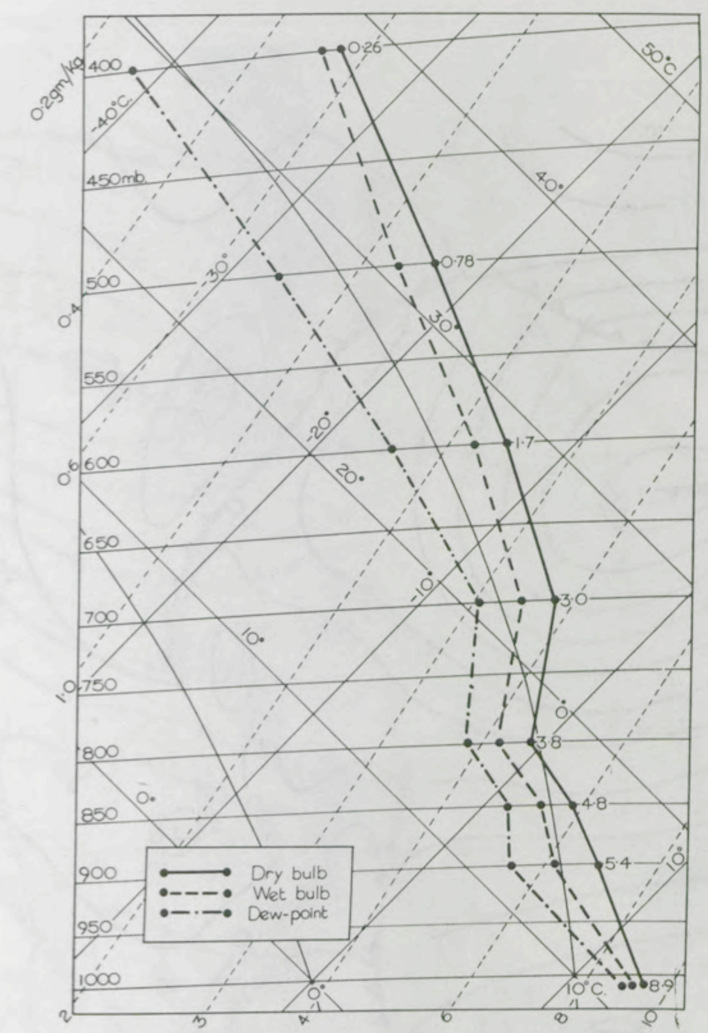


Fig. 2.4(*b*) Tephigram for Gibraltar, 1400 G.M.T., 6 February 1953.
The figures beside plotted points are humidity mixing ratios in grams per kilogram.

H

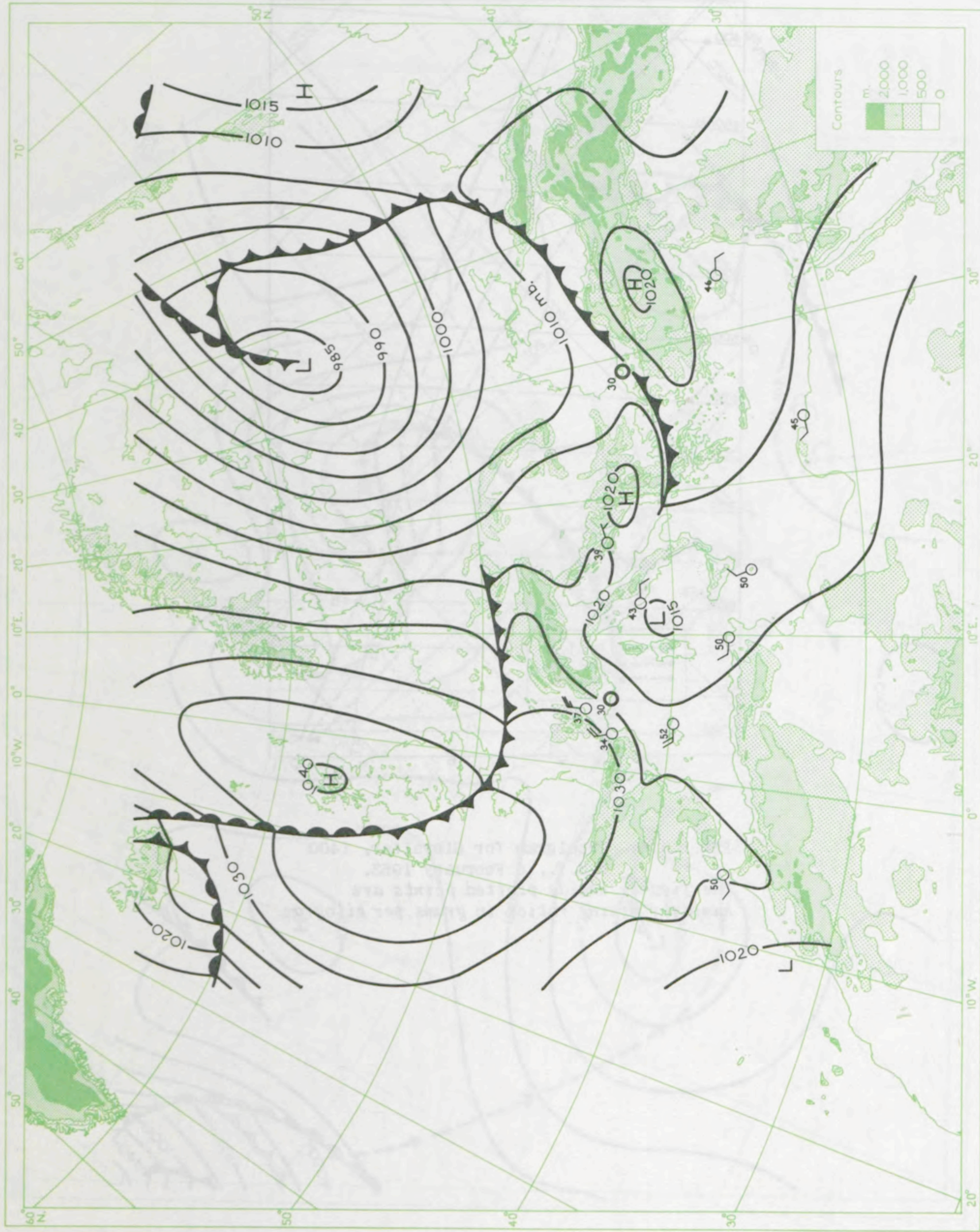


Fig.2.5(a) Synoptic situation, 0000 G.M.T., 1 February 1949

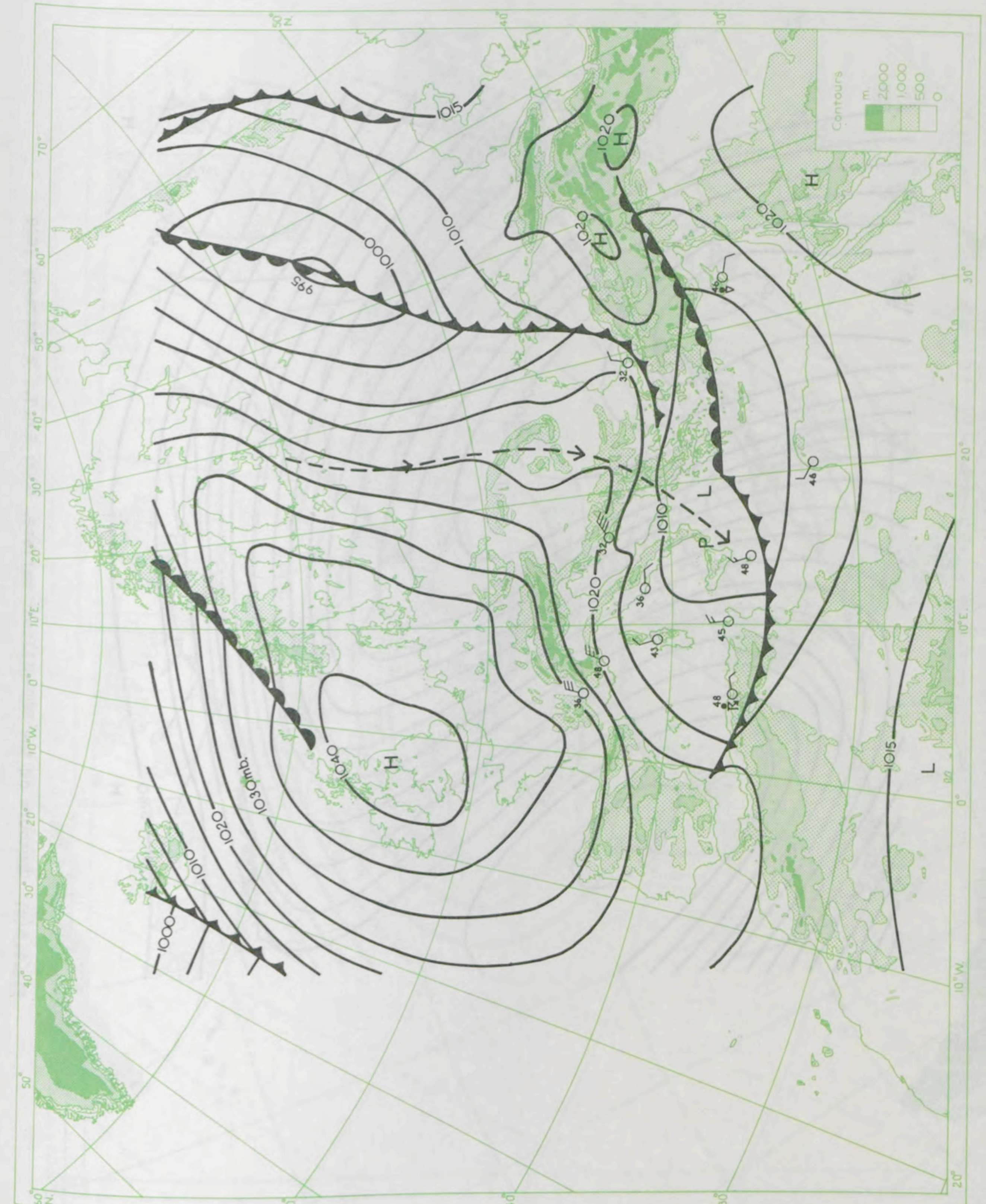


Fig.2.5(b) Synoptic situation, 0000 G.M.T., 2 February 1949
The broken line shows the previous trajectory of the continental arctic air at P.

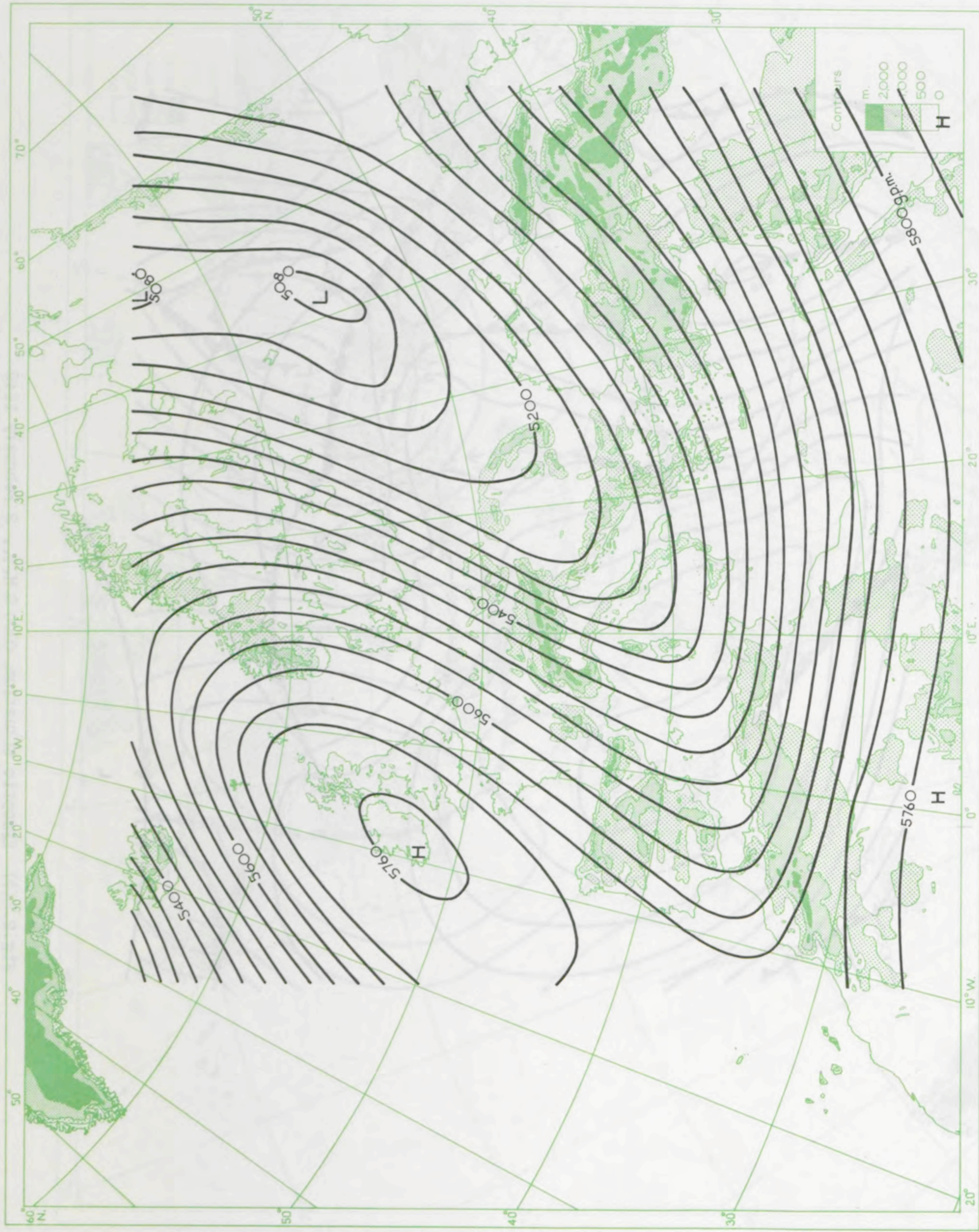


Fig.2.5(c) Contours of the 500-millibar surface, 0300 G.M.T., 2 February 1949

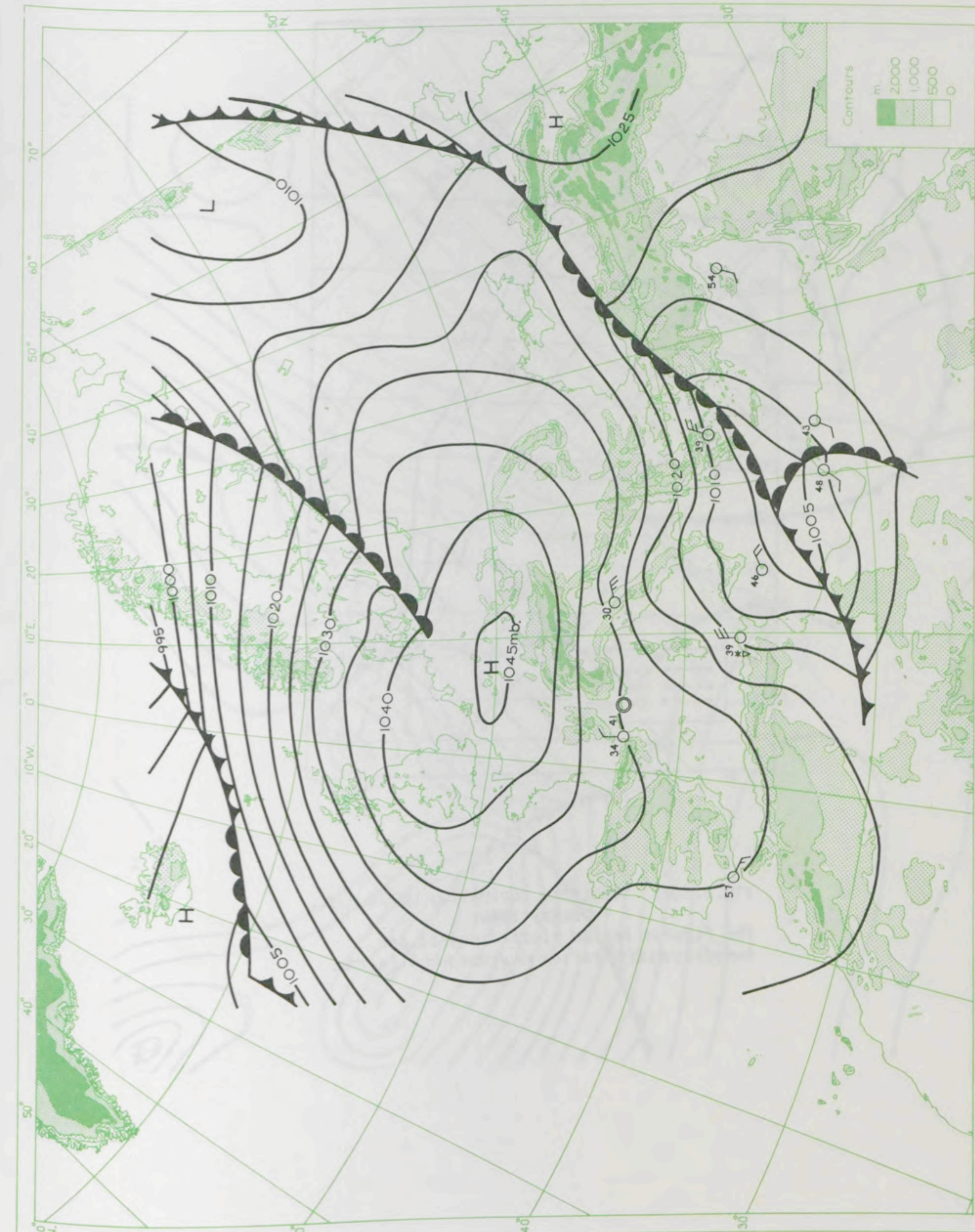


Fig.2.5(d) Synoptic situation, 0000 G.M.T., 3 February 1949

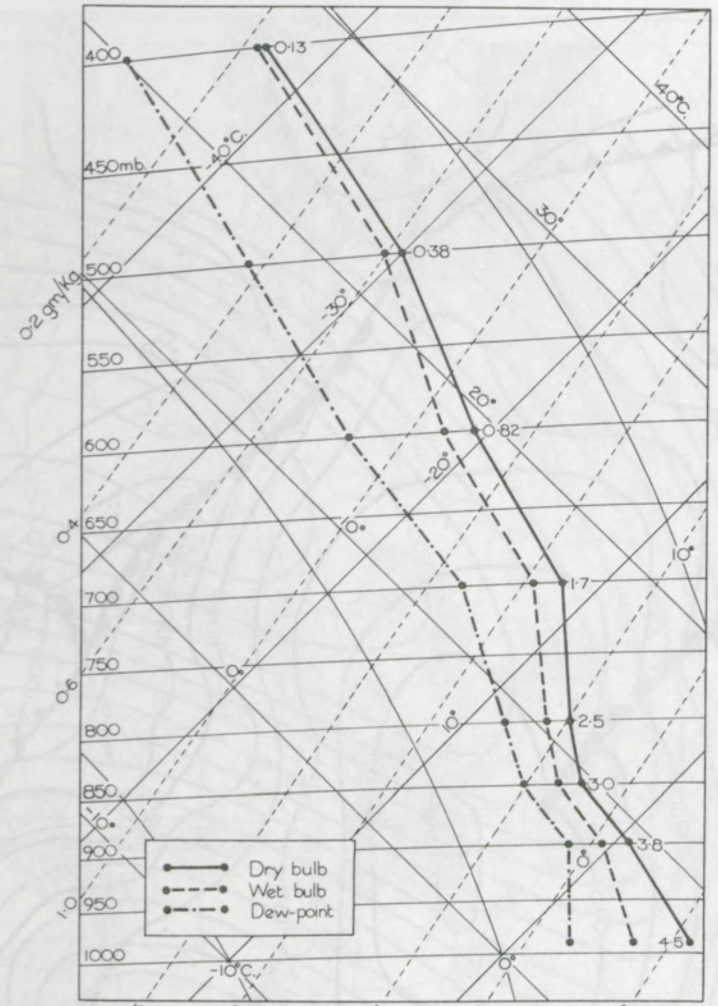


Fig. 2.5(*e*) Tephigram for Malta, 1500 G.M.T., 3 February 1949.
The figures beside plotted points are humidity mixing ratios in grams per kilogram.

Fig. 2.6(*a*) Synoptic situation, 1200 G.M.T., 5 February 1950.
The broken line shows the previous trajectories of the continental arctic air at P. The double arrow shows the track of the depression.

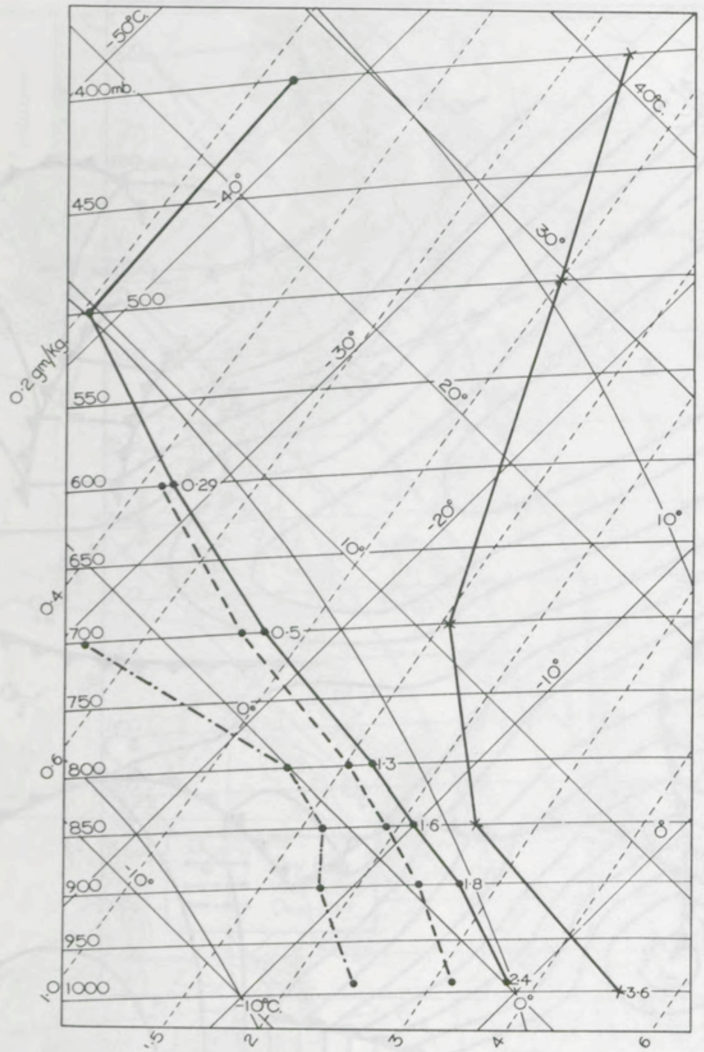


Fig.2.6(*b*) Tephigrams for Nicosia and Cairo Airport, 5 February 1950

NICOSIA

Dry bulb)
Wet bulb) 1500 G.M.T., 5 February 1950
Dew-point)

CAIRO AIRPORT

Dry bulb, 1500 G.M.T., 5 February 1950

The figures beside plotted points are humidity mixing ratios in grams per kilogram.

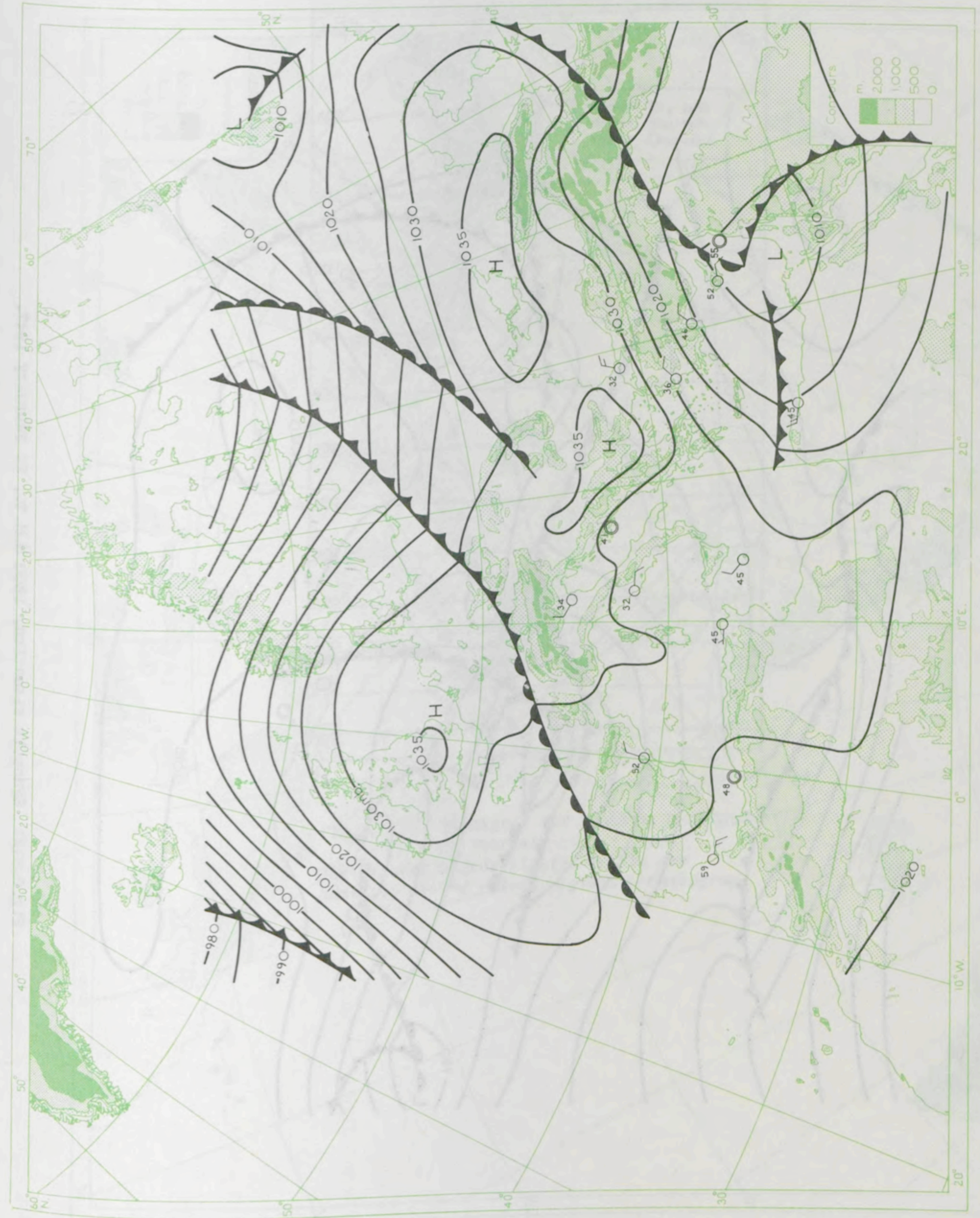


Fig.2.7 Synoptic situation, 0000 G.M.T., 25 January 1949

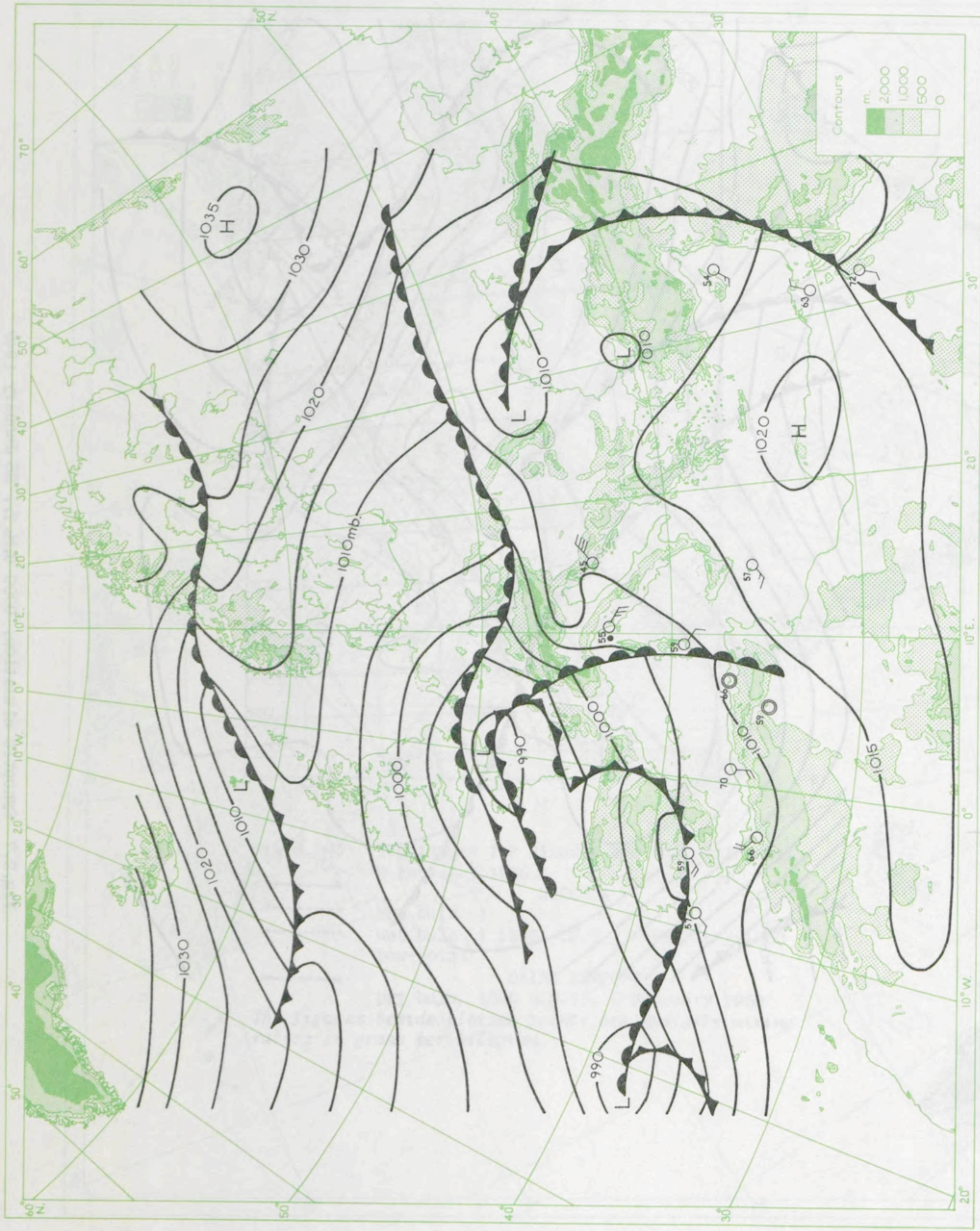


Fig. 2.8(*a*) Synoptic situation, 1800 G.M.T., 21 February 1947.

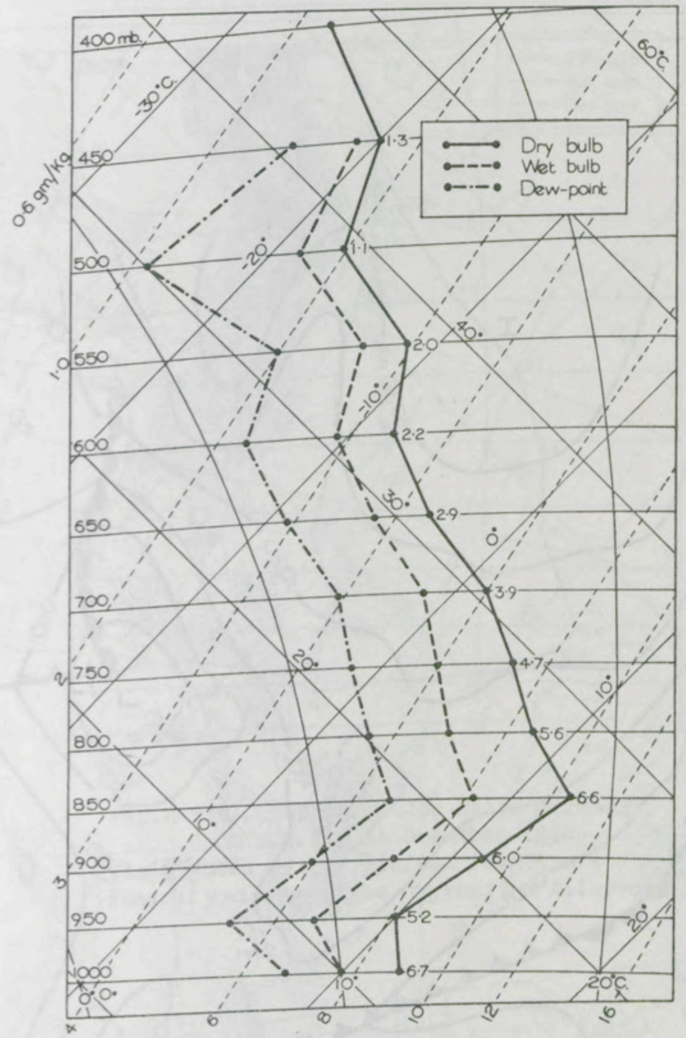


Fig. 2.8(*b*) Tephigram for Algiers, 0600 G.M.T., 21 February 1947.
The figures beside plotted points are humidity mixing ratios in grams per kilogram.

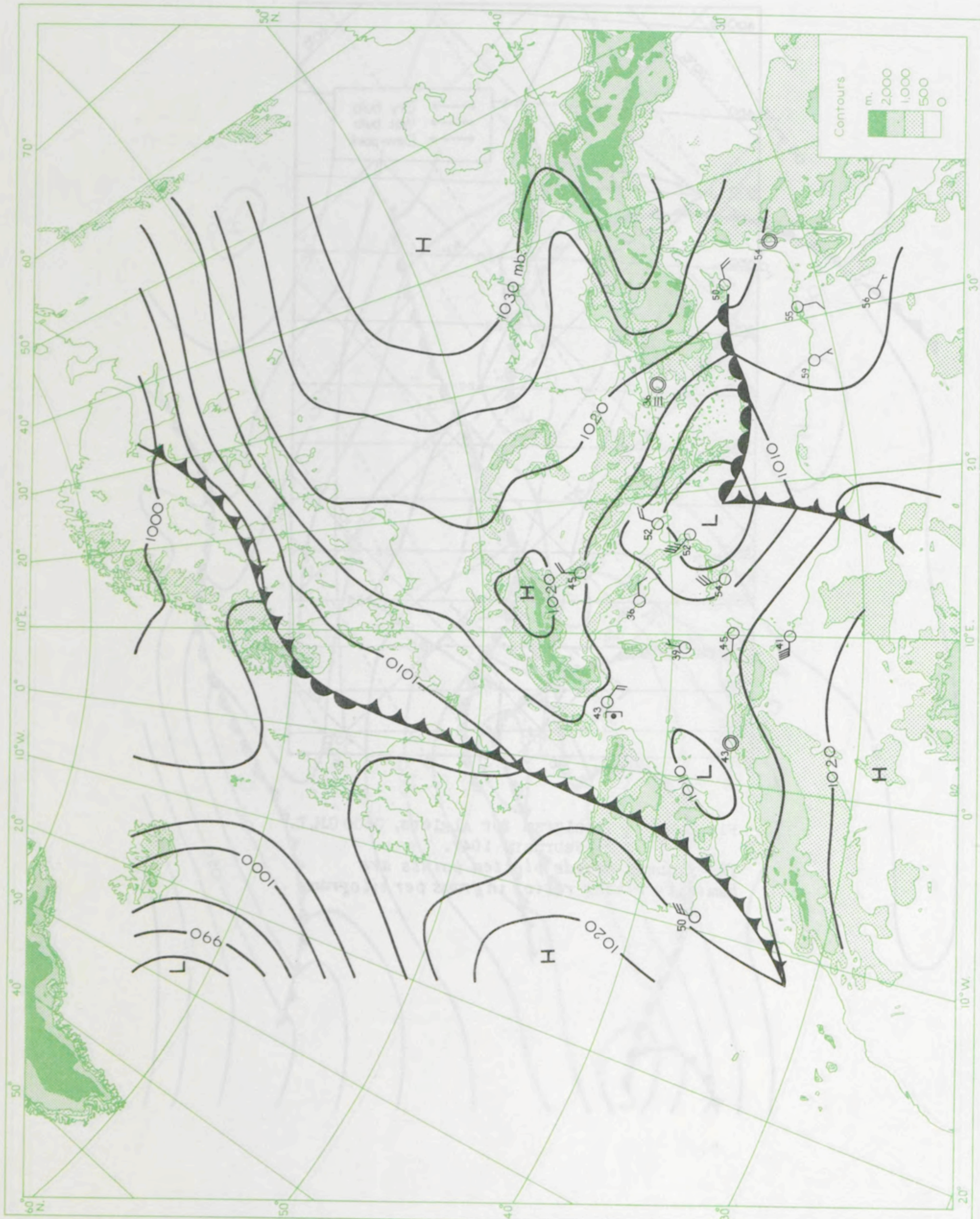


Fig.2.9(*a*) Synoptic situation, 0500 G.M.T., 24 December 1946.

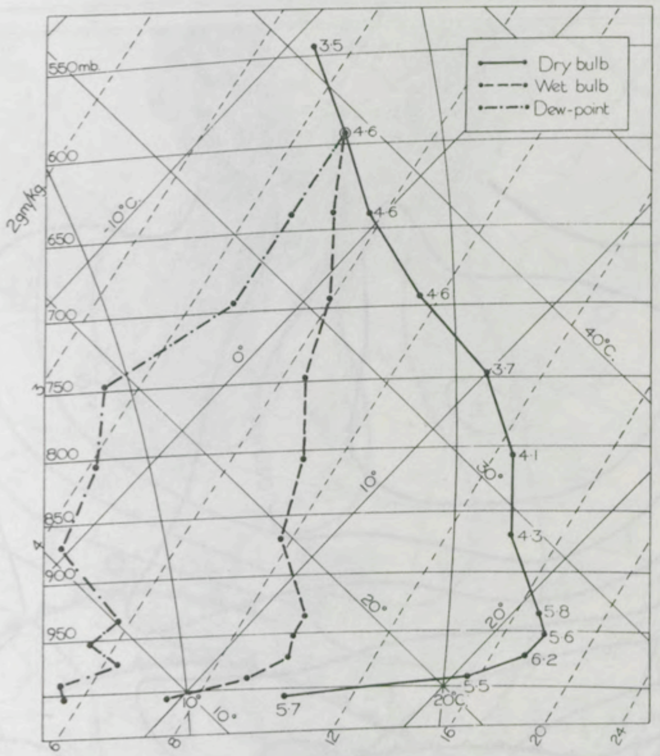


Fig.2.9(*b*) Tephigram for Cairo (Almaza), 0500 G.M.T., 24 December 1946.
The figures beside plotted points are humidity mixing ratios in grams per kilogram.

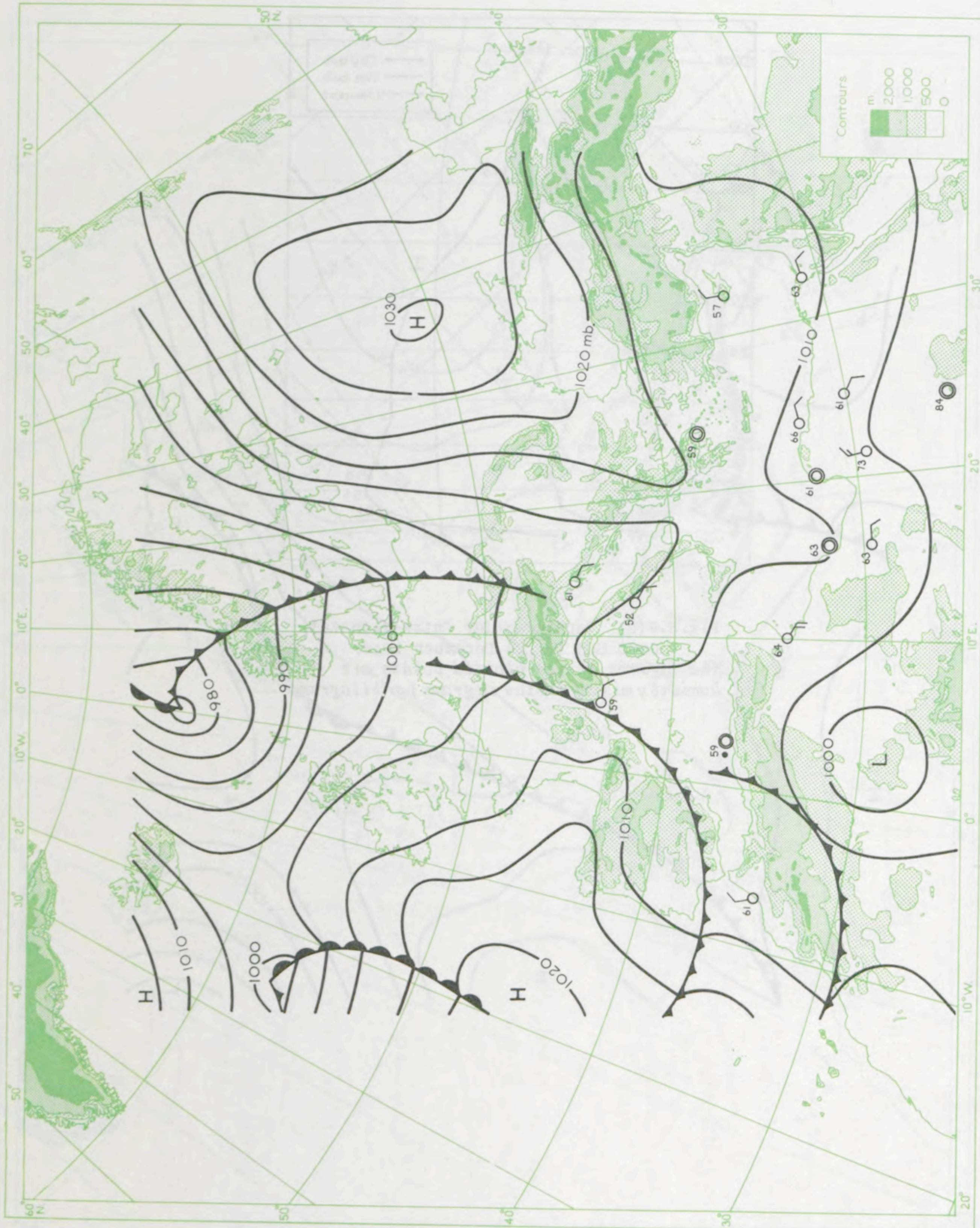


Fig.2.10(a) Synoptic situation, 0000 G.M.T., 6 May 1949.

Fig.2.10(b) Synoptic situation, 0000 G.M.T., 7 May 1949.

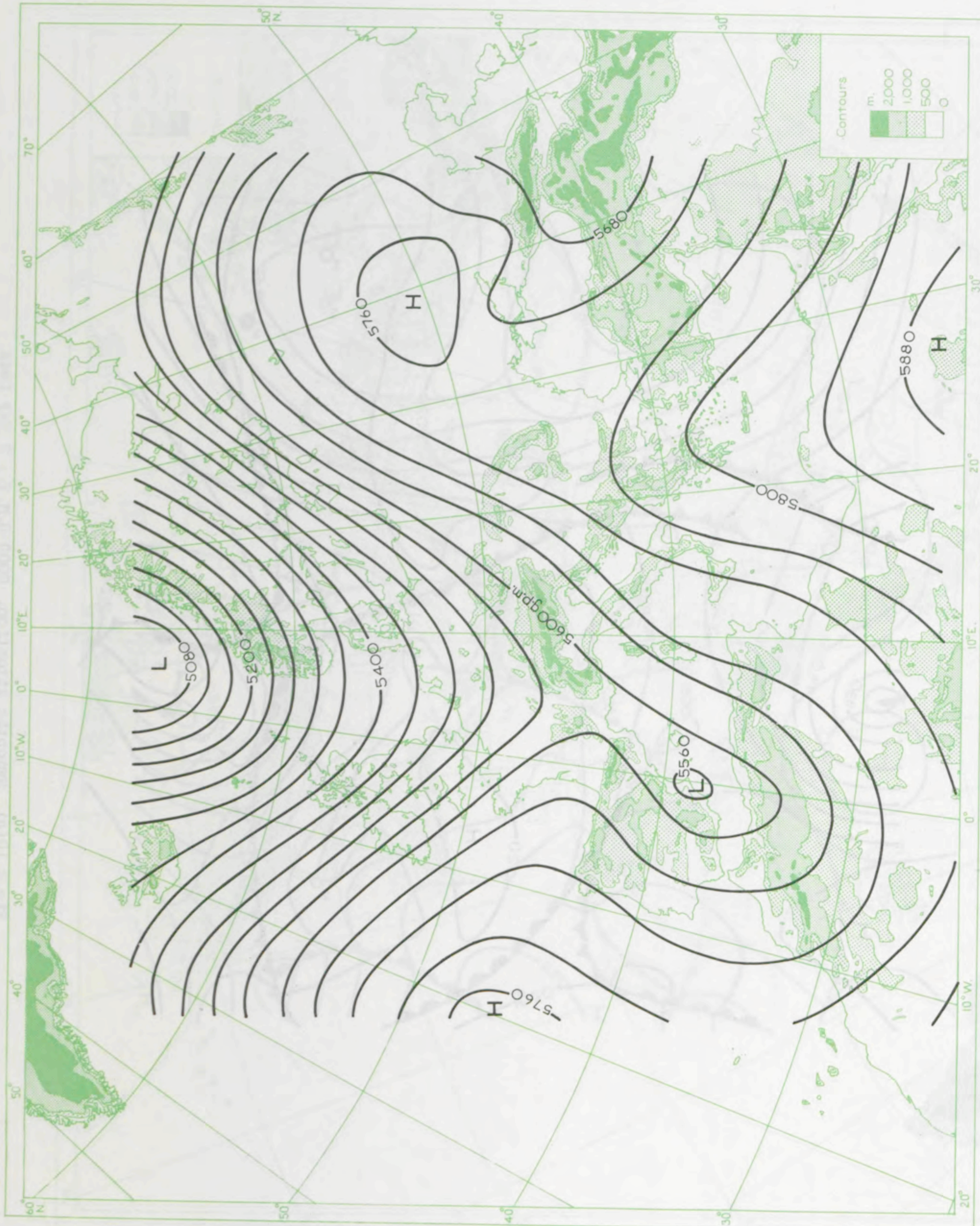


Fig.2.10(c) Contours of the 500-millibar surface, 0300 G.M.T., 7 May 1949

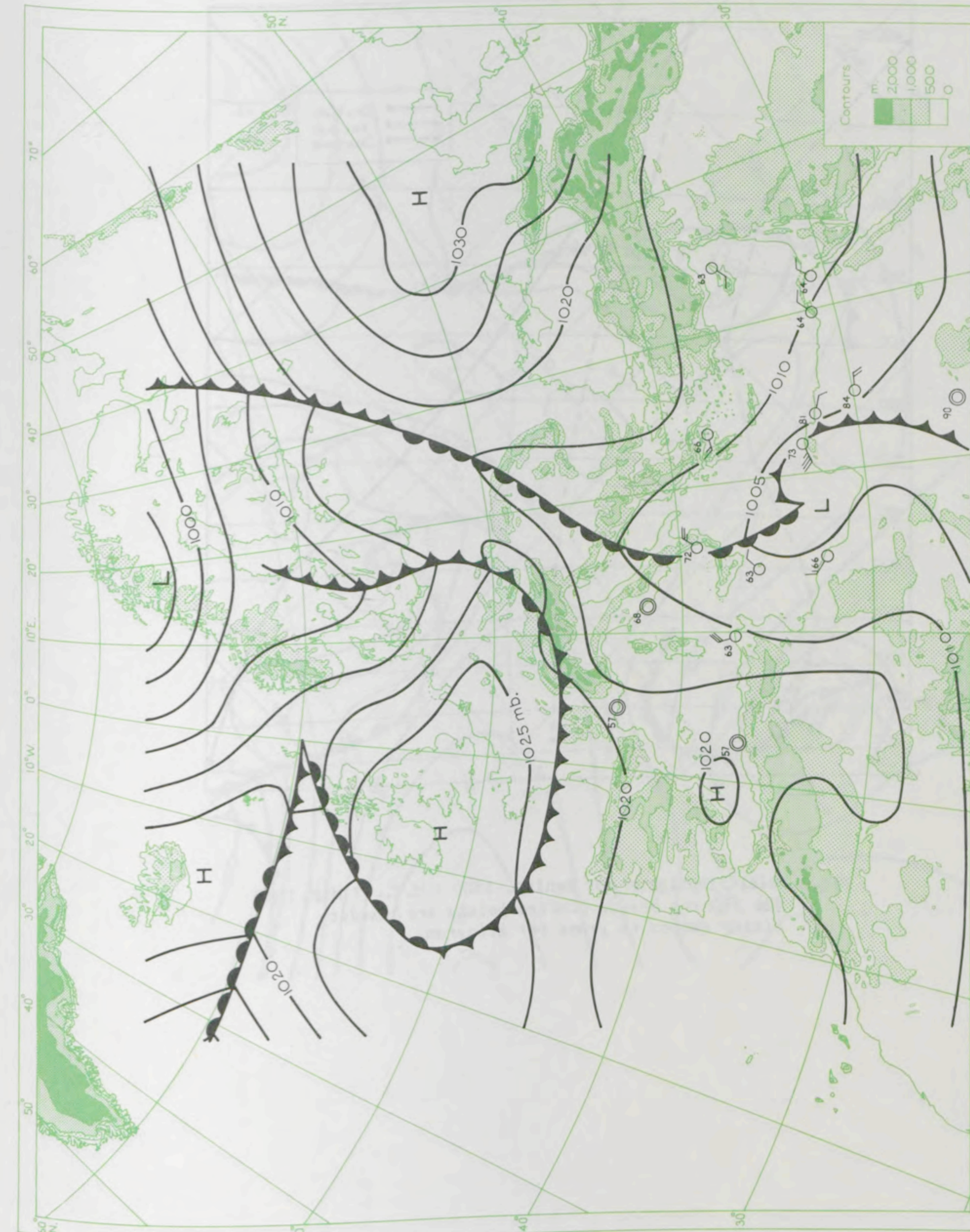


Fig.2.10(d) Synoptic situation, 0000 G.M.T., 8 May 1949

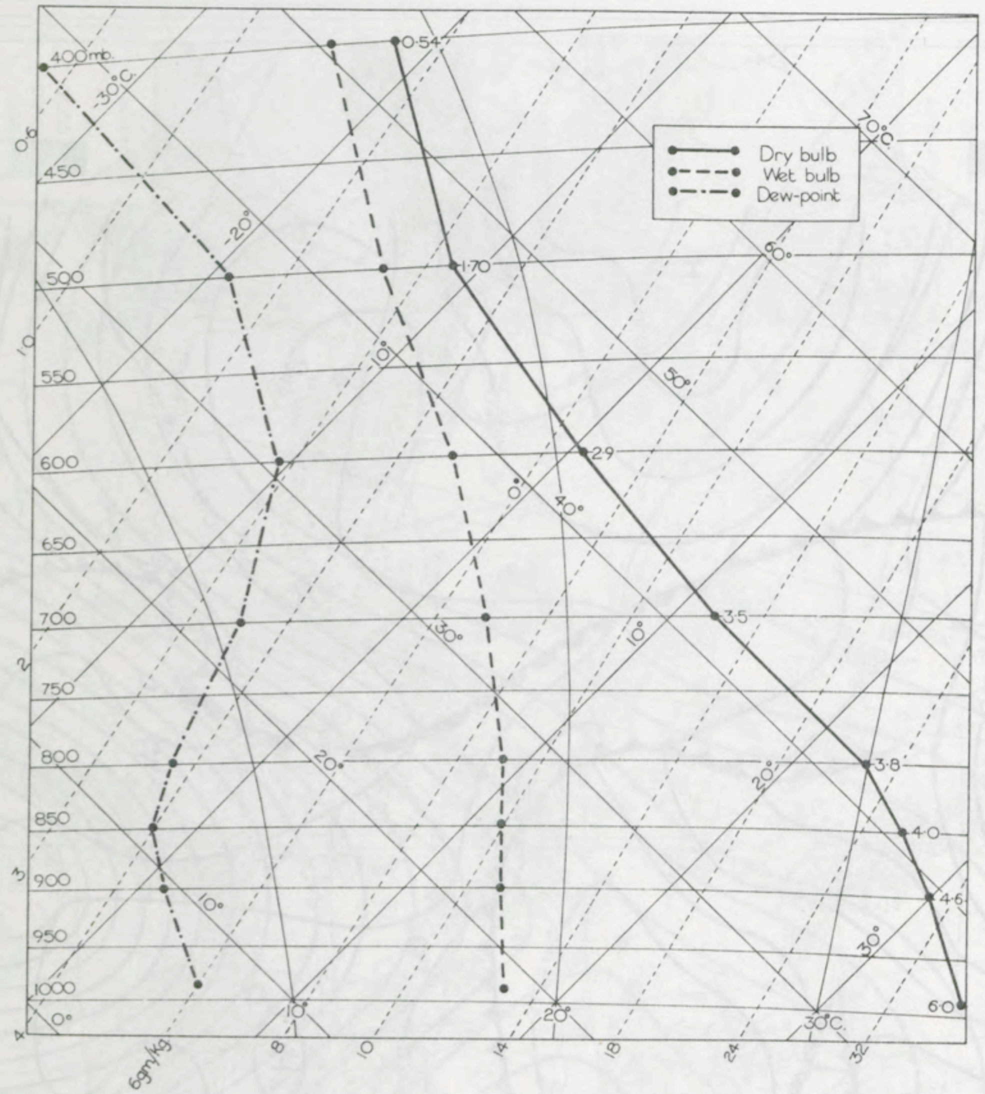


Fig.2.10(*e*) Tephigram for Benina, 1500 G.M.T., 7 May, 1949
The figures beside plotted points are humidity mixing ratios in grams per kilogram.

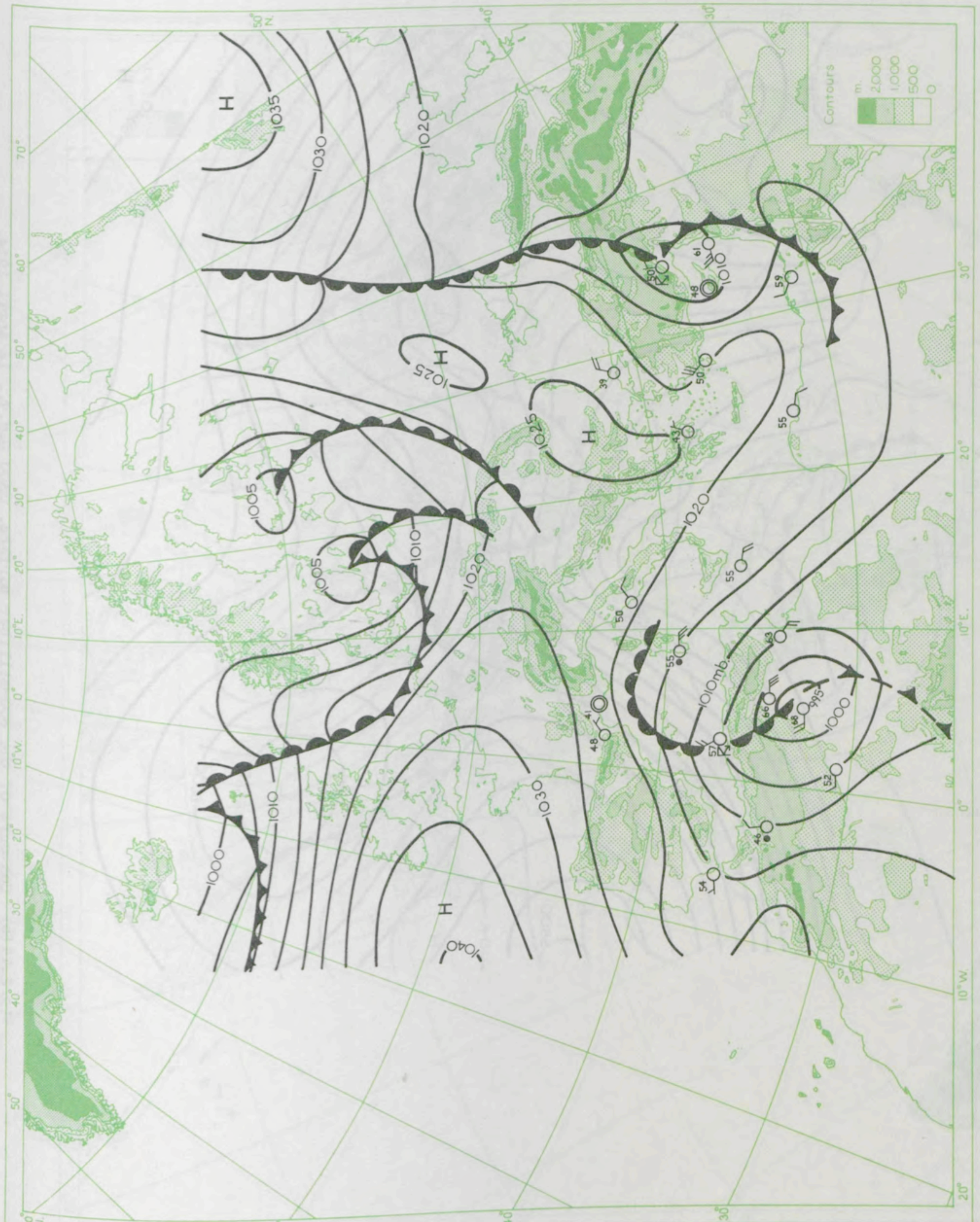


Fig.2.11(*a*) Synoptic situation, 0000 G.M.T., 14 April 1954.

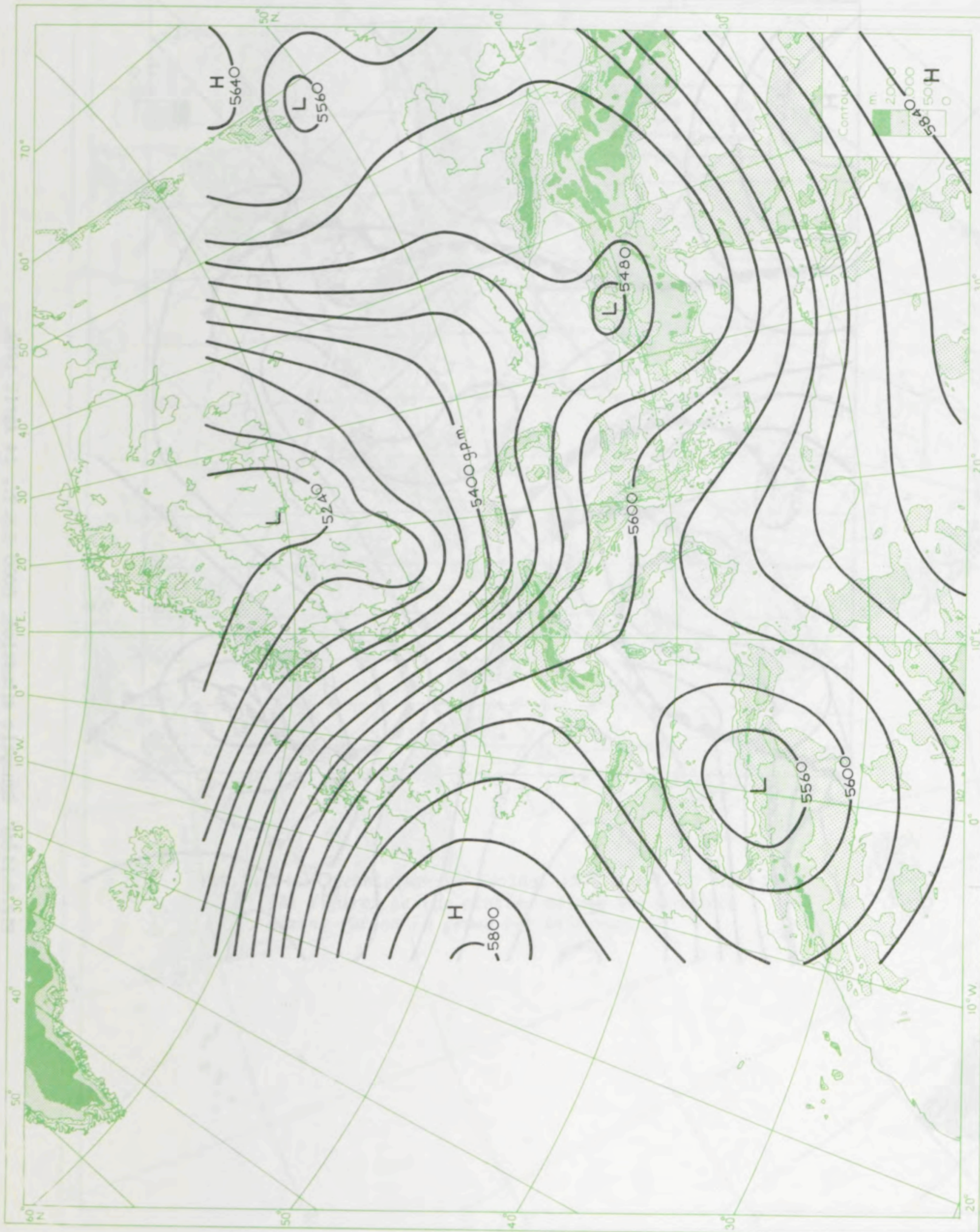


Fig.2.11(b) Contours of the 500-millibar surface, 0300 G.M.T., 14 April 1954.

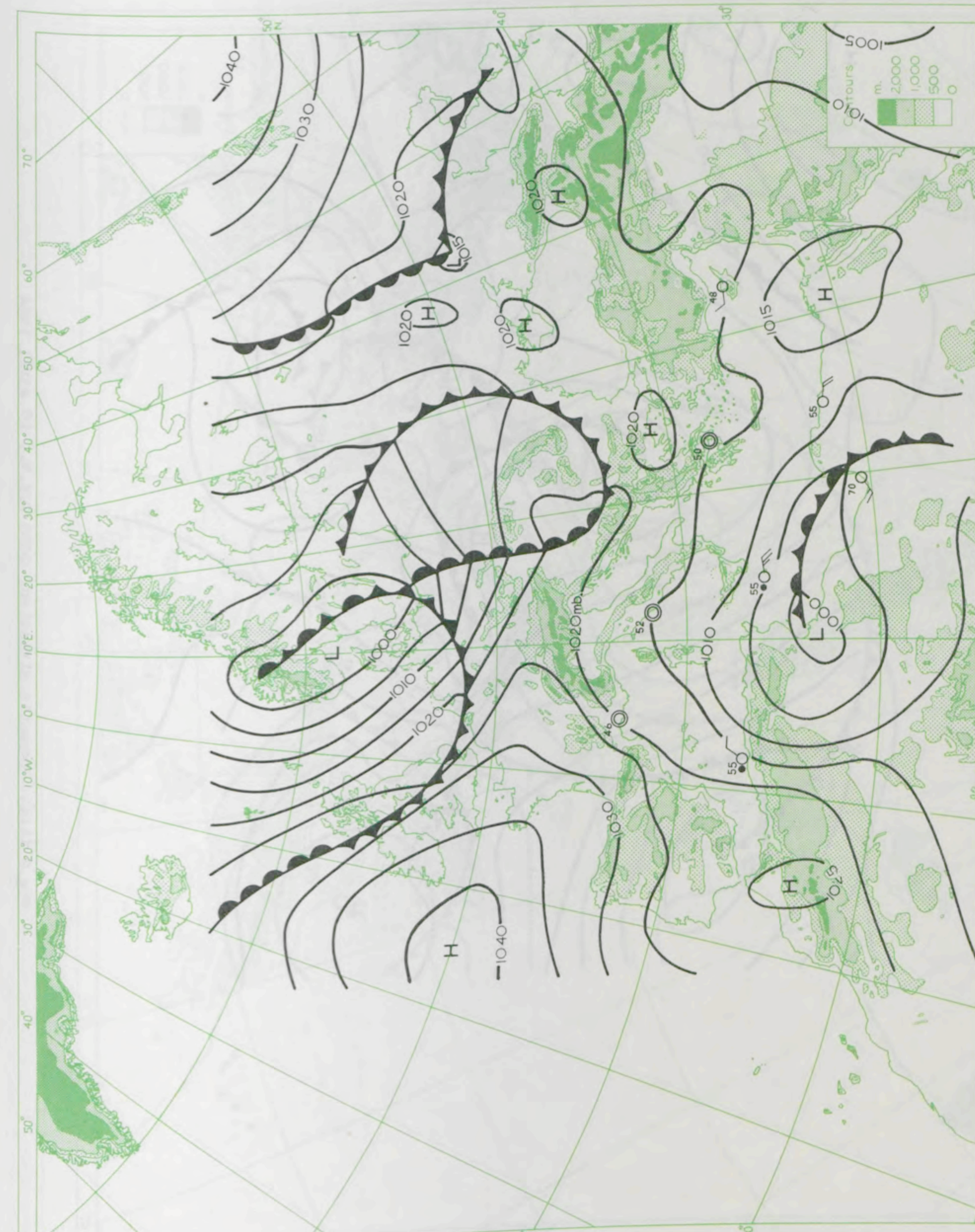


Fig.2.11(c) Synoptic situation, 0000 G.M.T., 15 April 1954

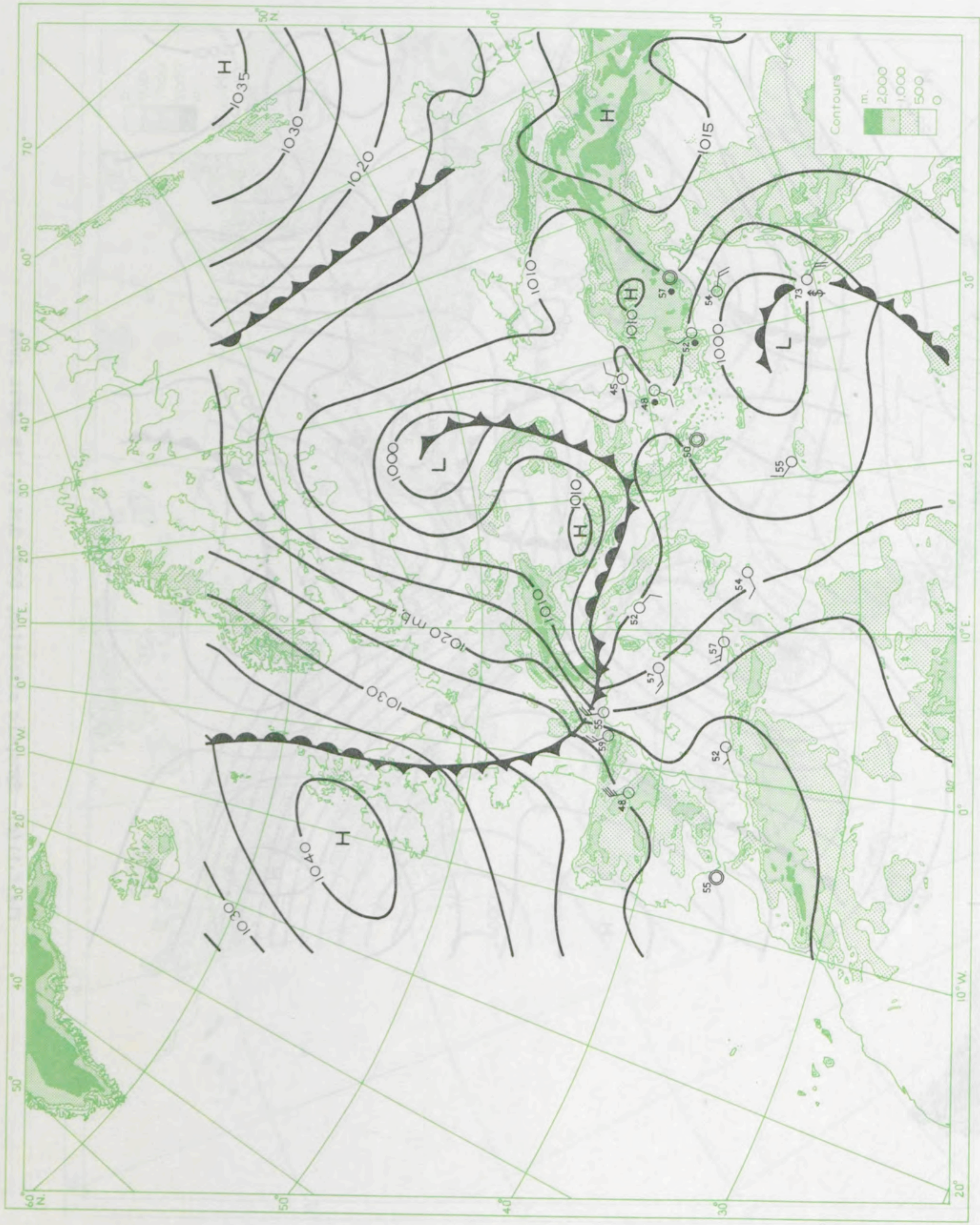


Fig.2.11(d) Synoptic situation, 0000 G.M.T., 16 April 1954

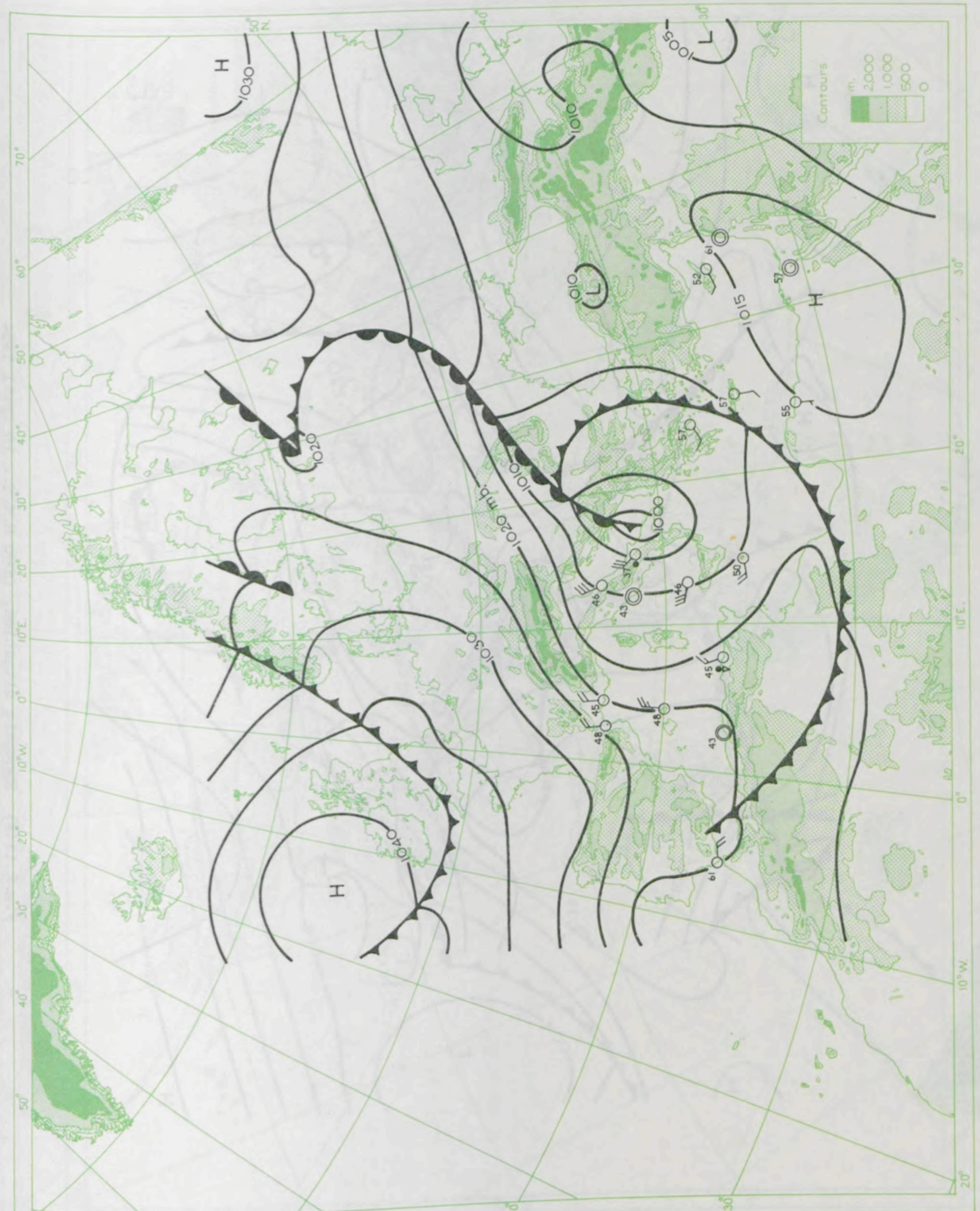


Fig.2.11(e) Synoptic situation, 0000 G.M.T., 18 April 1954

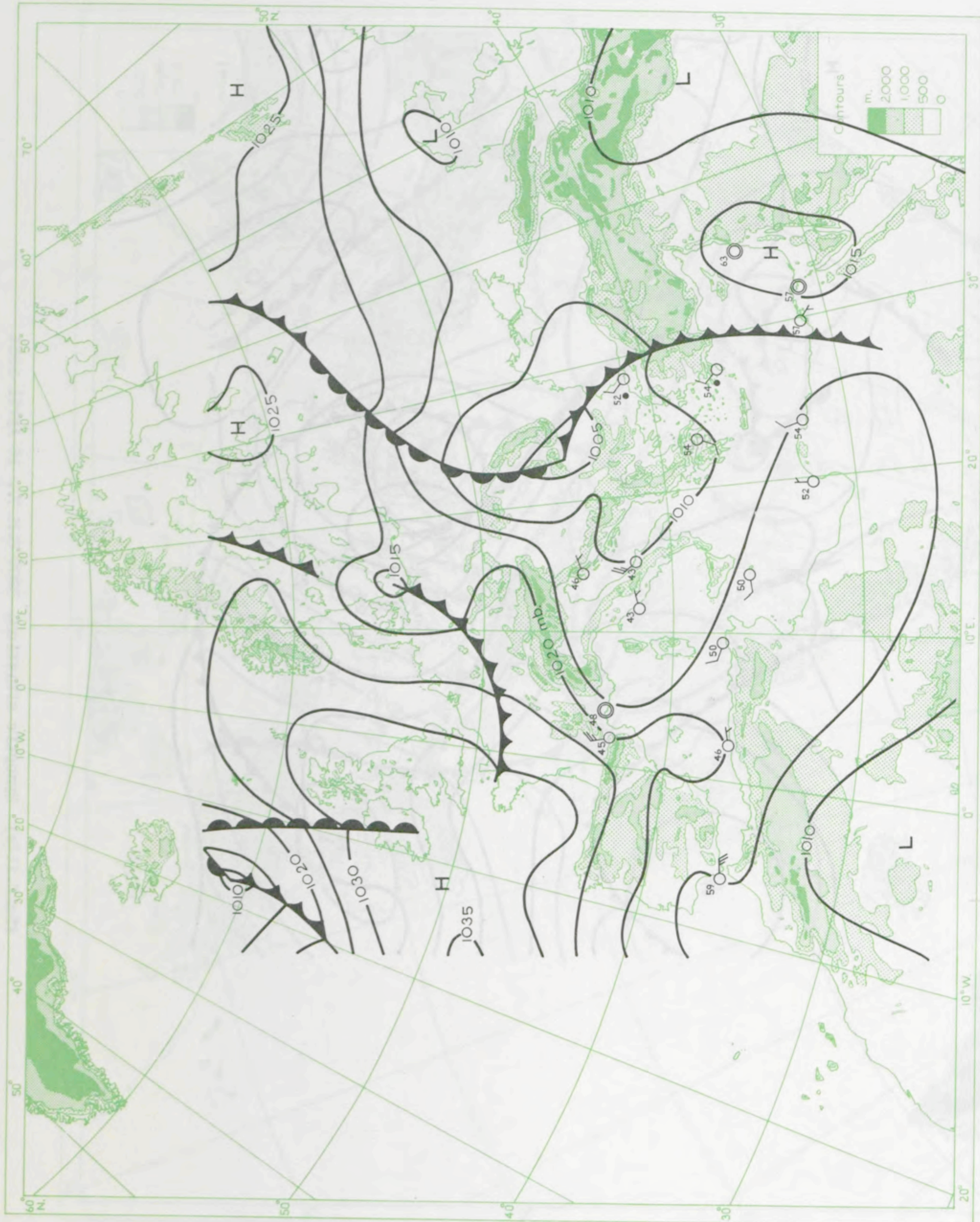


Fig.2.11(*f*) Synoptic situation, 0000 G.M.T., 19 April 1954

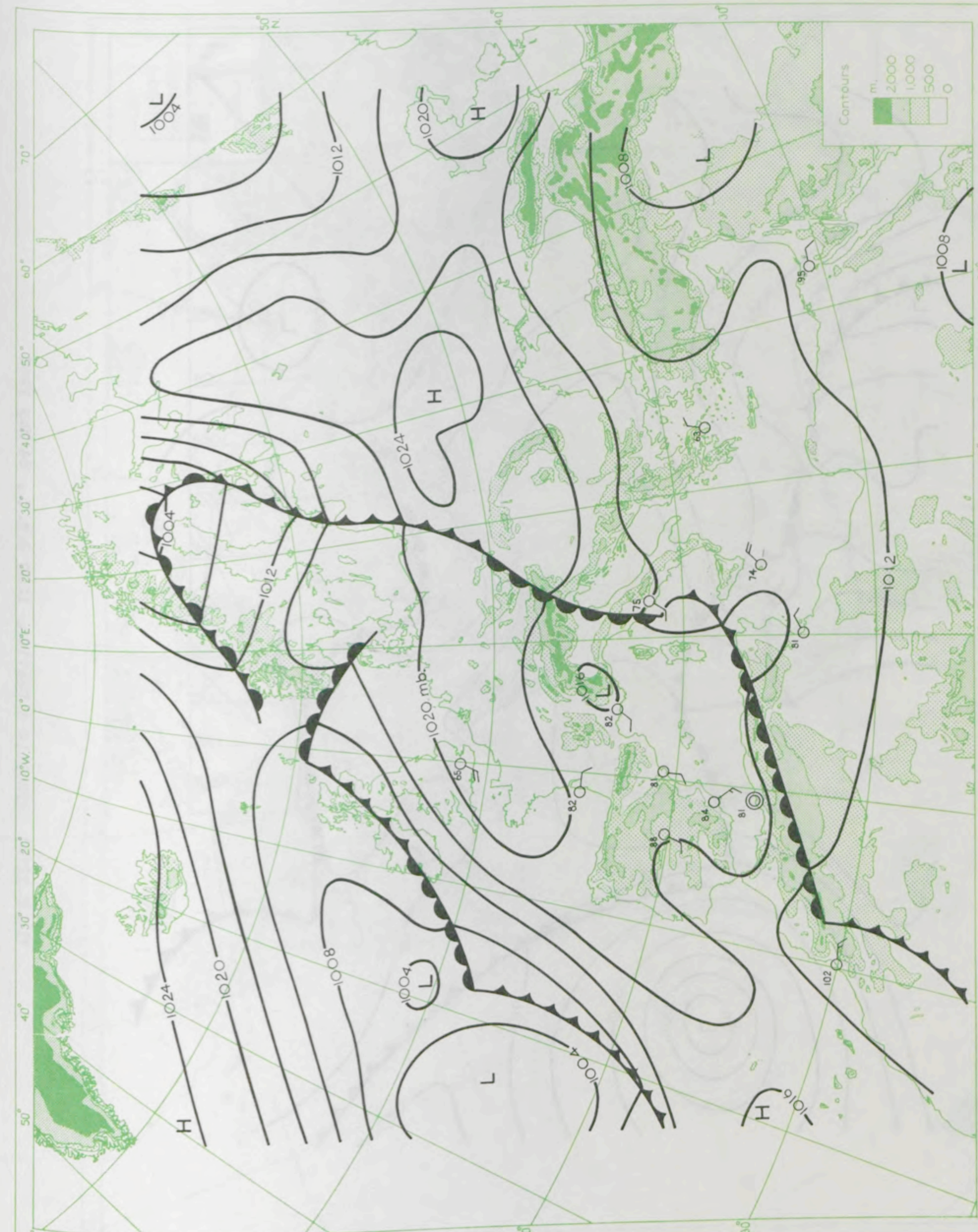


Fig.2.12(*a*) Synoptic situation, 1200 G.M.T., 23 May 1953

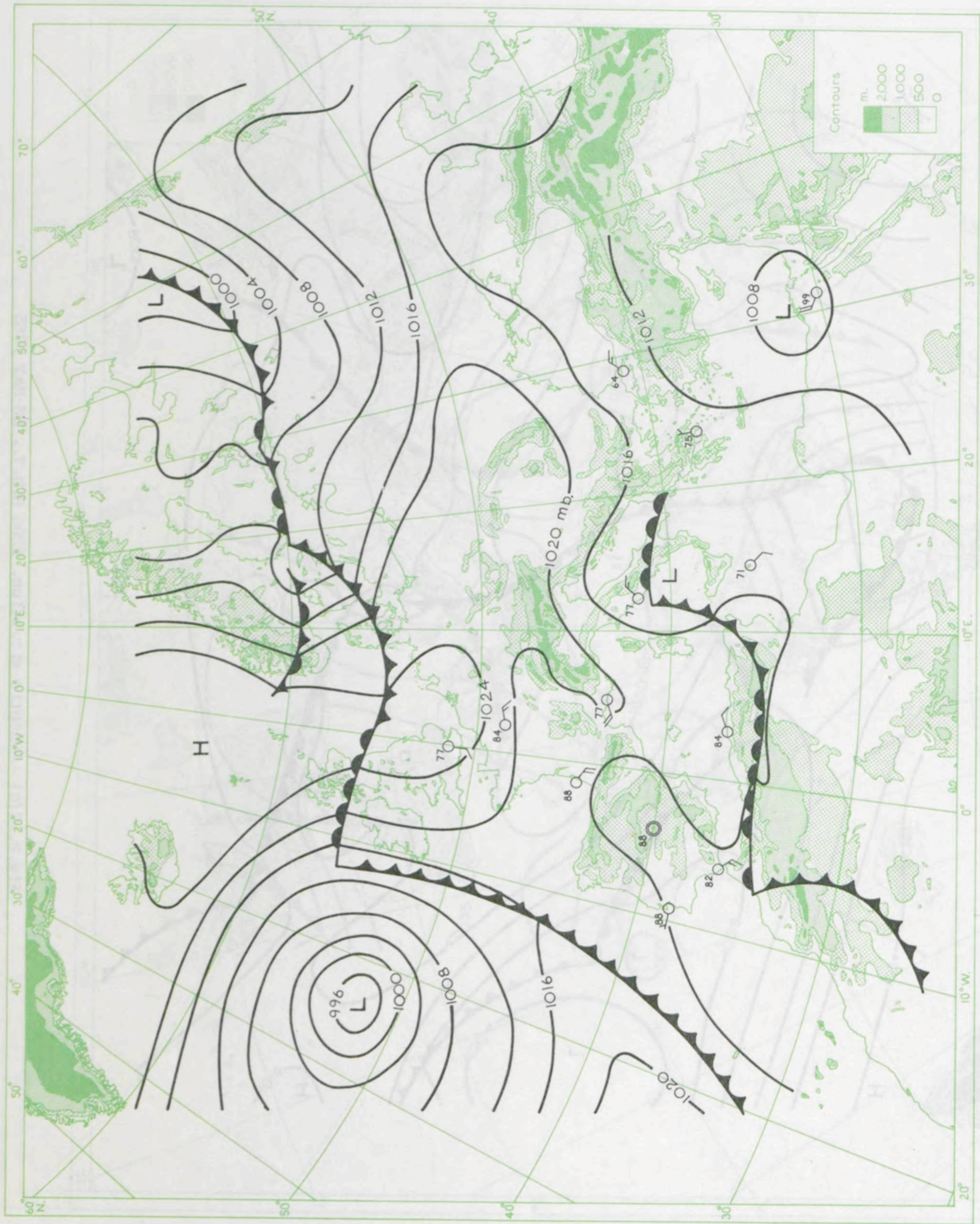


Fig.2.12(b) Synoptic situation, 1200 G.M.T., 24 May 1953

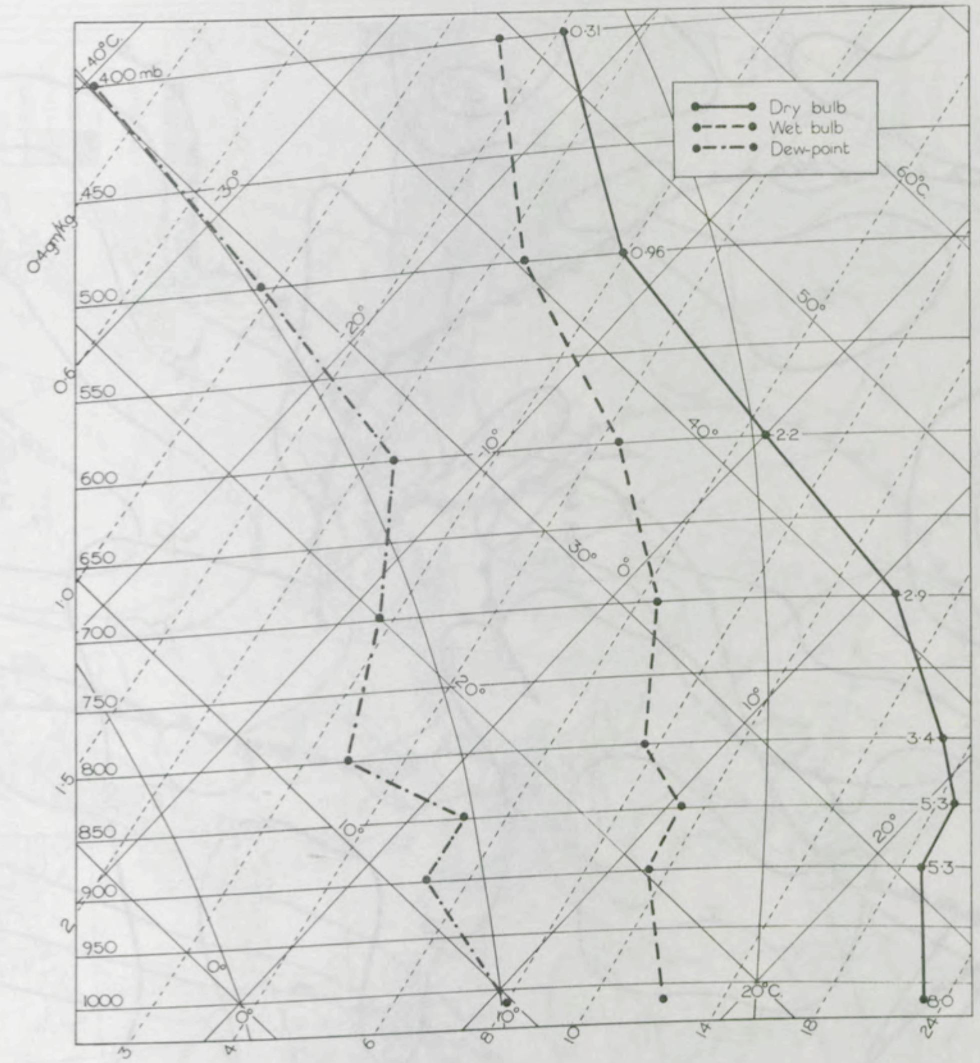


Fig.2.12(c) Tephigram for Gibraltar, 1400 G.M.T., 24 May 1953

The figures beside plotted points are humidity mixing ratios in grams per kilogram.

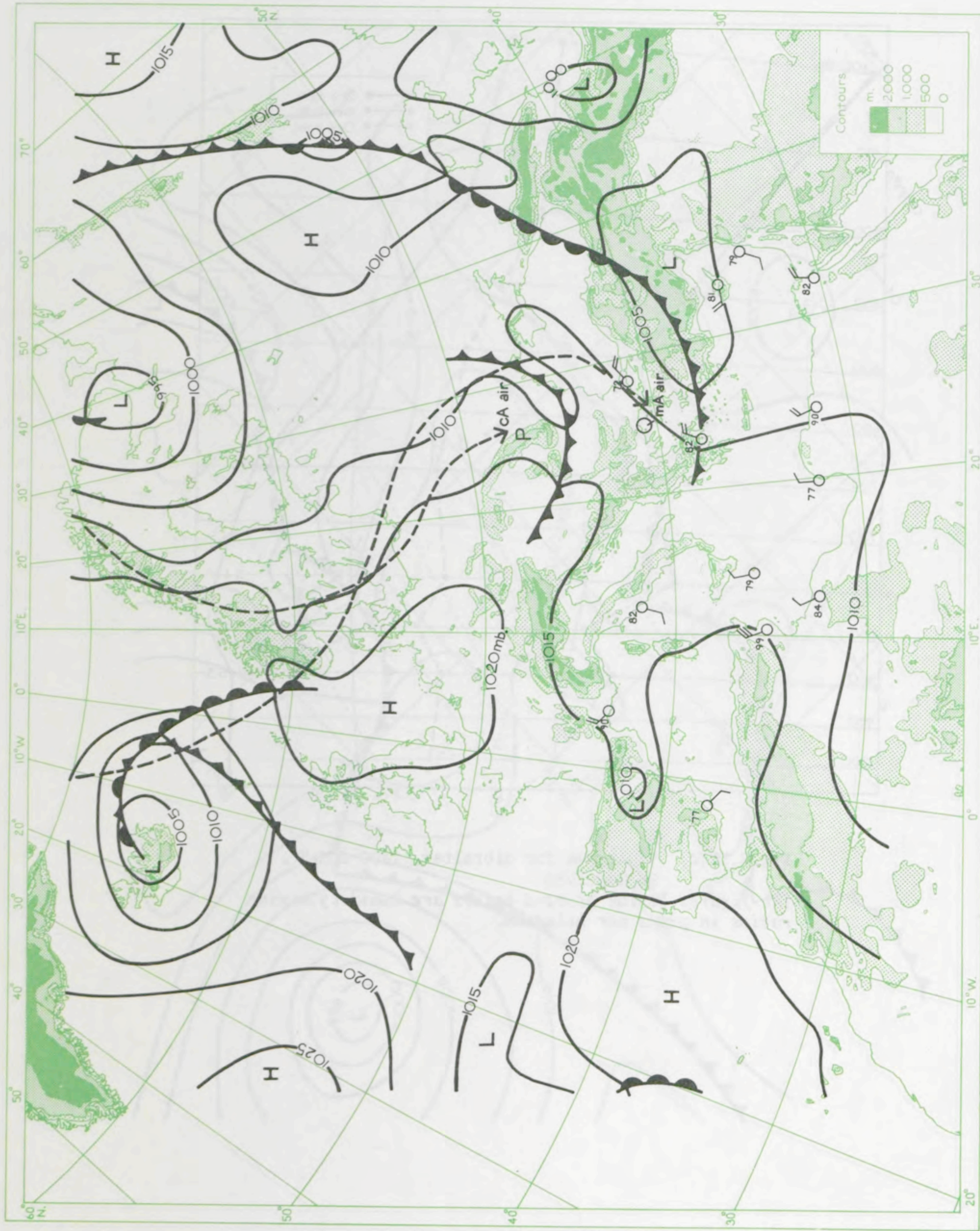


Fig.2.13 Synoptic situation, 1800 G.M.T., 21 July 1951.
The broken lines show the previous trajectories of the continental arctic and maritime arctic air at P and Q respectively.

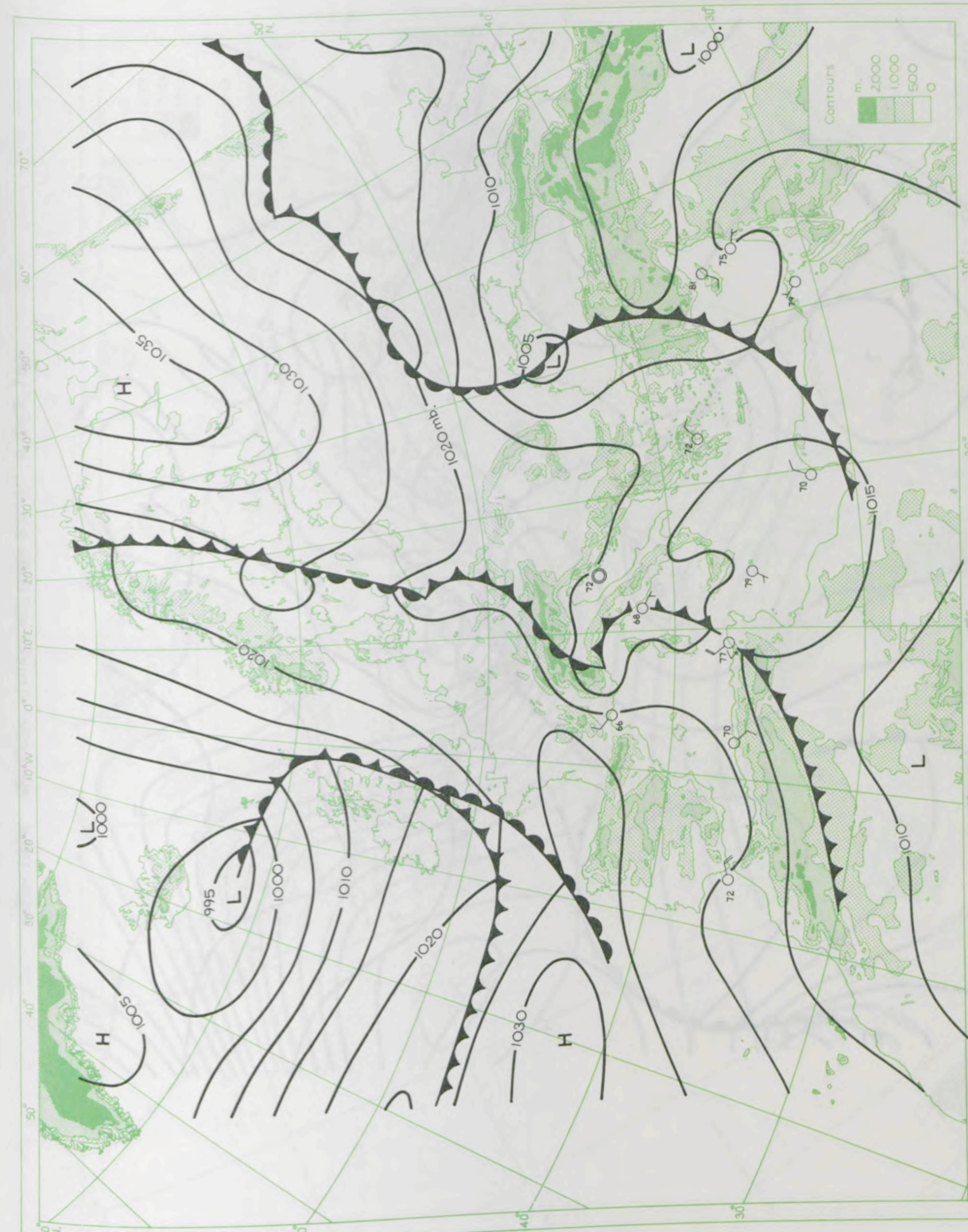


Fig.2.14 Synoptic situation, 0000 G.M.T., 22 August 1951.

Fig.2.15(*a*) Synoptic situation, 0000 G.M.T., 5 July 1955

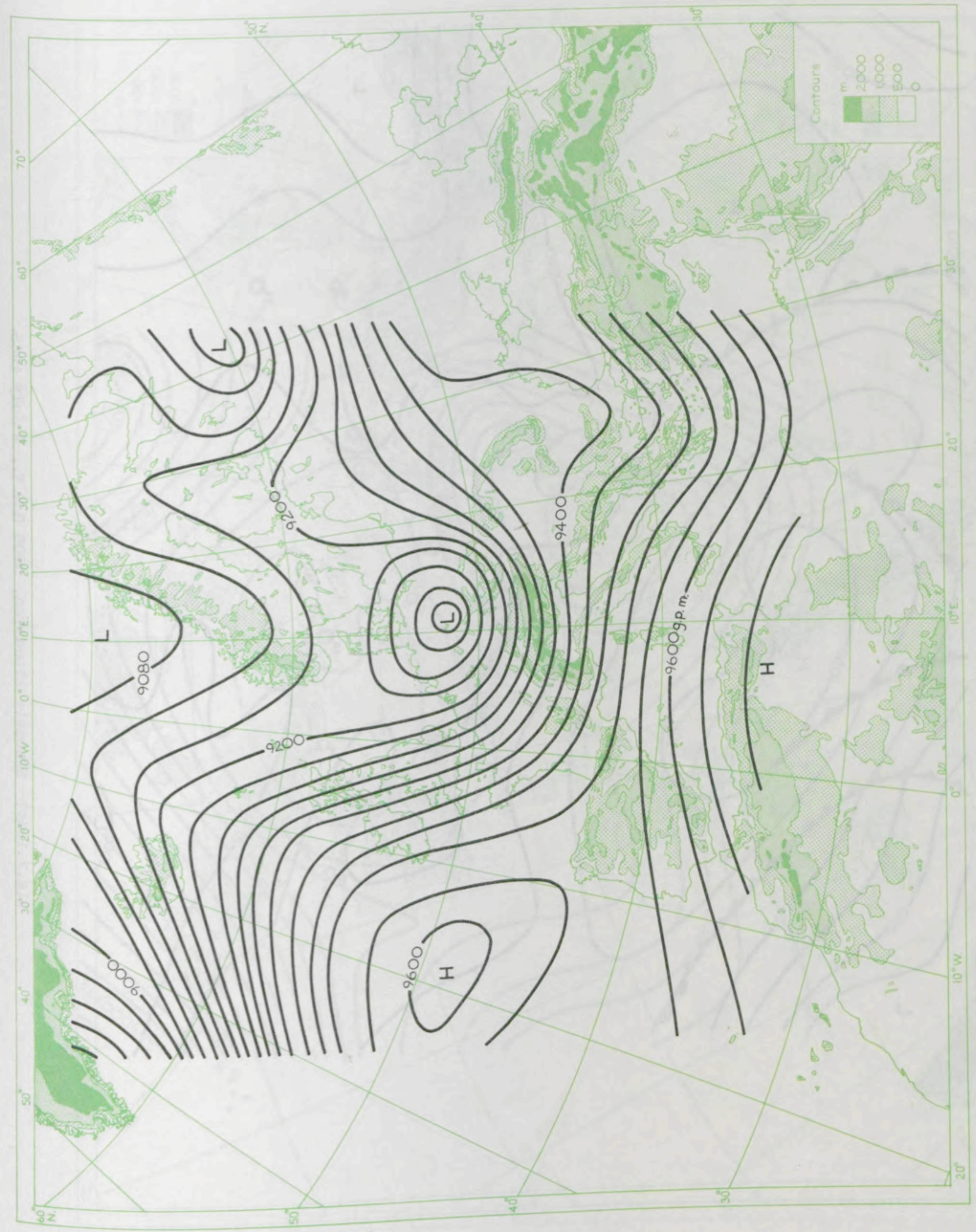


Fig.2.15(*b*) Contours of the 300-millibar surface, 0300 G.M.T., 5 July 1955.

Fig.2.15(c) Synoptic situation, 0000 G.M.T., 9 July 1955.

Fig.2.15(d) Contours of the 300-millibar surface, 0300 G.M.T., 9 July 1955.

Fig.2.15(e) Thickness of the 1000–500–millibar layer, 0300 G.M.T., 9 July 1955.

Fig.2.16(a) Synoptic situation, 1800 G.M.T., 5 July 1948.

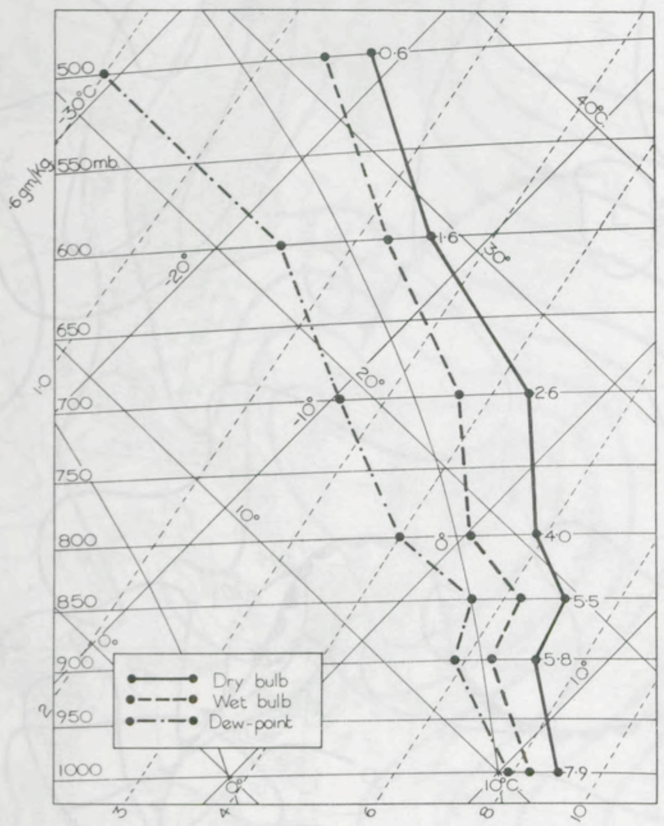


Fig.2.16(*b*) Tephigram for Salon, near Marseilles (43°40'N., 5°05'E.), 0230 G.M.T. 6 July 1948.
The figures beside plotted points are humidity mixing ratios in grams per kilogram.

Fig.2.17(*a*) Synoptic situation, 0000 G.M.T., 17 August 1949.

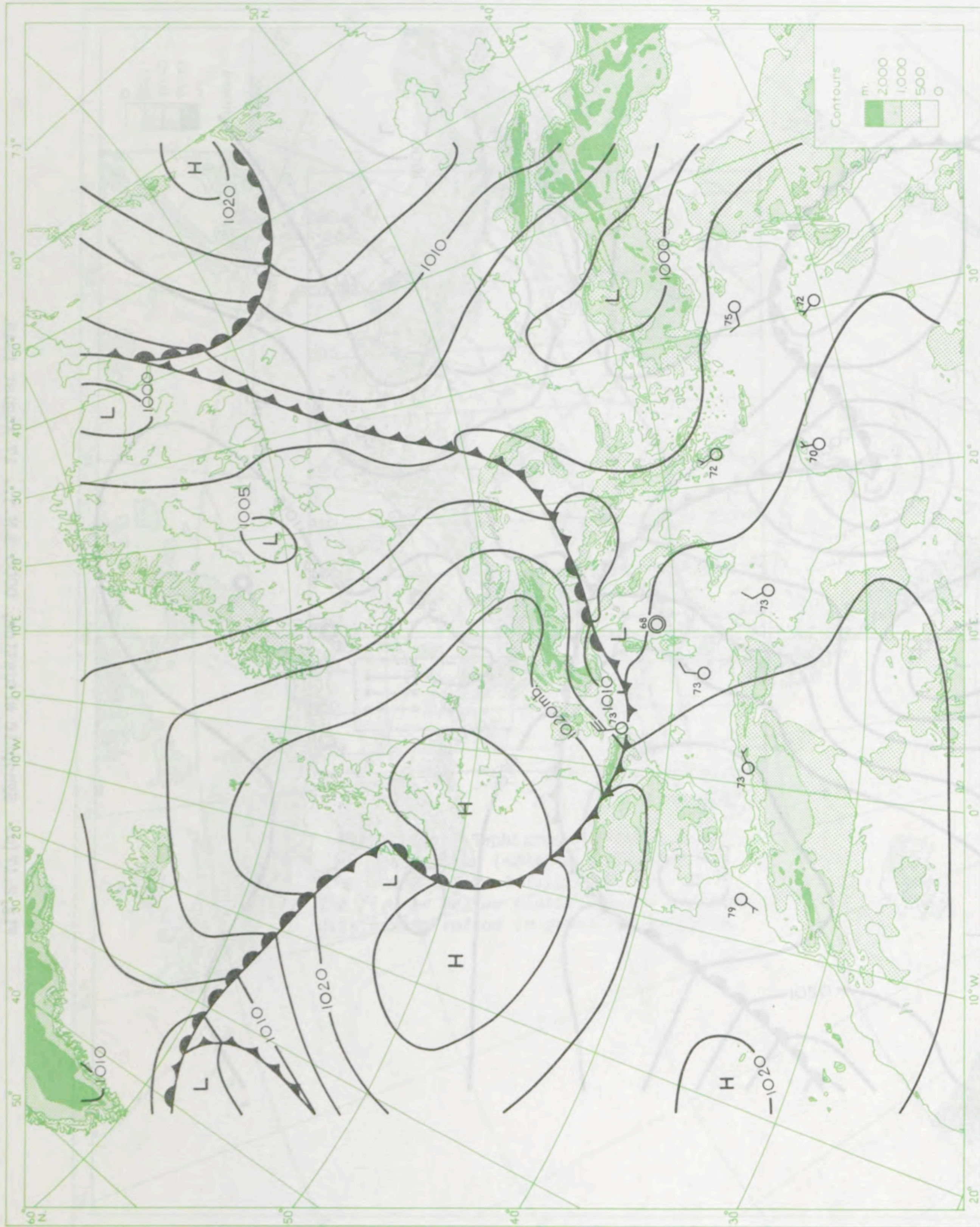


Fig.2.17(b) Synoptic situation, 0000 G.M.T., 18 August 1949

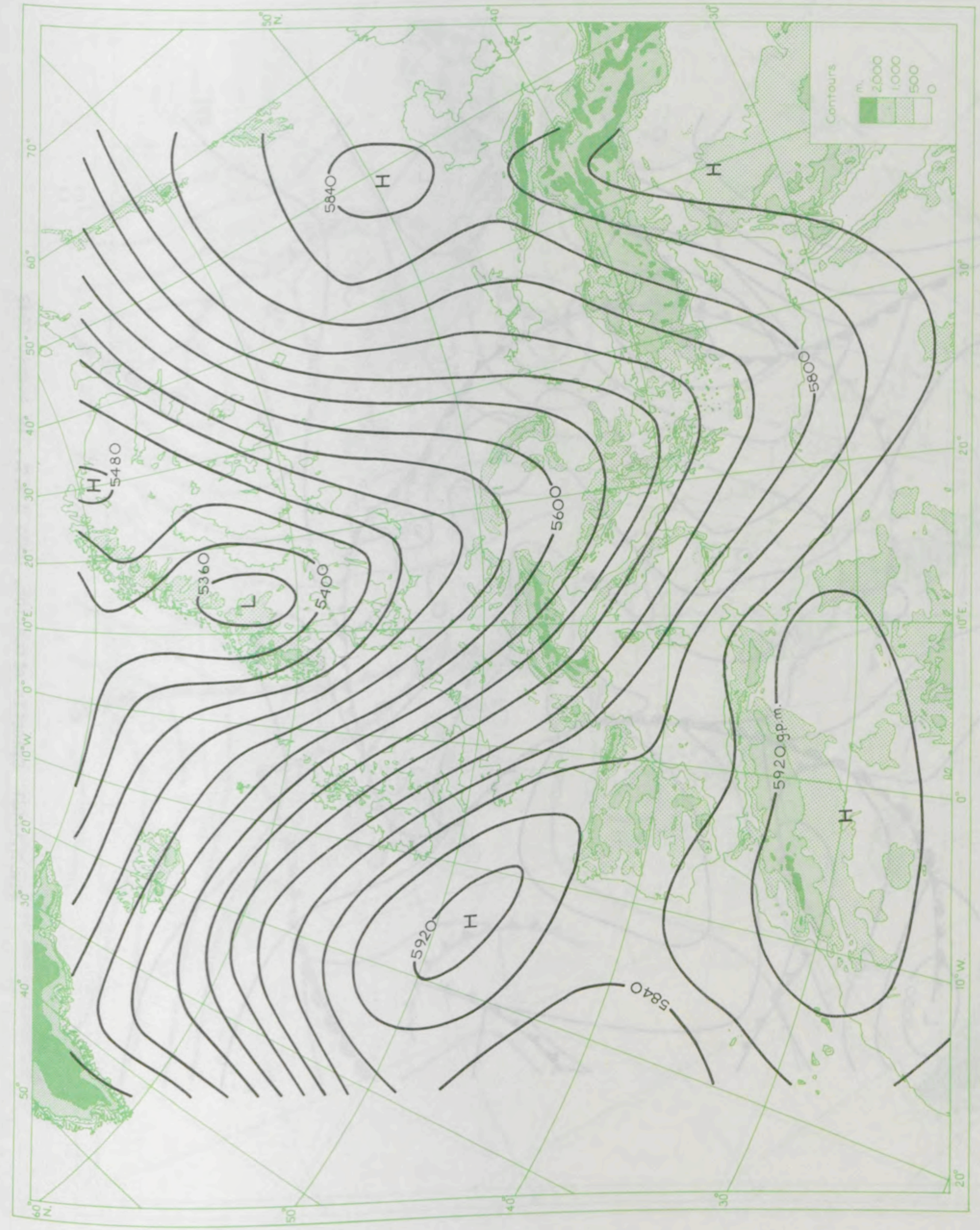


Fig.2.17(c) Contours of the 500-millibar surface, 0300 G.M.T., 18 August 1949

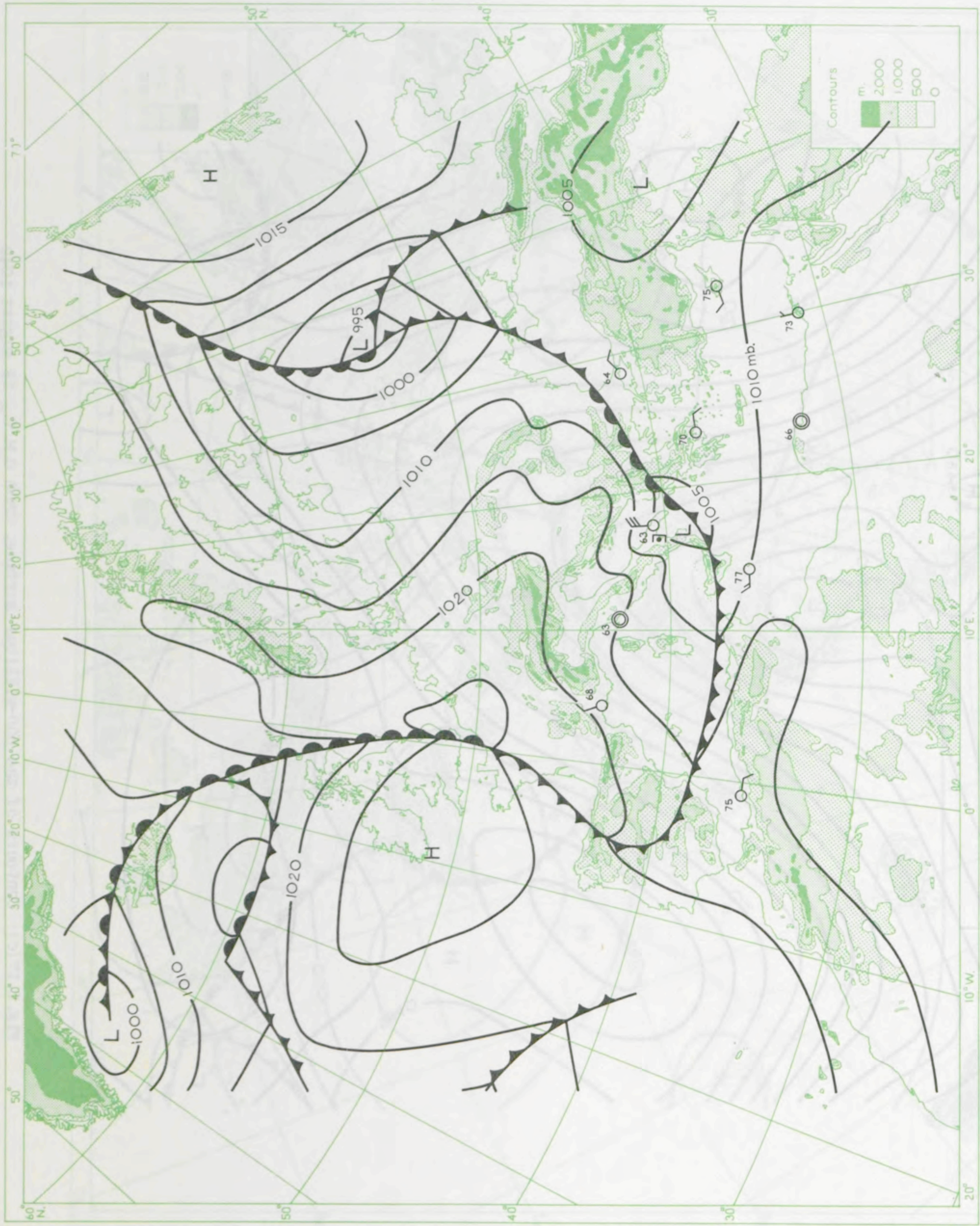


Fig.2.17(d) Synoptic situation, 0000 G.M.T., 19 August 1949

Fig.2.17(e) Synoptic situation, 0000 G.M.T., 20 August 1949

Fig.2.17(f) Contours of the 500-millibar surface, 0300 G.M.T., 20 August 1948

Fig.2.18(a) Synoptic situation, 1800 G.M.T., 14 July 1947.

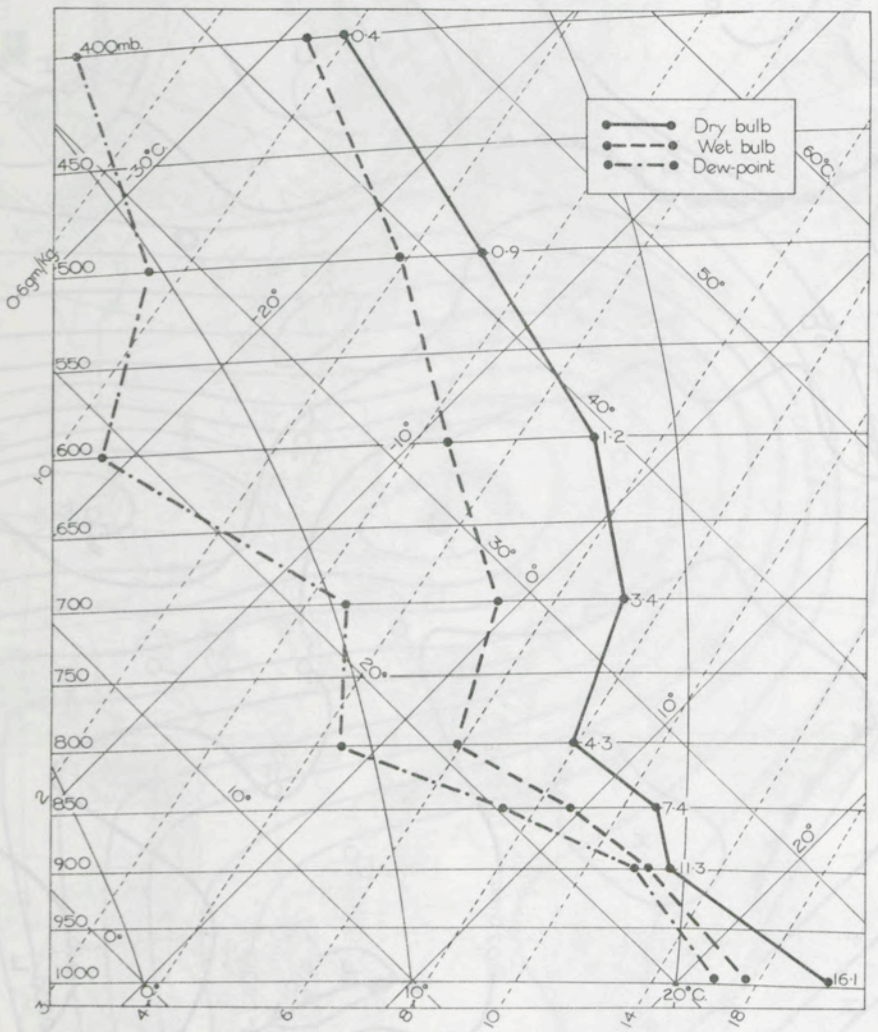


Fig.2.18(*b*) Tephigram for Malta, 1700 G.M.T., 14 July 1947.
The figures beside plotted points are humidity mixing ratios in grams per kilogram.

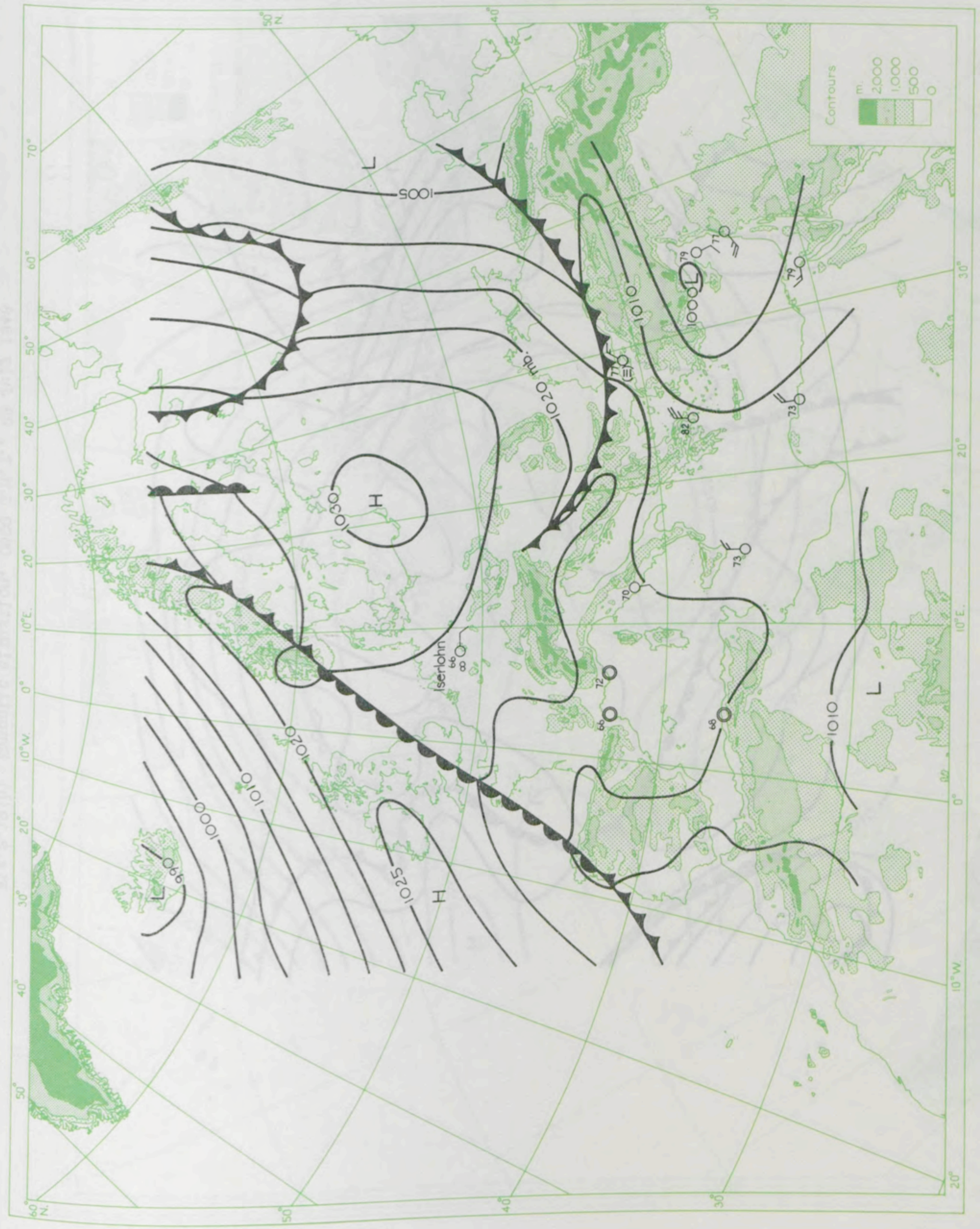


Fig.2.19(*a*) Synoptic situation, 0600 G.M.T., 27 July 1948.

Fig.2.19(b) Synoptic situation, 0600 G.M.T., 28 July 1948

Fig.2.19(c) Contours of the 500-millibar surface, 0300 G.M.T., 28 July 1948

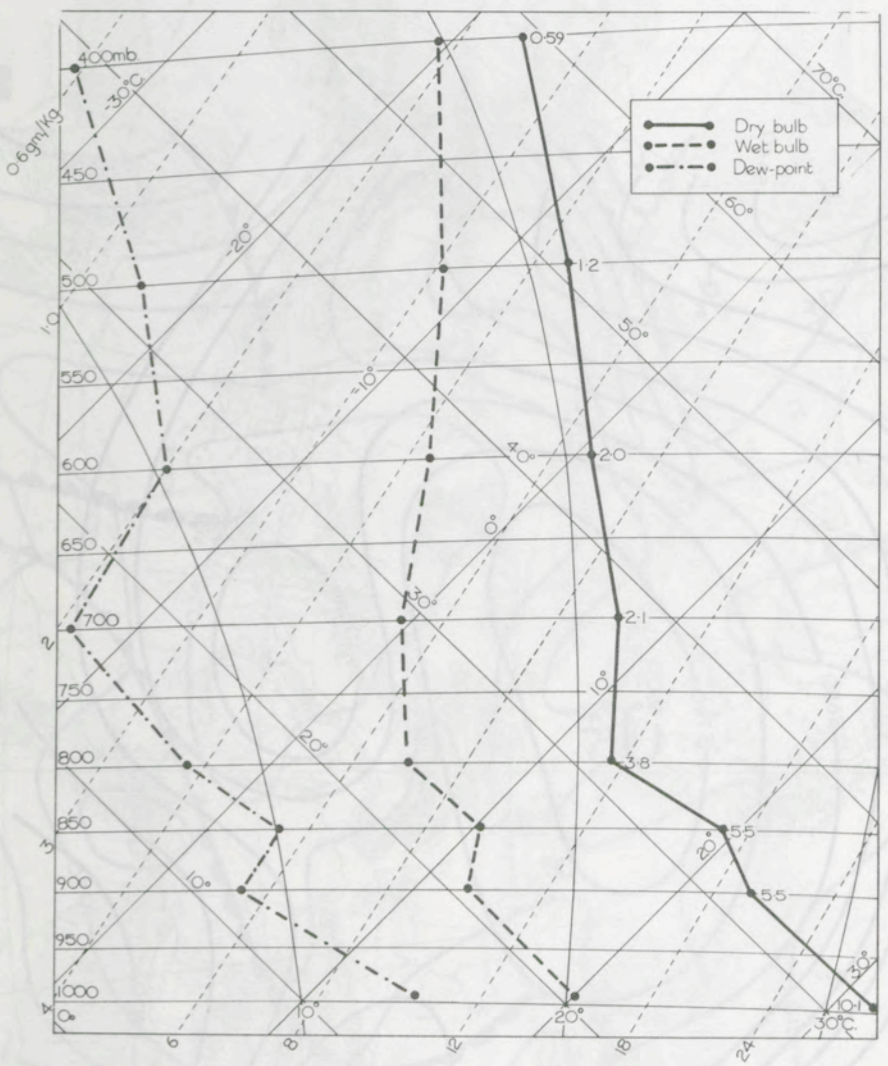


Fig.2.19(*d*) Tephigram for Iserlohn, 1500 G.M.T., 27 July 1948.
The figures beside plotted points are humidity mixing ratios in grams per kilogram.

Fig.2.20(*a*) Synoptic situation, 0000 G.M.T., 19 July 1949.
The broken line shows a line of convergence.

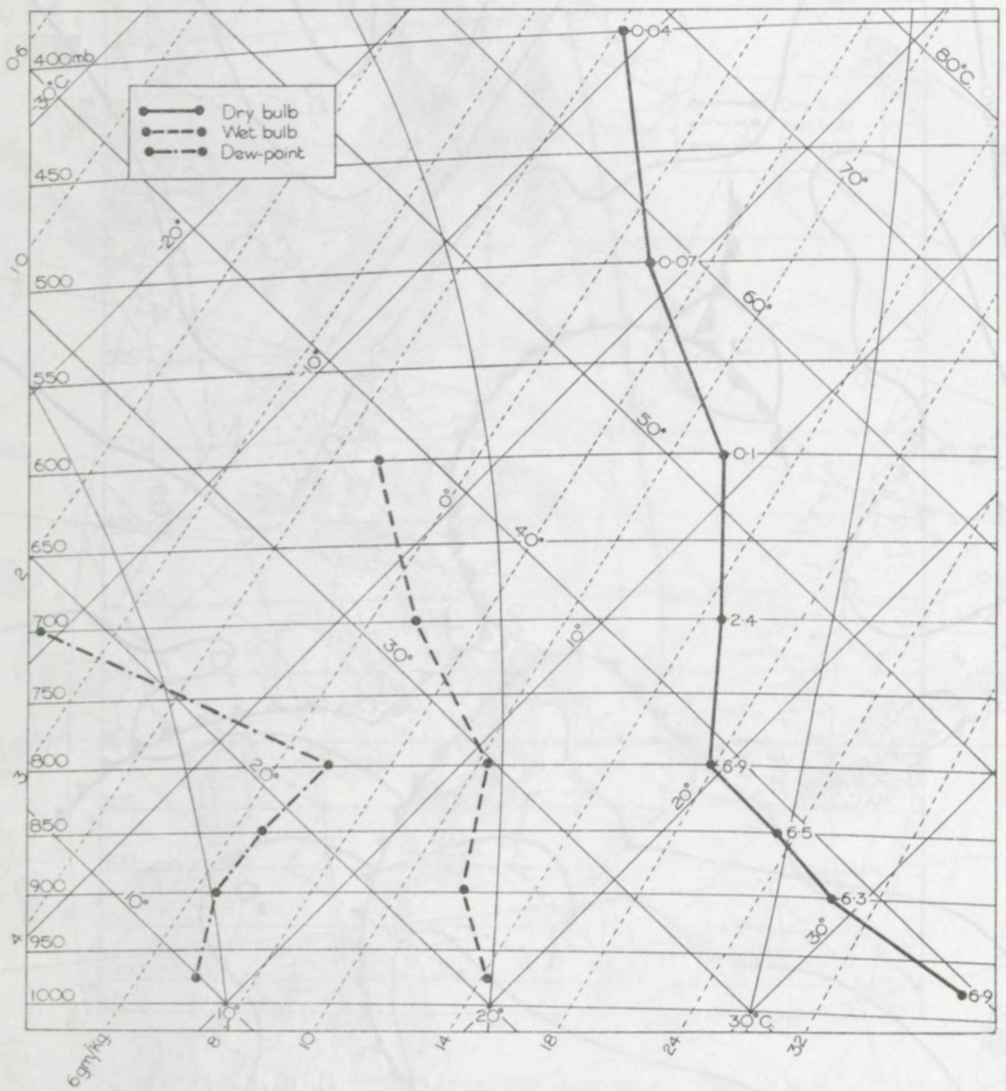


Fig.2.20(*b*) Tephigram for Nicosia, 1500 G.M.T., 19 July 1949.
The figures beside plotted points are humidity mixing ratios in grams per kilogram.

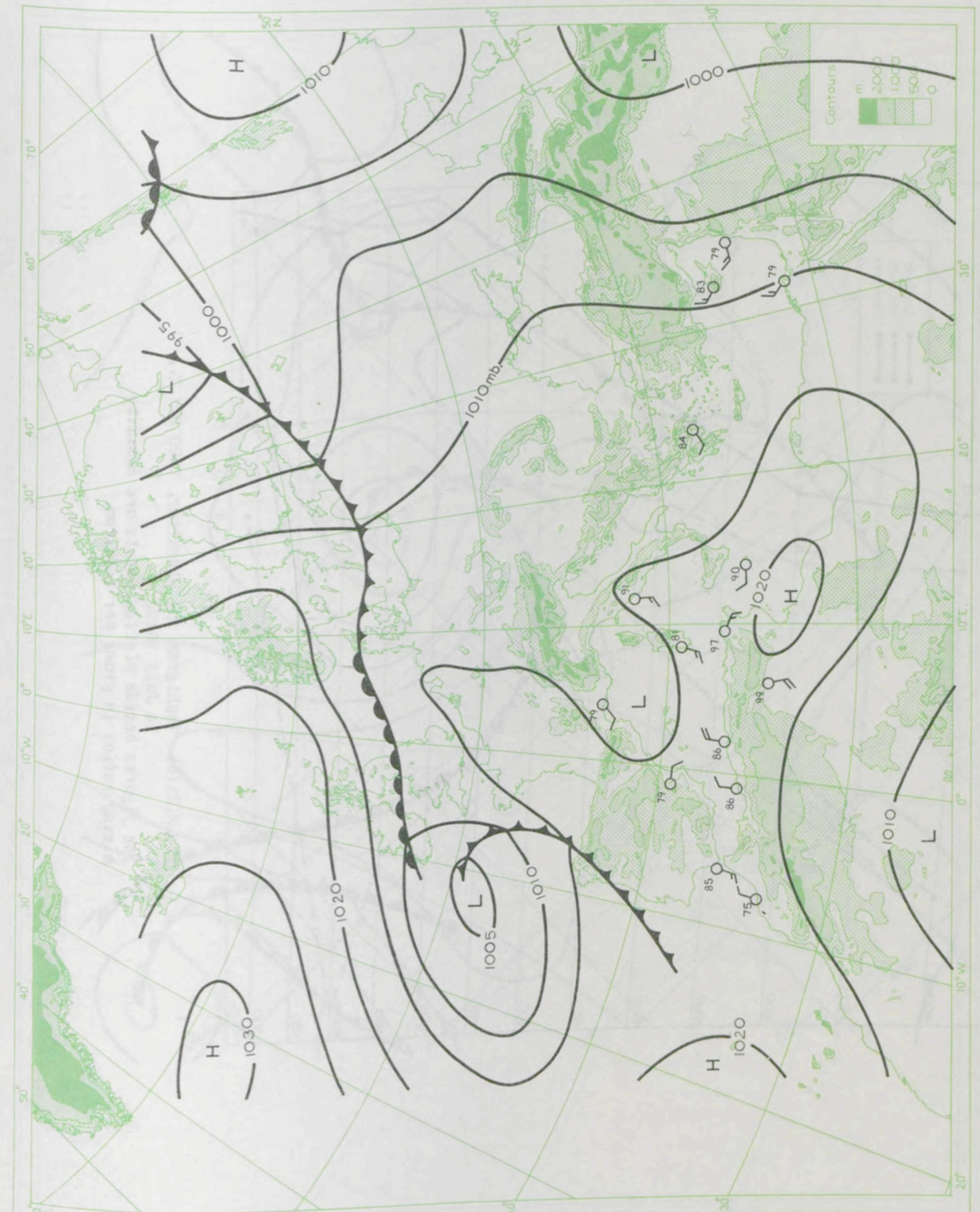


Fig.2.21(*a*) Synoptic situation, 1200 G.M.T., 14 July 1949.

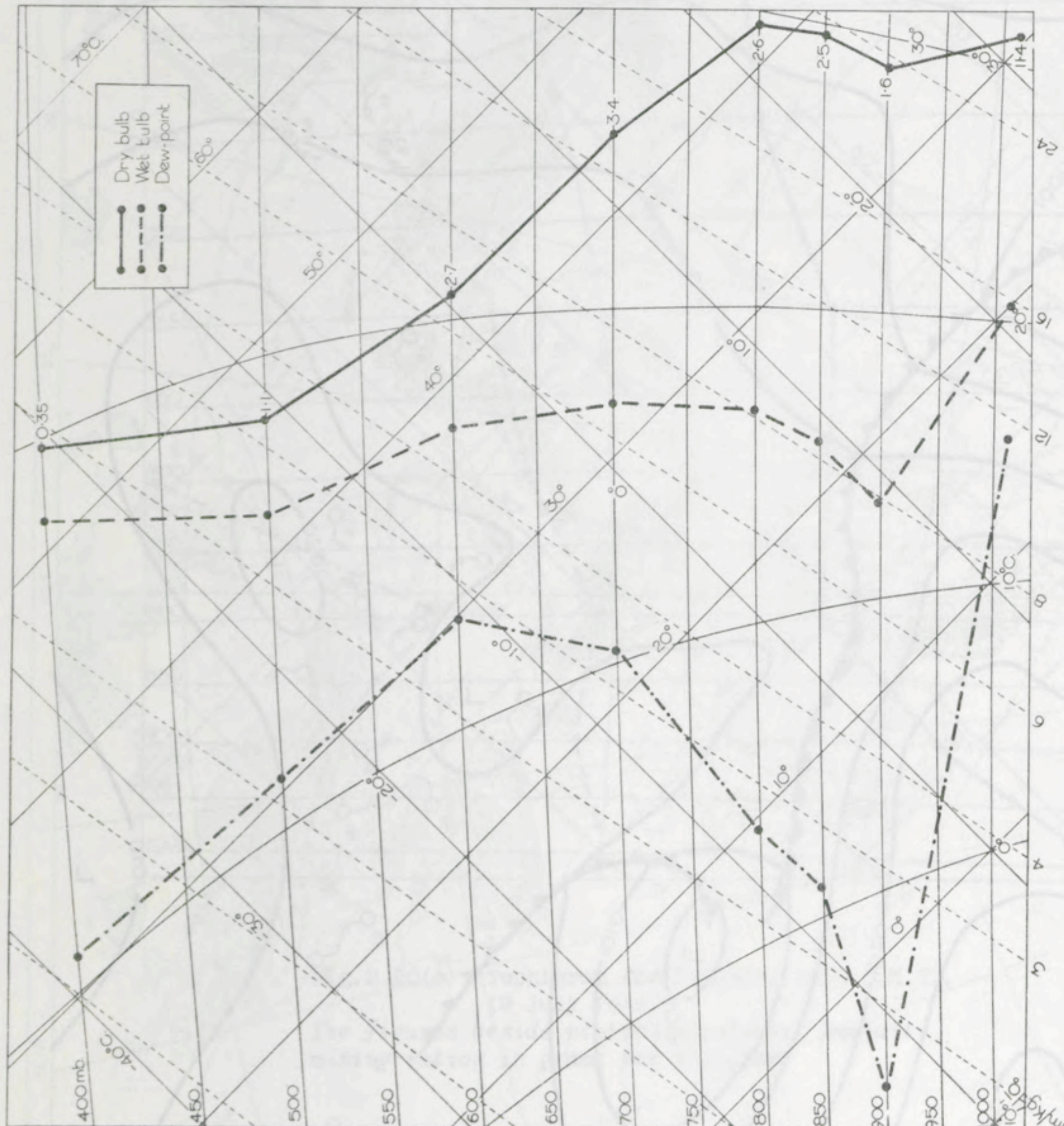


Fig.2.21(b) Tephigram for Gibraltar, 1500 G.M.T., 14 July 1949.
The figures beside plotted points are humidity mixing ratios in grams per kilogram.

Fig.2.22(a) Synoptic situation, 0000 G.M.T., 13 September 1953.

Fig.2.22(b) Synoptic situation, 0000 G.M.T., 19 September 1953.

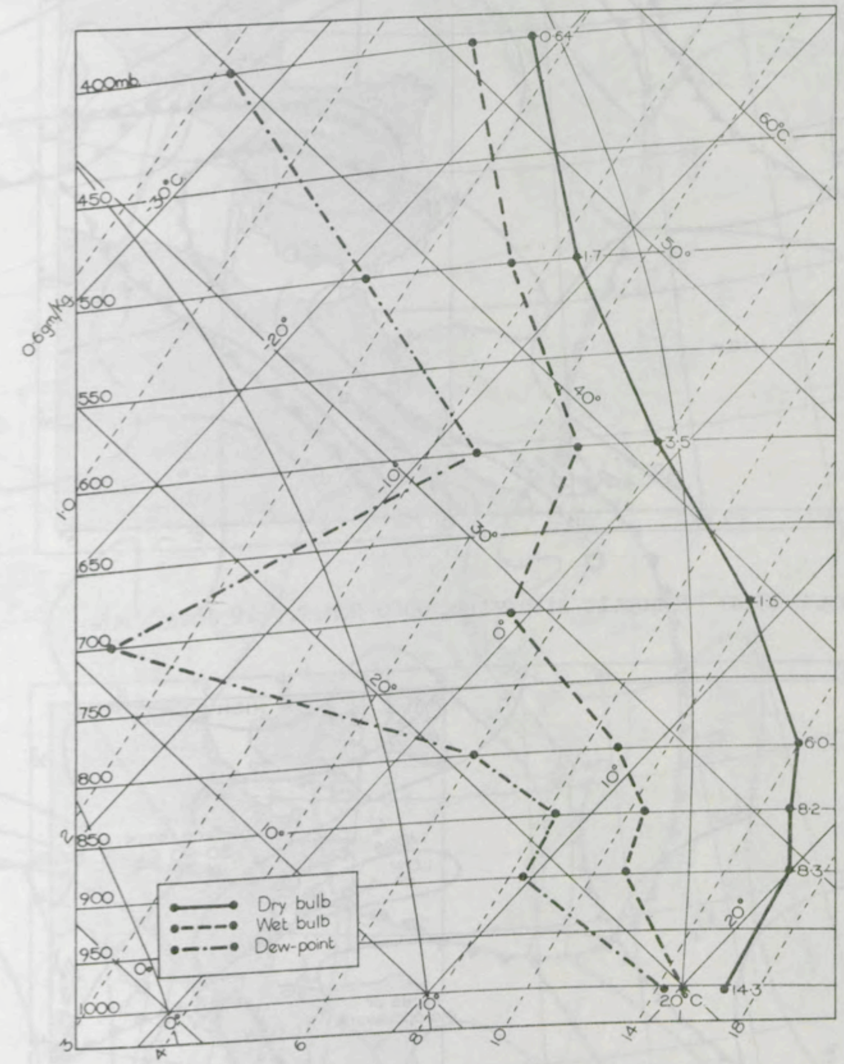


Fig.2.22(c) Tephigram for Malta, 0200 G.M.T., 19 September 1953.
The figures beside plotted points are humidity mixing ratios in grams per kilogram.

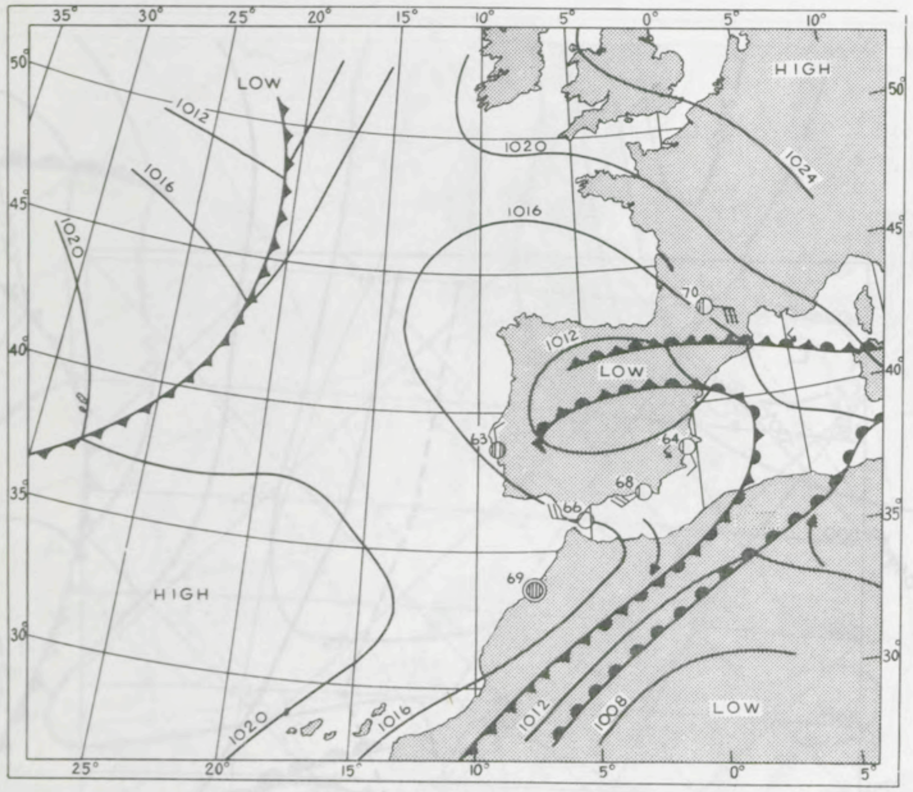


Fig. 2.23(a) Synoptic situation, 0000 G.M.T., 19 June 1945.

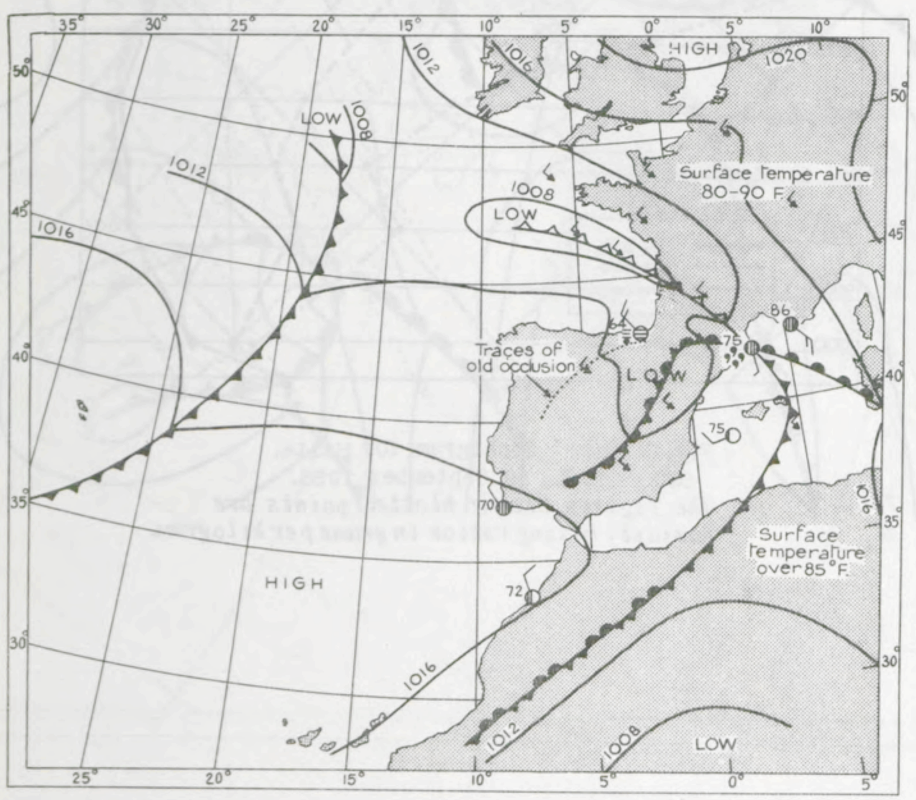


Fig. 2.23(b) Synoptic situation, 1200 G.M.T., 19 June 1945.

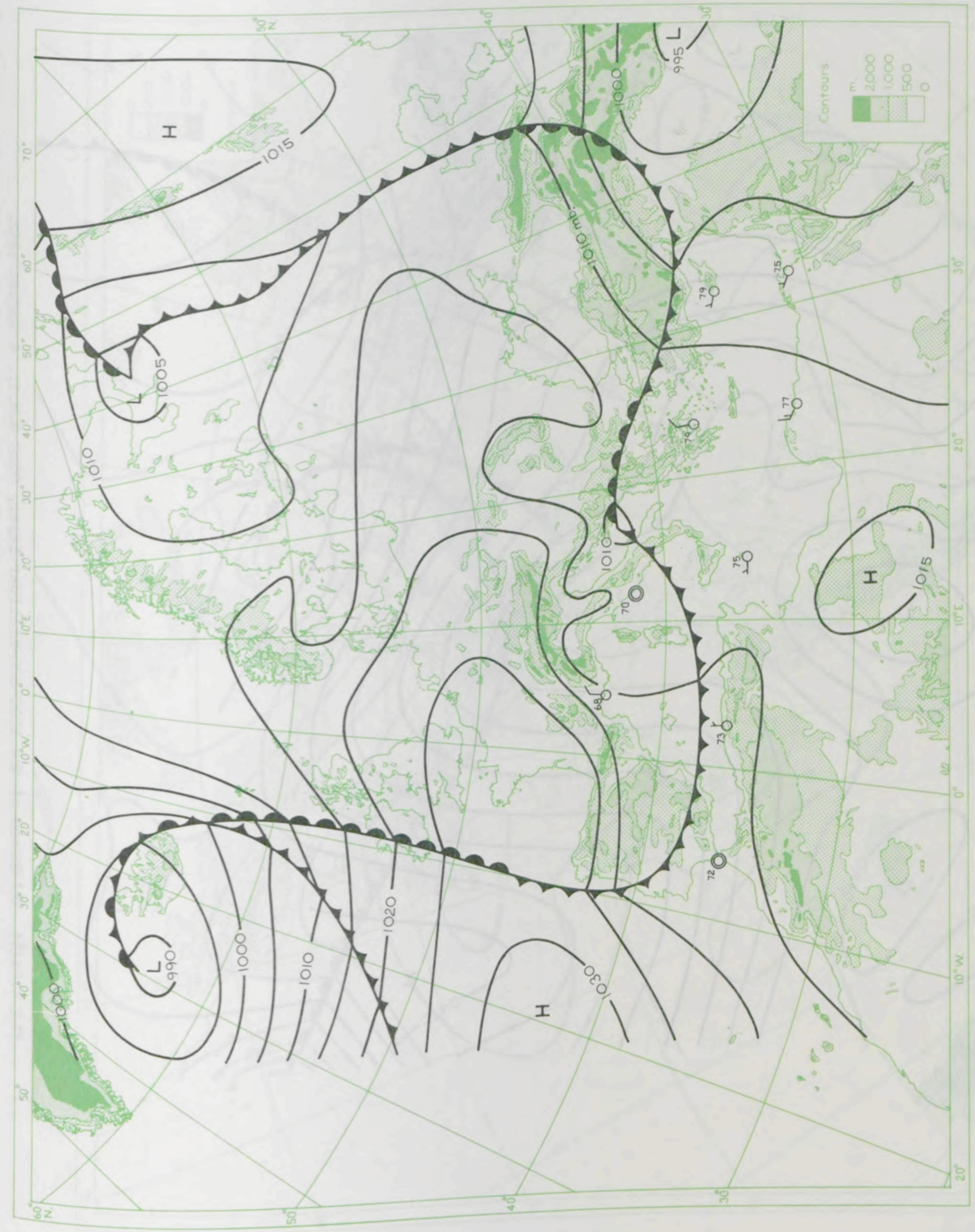


Fig. 2.24(a) Synoptic situation, 0000 G.M.T., 4 August 1953

Fig.2.24(b) Thickness of the 1000-500-millibar layer, 0300 G.M.T., 4 August 1953.

Fig.2.24(c) Synoptic situation, 0000 G.M.T., 6 August 1953.

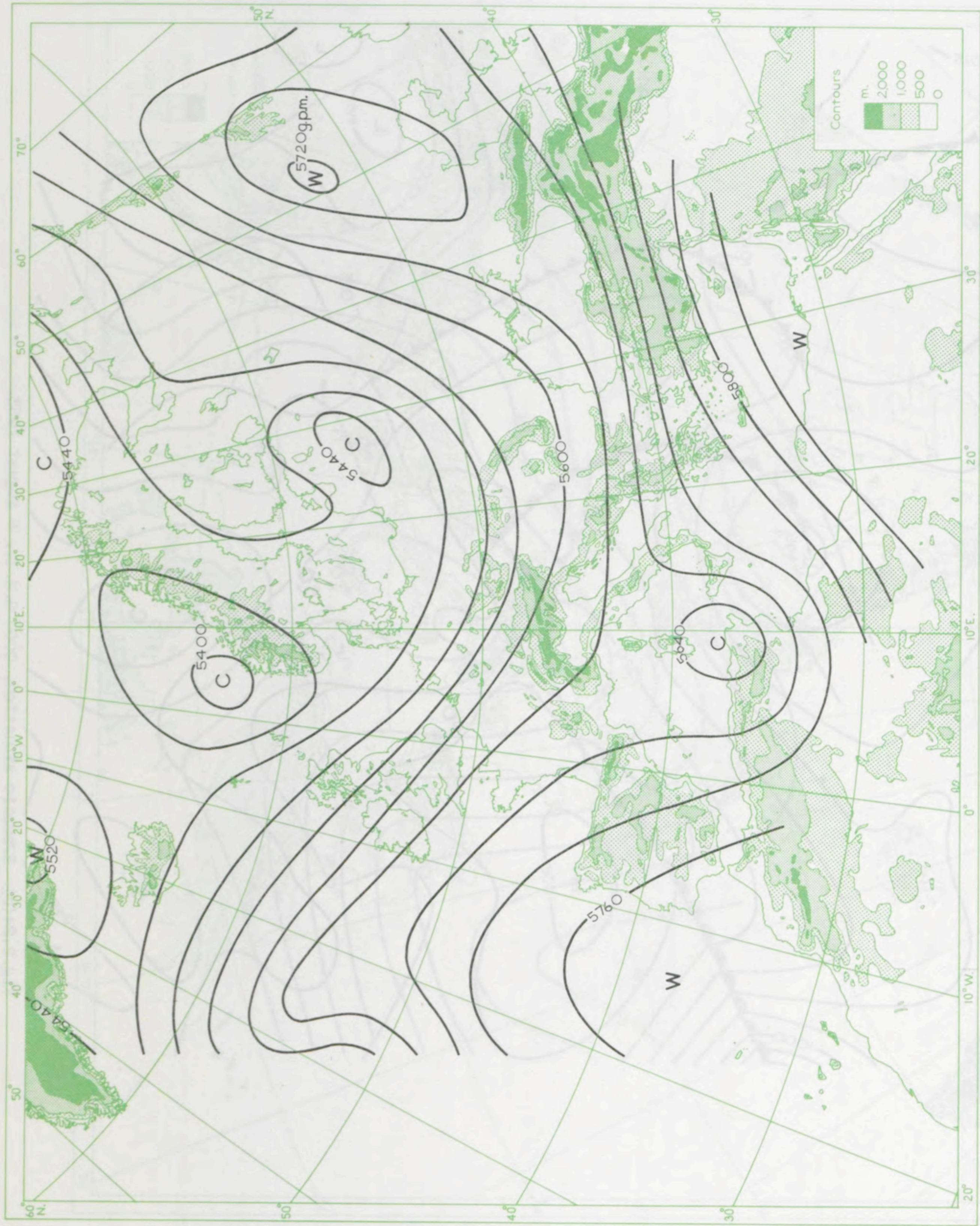


Fig.2.24(d) Thickness of the 1000–500-millibar layer, 0300 G.M.T., 6 August 1953.

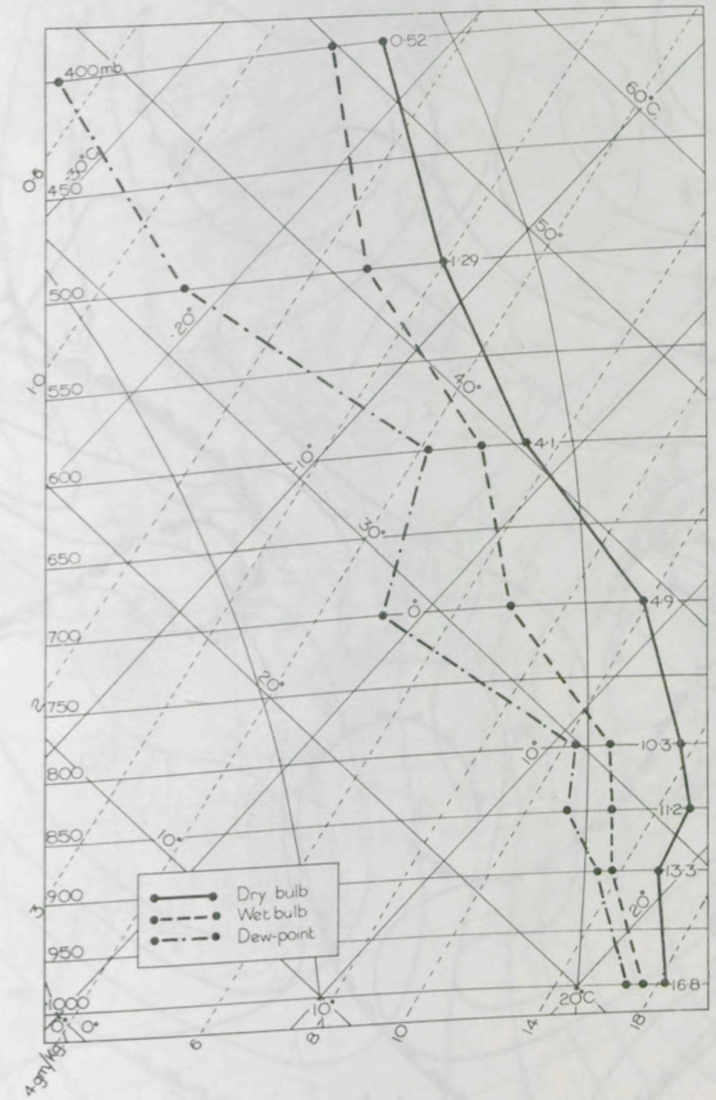


Fig.2.24(e) Tephigram for Malta, 0200 G.M.T., 6 August 1953.

The figures beside plotted points are humidity mixing ratios in grams per kilogram.

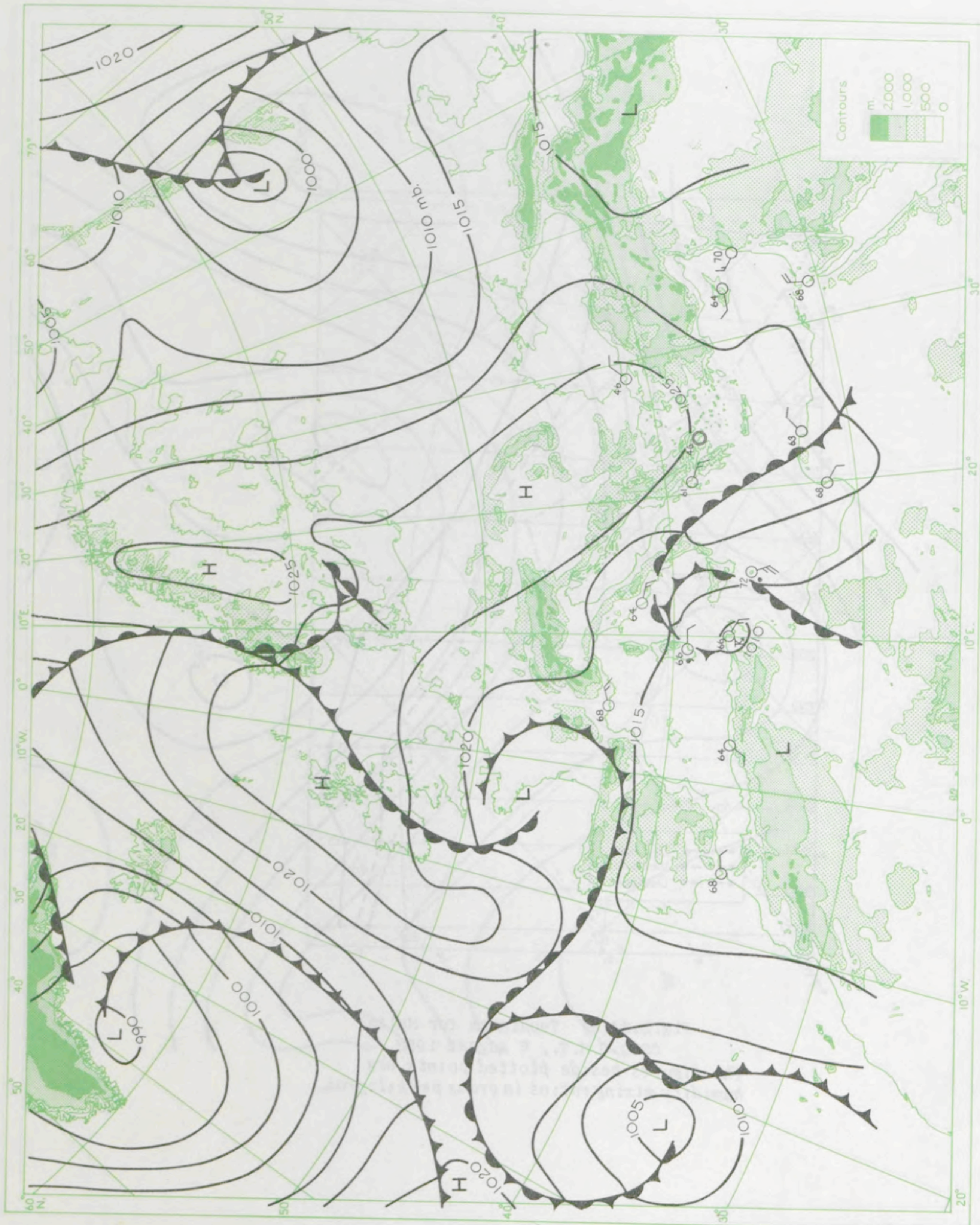


Fig. 2.25 Synoptic situation, 1800 G.M.T., 23 October 1950.

Fig. 2.26 Synoptic situation, 1800 G.M.T., 24 January 1947.

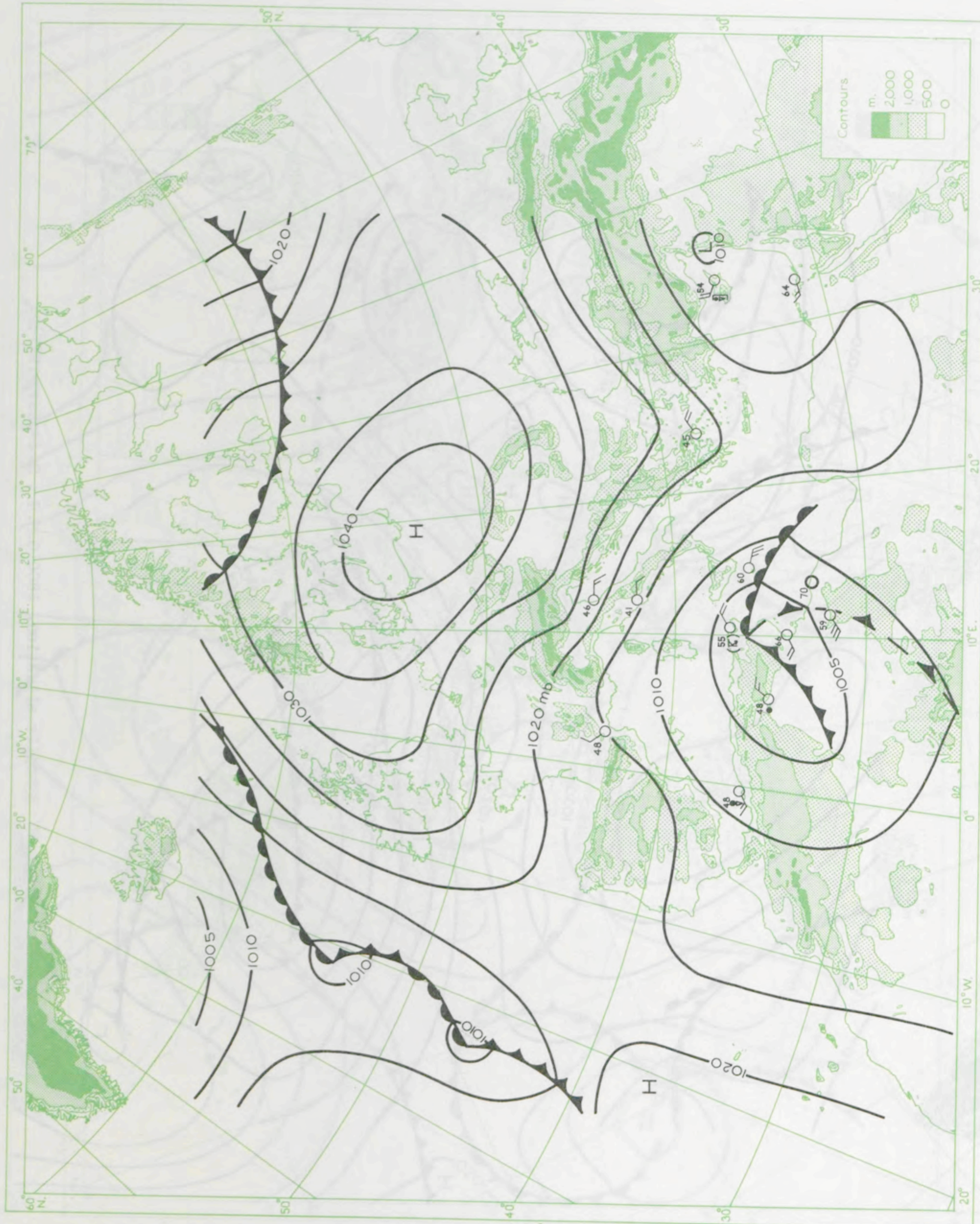


Fig.2.27 Synoptic situation 1200 G.M.T., 23 January 1950.

Fig.2.28 Synoptic situation, 1800 G.M.T., 17 February 1947.
The double arrow shows the track of the depression.

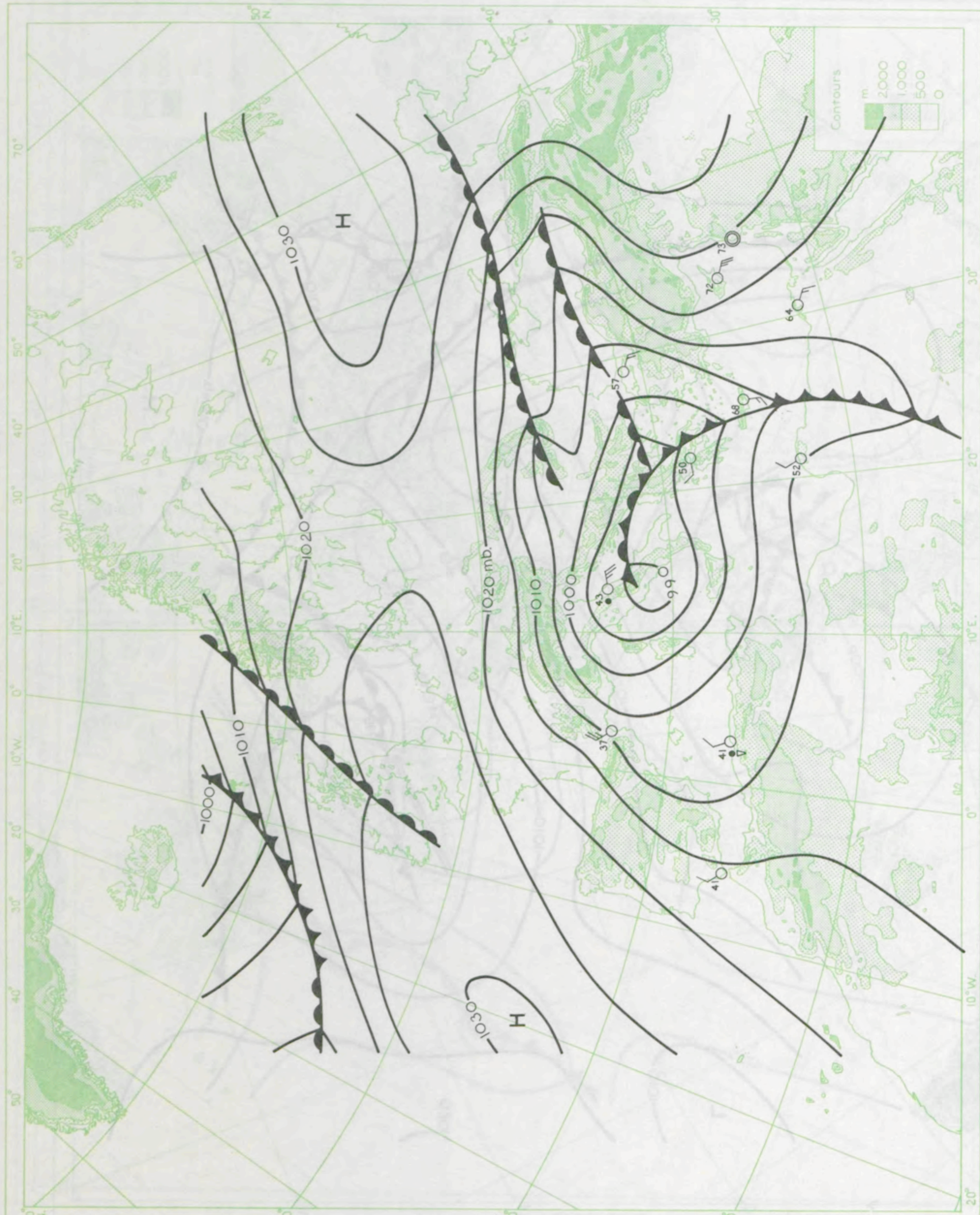


Fig.2.29 Synoptic situation, 0000 G.M.T., 16 February 1953.

Fig.2.30(a) Synoptic situation, 0000 G.M.T., 1 February 1953.

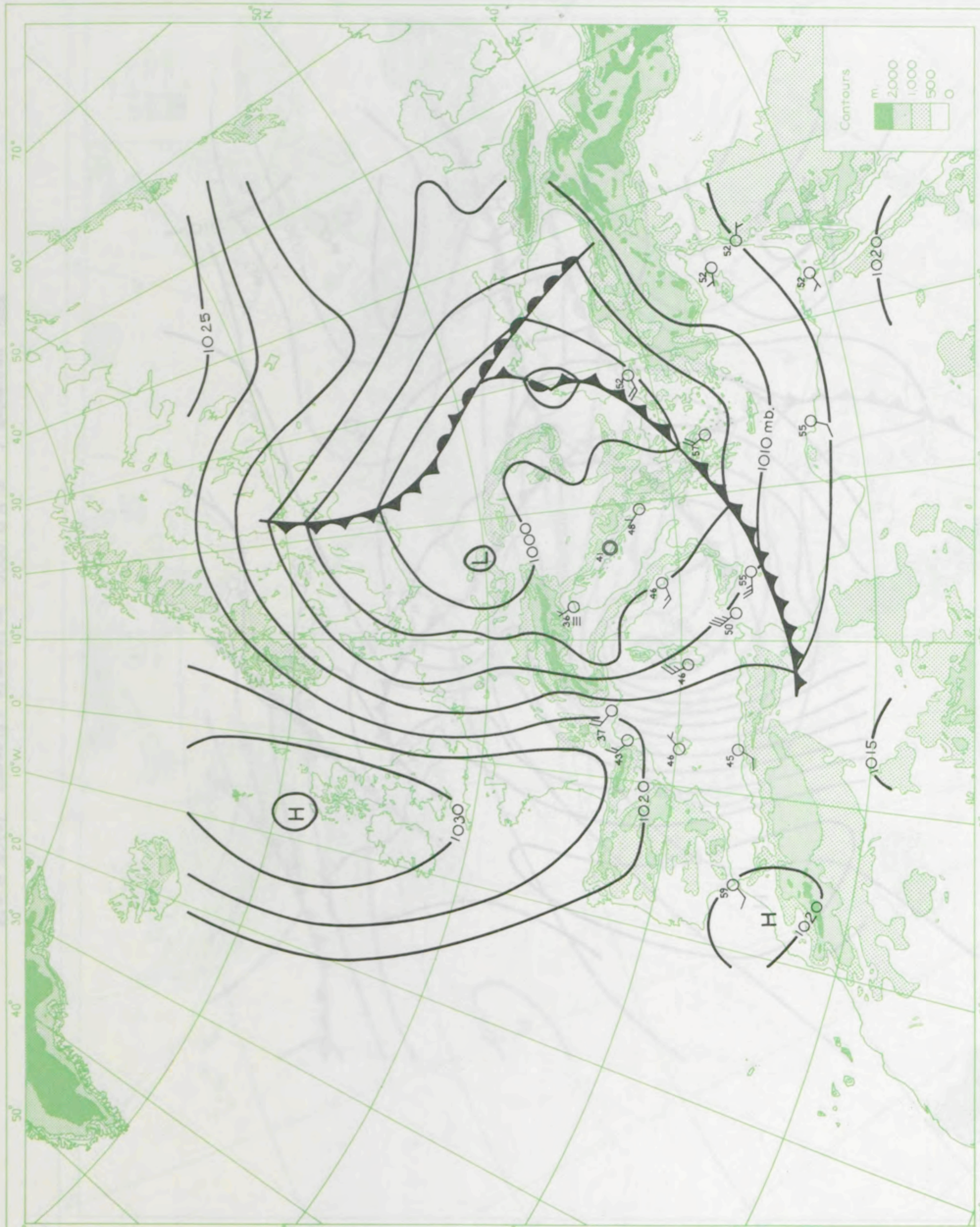


Fig.2.30(b) Synoptic situation, 0000 G.M.T., 2 February 1953.

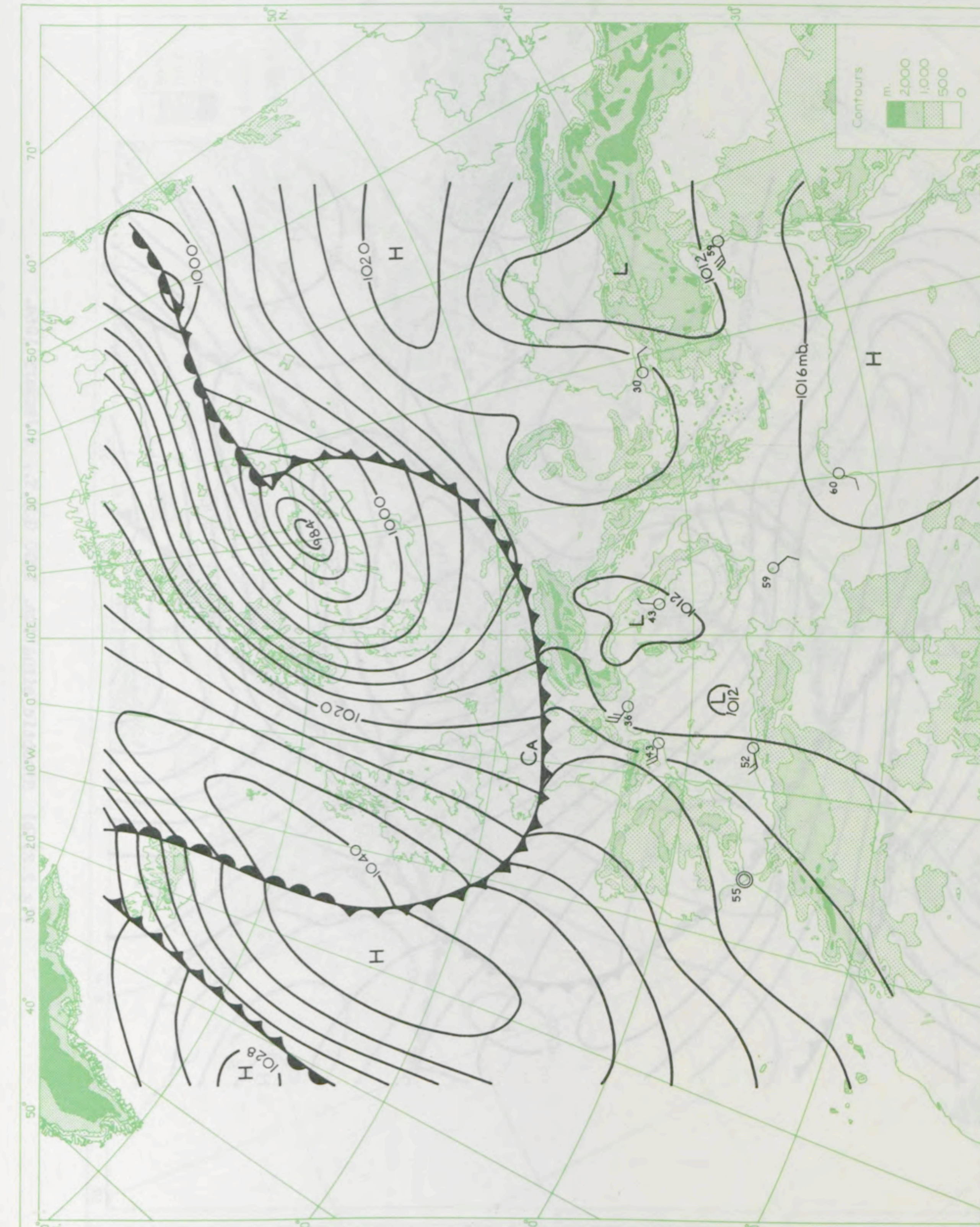


Fig.2.31(a) Synoptic situation, 1200 G.M.T., 3 January 1954.

Fig.2.31(b) Synoptic situation, 1200 G.M.T., 4 January 1954.

Fig.2.31(c) Synoptic situation, 0000 G.M.T., 6 January 1954.

Fig. 2.31(*d*) Contours of the 225-millibar surface, 0300 G.M.T., 6 January 1954.

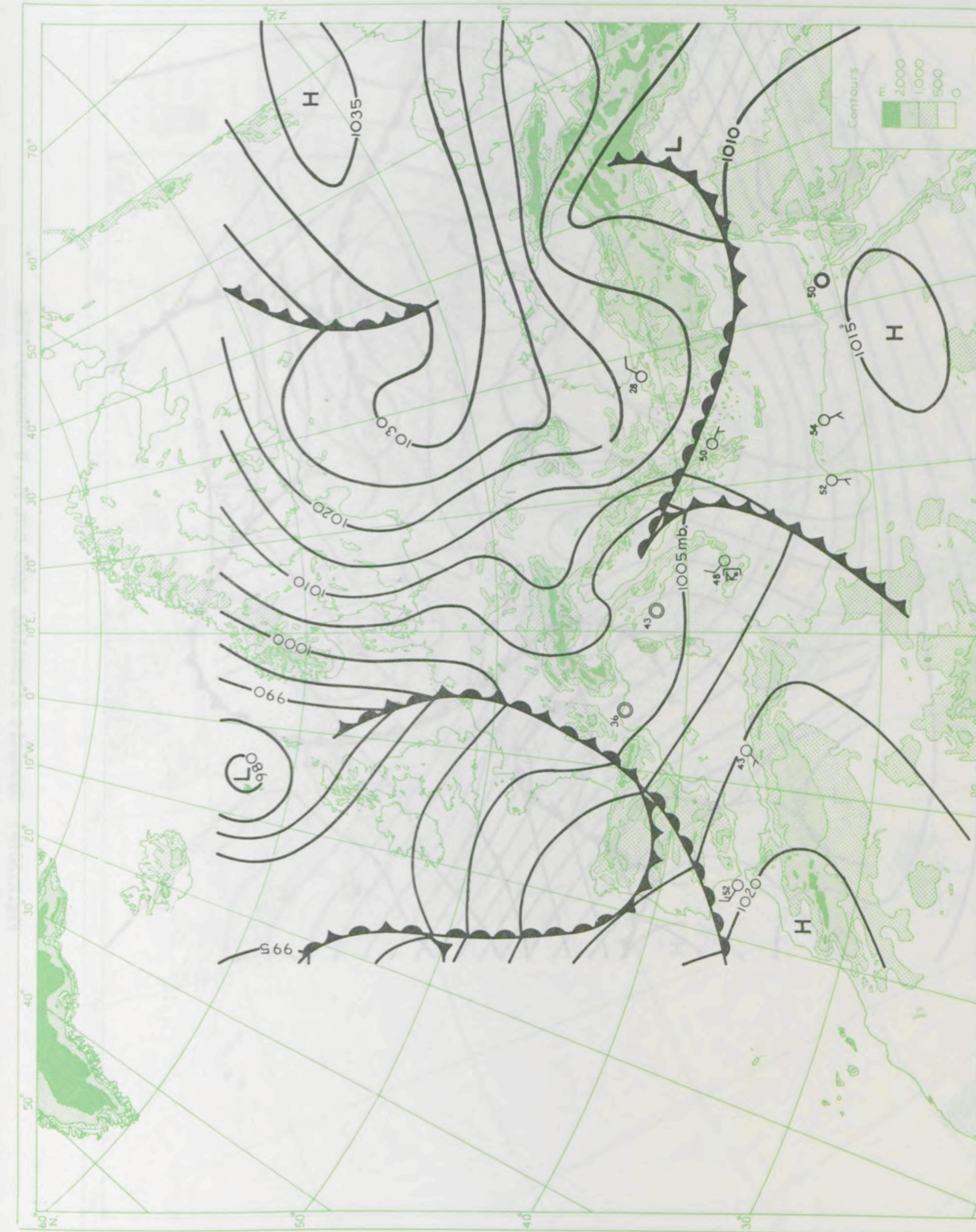


Fig. 2.32(*a*) Synoptic situation, 0000 G.M.T., 8 February 1954.

Fig.2.32(b) Synoptic situation, 0000 G.M.T., 9 February 1954.

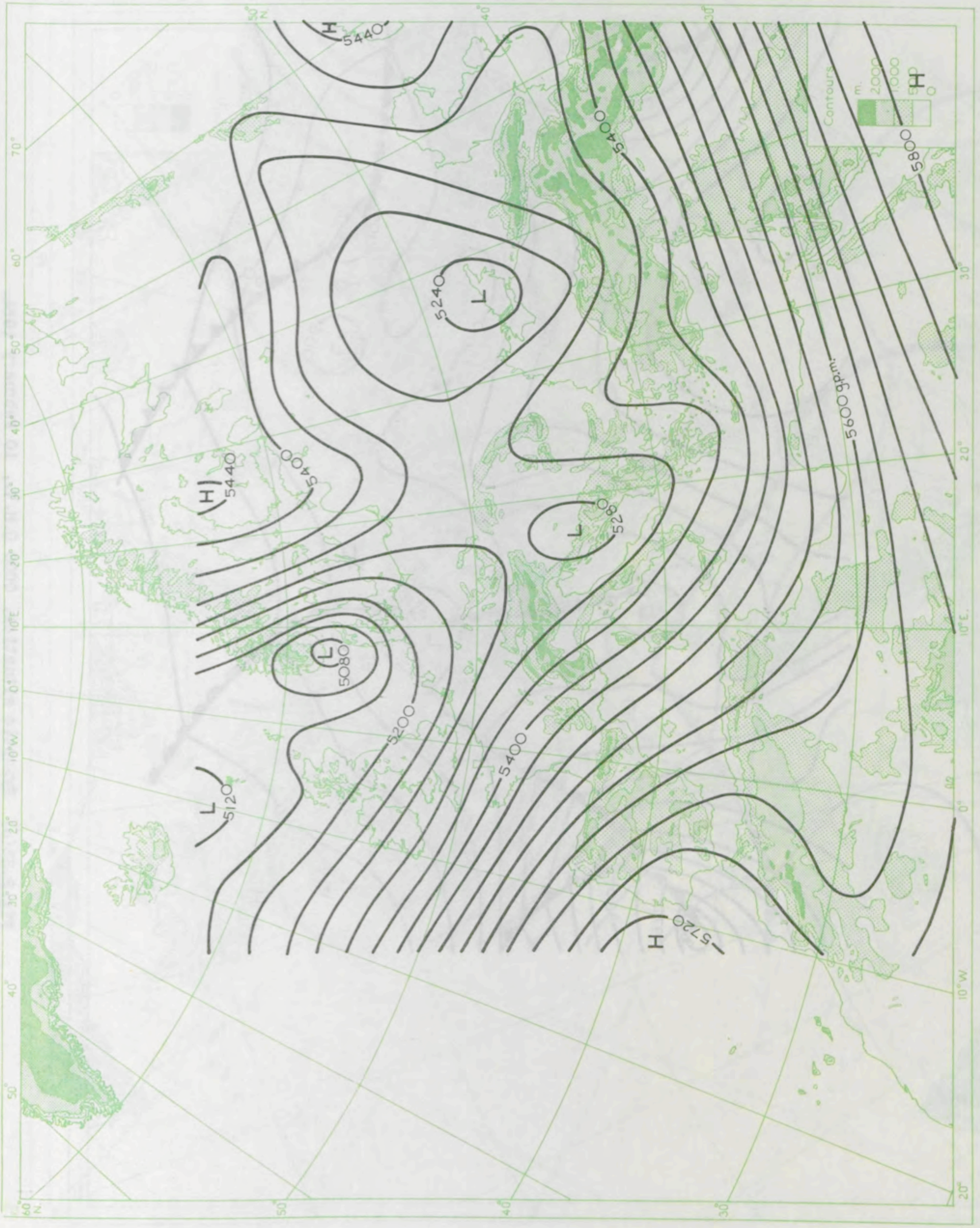


Fig.2.32(c) Contours of the 500-millibar surface, 0300 G.M.T., 9 February 1954.

Fig.2.32(d) Synoptic situation, 0000 G.M.T., 10 February 1954.

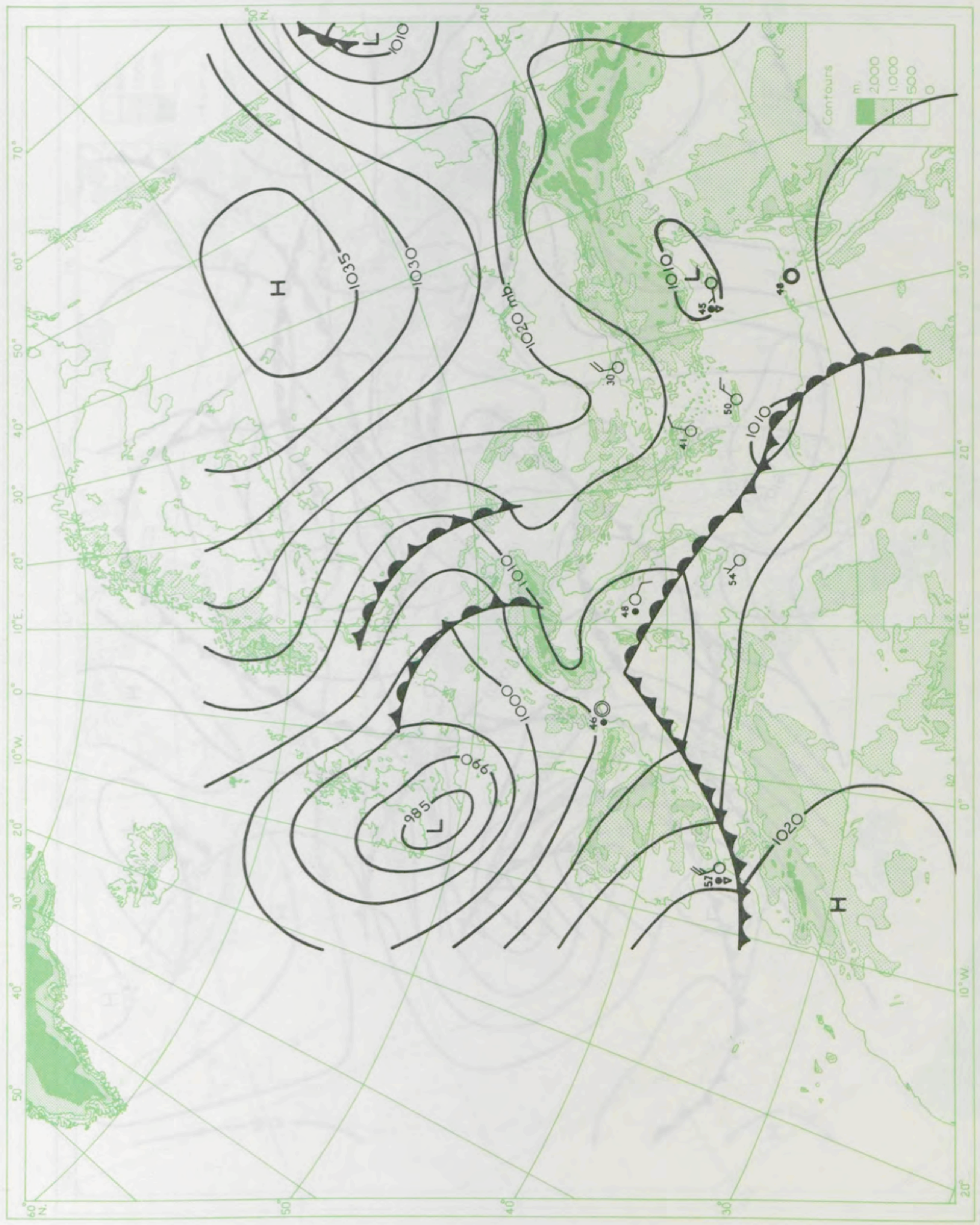


Fig.2.32(e) Synoptic situation, 0000 G.M.T., 11 February 1954.

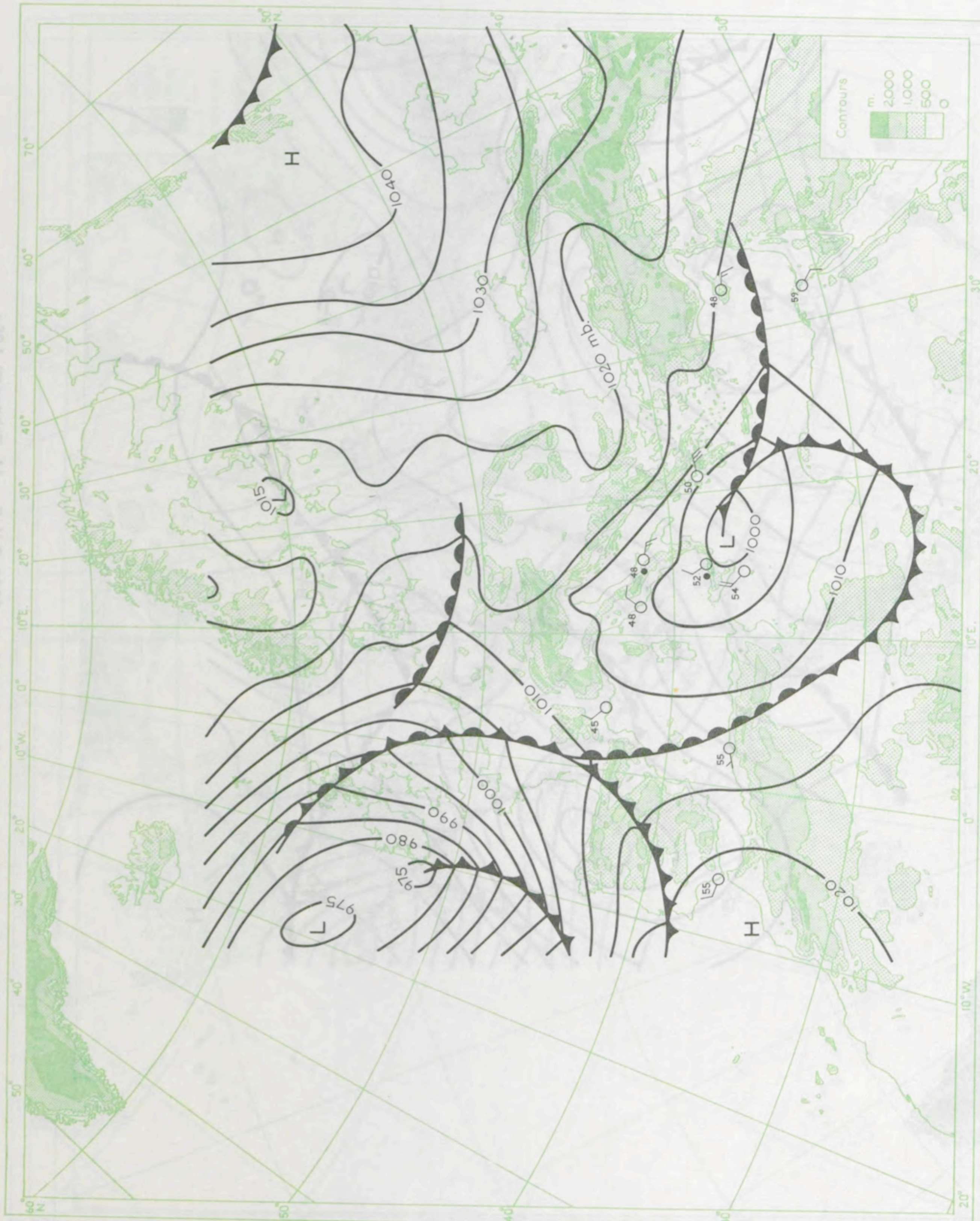


Fig.2.32(*f*) Synoptic situation, 0000 G.M.T., 13 February 1954.

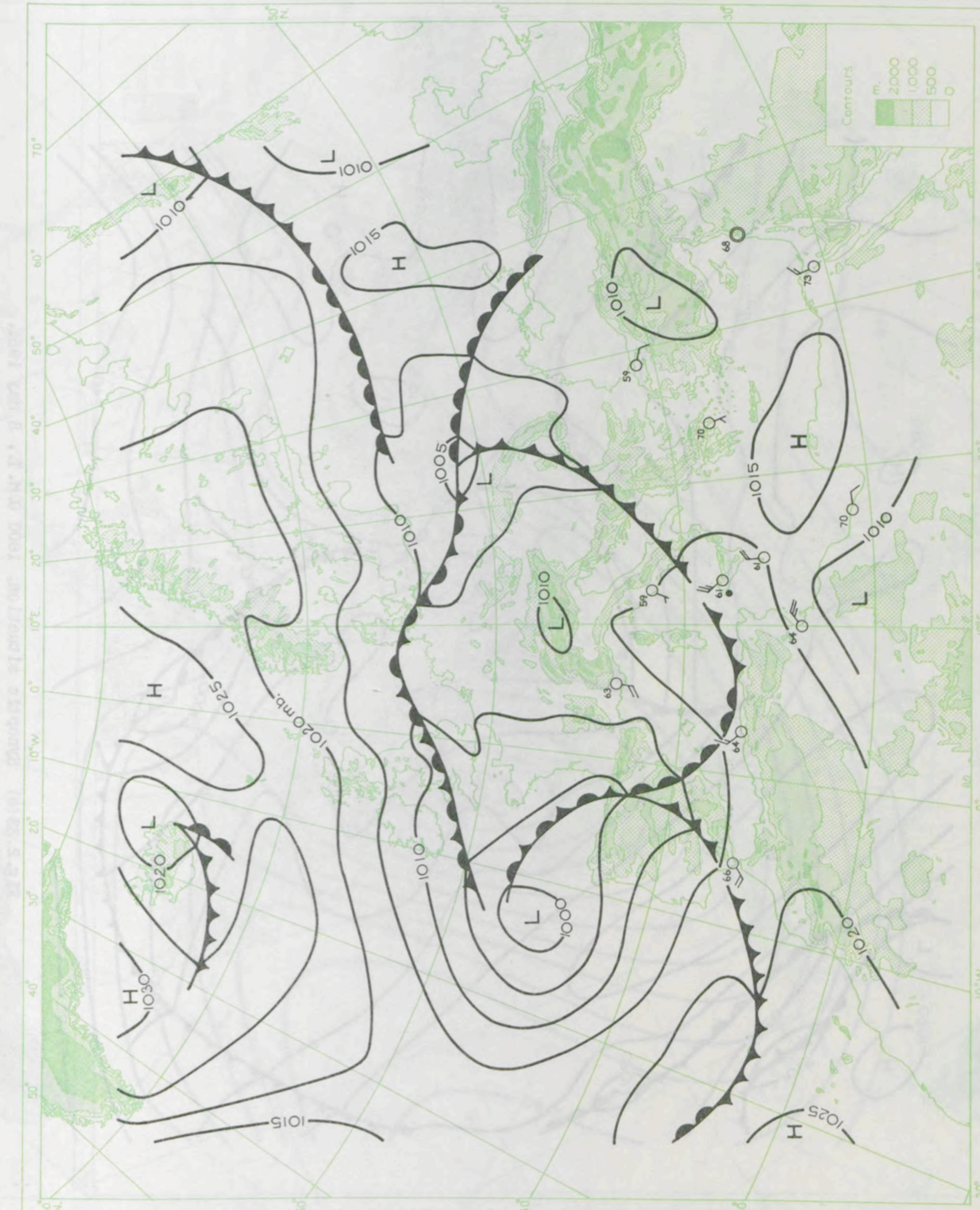


Fig.2.33(*a*) Synoptic situation, 1800 G.M.T., 5 May 1951.

Fig.2.33(b) Synoptic situation, 1800 G.M.T., 8 May 1951.

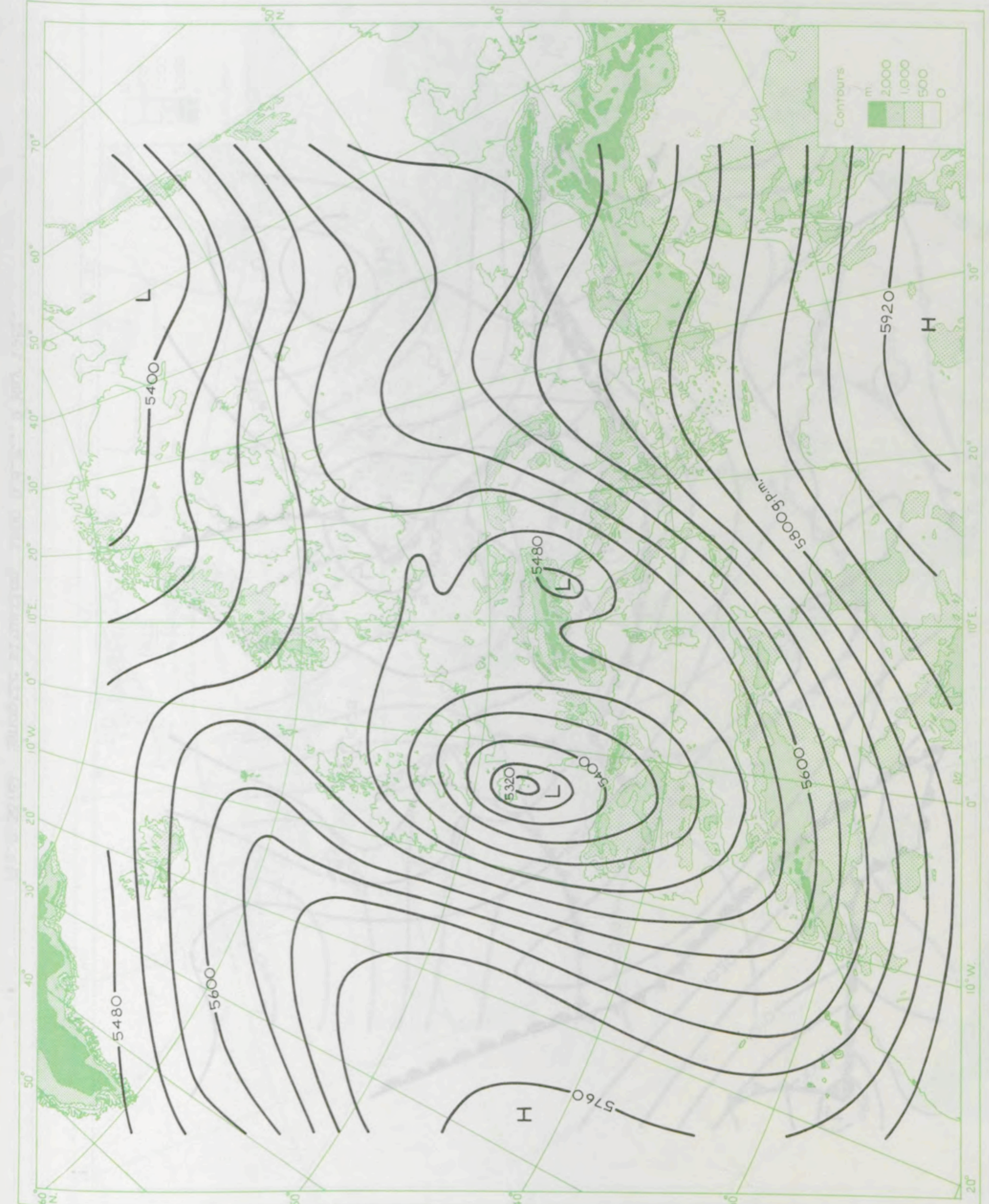


Fig.2.33(c) Contours of the 500-millibar surface, 0300 G.M.T., 9 May 1951.

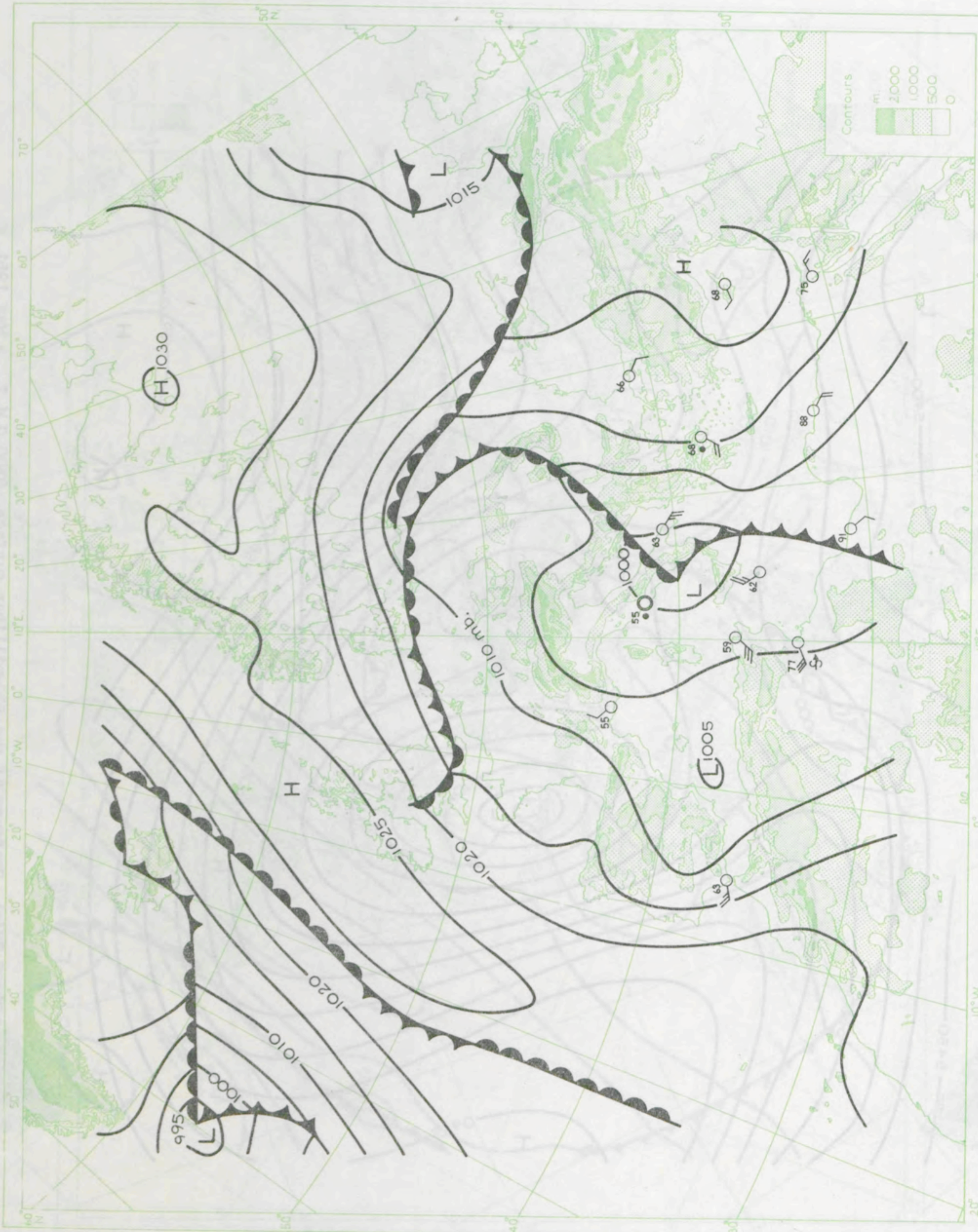


Fig.2.33(d) Synoptic situation, 1800 G.M.T., 9 May 1951.

Fig.2.34(a) Synoptic situation, 1200 G.M.T., 30 October 1950.

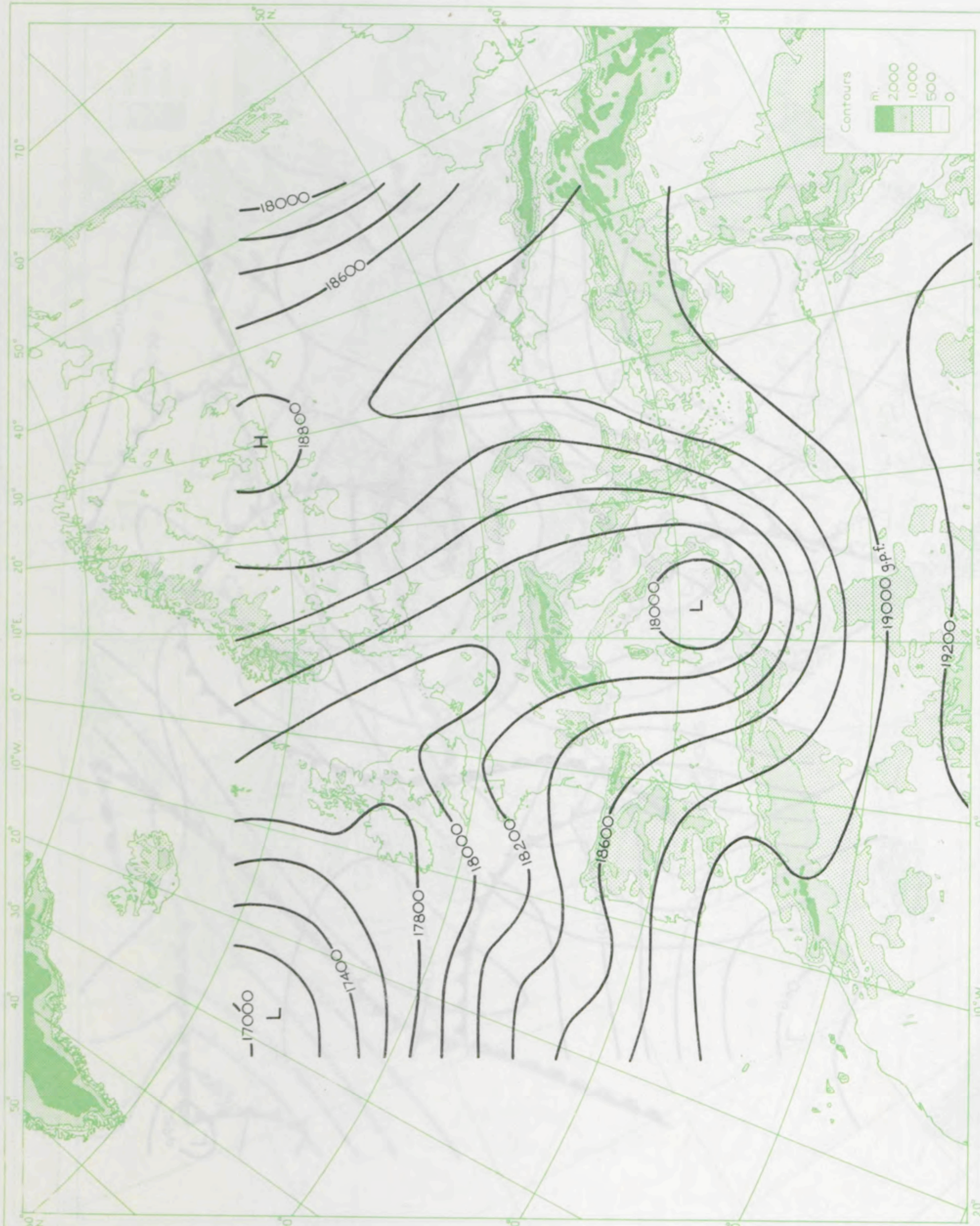


Fig.2.34(b) Contours of the 500-millibar surface, 1500 G.M.T., 30 October 1950.

Fig.2.35(a) Synoptic situation, 0000 G.M.T., 7 April 1954.

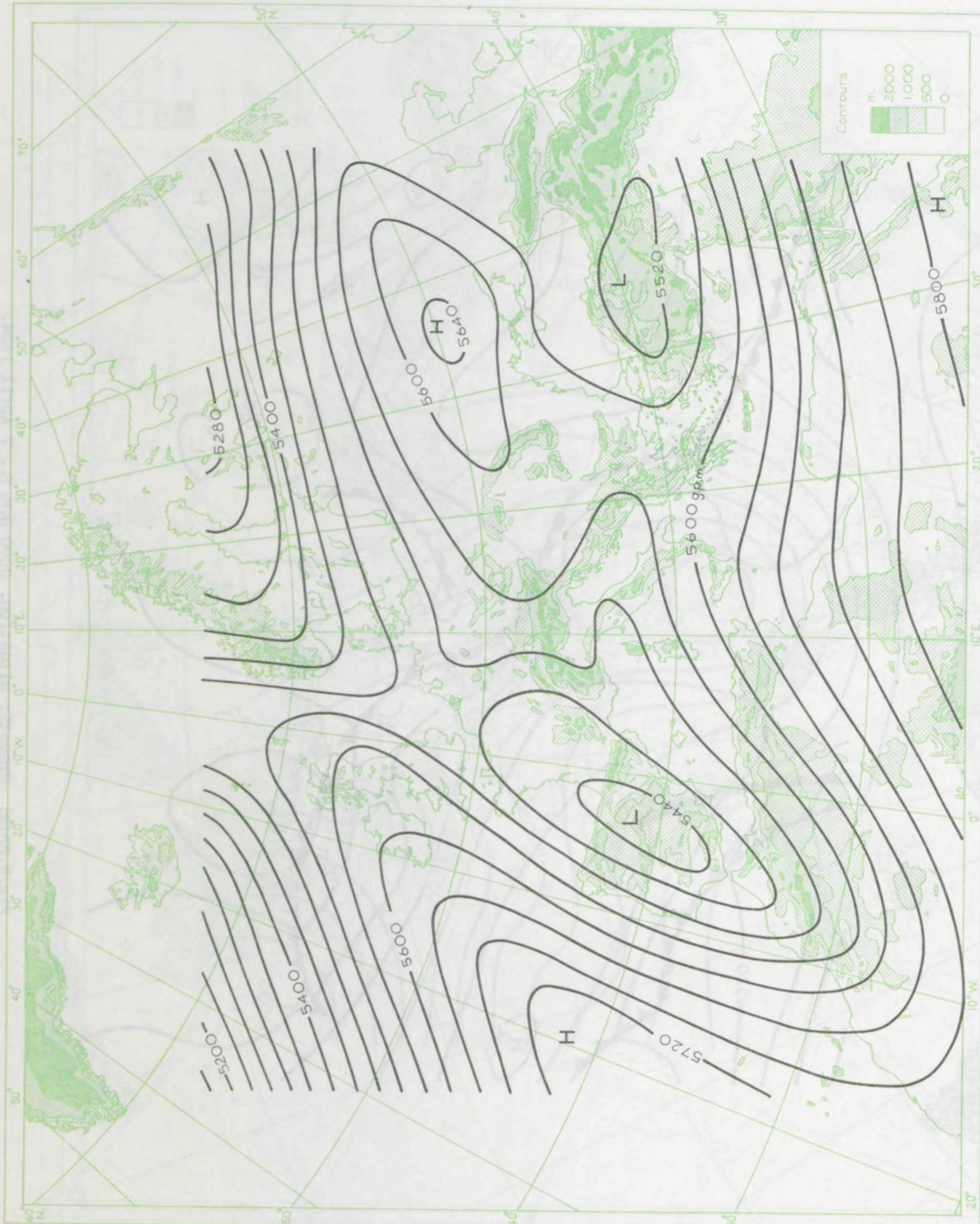


Fig.2.35(b) Contours of the 500-millibar surface, 0300 G.M.T., 7 April 1954.

Fig.2.35(c) Synoptic situation, 0000 G.M.T., 8 April 1954.

Fig. 2.35(d) Contours of the 500-millibar surface, 0300 G.M.T., 8 April 1954.

Fig. 2.35(e) Synoptic situation, 0000 G.M.T., 9 April 1954.

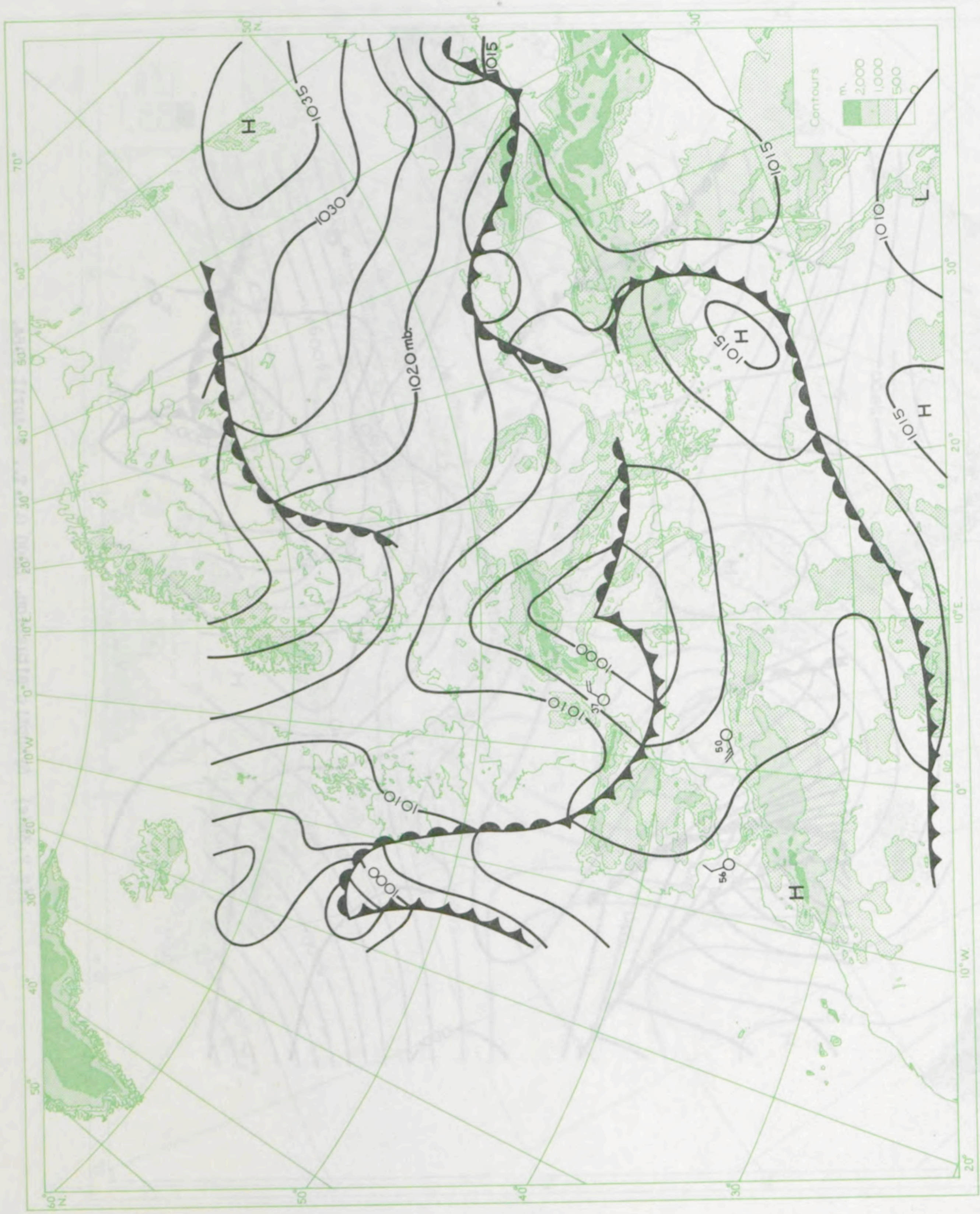


Fig.2.36(a) Synoptic situation, 1200 G.M.T., 9 March 1946.

Fig.2.36(b) Synoptic situation, 1200 G.M.T., 11 March 1946.

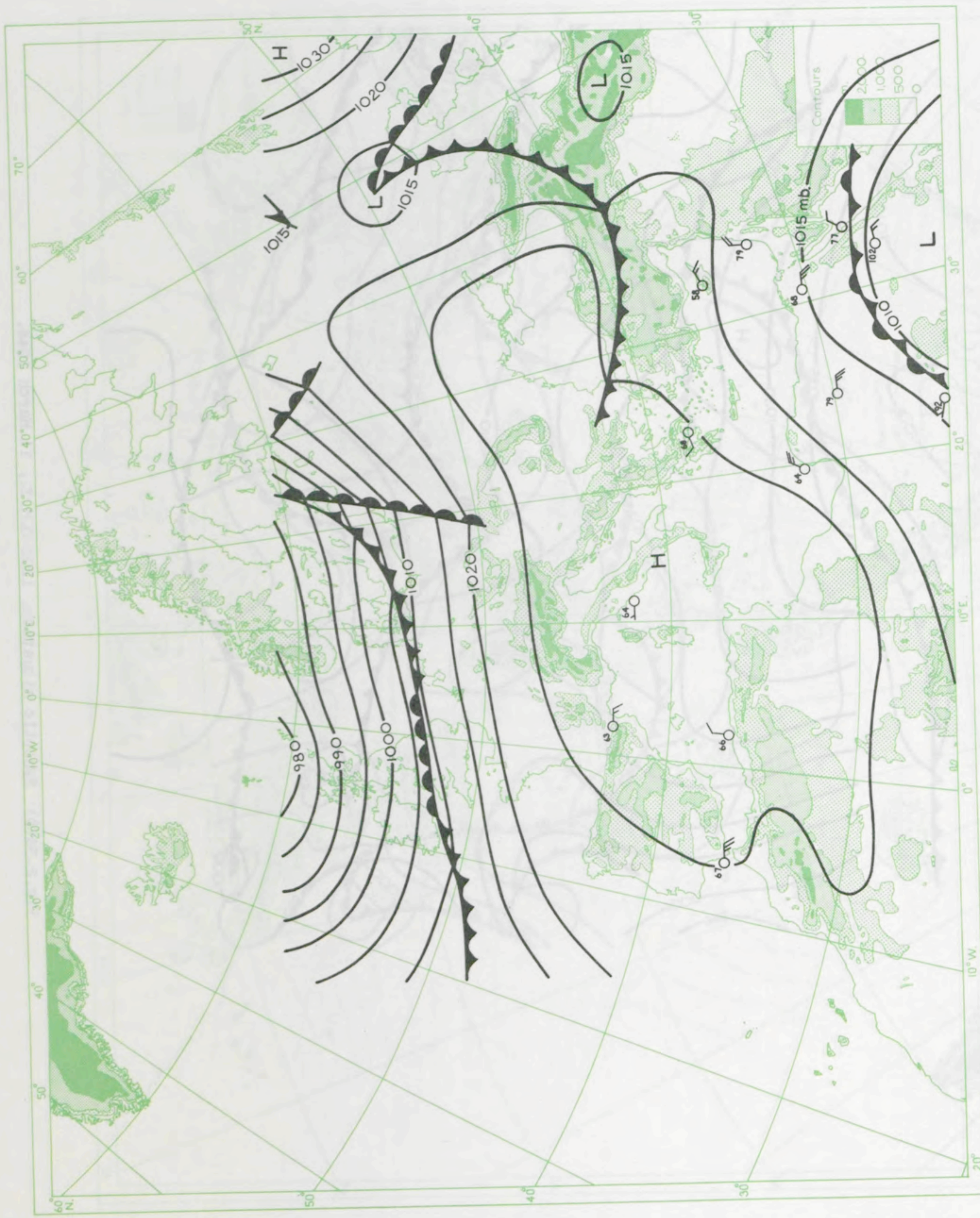


Fig. 2.37 (a) Synoptic situation, 1200 G.M.T., 29 March 1953.

Fig. 2.37 (b) Synoptic situation, 1200 G.M.T., 30 March 1953.

Fig.2.38 Synoptic situation, 0600 G.M.T., 14 March 1953.
The shading in North Africa shows precipitation area.

Fig.2.39(*a*) Synoptic situation, 0000 G.M.T., 16 November 1953.

Fig. 2.39(b) Synoptic situation, 0000 G.M.T., 17 November 1953.

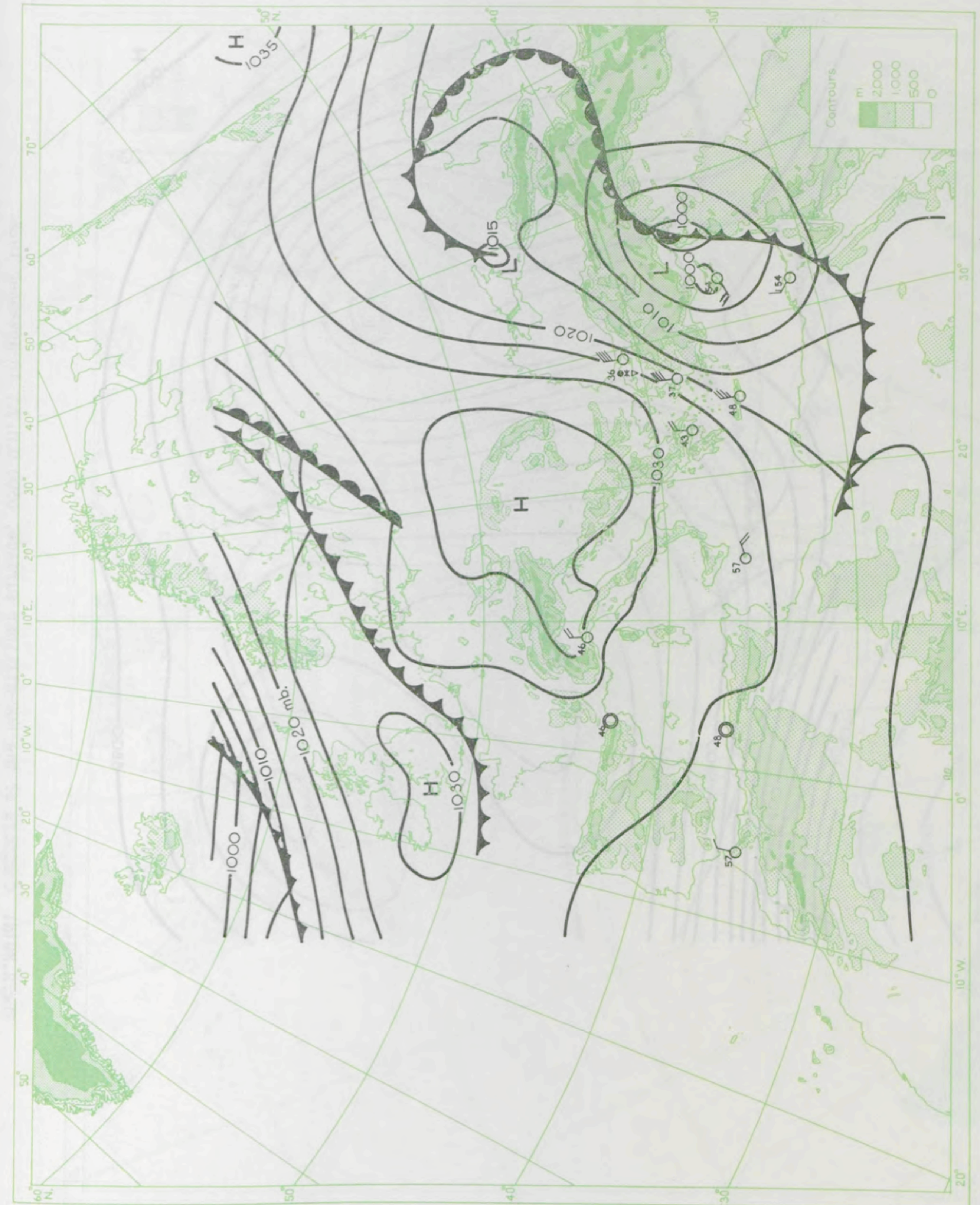


Fig. 2.39(c) Synoptic situation, 0000 G.M.T., 18 November 1953.

Fig.2.39(d) Contours of the 500-millibar surface, 0300 G.M.T., 18 November 1953.

Fig.2.40(a) Synoptic situation, 0000 G.M.T., 6 March 1953.

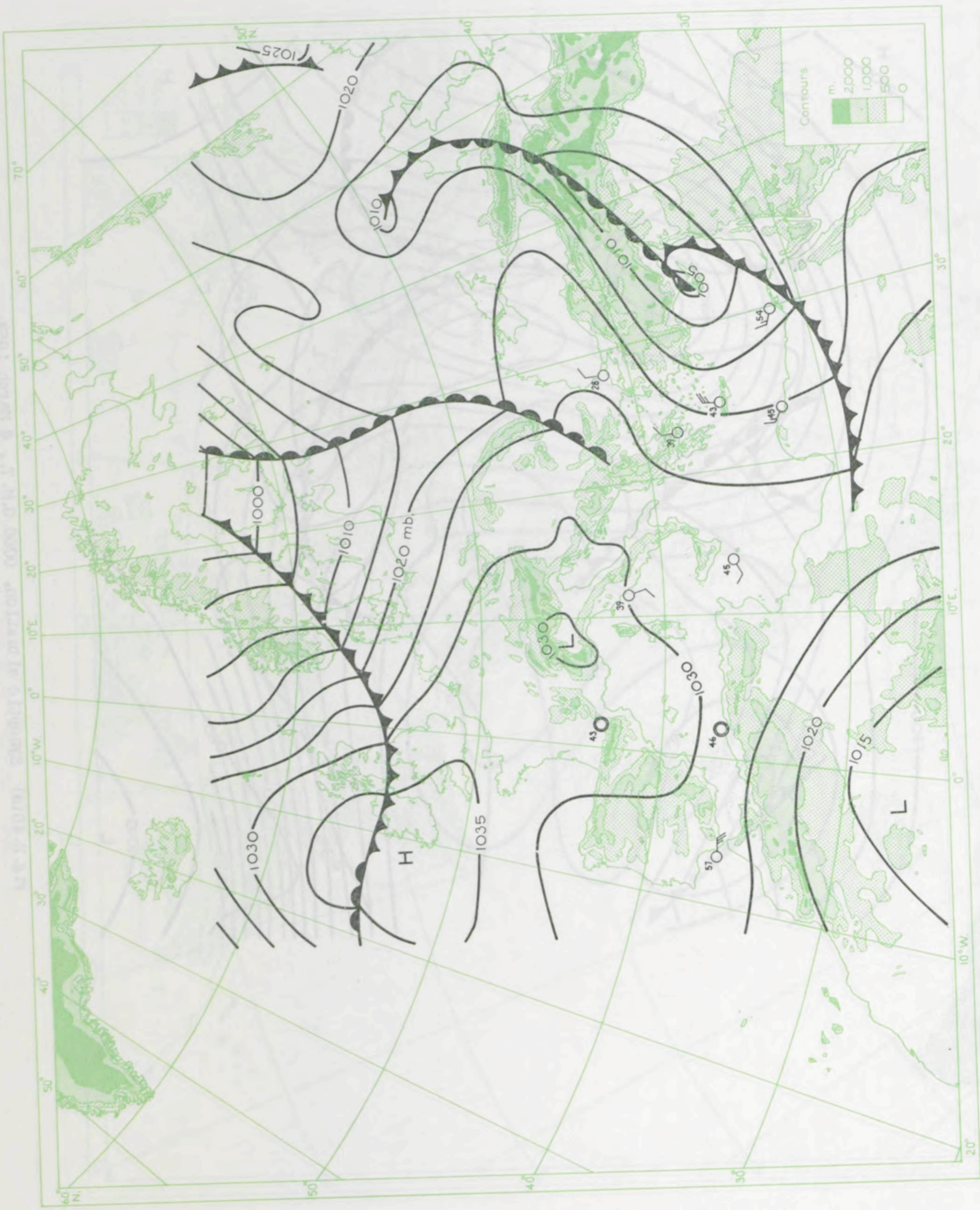


Fig.2.40(b) Synoptic situation, 0000 G.M.T., 7 March 1953.

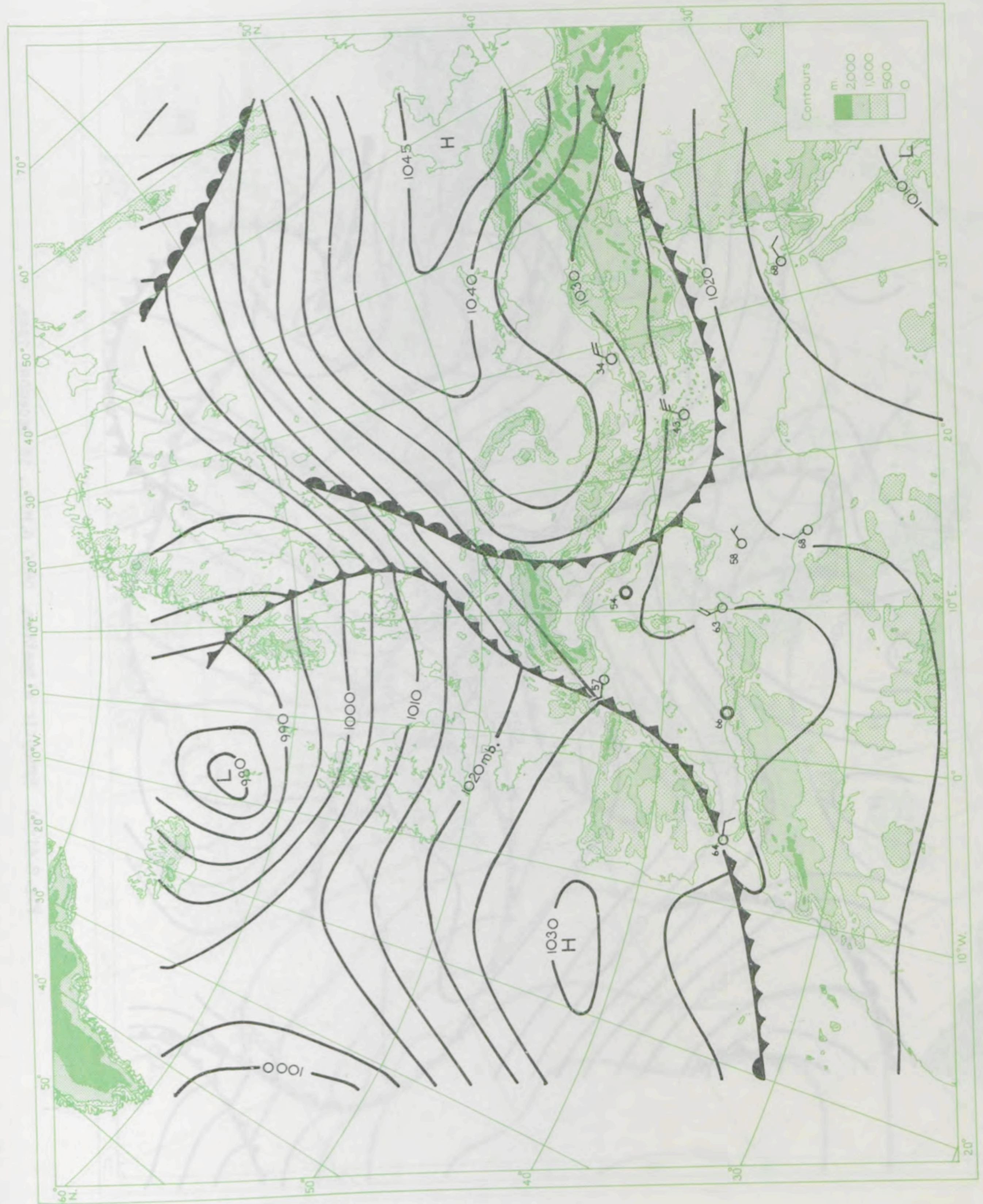


Fig.2.41(a) Synoptic situation, 1200 G.M.T., 15 December 1948.

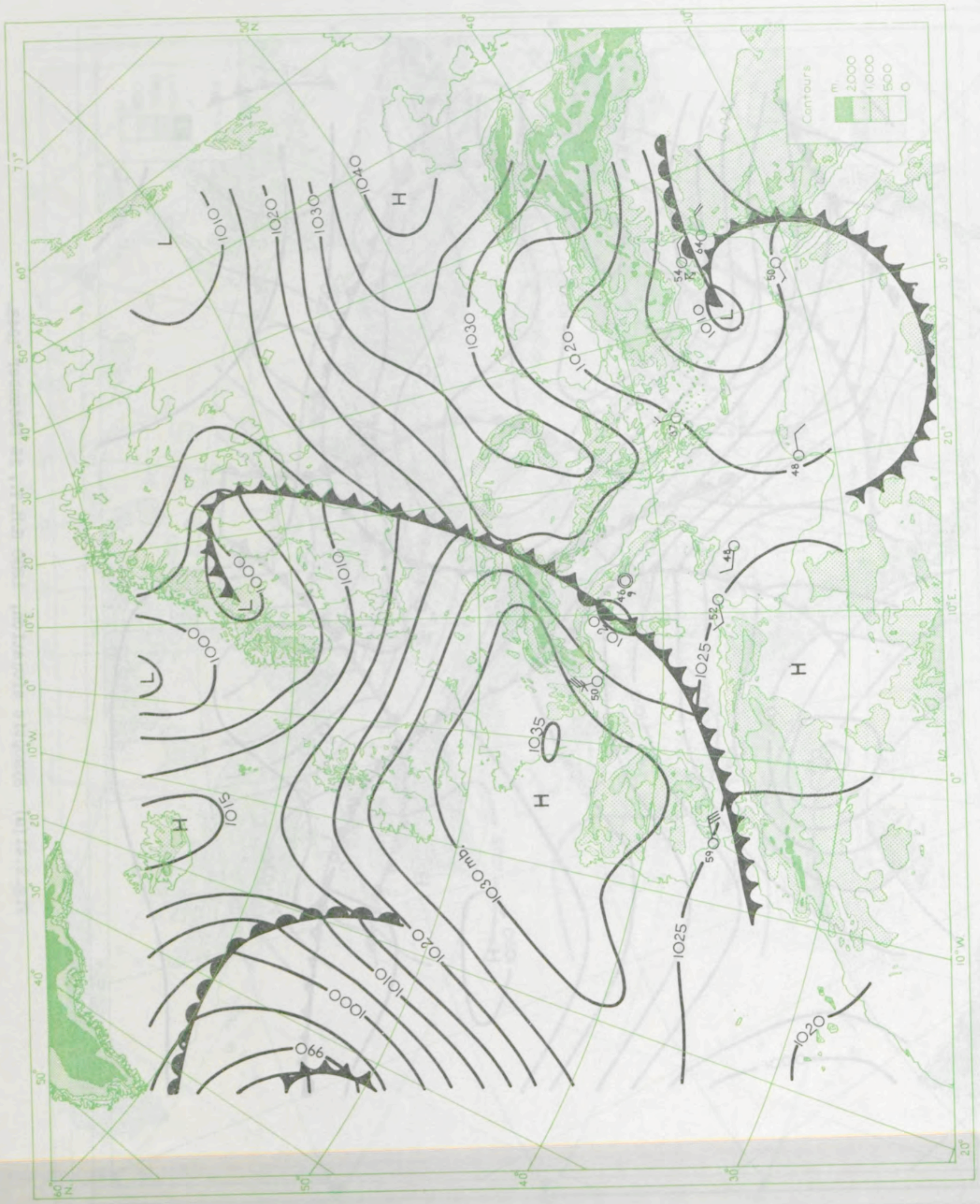


Fig. 2.41(b) Synoptic situation, 0600 G.M.T., 18 December 1948.

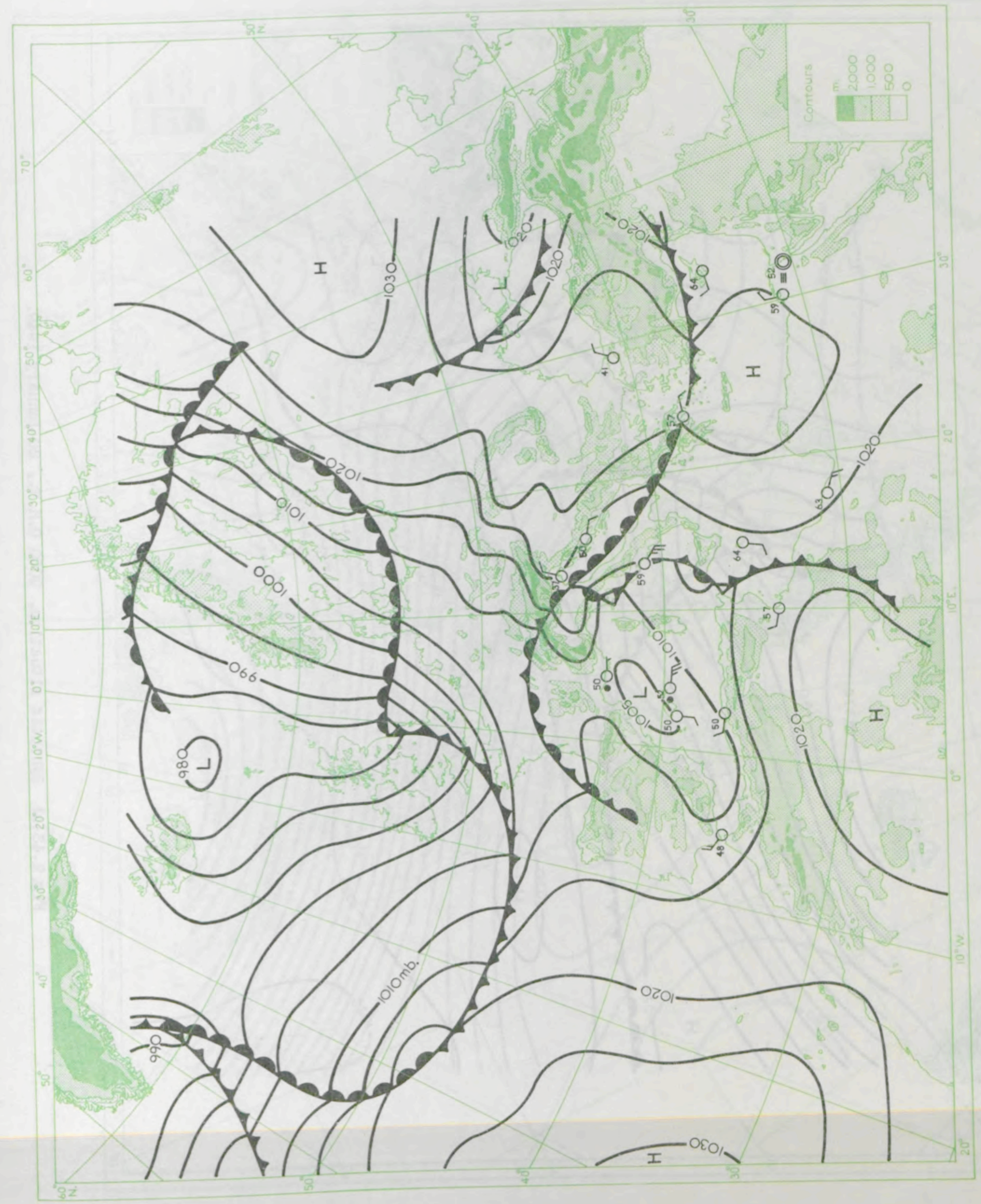


Fig. 2.42 Synoptic situation, 0000 G.M.T., 15 December 1949.

Fig.2.43(*a*) Synoptic situation, 0000 G.M.T., 20 January 1949.

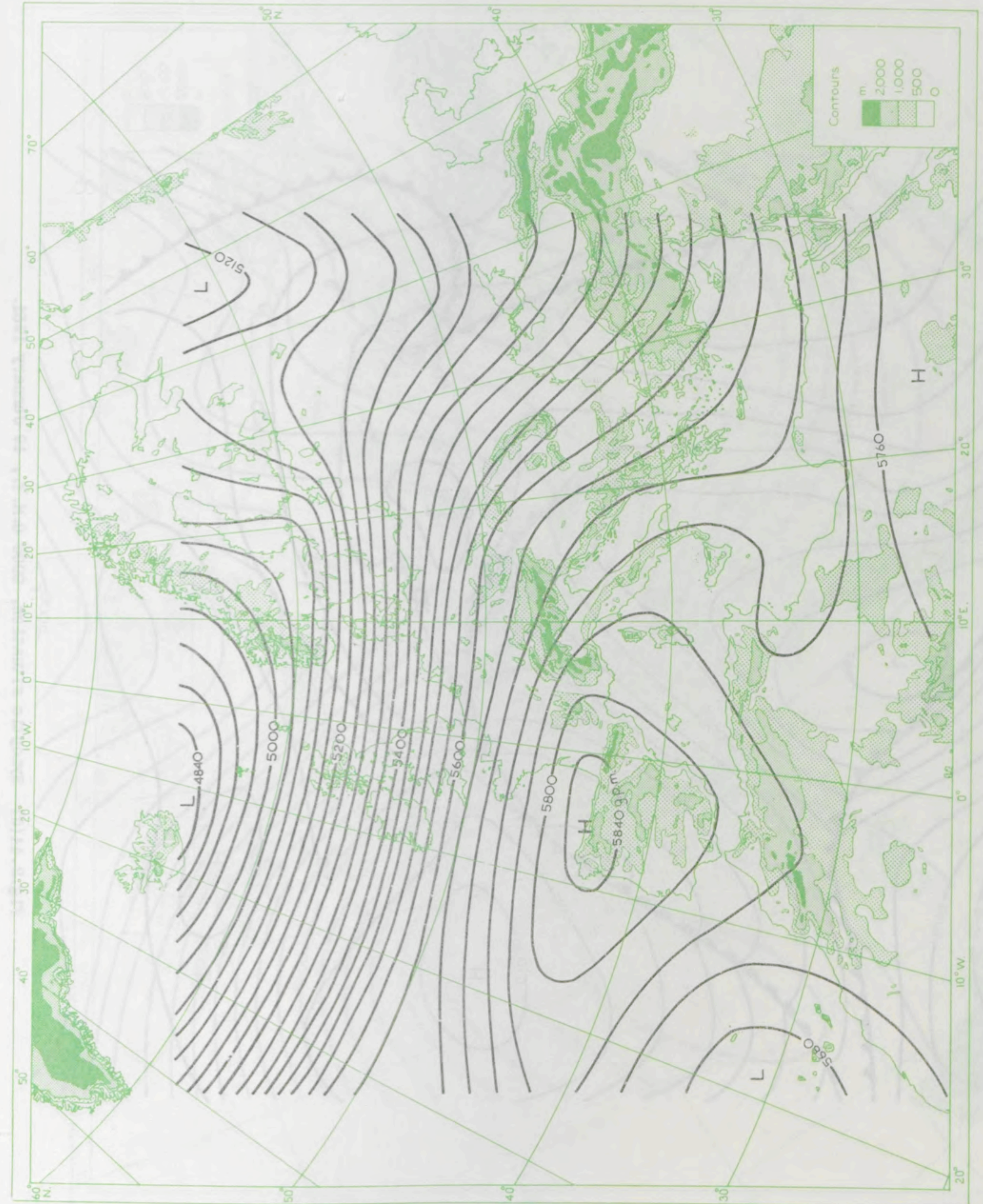


Fig.2.43(*b*) Contours of the 500-millibar surface, 0300 G.M.T., 20 January 1949.

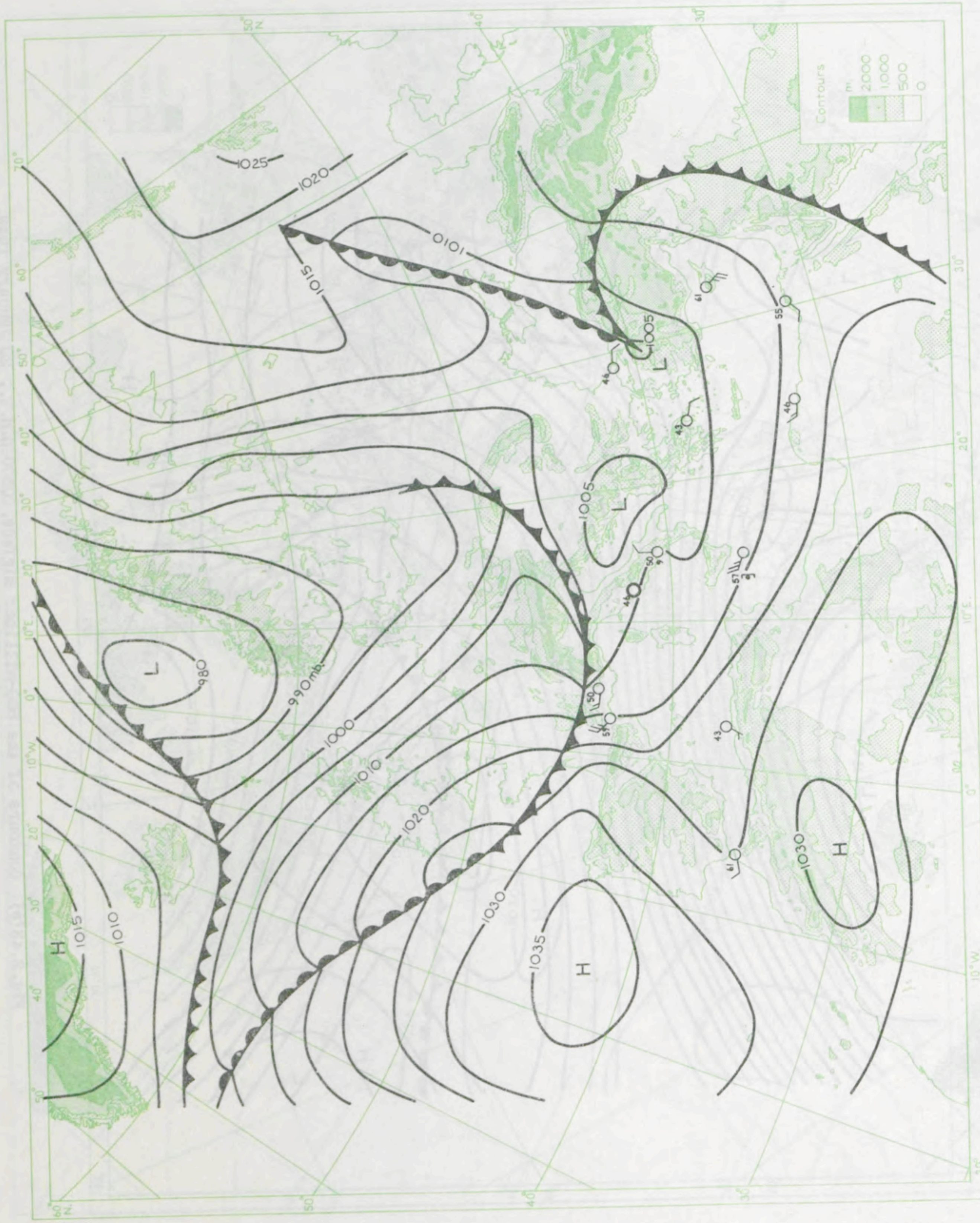


Fig.2.44(*a*) Synoptic situation, 0000 G.M.T., 19 January 1951.

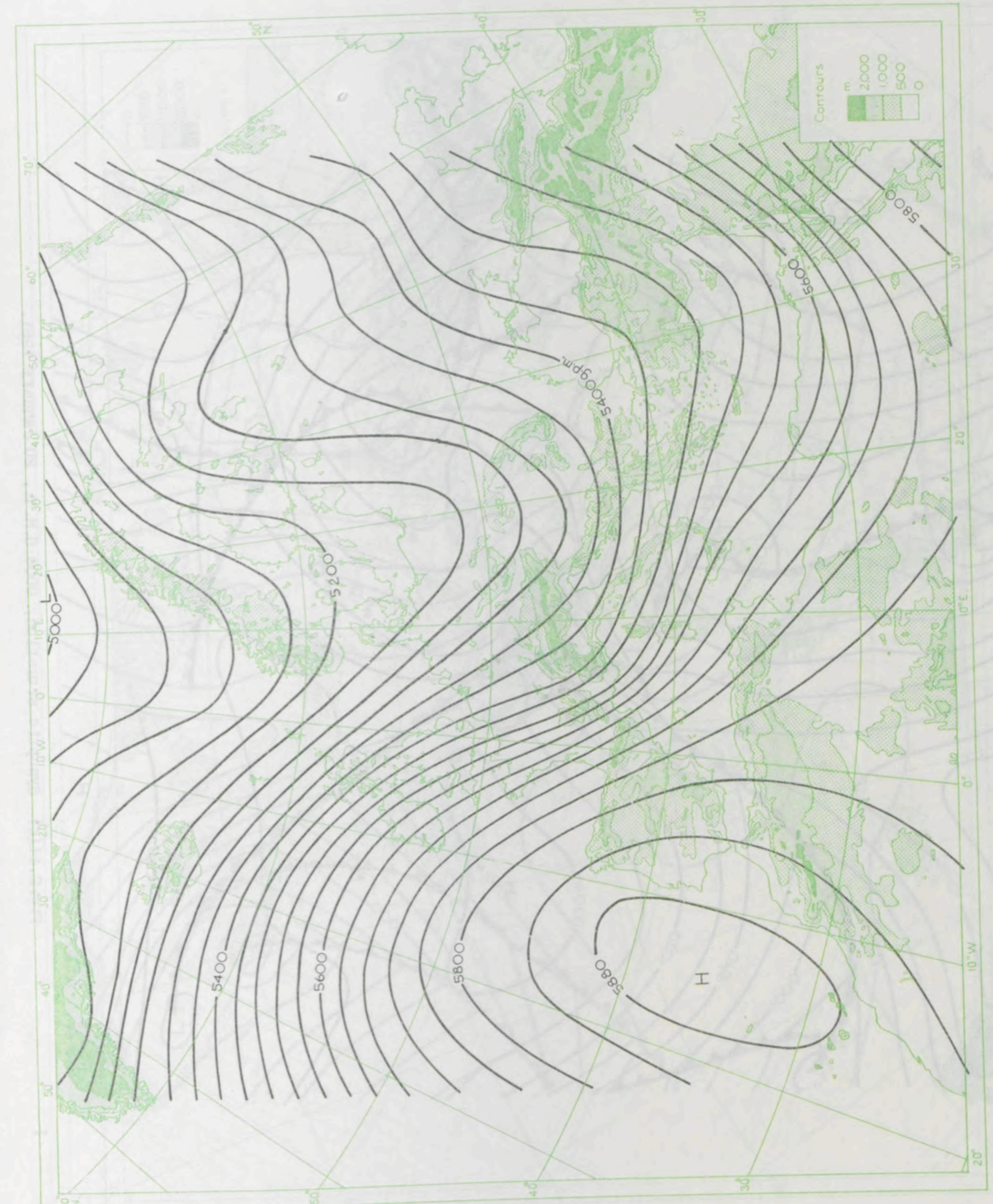


Fig.2.44(*b*) Contours of the 500-millibar surface, 0300 G.M.T., 19 January 1951.

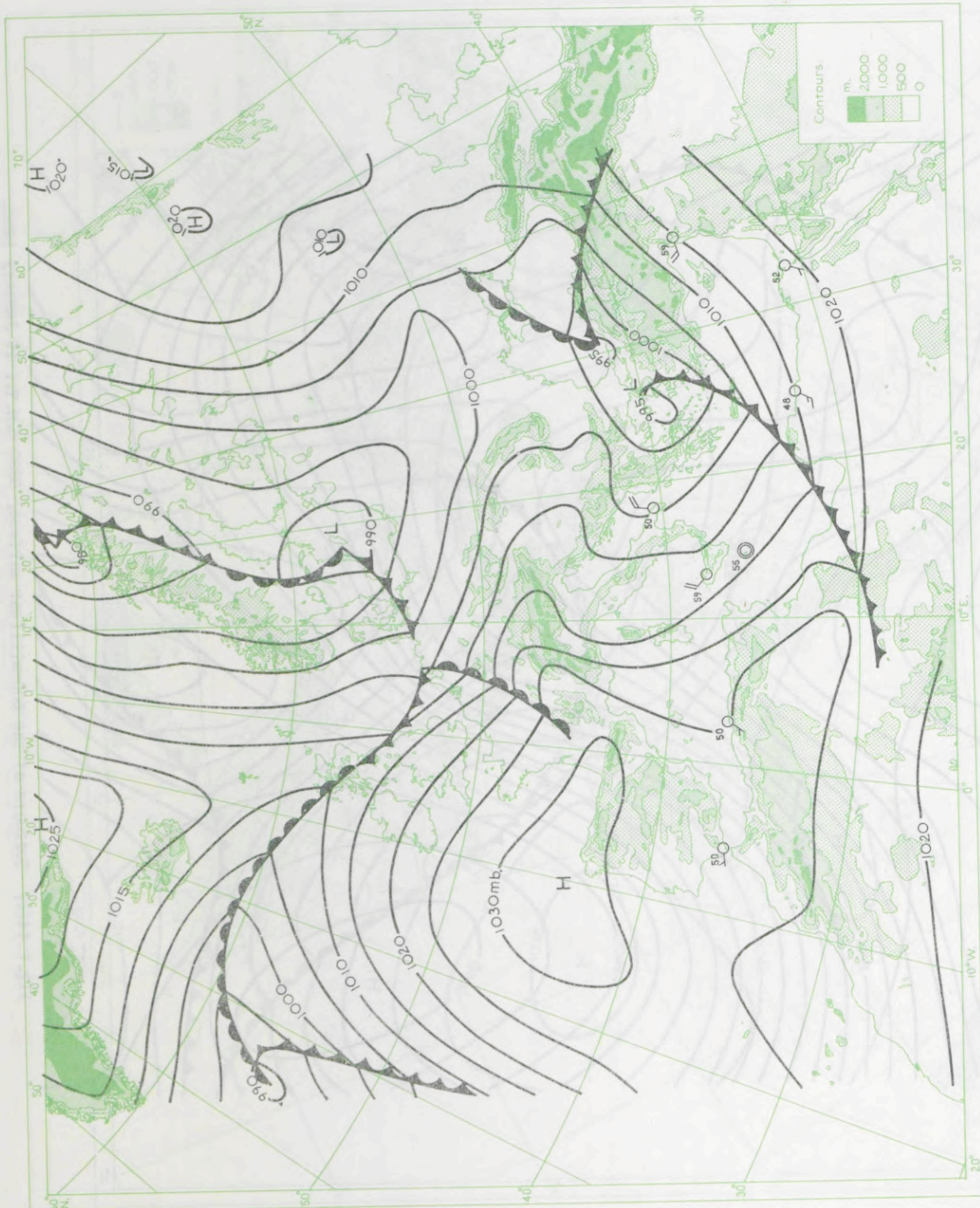


Fig.2.44(c) Synoptic situation, 0000 G.M.T., 20 January 1951.

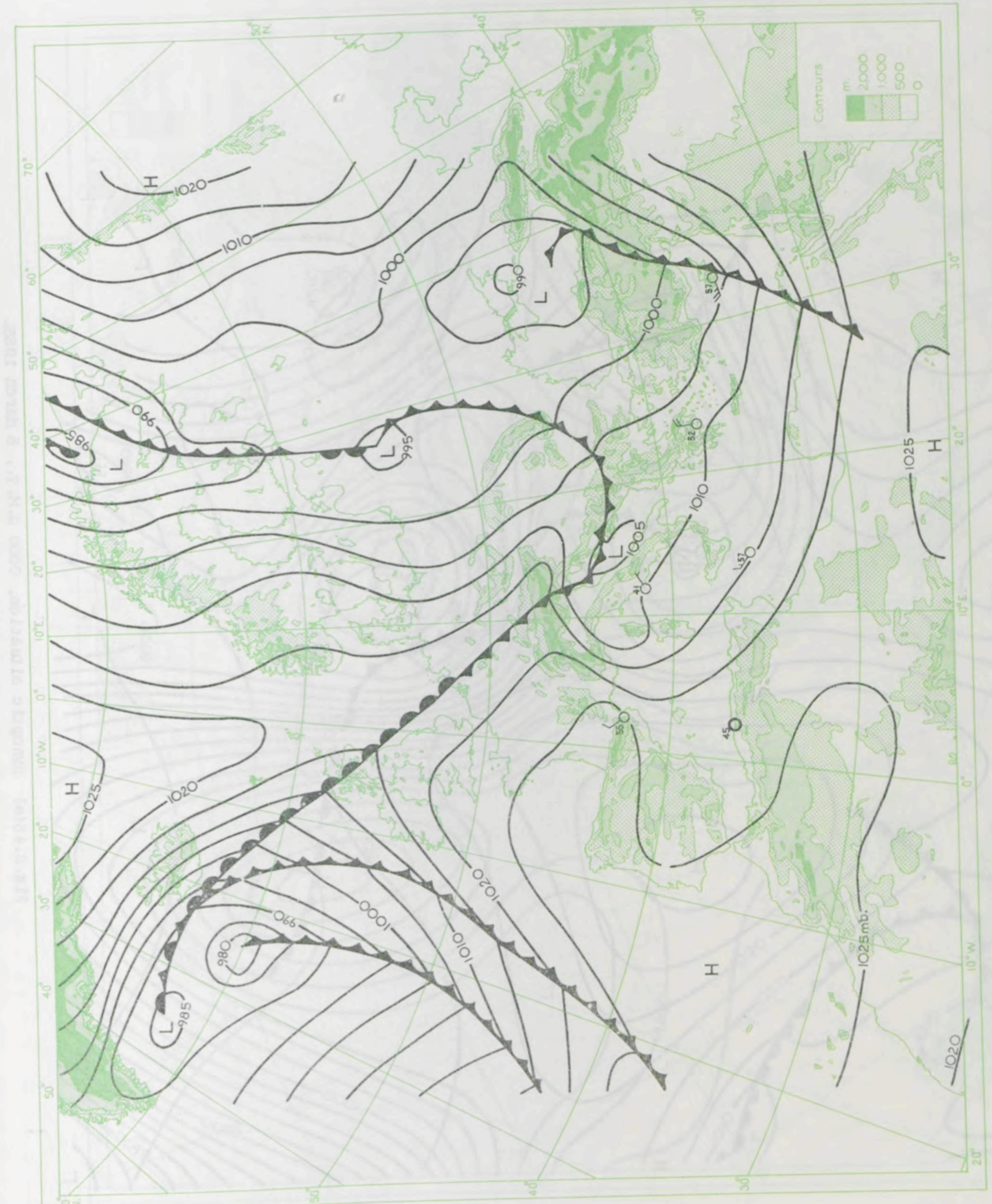


Fig.2.44(d) Synoptic situation, 0000 G.M.T., 21 January 1951.

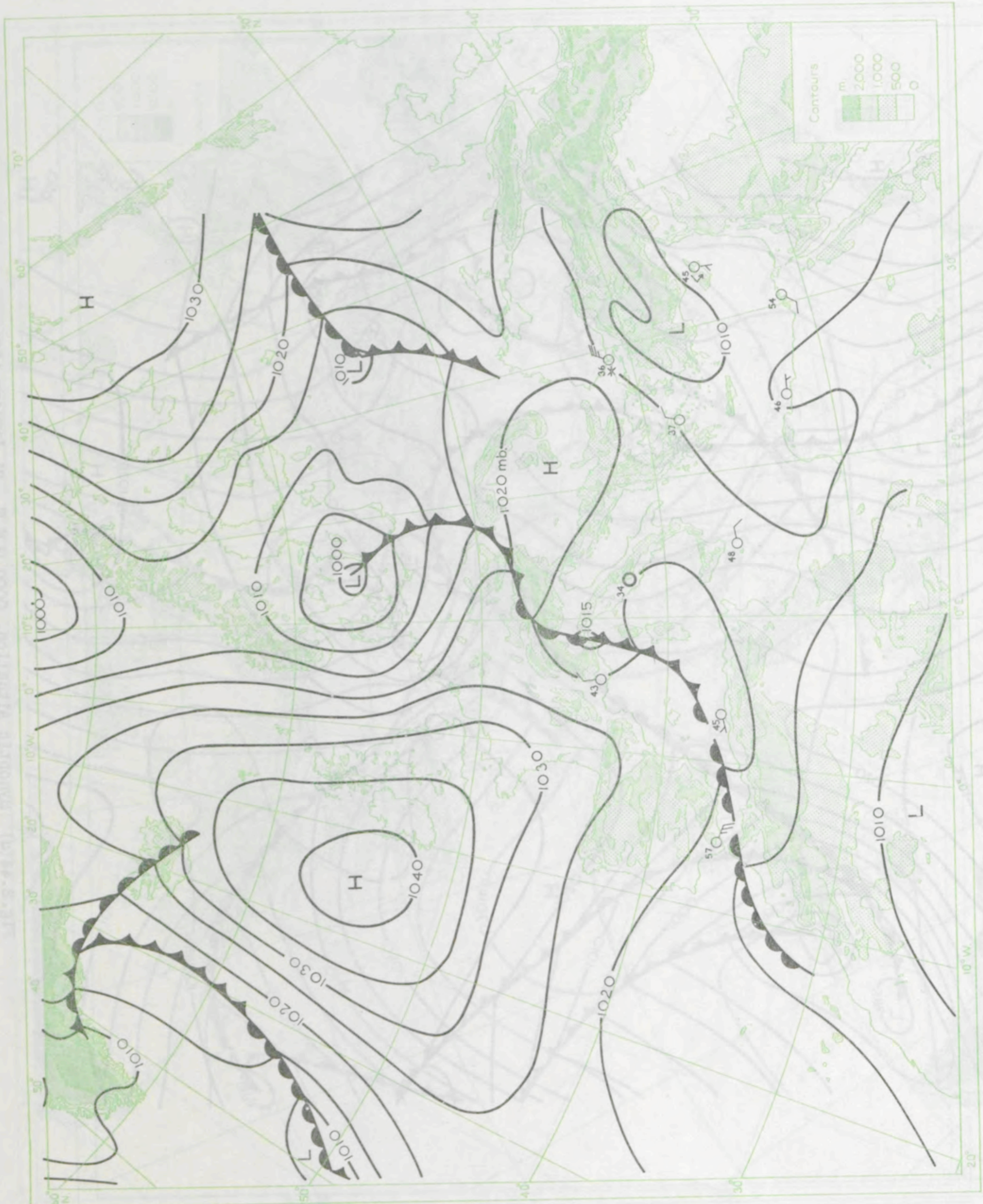


Fig.2.45(a) Synoptic situation, 0000 G.M.T., 5 March 1955.

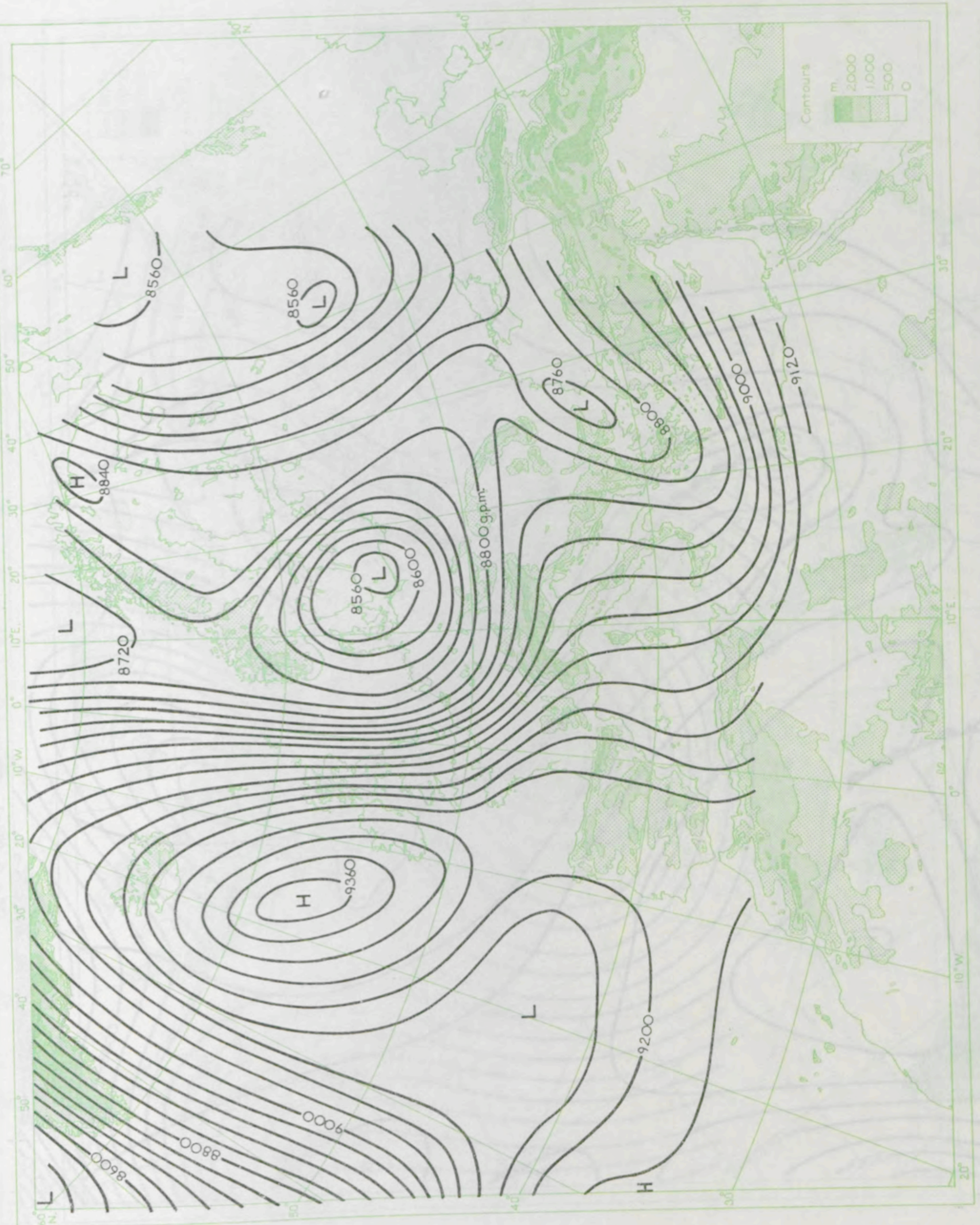


Fig.2.45(b) Contours of the 300-millibar surface, 0300 G.M.T., 5 March 1955.

Fig.2.45(c) Synoptic situation, 0000 G.M.T., 8 March 1955.
The broken line shows a line of convergence.

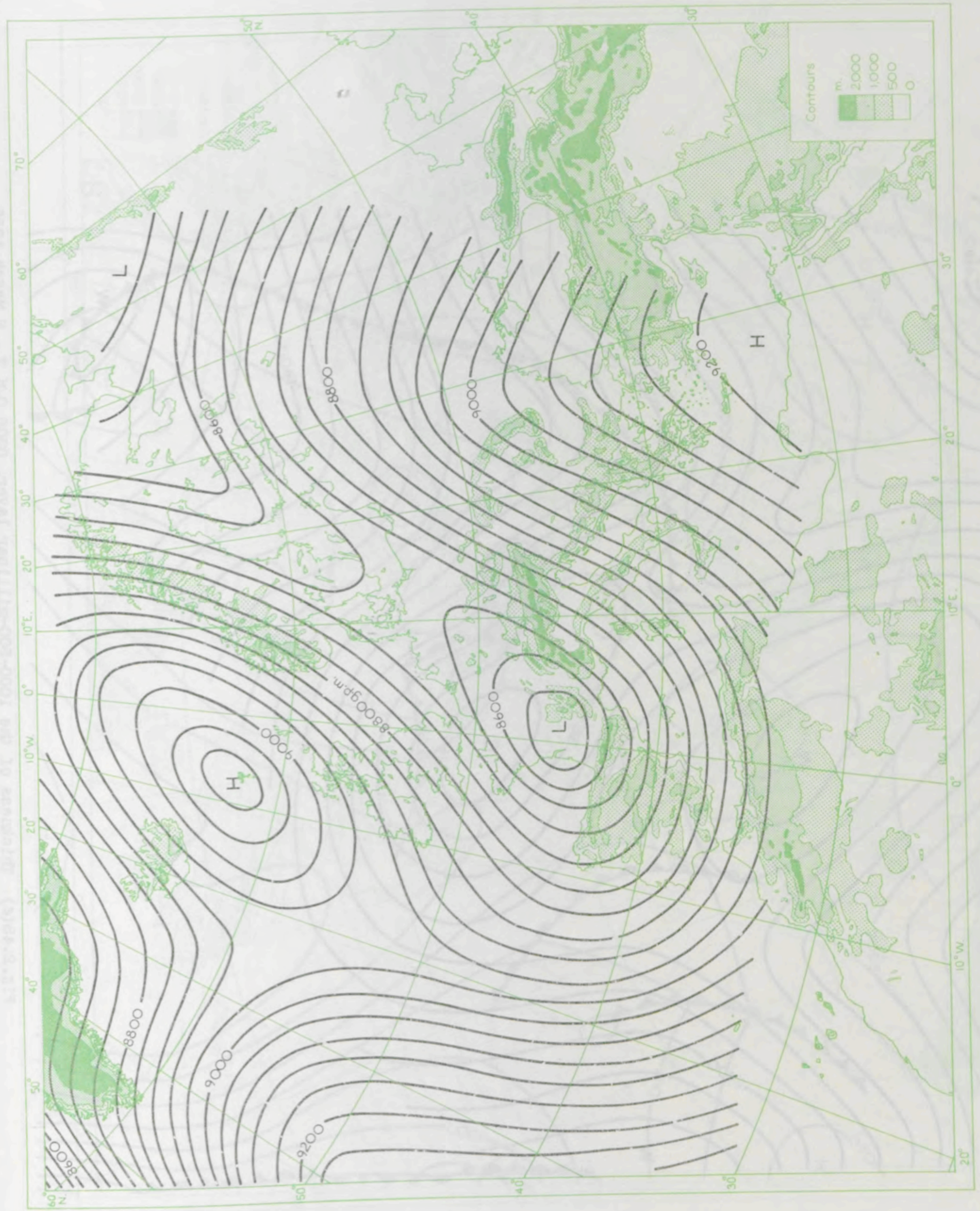


Fig.2.45(d) Contours of the 300-millibar surface, 0300 G.M.T., 8 March 1955.

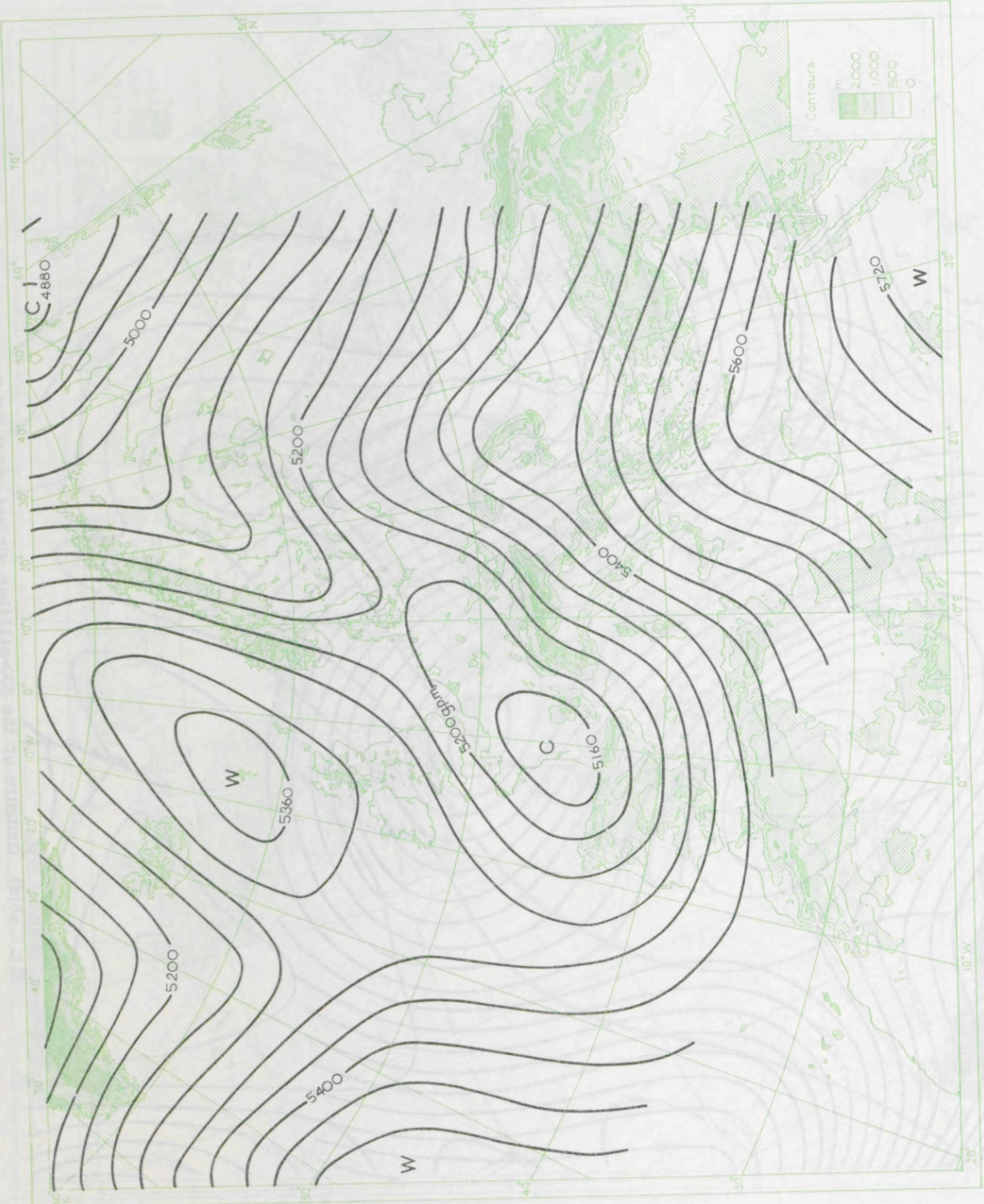


Fig.2.45(e) Thickness of the 1000-500-millibar layer, 0300 G.M.T., 8 March 1955.

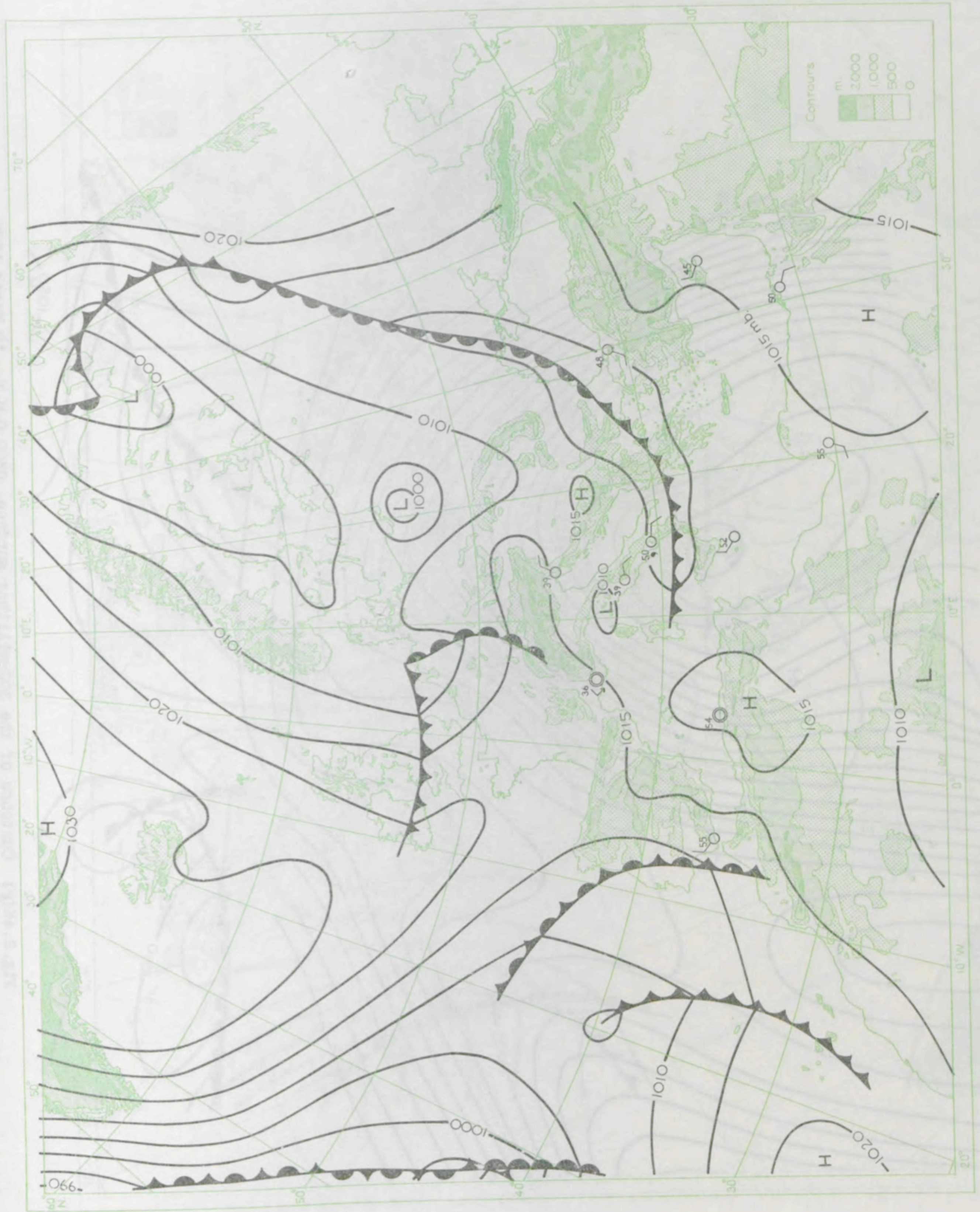


Fig.2.45(f) Synoptic situation, 0000 G.M.T., 19 March 1955.

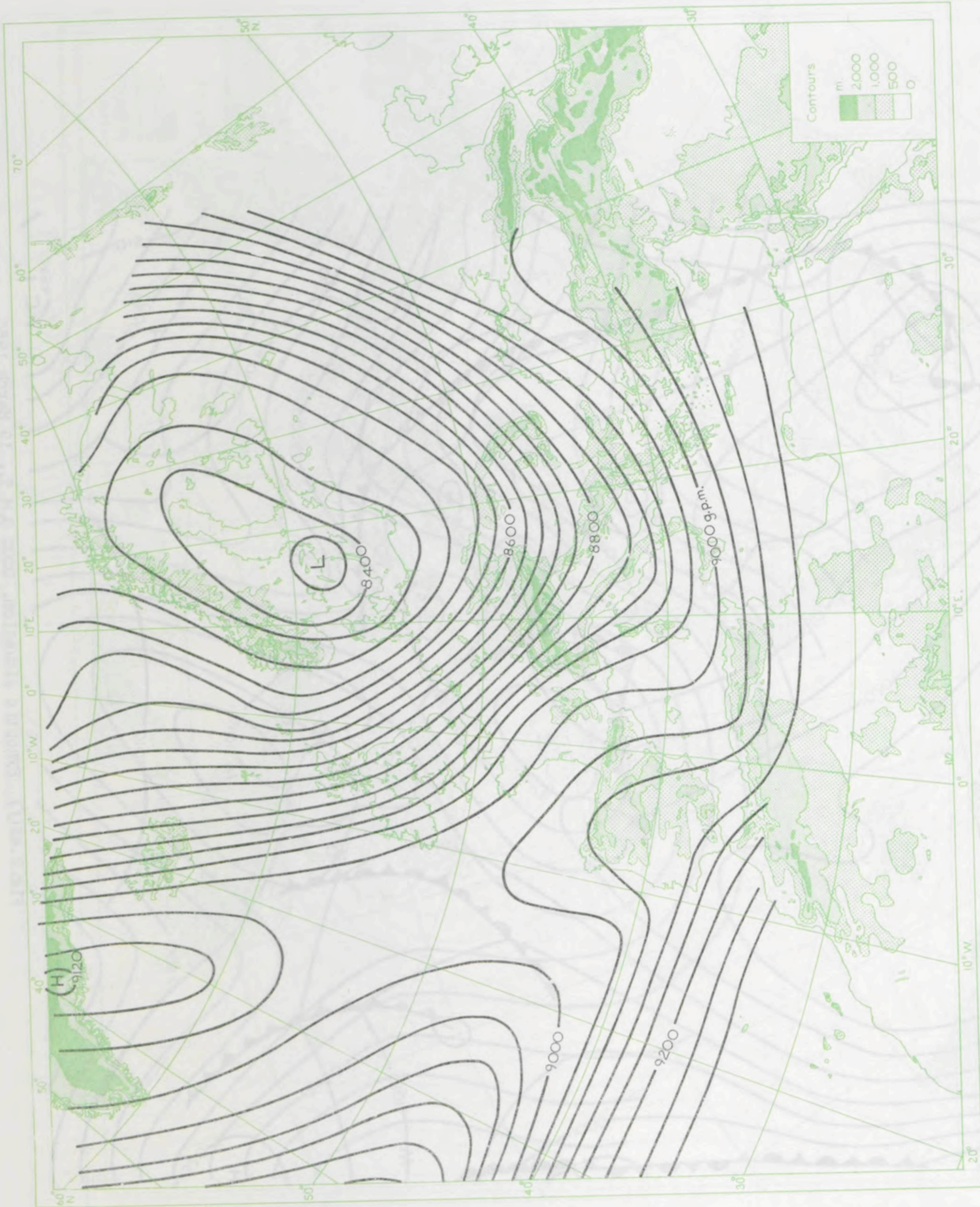


Fig.2.45(g) Contours of the 300-millibar surface, 0300 G.M.T., 19 March 1955.

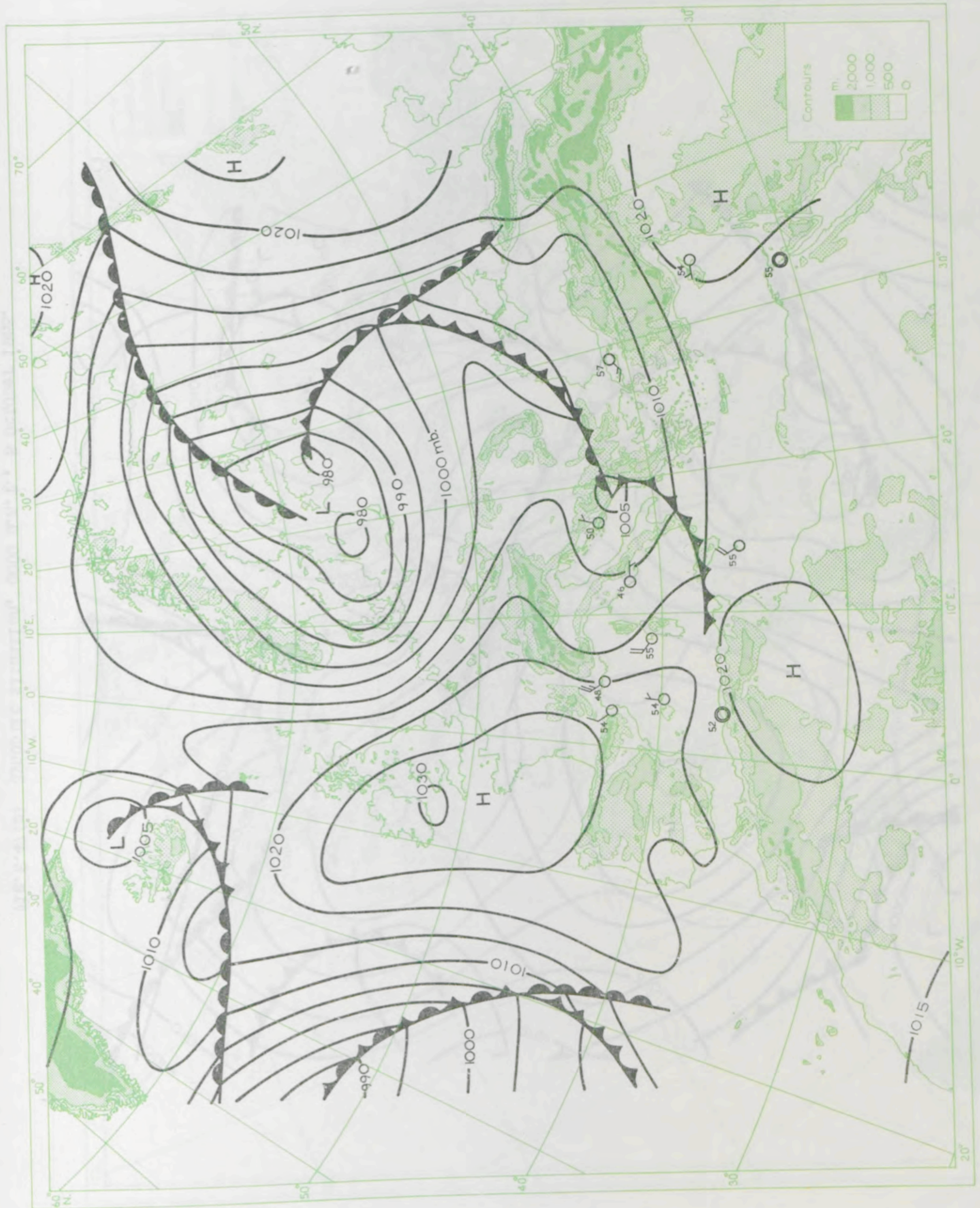


Fig.2.46 Synoptic situation, 0000 G.M.T., 9 April 1949.

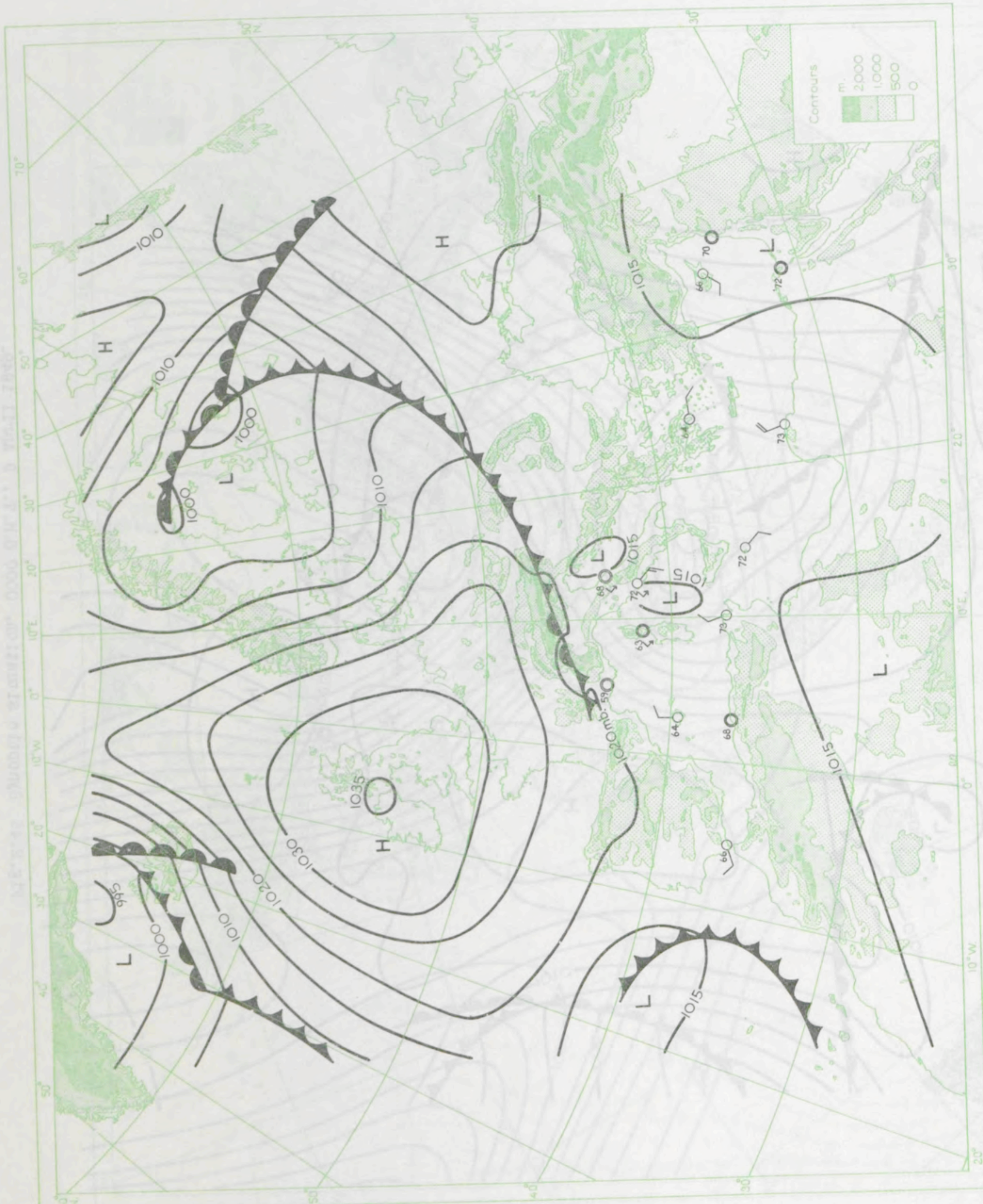


Fig. 2.47(*a*) Synoptic situation, 0000 G.M.T., 5 October 1953.

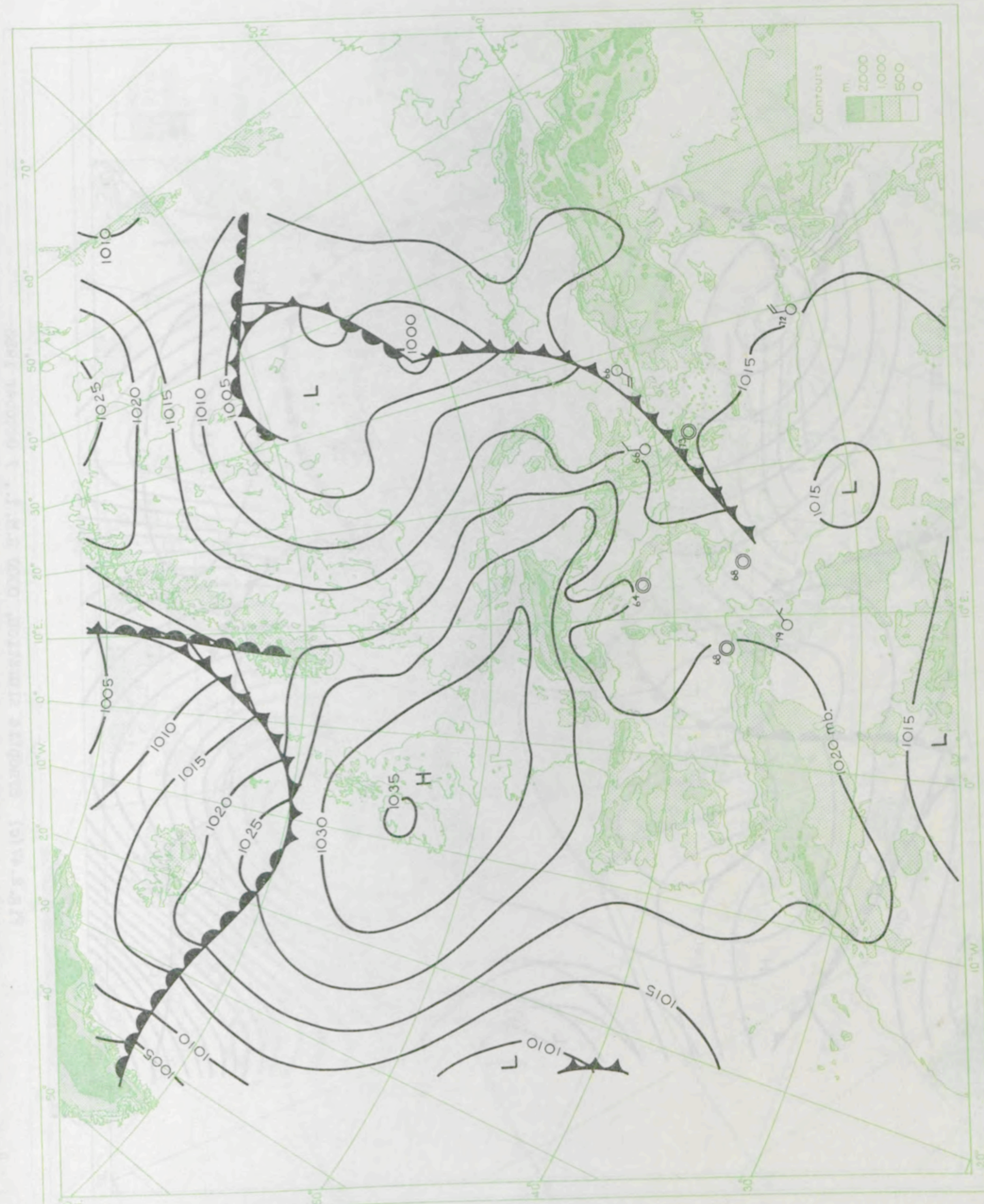


Fig. 2.47(*b*) Synoptic situation, 0000 G.M.T., 6 October 1953.

Fig.2.47(c) Synoptic situation, 0000 G.M.T., 7 October 1953

Fig.2.47(d) Contours of the 225-millibar surface, 0300 G.M.T., 7 October 1953.

Fig.2.47(e) Synoptic situation, 0000 G.M.T., 8 October 1953.

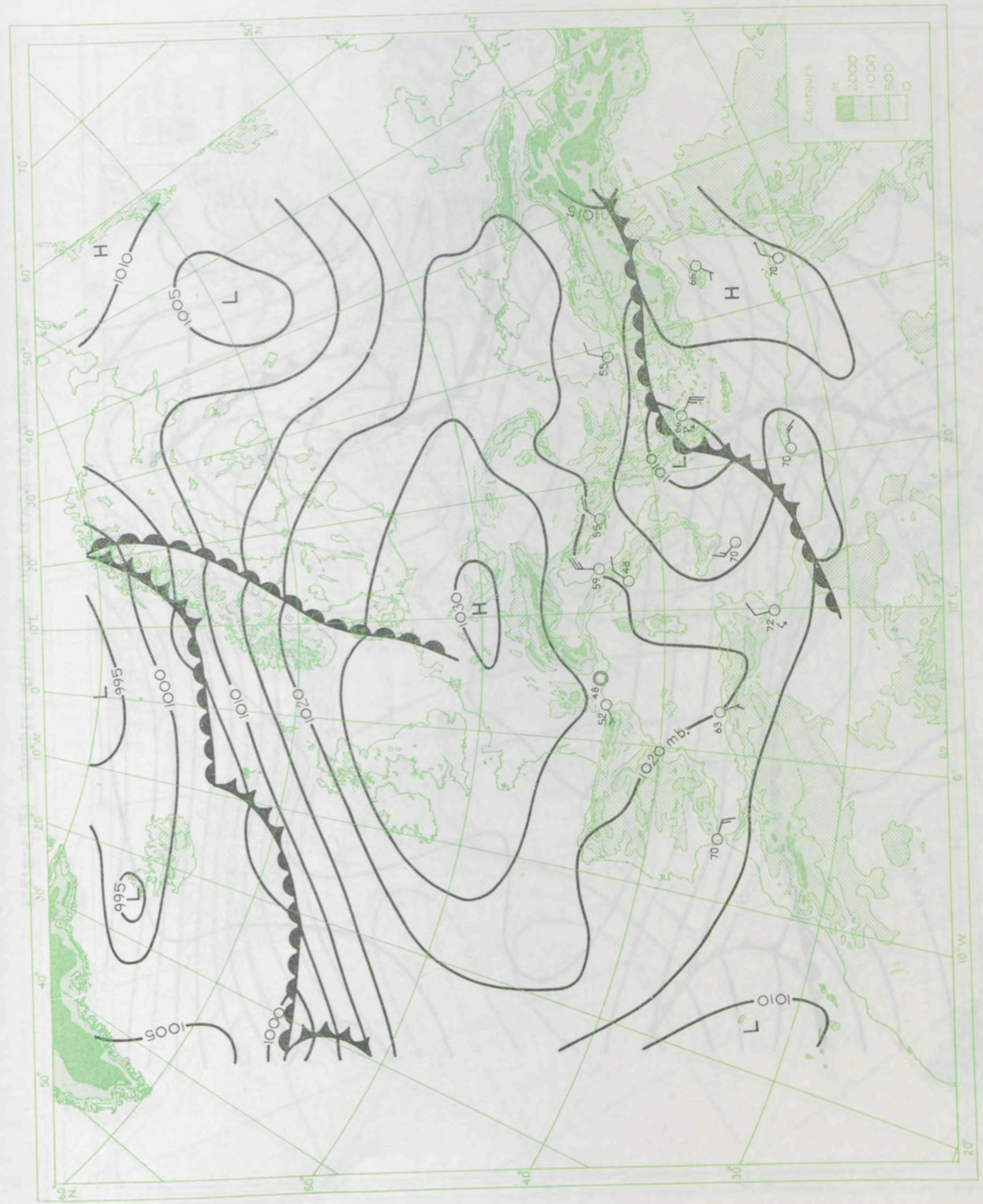


Fig.2.47(f) Synoptic situation, 0000 G.M.T., 9 October 1953.

Fig.2.47(*g*) Synoptic situation, 0000 G.M.T. 10 October 1953.

Fig.2.47(*h*) Thickness of the 1000-500-millibar layer, 0300 G.M.T., 10 October 1953.

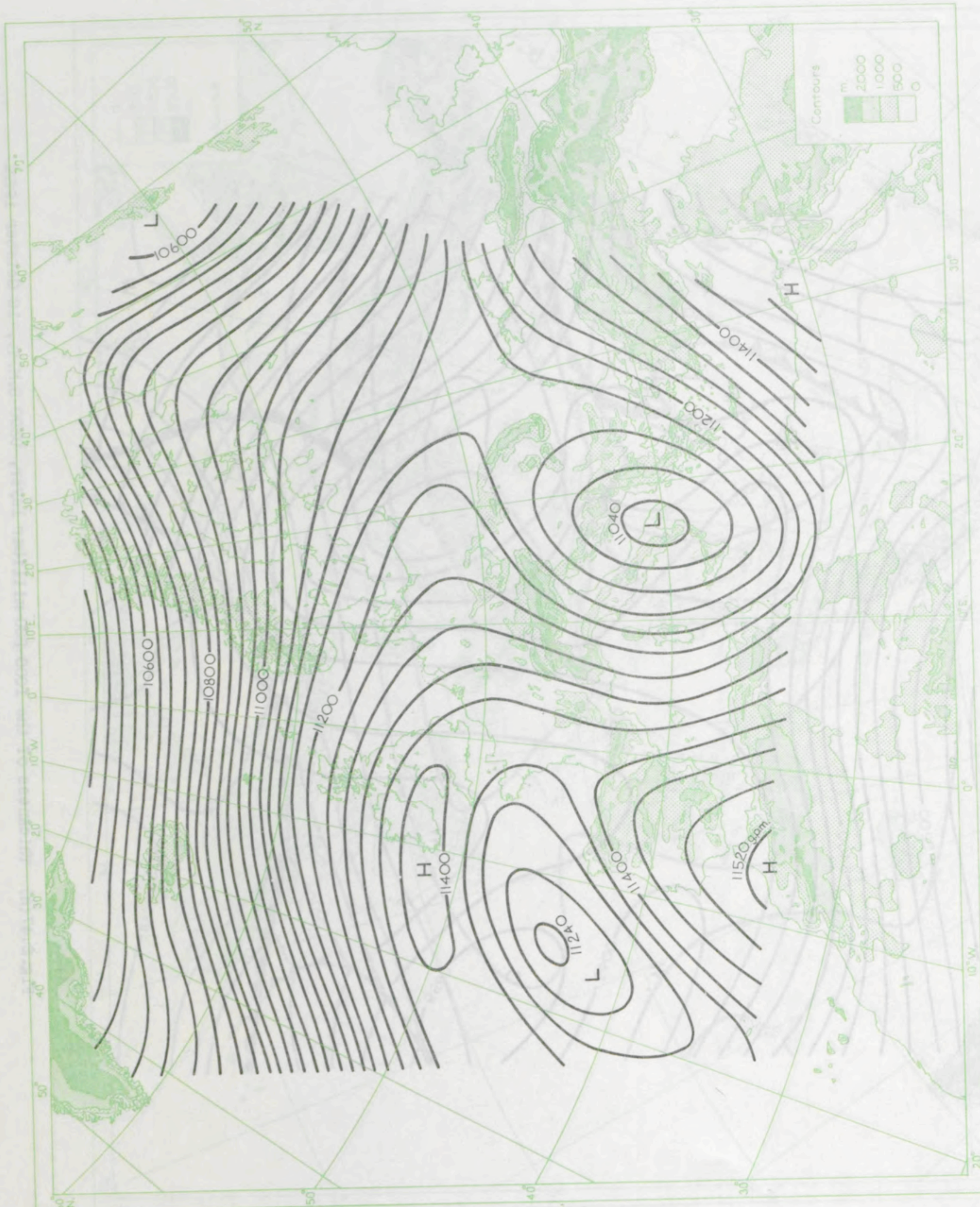


Fig.2.47(i) Contours of the 225-millibar surface, 0300 G.M.T., 10 October 1953.

Fig.2.48(a) Synoptic situation, 0000 G.M.T., 22 October 1951.

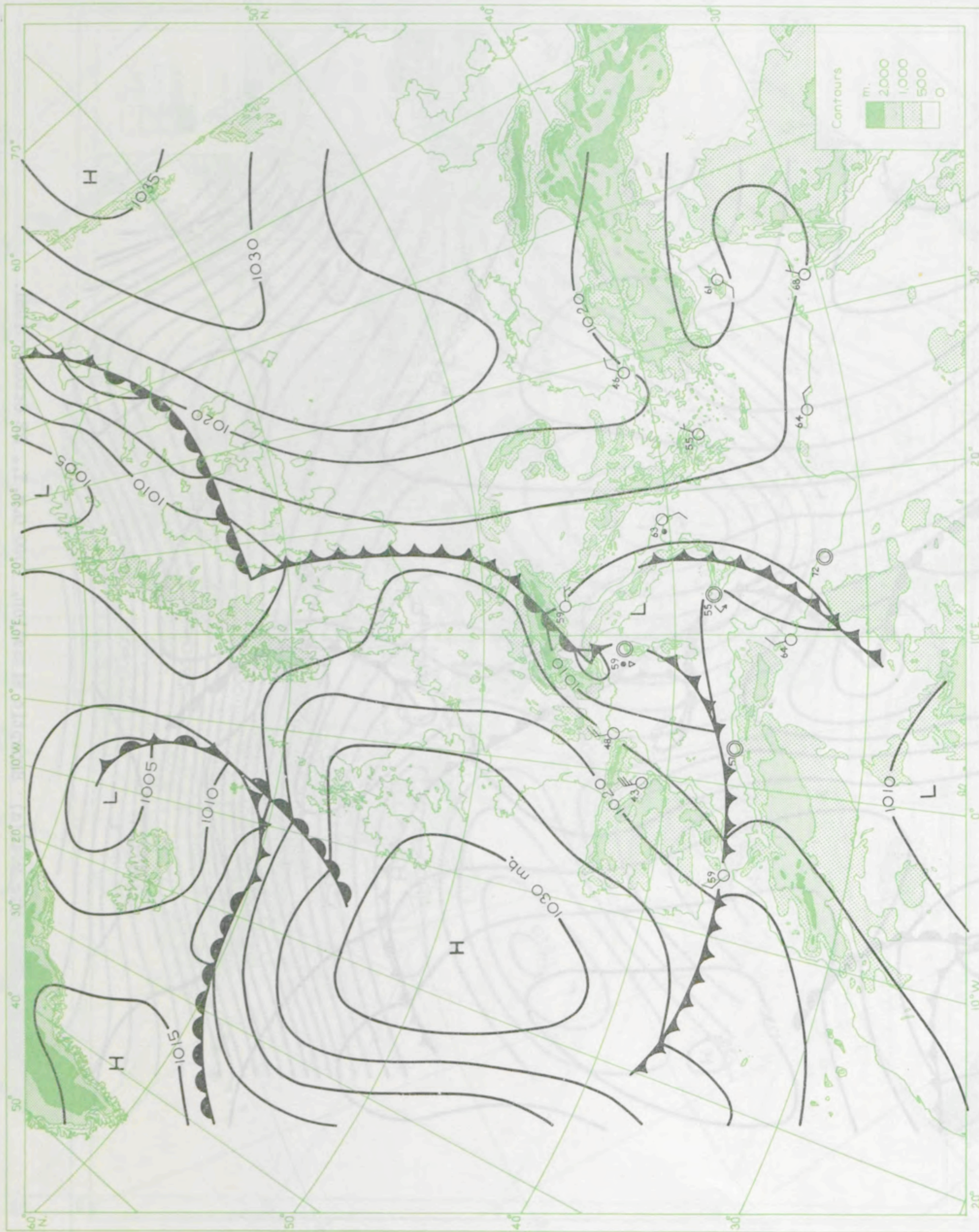


Fig.2.48(b) Synoptic situation, 0000 G.M.T., 23 October 1951

Fig.2.48(c) Contours of the 500-millibar surface, 0300 G.M.T., 23 October 1951.

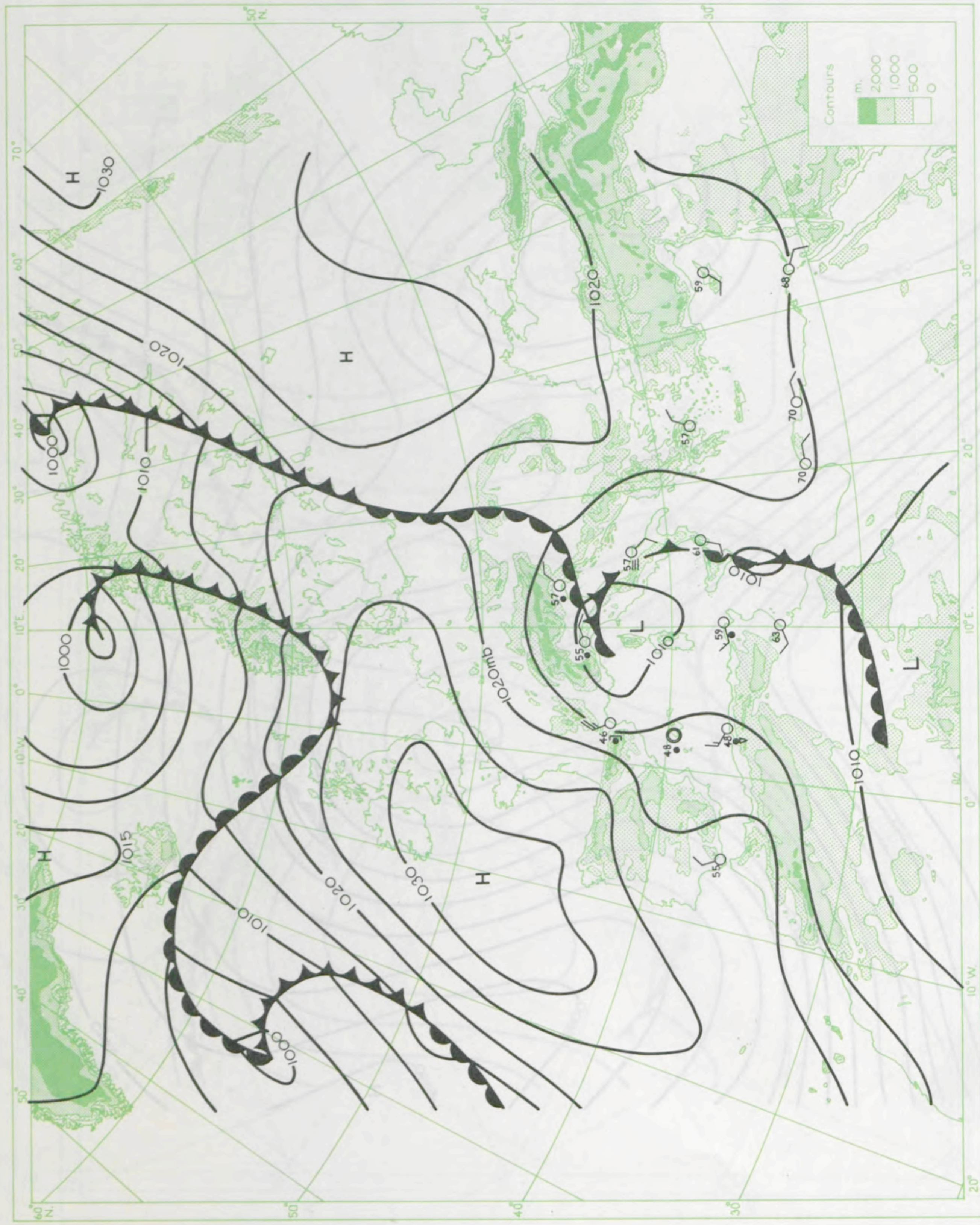


Fig.48(d) Synoptic situation, 0000 G.M.T., 24 October 1951.

Fig.2.49 Synoptic situation, 1200 G.M.T., 24 May 1946.
The broken line shows a line of convergence.

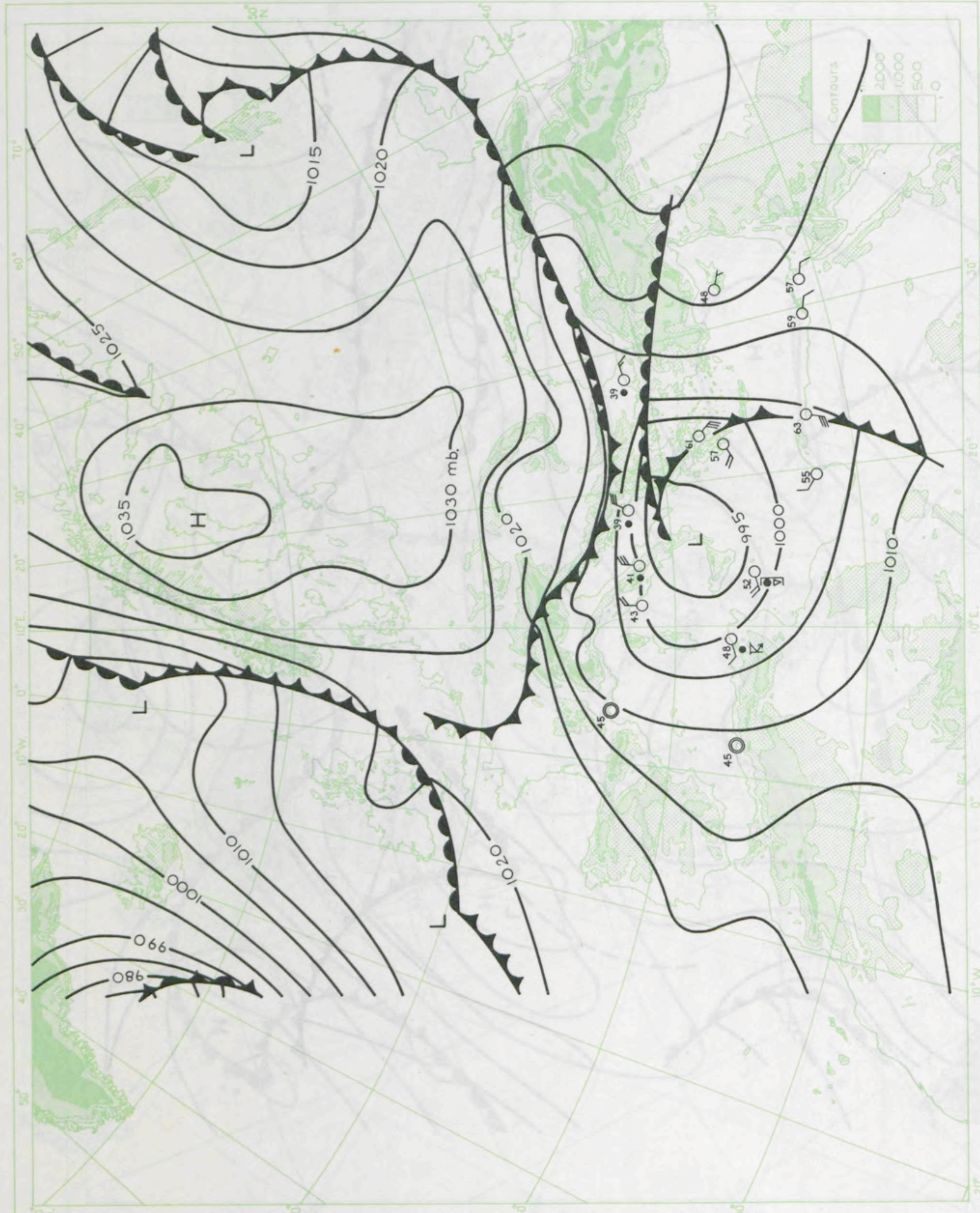


Fig. 2.50(*a*) Synoptic situation, 0000 G.M.T., 18 February 1954.

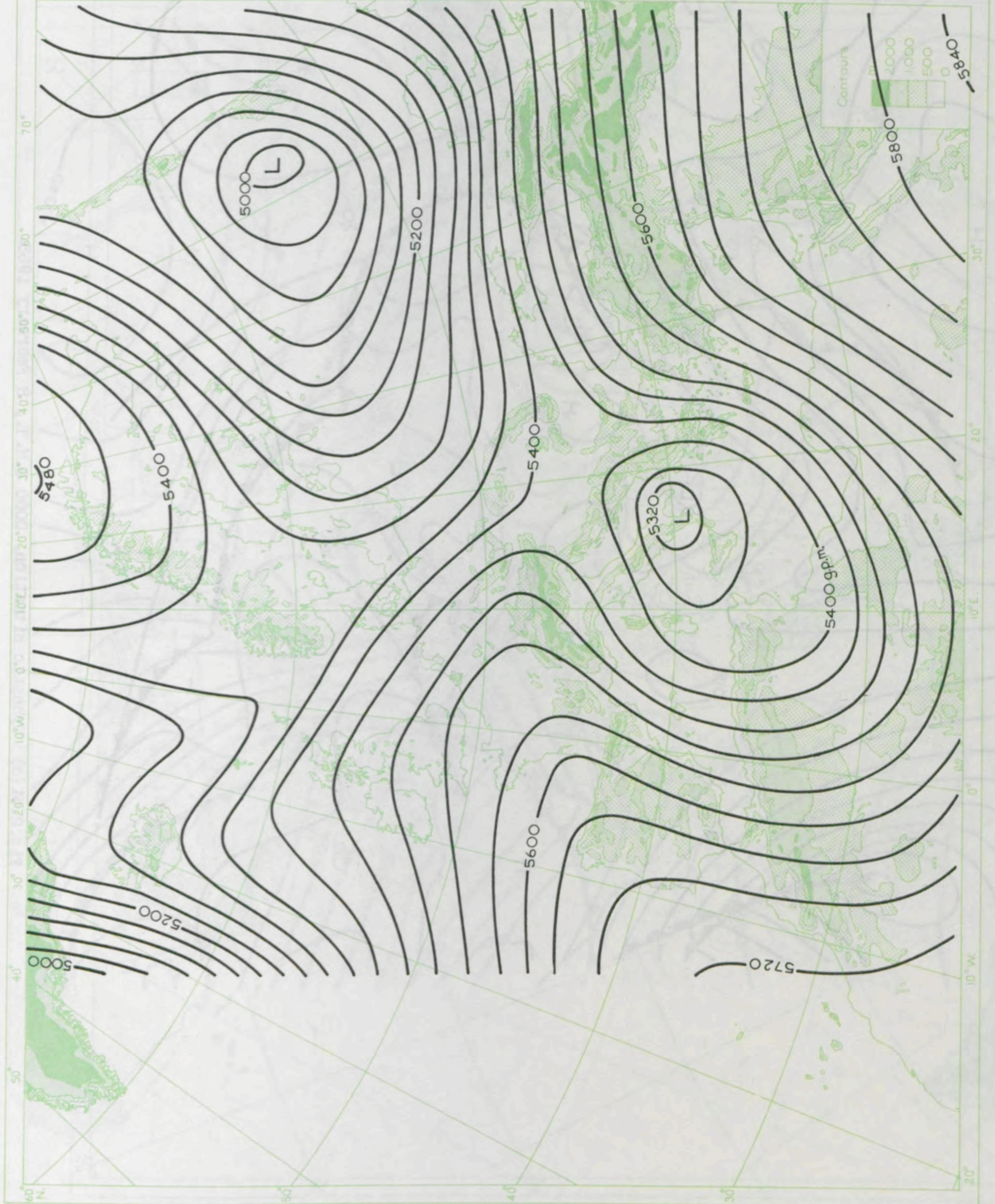


Fig. 2.50(*b*) Contours of the 500-millibar surface, 0300 G.M.T., 18 February 1954.

Fig. 2.51 (*a*) Synoptic situation, 0000 G.M.T., 8 February 1953.

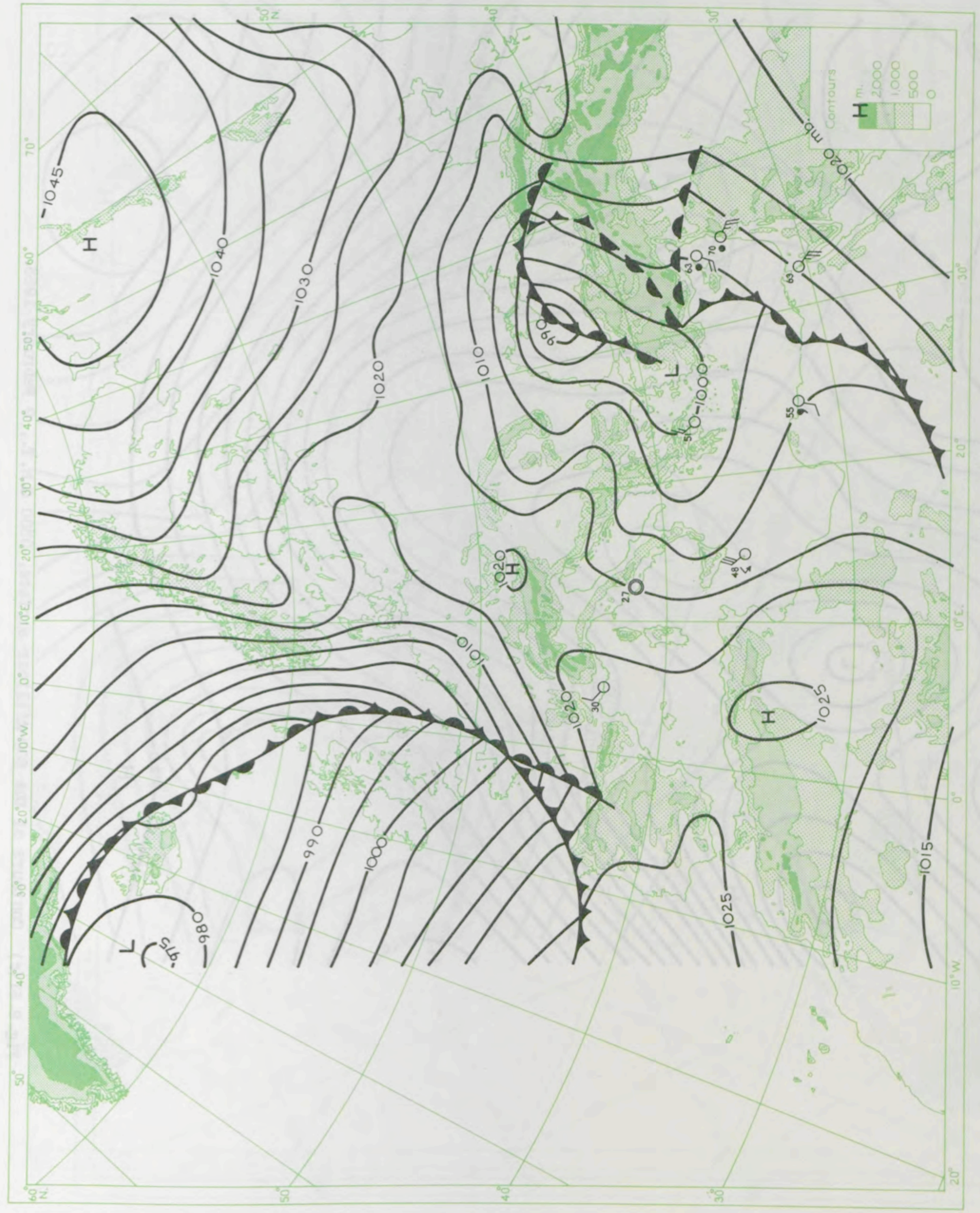


Fig. 2.51 (*b*) Synoptic situation, 0000 G.M.T., 9 February 1953.

Fig.2.51(c) Contours of the 500-millibar surface, 0300 G.M.T., 9 February 1953.

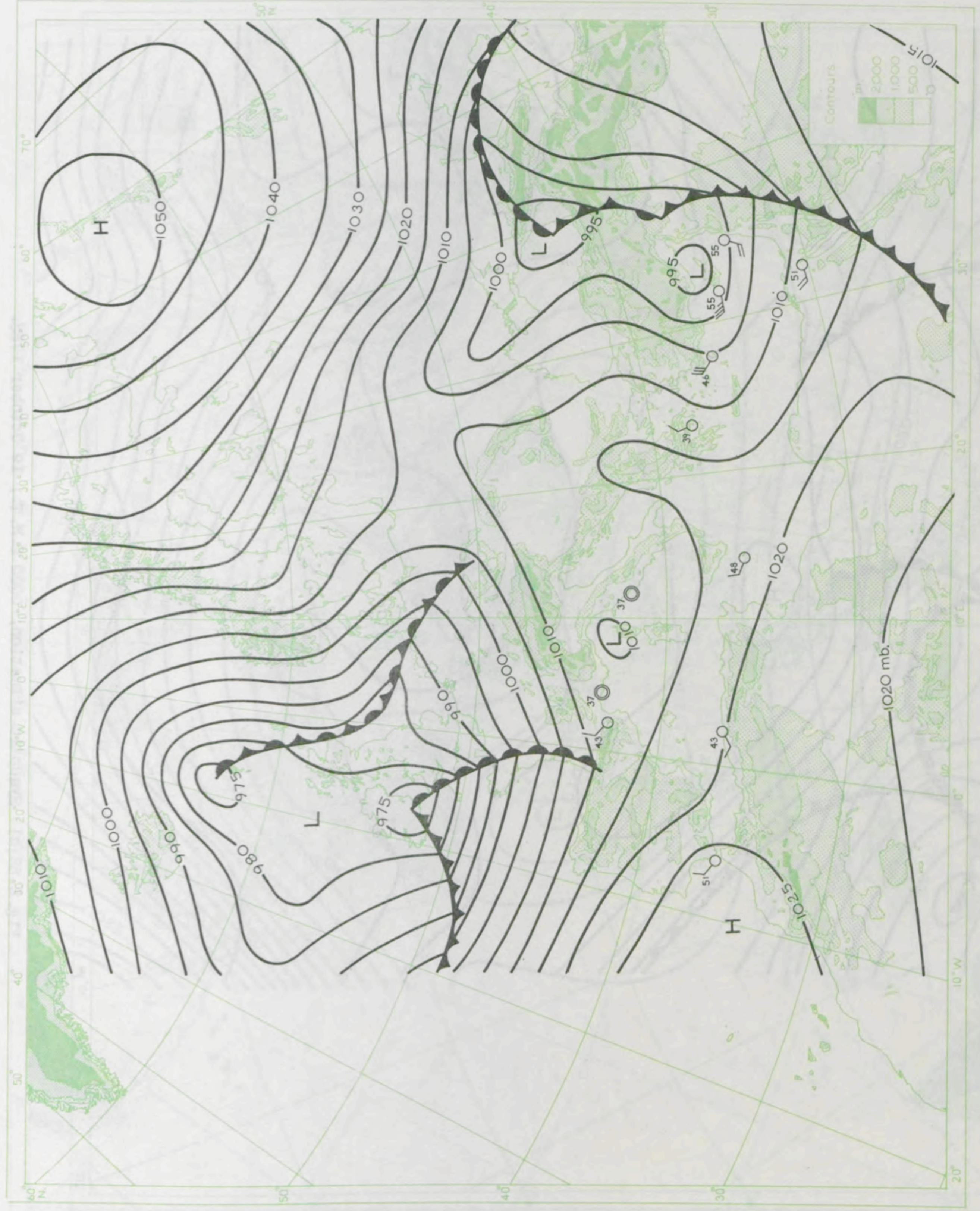


Fig.2.51(d) Synoptic situation, 0000 G.M.T., 10 February 1953.

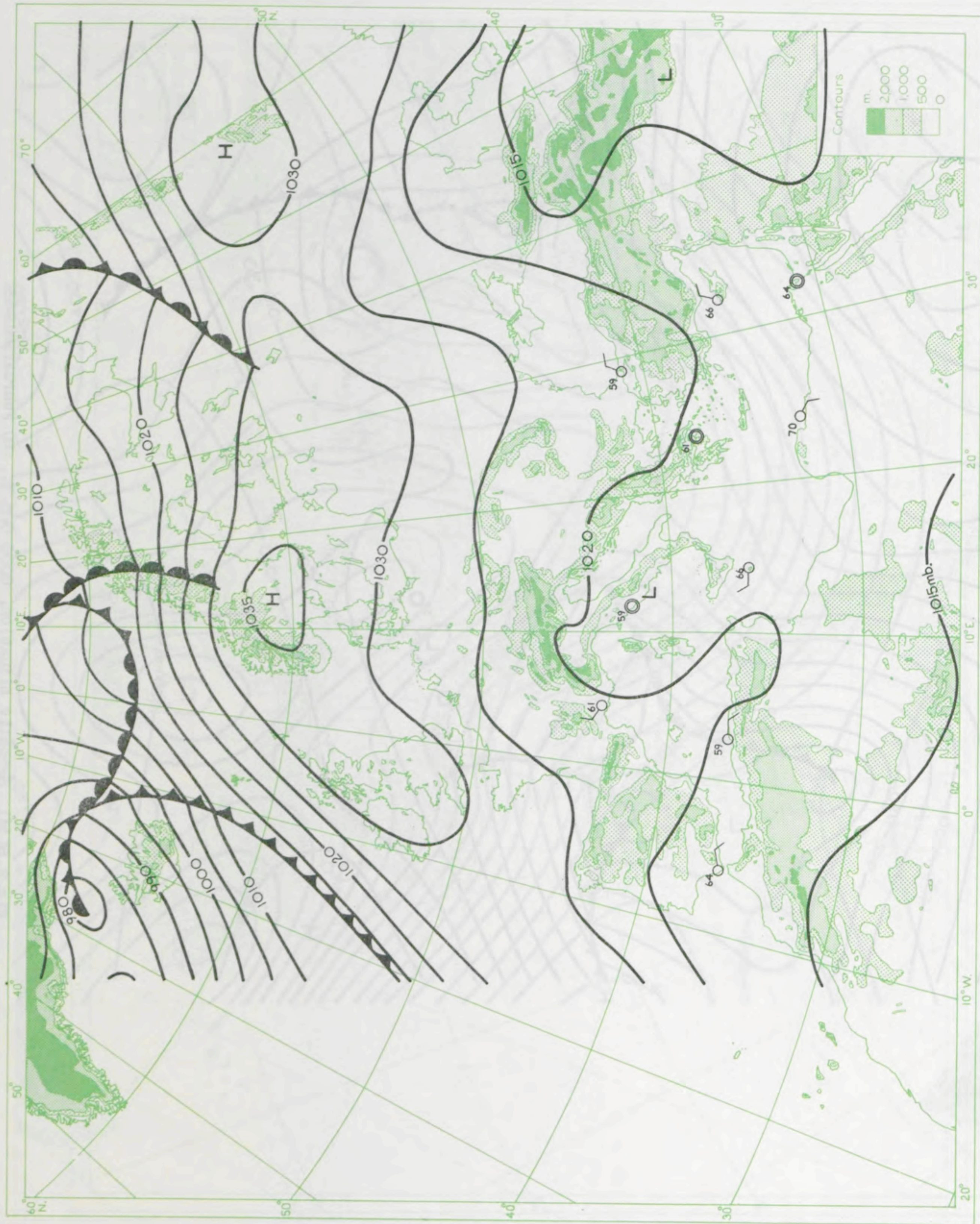


Fig. 2.52(*a*) Synoptic situation, 0000 G.M.T., 19 October 1953.

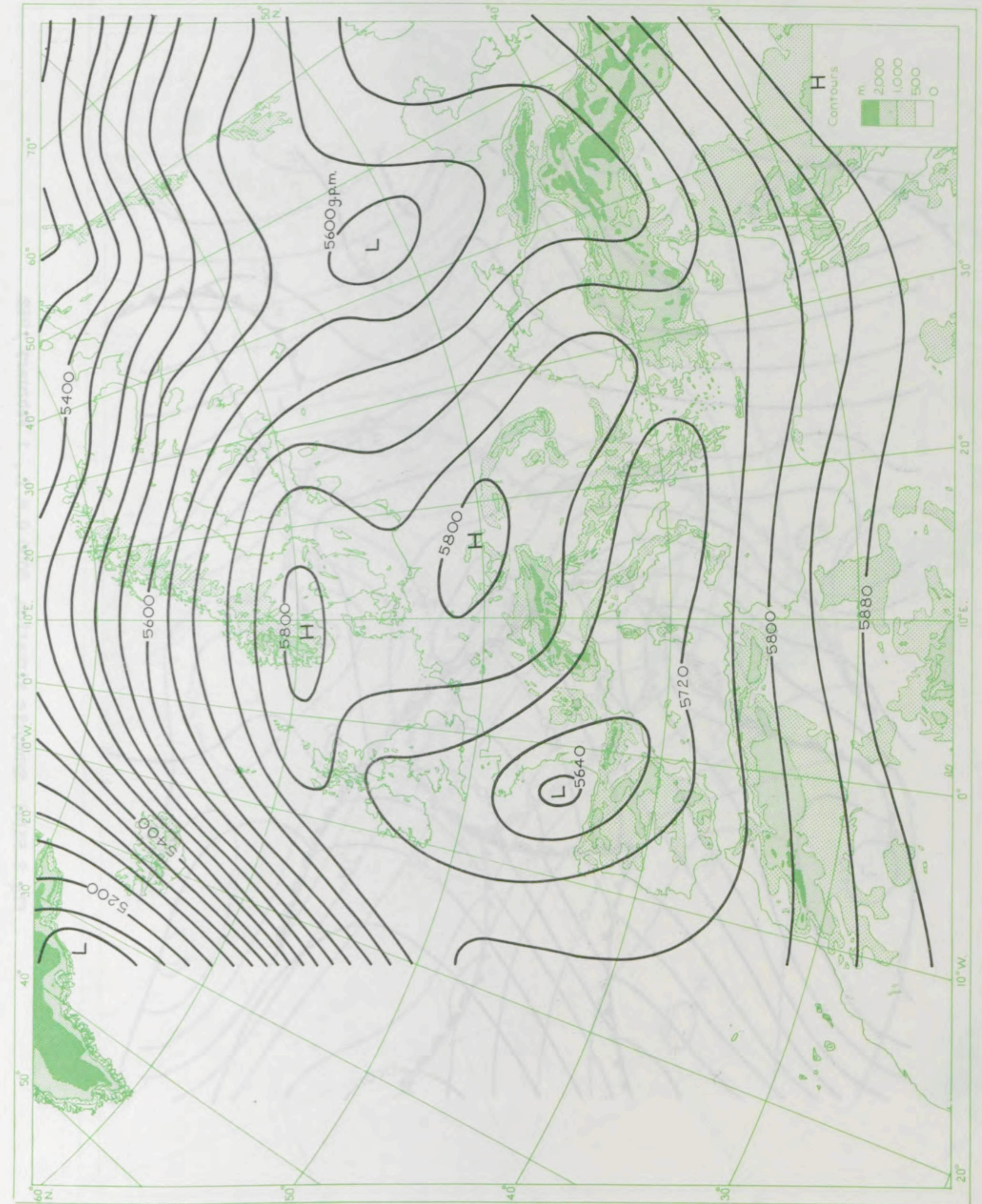


Fig. 2.52(*b*) Contours of the 500-millibar surface, 0300 G.M.T., 19 October 1953.

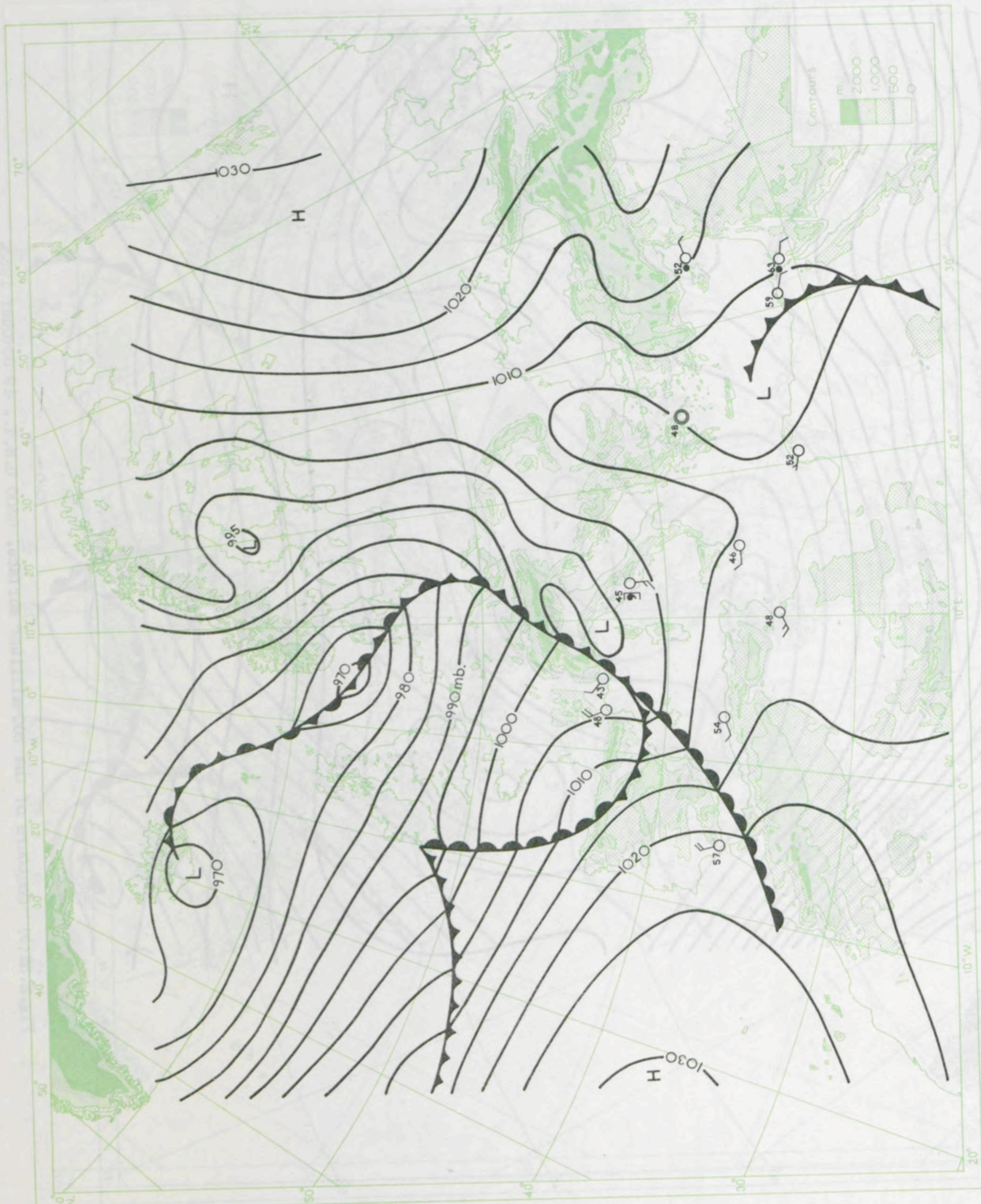


Fig.2.53(*a*) Synoptic situation, 0000 G.M.T., 1 February 1952.

Fig.2.53(*b*) Synoptic situation, 0000 G.M.T., 2 February 1952.

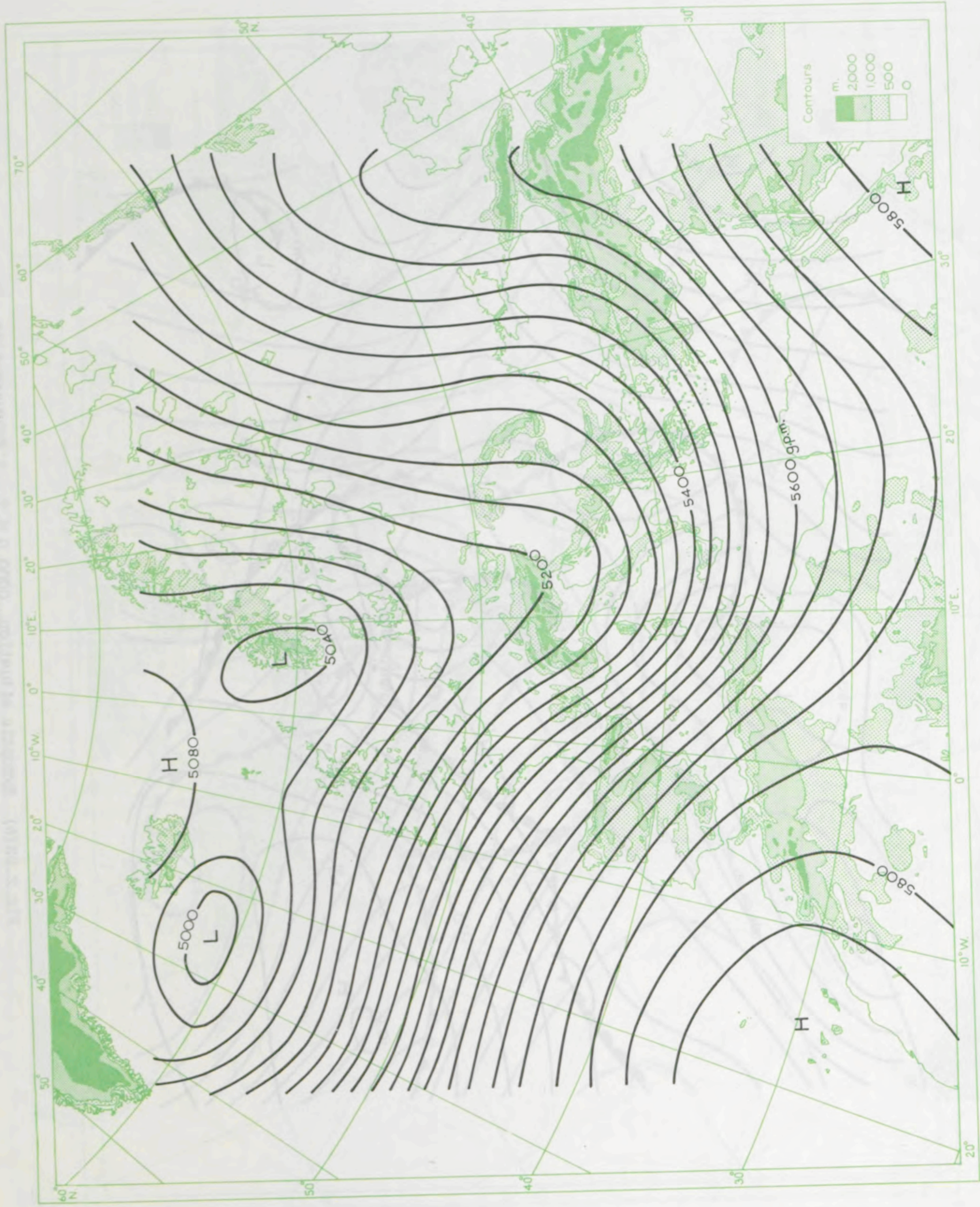


Fig.2.53(c) Contours of the 500-millibar surface, 0300 G.M.T., 2 February 1952.

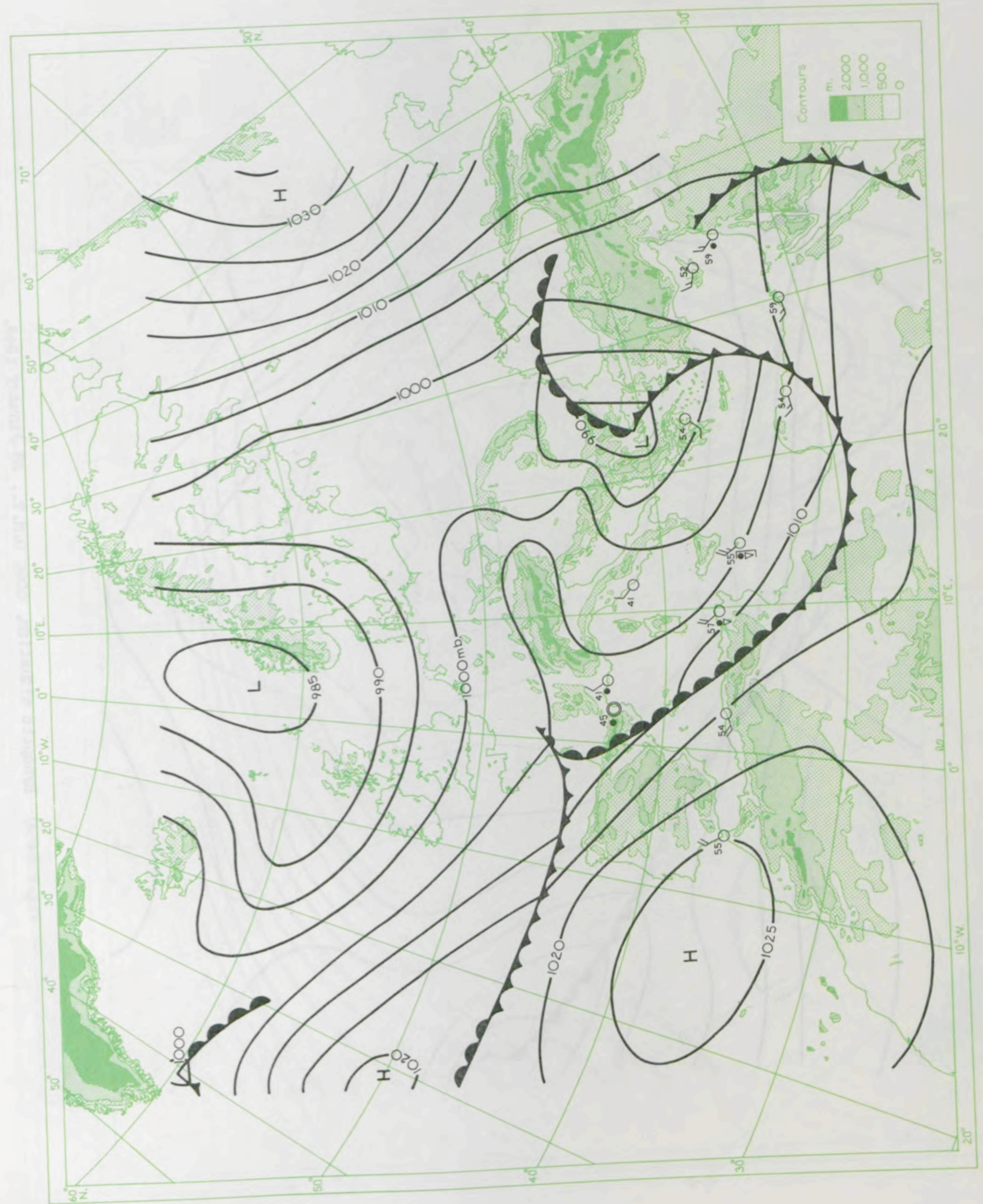


Fig.2.53(d) Synoptic situation, 0000 G.M.T., 3 February 1952.

Fig. 2.54(*a*) Synoptic situation, 0000 G.M.T., 28 January 1949.

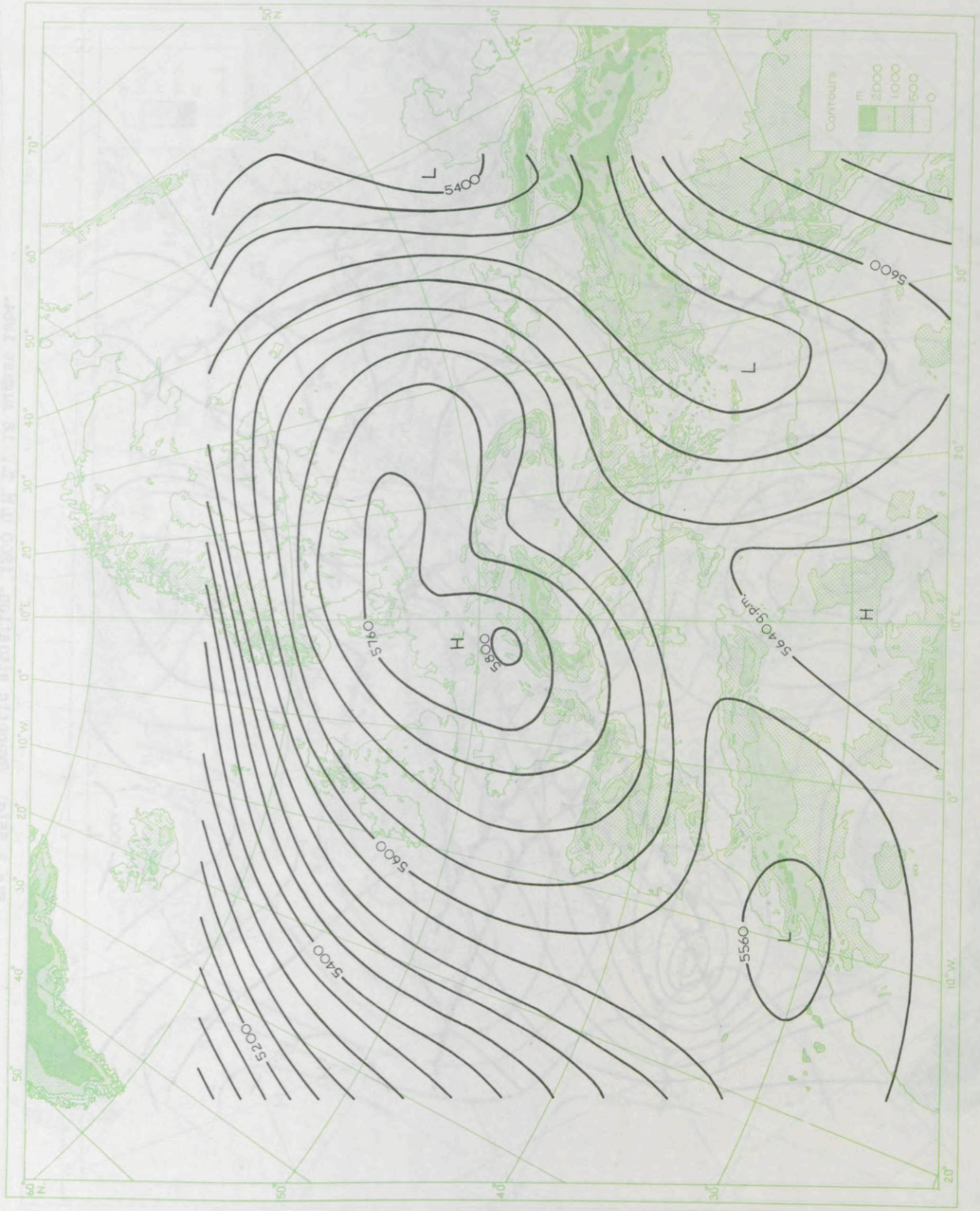


Fig. 2.54(*b*) Contours of the 500-millibar surface, 0300 G.M.T., 28 January 1949.

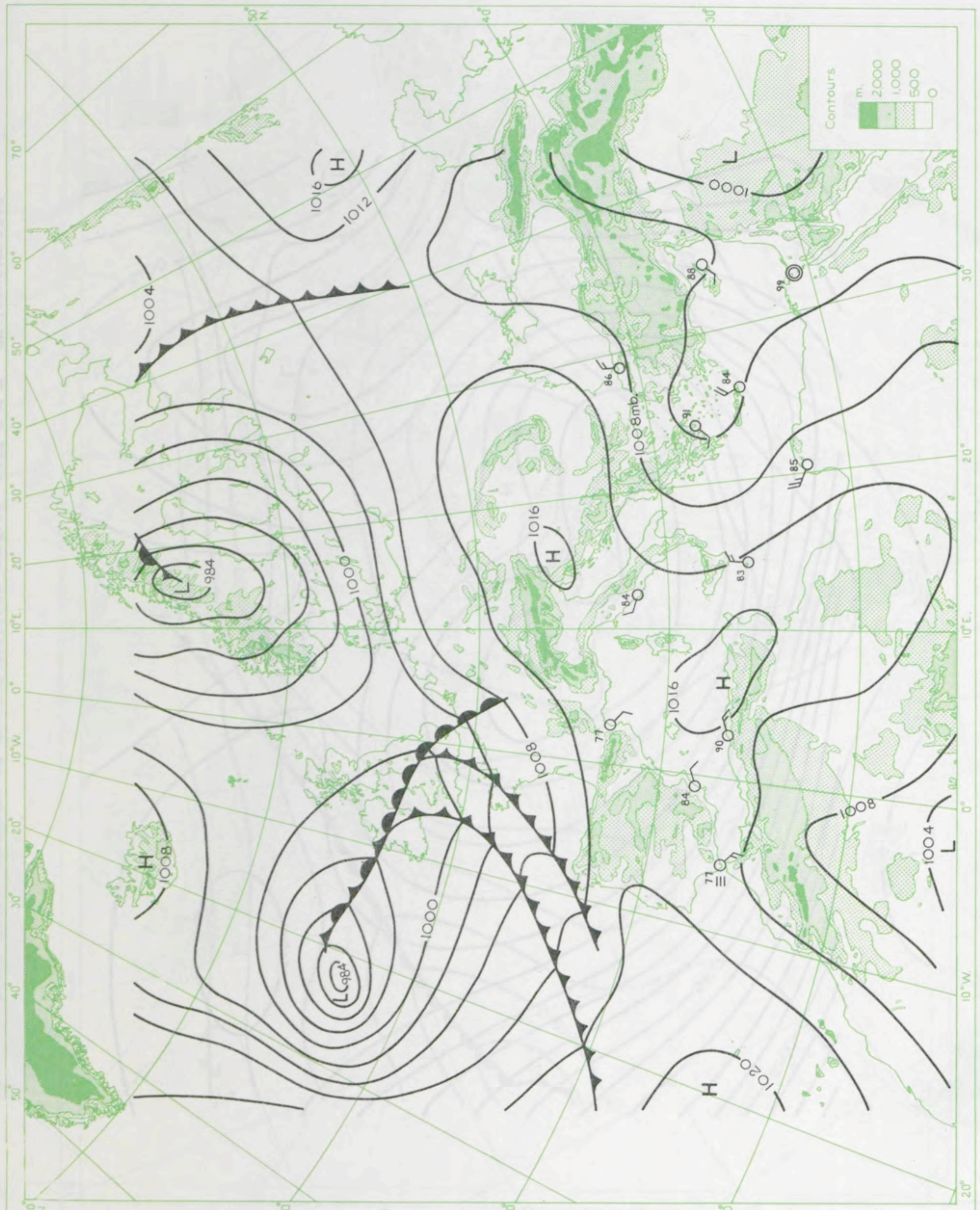


Fig.2.55(a) Synoptic situation, 1200 G.M.T., 12 August 1954.

Fig.2.55(b) Synoptic situation, 1200 G.M.T., 13 August 1954.

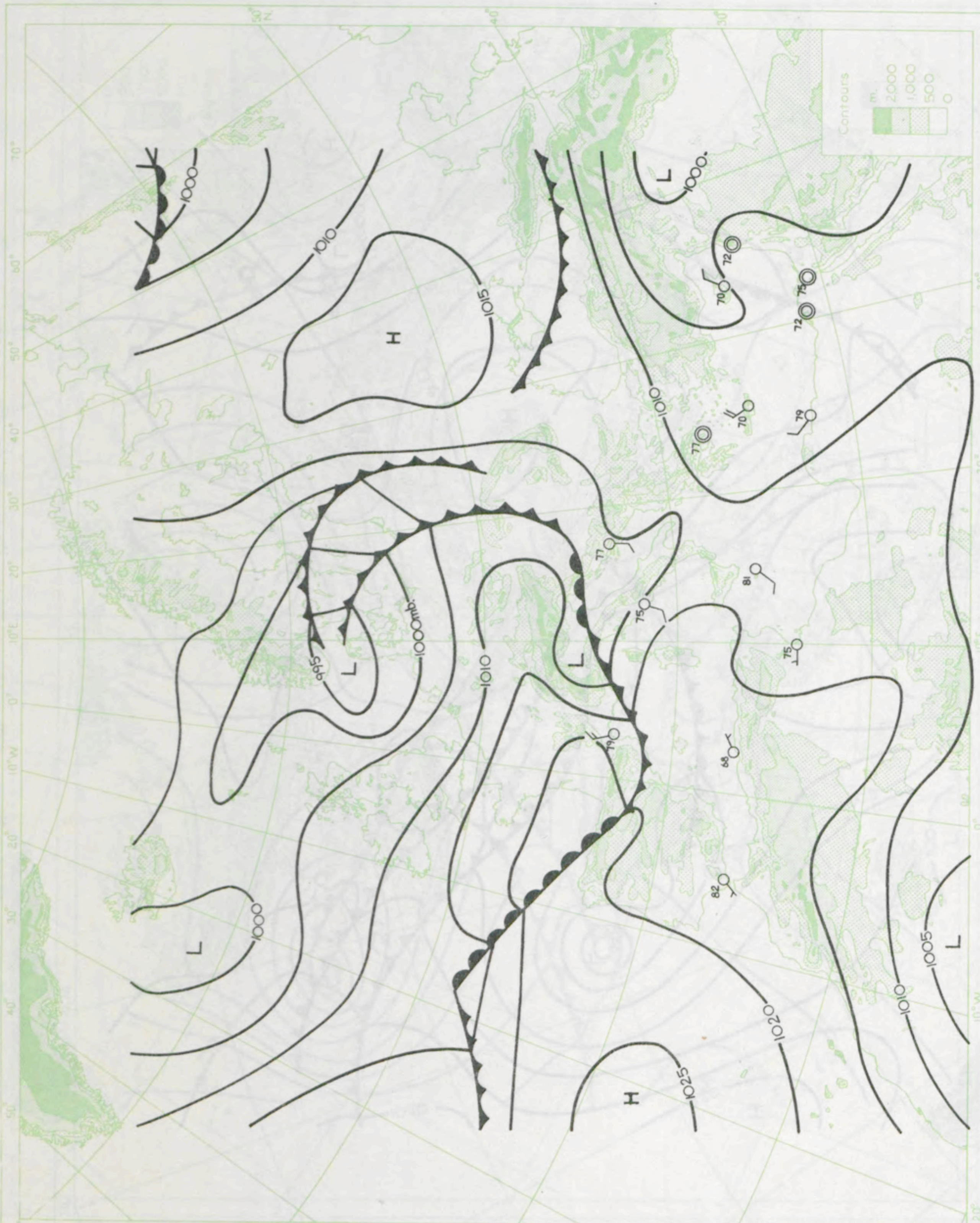


Fig.2.58(*a*) Synoptic situation, 0000 G.M.T., 24 July 1950.

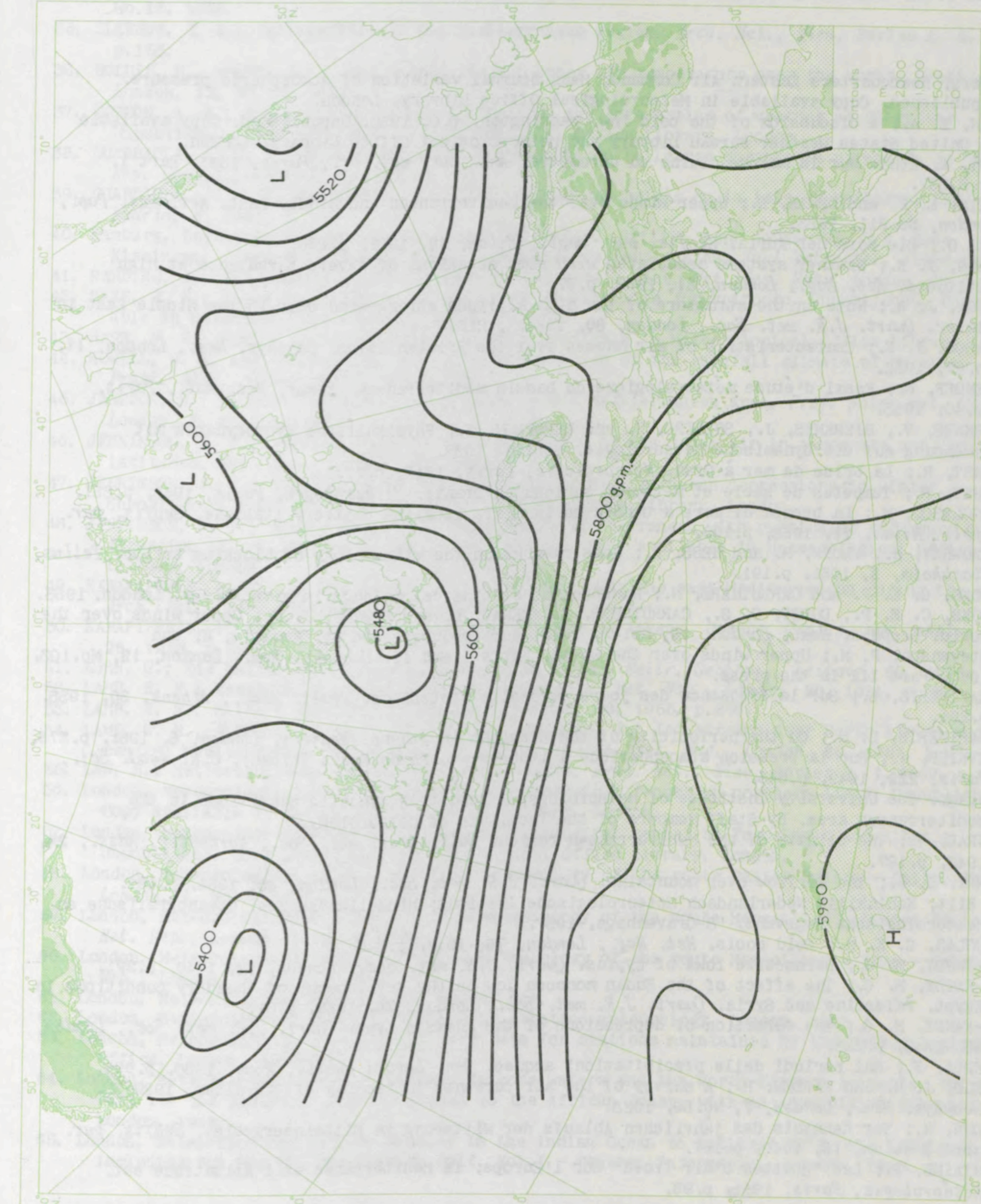


Fig.2.58(*b*) Contours of the 500-millibar surface, 0300 G.M.T., 24 July 1950.

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