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FOREWORD

This report describes how the natural geomagnetic environment influences Magnetic Anomaly Detectors (MAD) used by Naval aircraft in ASW operations. It has been developed from training materials originally prepared by the U. S. Naval Oceanographic Office for use in an Applied Environmental Science for Patrol Anti-Submarine Warfare Systems course.

Comments on the usefulness of this report and suggestions for improvement are welcomed.



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Captain, U. S. Navy
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INTRODUCTION

Magnetic Anomaly Detectors (MAD) have been carried aboard U. S. Naval Aircraft for about 25 years. From the ASQ-1 of the 1940's to today's ASQ-10, the basic principle of the system has remained the same. What has improved over the years are such things as the electronic circuits, compensation procedures, and a better understanding of the natural environment in which the detectors operate.

During the two and one-half decades of the evolution of MAD gear many reports have been prepared for the purposes of instructing those responsible for the operation of MAD devices as to the proper maintenance, repair, and tactical use of these detectors. Those reports that have dealt with the principles of operation of MAD, or the geomagnetic environment in which MAD operates, have been written primarily for the information of the scientist or engineer involved in the development of the instrumentation. This report has been prepared in an effort to better inform those directly involved in MAD operations about certain principles of operation and the natural environmental factors affecting the MAD equipment.

ORIGINS OF THE STUDY OF GEOMAGNETICS

Everyone engaged in Naval Aviation is well acquainted with man's most successful magnetic sensing device, the magnetic compass. The magnetic compass, in one form or another, has been used for centuries; it is a simple reliable device which even today is a most important navigation instrument.

It is uncertain who first exploited the directional properties of the earth's magnetic field; both Asians and Europeans have been cited as the originators of the magnetic compass. It is known that the peculiar properties of what was called the lodestone were mentioned in ancient Greek literature some 600 B.C.

The lodestone, or magnetite as it would later be called, was said to have great powers that could cure many sorts of maladies. One of the myths connected with the magic stone warned that if it was rubbed with garlic it would lose its directive properties, therefore, sailors of the Middle Ages, were warned not to eat garlic or onions for fear of depriving the compass of its directive properties. (The admonition against garlic and onions could well serve the "flying sailors" of the Twentieth Century.)

Many names are involved with the development of the magnetic compass; one of the first authoritative European reports on the properties of the magnet and

the construction of the compass, was written by the Frenchman, Pierre Pelerin de Marcourt, known also as Petrus Peregrinus. He reported his experiments with the magnet and compass in a letter to a friend written in 1269.

The development of the compass contributed greatly to the epic voyages of discovery of the 15th and 16th centuries. During these long voyages it was noted that the compass did not in fact point to true north. This discrepancy between the direction that the compass pointed and true north was also noted by the astronomers of the era. By the first half of the 15th century the angular difference between true north and magnetic north had been documented. Thus magnetic variation became an acknowledged fact. The term magnetic variation is still used by the marine and air navigators of today. Magnetic declination is the name used for the same angle by the geophysicist.

On most modern charts used for air navigation, lines of equal magnetic variation are drawn. These lines are called isogonic lines. One of the earliest charts presenting lines of equal variation was the work of astronomer Edmond Halley. In 1701 Halley published a chart showing the variation lines over the Atlantic Ocean based upon observation made aboard the British ship "Paramour" between 1698 and 1701, a survey funded by the British Government.

In 1544, a Nuremberg instrument maker named Hartmann, recorded the fact that when he magnetized a perfectly balanced compass needle the north end tended to dip below the horizon. A contemporary of Hartmann in London, Robert Norman, became intrigued by the tendency of the compass needle to dip. He was the first to devise an instrument to measure the dip of the magnetic field, or magnetic inclination to give the angle its more formal name.

Norman's investigations led him to publish a book called, "The Newe Attractive" in 1581. In the book Norman theorized that the compass needle was influenced by a point within the earth instead of being influenced by the heavens, as most people of that time thought.

William Gilbert, in 1600, published one of the great works in the science of geomagnetics. Gilbert in his "De Magnetic" proposed that the earth itself was a "great magnet"; that like the lodestone, the earth had magnetic poles and a magnetic equator. Much of the material Gilbert presented was based on his own very careful experimentation. Gilbert believed that the earth's magnetic field was uniformly distributed throughout the globe, and that although the field may differ in direction from place to place that it held its direction with time, except in those instances when some geologic catastrophe might change it.

If Gilbert's theory had been right, that the field remained stable with time, the study of geomagnetics would be far simpler. However, shortly after Gilbert's death, Henry Gellibrand, a professor of mathematics, determined the magnetic variation at a location near London was $4^{\circ}05'$ East. His observations were made in June 1634. Gellibrand searched the records of previous observers and discovered that in 1580 the variations in the area had been $11^{\circ}15'$ East. The practical importance of Gellibrand's discovery to the navigators of his and succeeding times was immense. The records of variation observations in the London area are most interesting; they show that in 1600 the magnetic variation was about 10° East and by 1800 the variation had changed to 24° West. The 1965 World Variation Chart shows the value at London to be $7-1/2^{\circ}$ West.

Another Londoner, George Graham, is generally credited with the discovery of the fact that in addition to the long term change Gellibrand observed, that there is also a daily change of the field. After making many observations at various times of the day, he announced his findings of the daily variations in 1722. Daily variation is not of much importance in navigation, but it must be taken into consideration in land surveys of large areas using magnetic compasses.

Much of the early knowledge of the earth's magnetic field was gained from the observations of the mariners and explorers of the era of the wooden hulled ships. The explorers of the Arctic and Antarctic contributed much knowledge about the magnetic polar areas. These men had both a scientific and a practical navigational interest in determining the variation of the earth's field. In the early 1800's magnetic observatories were set up in many countries in order to more systematically record the changes in the magnetic field components. One of the first observatories operated in the United States was located at Girard College, Philadelphia, from 1840 to 1845.

The latter part of the 1800's saw a great increase in the number of magnetic observatories. Many land surveys were undertaken for the purpose of determining the magnetic variation. In Sweden a special instrument was developed for the purpose of conducting surveys for iron ore. This instrument had its magnetic needle suspended so that it could rotate in both the horizontal and vertical plane. The first magnetic prospecting survey was conducted in the United States in New Jersey in 1880 using an American version of the Swedish mining compass.

Although much work had been done in establishing magnetic observatories and conducting surveys over land, until the 1900's, very little work had been done defining the earth's field over the three-quarters of the earth covered by the oceans. The early surveyors at sea were interested only in magnetic

variation observations. The Department of Terrestrial Magnetism of the Carnegie Institute of Washington was one of the pioneers in magnetic surveys at sea. The specially designed and equipped magnetic survey vessel CARNEGIE covered about 300,000 line miles of ocean survey work from 1909-1929. Carnegie made observations of variation, dip, and horizontal intensity. Unfortunately the CARNEGIE was destroyed by fire in Samoa in November 1929.

Today, the U. S. Naval Oceanographic Office is charged with the responsibility of publishing a series of world charts that define the various components of the earth's magnetic field. In order to provide the information for these charts, Project MAGNET, a world-wide survey of the ocean areas of the globe was started in 1953. This airborne survey is conducted using two specially modified and equipped U. S. Naval Aircraft, one a C-54, the other a C-121. In a typical year these aircraft will provide 230,000 line miles of data for the charting program. The magnetometer used aboard these aircraft is a Vector Airborne Magnetometer (VAM). This instrument was developed by the Naval Ordnance Laboratory from the AN/ASQ-3A magnetometer, a MAD device. Project MAGNET observations include total intensity, dip, and variation. Figure 1 shows the relationship of the components of the earth's field.

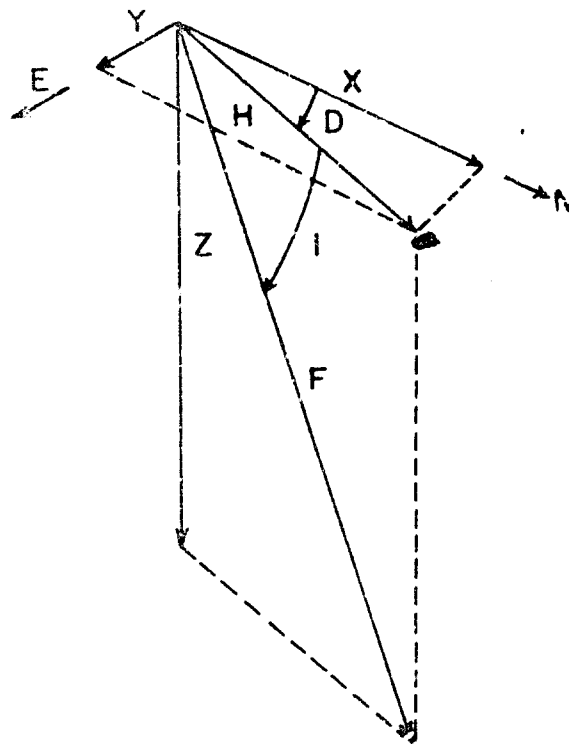
MAGNETIC AIRBORNE DETECTION

The field of exploration geophysics has enjoyed a rapid growth in the 20th century. Many techniques and instruments have been invented that have proved most useful in the discovery of mineral resources.

Those geophysicists who specialized in magnetic prospecting were quick to recognize the great advantage that could be gained if a method could be found to obtain valid magnetic measurements from an aircraft. In 1941, Gulf Research and Development Corporation perfected a flux-gate magnetometer that could be used in the air.

Gulf's magnetometer shared a common experience with many young men in the early 1940's; it was drafted. The National Defense Research Committee (NDRC) recognized the great anti-submarine warfare potential of this magnetometer, and before it could hunt for minerals and oil it was assigned the task of hunting submarines. NDRC sponsored the development of the AN/ASQ-1 and 2. Later development of MAD was undertaken by NOL.

MAD was not widely used in World War II because it was not available in quantity until the later stages of the war. Probably the first significant use of MAD was aboard PBY aircraft used to establish a barrier at the Straits of Gibraltar during 1944. Several submarines were sunk as a result of initial MAD contact.



F - TOTAL INTENSITY
 H - HORIZONTAL INTENSITY
 Z - VERTICAL INTENSITY
 Y - EAST COMPONENT
 X - NORTH COMPONENT
 D - MAGNETIC DECLINATION
 I - INCLINATION

FIGURE 1. RELATIONSHIP OF THE EARTH'S MAGNETIC FIELD COMPONENTS

These sinkings discouraged the Germans from using the Straits as a passage to the Mediterranean Sea.

The ASQ-10 magnetometer being flown aboard modern fleet aircraft can be described as a flux-gate or saturable core magnetometer. The sensing element of the ASQ-10 responds to changes in the total field component of the earth's field, designated by the F in Figure 1. The standard unit of measurement of F is the gamma. Figure 2 shows how the value of F varies over the earth's surface. When the earth's field is presented at this scale a rather smooth pattern results. However, later in this report when a small area of the earth is examined in detail it will be seen that the field does in fact have many irregularities.

The prospector is interested in the large relative changes in total intensity that are caused by the particular geologic structure in a survey area. The MAD operator is interested in detecting a much smaller change in the earth's field caused by the distortion of the total field component when a submarine's magnetic field is superimposed on the natural field.

Both the prospector and the MAD operator use the earth's field balance to cancel the major portion of the earth's field. By means of this device the user can reduce the portion of the field he must deal with from a typical value of 50,000 gammas to 1,000 to 2,000 gammas. However, when the sensor is used in detecting submarines, a special filter is added to the magnetometer system; it is the output of the filter that is displayed to the MAD operator on his strip chart recorder.

THE MAD FILTER AND DETECTION FACTORS

In order to properly interpret the various types of signals that appear on the MAD recorder trace it is necessary to understand how the filter works. The filter has been added to the system so that the relatively small signal generated by the submarine can be separated from the natural gradient of the earth's field. Figure 3 illustrates the affect of superimposing the field of a submarine on the earth's field.

The submarine, like most magnetic bodies, can be considered to have a positive and negative pole. A magnetic body with two poles is termed a dipole. The shape and size of the signal that will appear on the MAD trace will depend on the following factors: (a) the size of the submarine; (b) how fast the aircraft is traveling; (c) the closest point of approach of the aircraft to the submarine; (d) the course of the aircraft as it passes through the submarine's field; (e) the magnetic heading of the submarine. Another factor, the effect of the natural magnetic background, will be discussed in the next section.

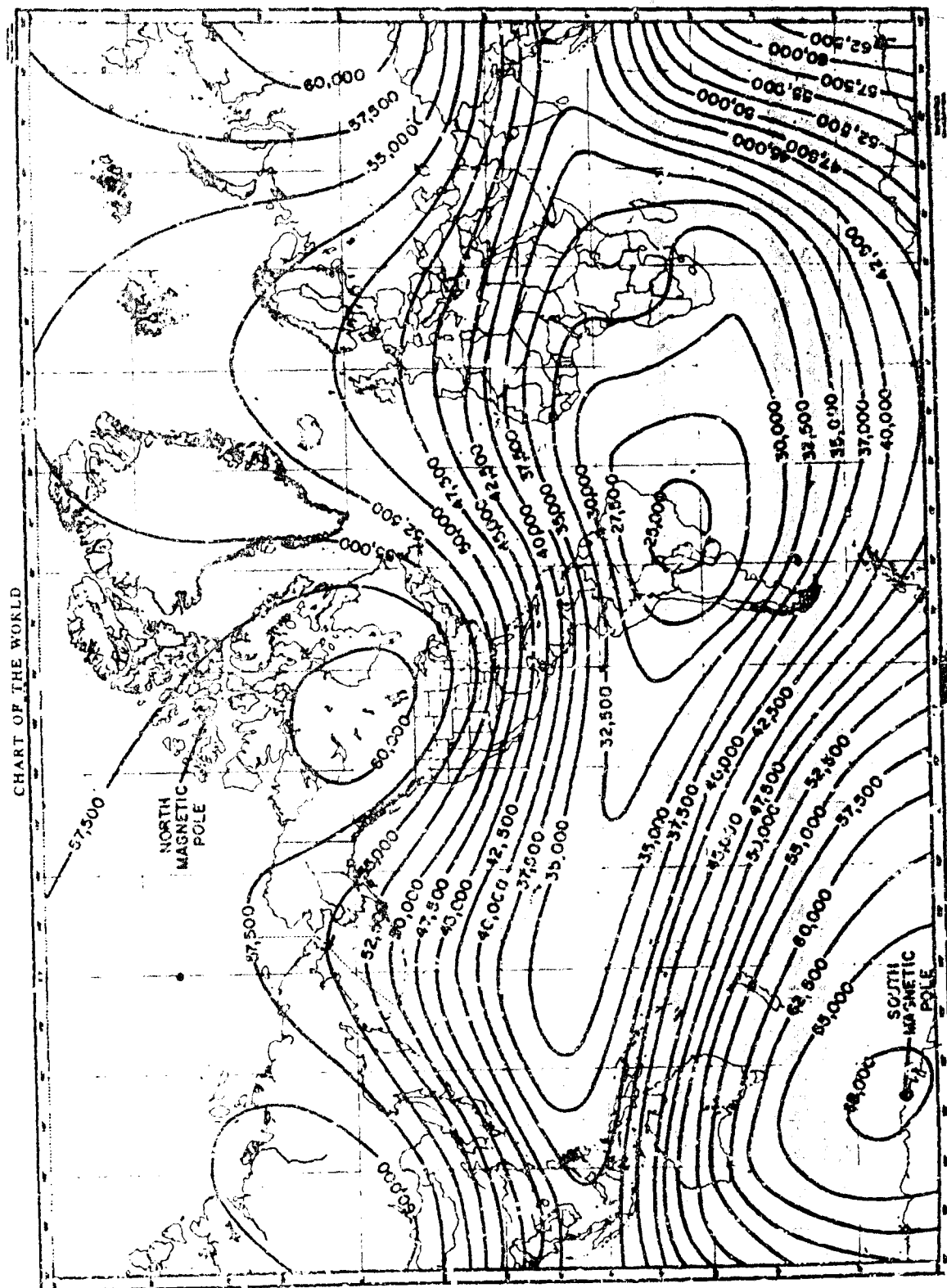


FIGURE 2. THE TOTAL INTENSITY OF THE EARTH'S MAGNETIC FORCE EXPRESSED IN GAMMA'S EPOCH 1965.0 BASED ON H.O. 1703

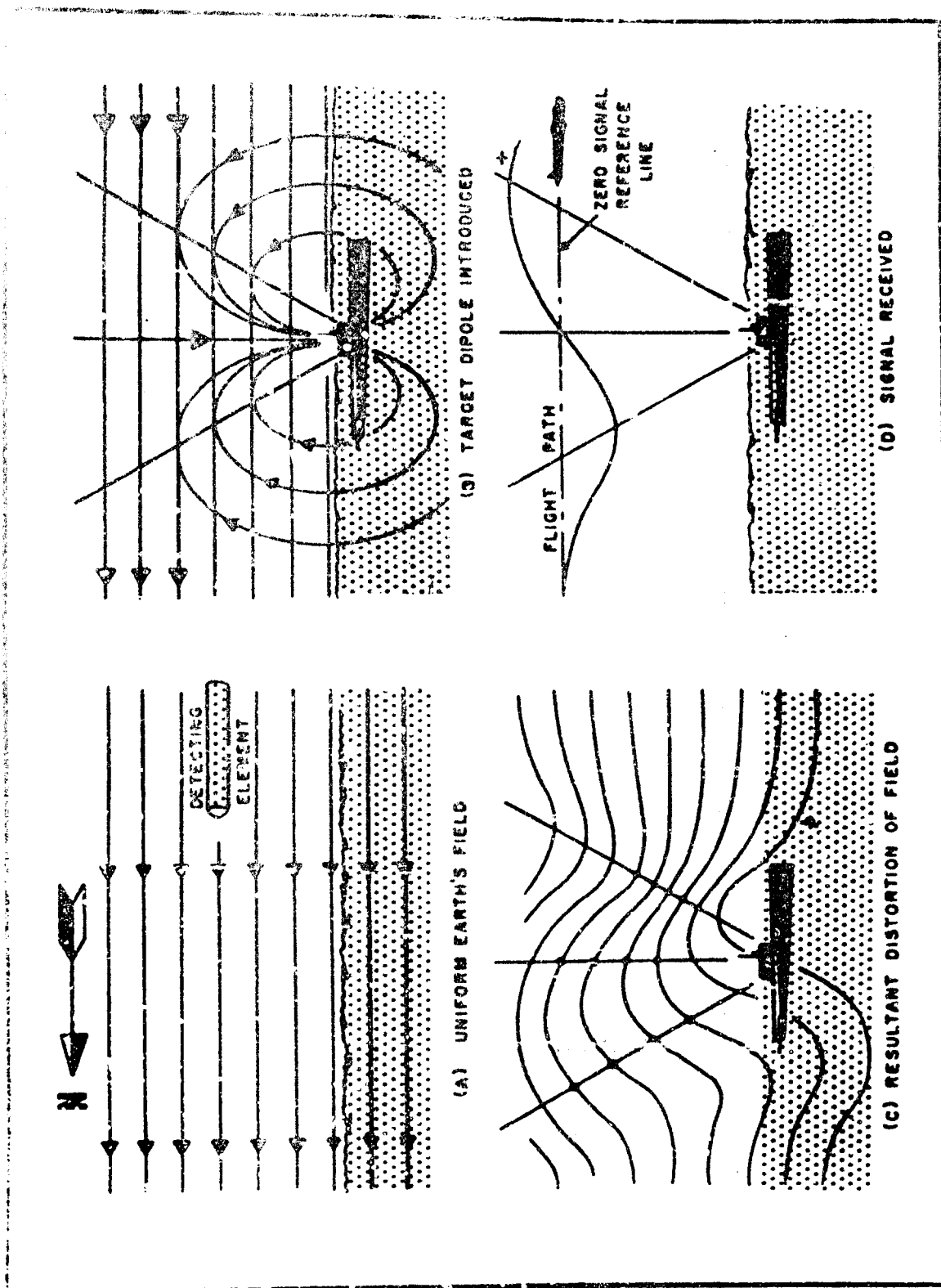


FIGURE 3. FORMATION OF AN ANOMALY IN THE EARTH'S MAGNETIC FIELD
(FROM "MAGNETIC AIRBORNE DETECTION", NAVAER 00-80T-55.)

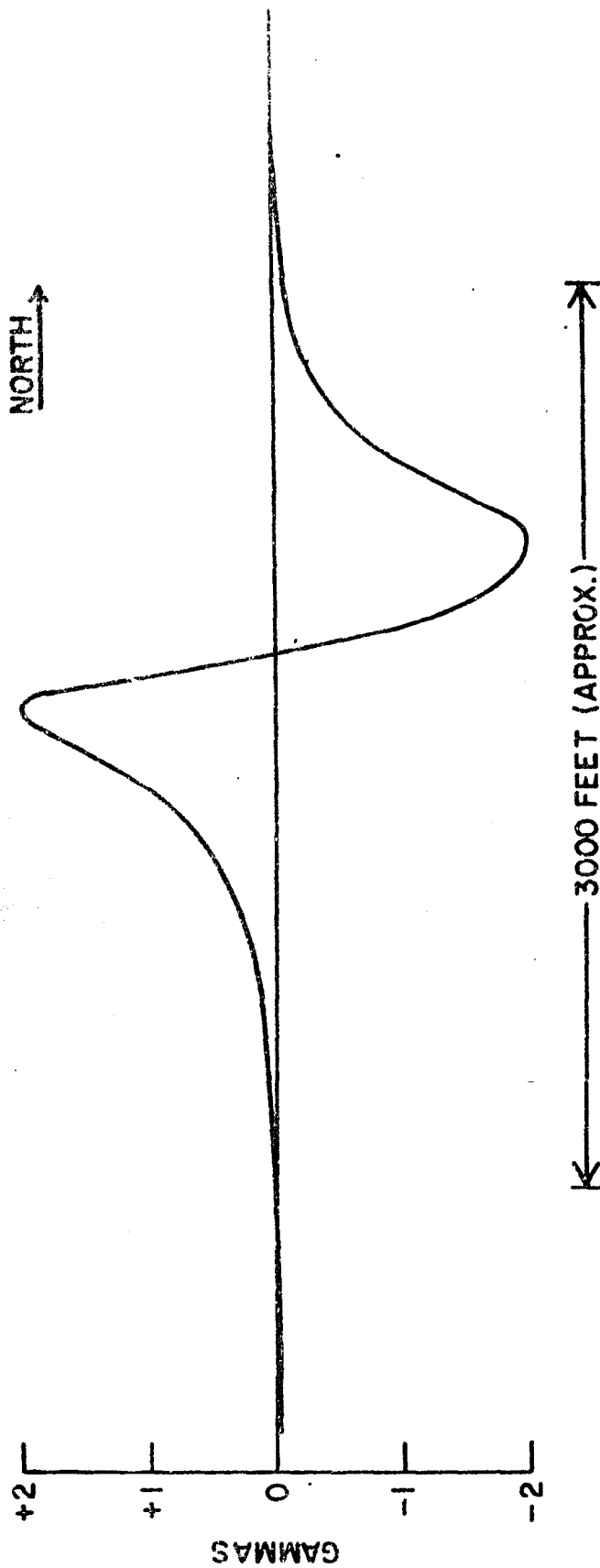
Figure 4 depicts the shape of a submarine signal as seen by the sensing element of the magnetometer. In this case the aircraft course was north magnetic at an altitude of 500 feet. The aircraft passed directly over a surfaced submarine headed north magnetic. The positive and negative segments of the submarine signal are evident. Although the submarine signal appears on the MAD recorder as a single form or shape, the signal is actually made up of a combination of several frequencies. A detailed analysis of this submarine signal shows that it is composed principally of the five frequencies shown in Figure 5. The figure shows the difference in amplitude of the various frequencies as well as the phase shift. The phase shift can be seen by noting the different stage in the cycle for each frequency at line A.

Figure 6 is an amplitude response curve for a filter used in an ASQ-10 MAD system. This type of filter is used in patrol aircraft whose usual maneuvering speed for MAD operations is about 180 knots. The filter is designed to admit those frequencies that compose the submarine signal while excluding the low frequencies such as would be produced as the aircraft moves through the earth's normal field, and the higher frequencies generated by the aircraft electrical systems. The five fundamental frequencies shown in Figure 5 are marked on the amplitude response curve, along with the percentage of the amplitude passed by the filter.

To aid in visualizing how the various frequencies combine to form the submarine signal, Figure 7 has been prepared. Starting with the five frequencies shown in Figure 5, Figure 7 first adds frequencies 1 and 2, then on each successive curve one more frequency is added; the bottom curve combines all five frequencies. The bottom curve shows a total amplitude of 3.5 gammas as compared to the original 4 gamma amplitude in Figure 4. This demonstrates that the five fundamental frequencies in this signal account for 87.5% of its amplitude. Other higher frequencies of smaller amplitude than the five shown make up the rest of the signal.

Figure 8 compares the detectable submarine signal with the resultant signal that would be seen on the MAD trace. The figure shows that the aircraft would have traveled about 3000 feet during the time the recognizable part of the submarine signal occurred on the MAD trace. At 180 knots this would mean about ten (10) seconds of time. After passing through the MAD filter, approximately 82% of the signal remains to be displayed on the MAD trace.

Figure 9 has been prepared to demonstrate the effect of a change of aircraft speed on the MAD signal processing system. If we take the same track



AIRCRAFT ALTITUDE 500 FEET
AIRCRAFT SPEED 180 KNOTS
AIRCRAFT COURSE NORTH MAGNETIC
HORIZONTAL SEPARATION OF AIRCRAFT AND SUBMARINE 0 FEET

FIGURE 4. DETECTABLE SUBMARINE SIGNAL

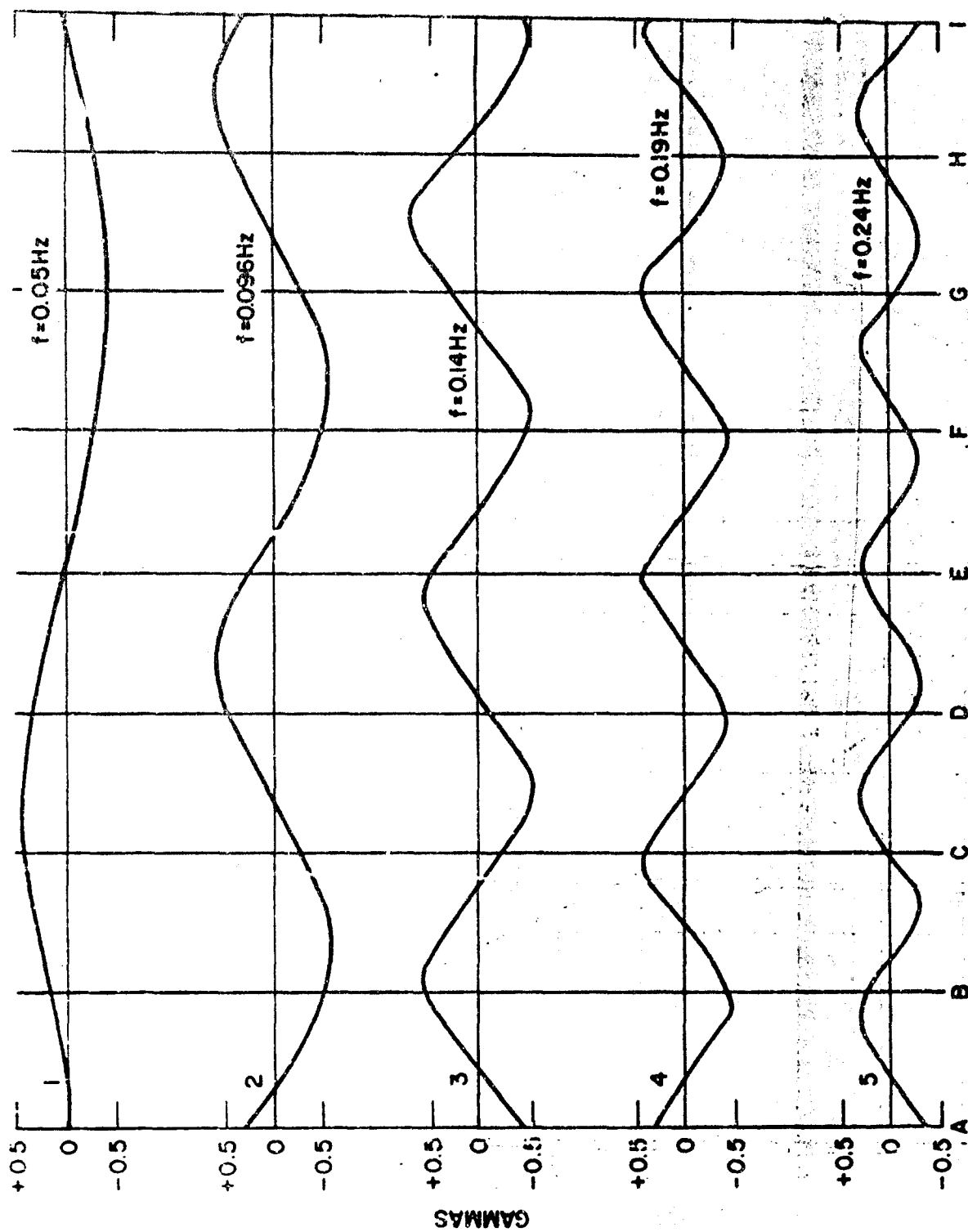


FIGURE 5. FUNDAMENTAL FREQUENCIES COMPOSING SUBMARINE SIGNAL

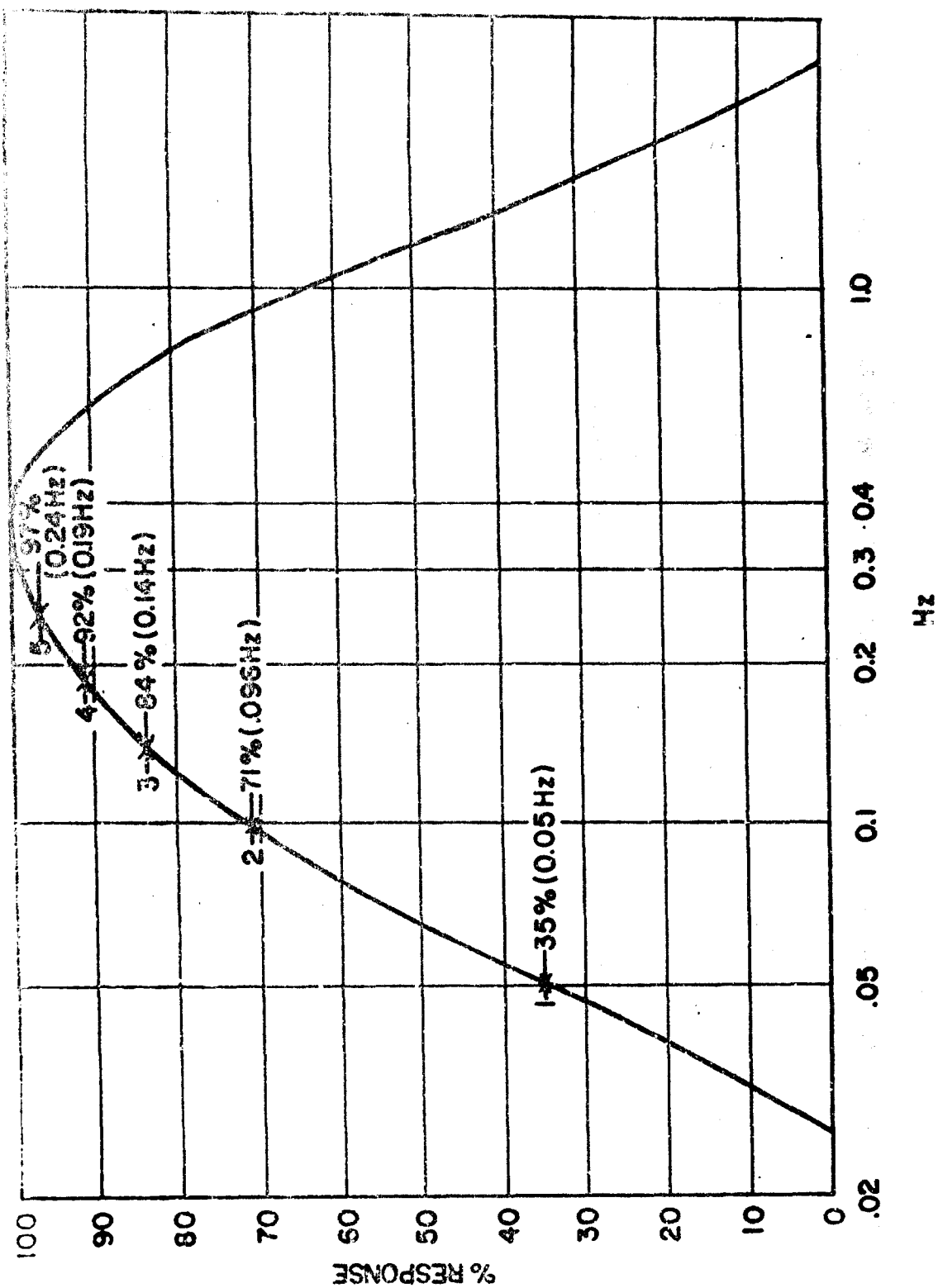


FIGURE 6. AMPLITUDE RESPONSE CURVE FOR A FILTER USED IN AN AN/ASQ-10

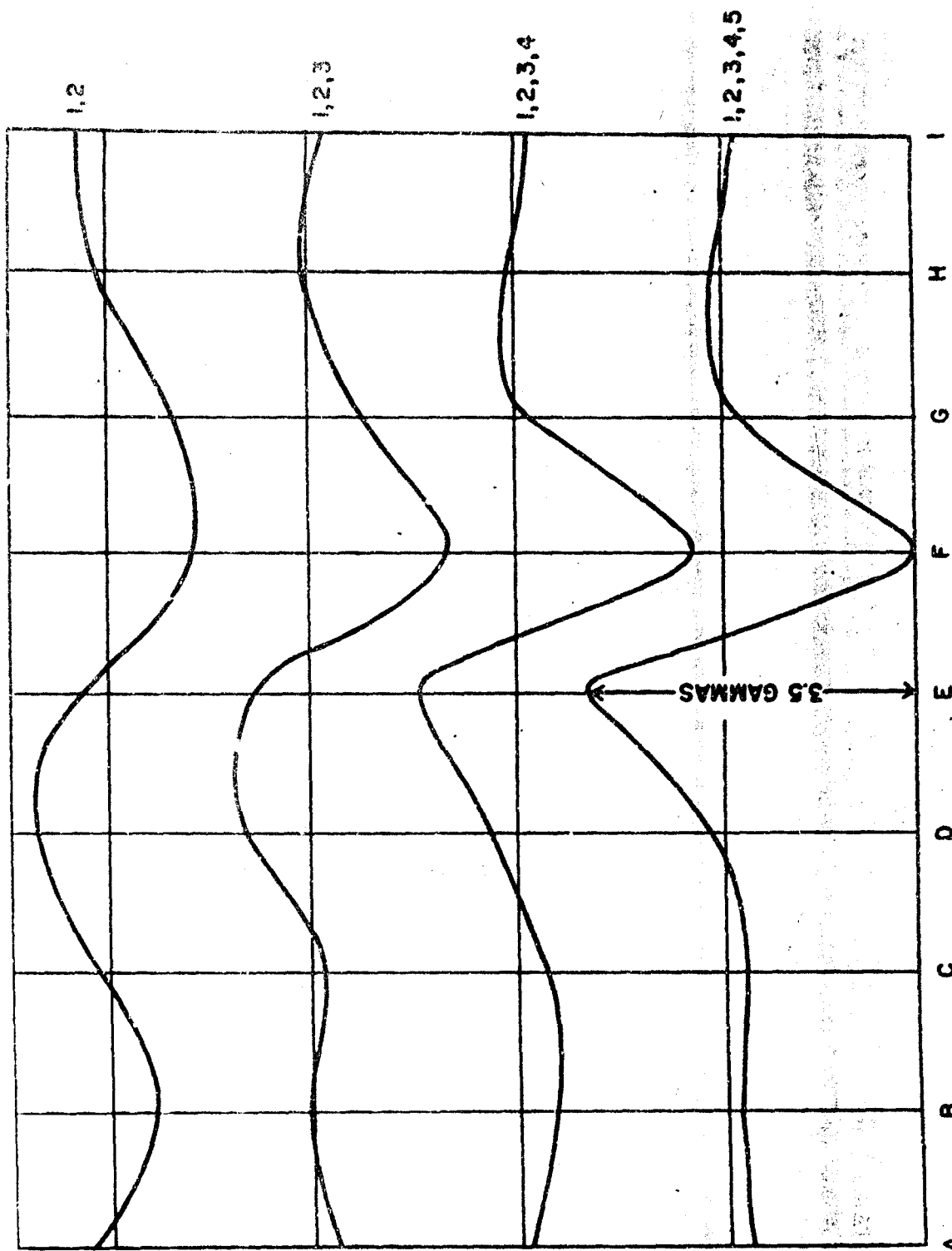


FIGURE 7. HOW THE FUNDAMENTAL FREQUENCIES COMBINE TO MAKE THE SUBMARINE SIGNAL

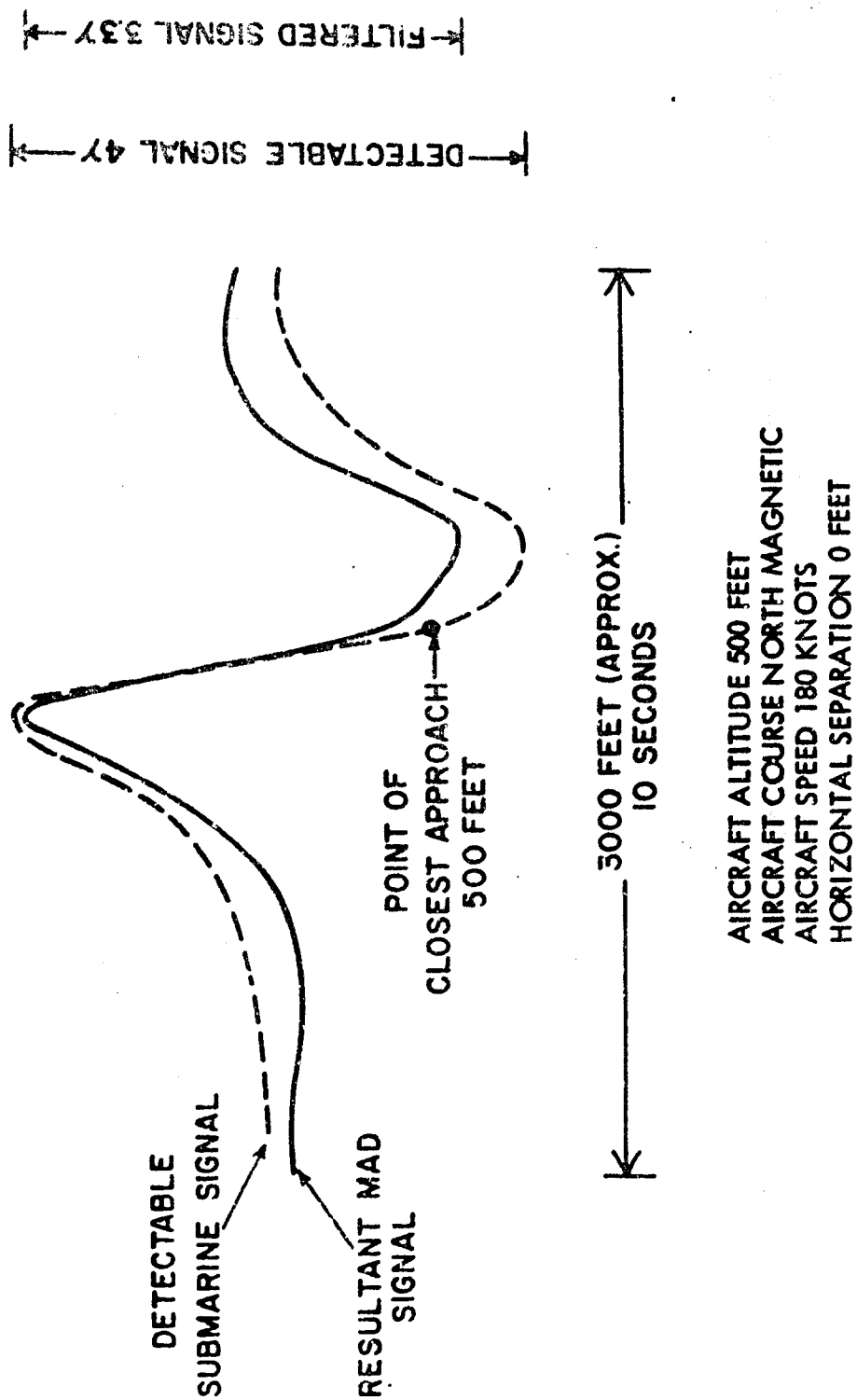
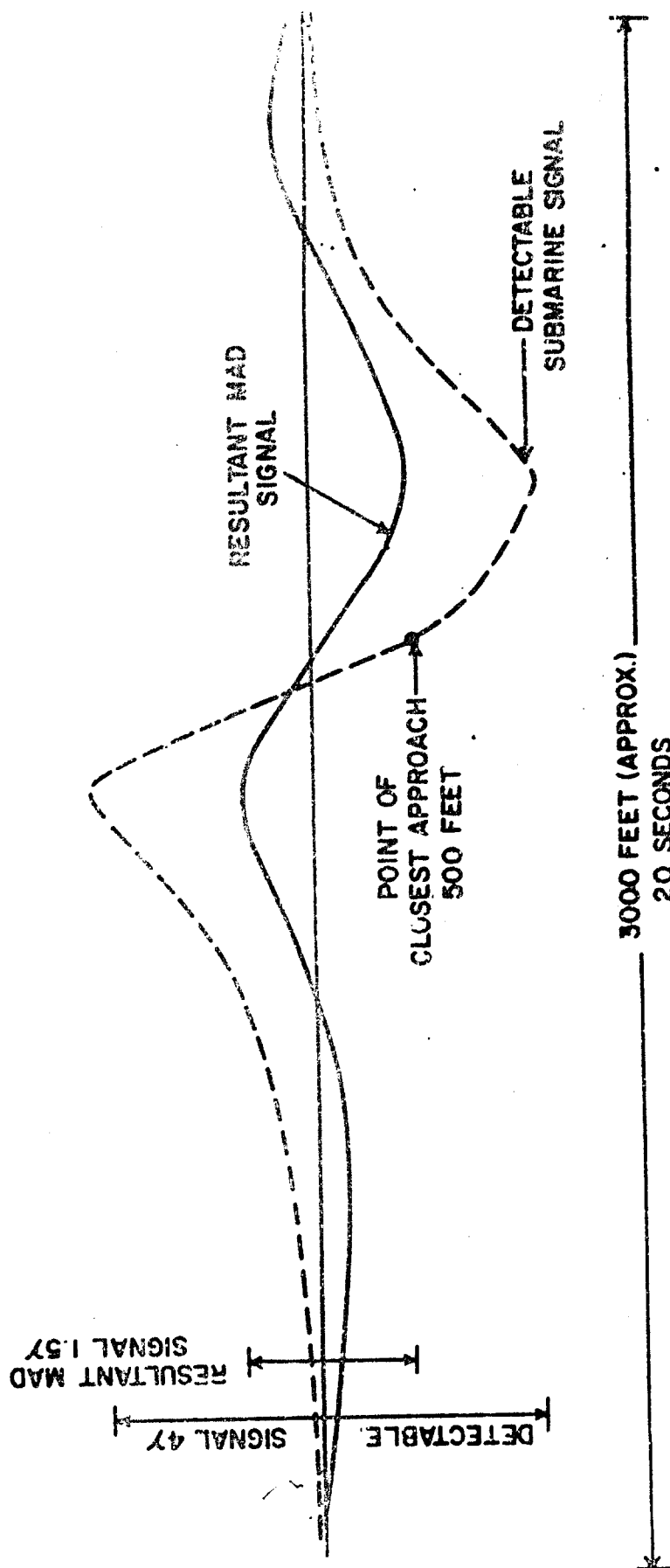


FIGURE 8. COMPARISON OF DETECTABLE SUBMARINE SIGNAL AND RESULTANT MAD SIGNAL



AIRCRAFT ALTITUDE 500 FEET
 AIRCRAFT COURSE NORTH MAGNETIC
 AIRCRAFT SPEED 90 KNOTS
 HORIZONTAL SEPARATION OF AIRCRAFT AND SUBMARINE 0 FEET

FIGURE 9. COMPARISON OF DETECTABLE SUBMARINE SIGNAL AND RESULTANT MAD SIGNAL

through the submarine field, but assume the speed has been reduced to 90 knots, the detectable submarine signal will still occur over 3000 feet of flight path, but it would take about 20 seconds of time to occur, rather than 10 seconds. The submarine signal will still be of the same amplitude but because of the slower speed the resultant frequency makeup of the signal would be different.

Figure 10 shows what the five fundamental frequencies are at the slower speed and just what percentage of the amplitude of these frequencies will pass through the filter. It is evident that a far lower percentage of the amplitude of these frequencies pass through the filter, than those shown in Figure 6. This demonstrates the fact that a filter designed for a carrying vehicle speed of 180 knots would not be suitable for a much lower speed. For this reason, in the days of the lighter-than-air craft, a filter centered at a lower frequency was used in the MAD equipment they carried. If helicopters are used for MAD work, they too must have a different filter because of their lower speed.

The amplitude of the submarine signal is quickly diminished as the aircraft moves further away from the submarine. Figure 11 shows what happens when the aircraft flies through the field of the submarine at the same altitude, speed, and heading, but on a parallel track that has a 400 foot horizontal separation from the first track presented in Figure 8. The detectable submarine signal has been reduced to 1.6 gammas and the resultant MAD signal has been reduced to 1.2 gammas.

Figure 12 has been prepared to illustrate that the signal generated by the same submarine can look very different depending on the aircraft's path through the submarine field. In this case the aircraft altitude and speed were the same, 500 feet and 180 knots, but its course was east magnetic and its horizontal separation from the submarine was 200 feet. The resultant submarine signal had only one distinct negative peak, not the positive and negative peaks shown in other illustrations. A parallel track through the submarine's field that passed 200 feet south of the submarine would have only a positive peak. If an analysis of the frequency content of this signal were made, the fundamental frequencies comprising the signal would be found to be very much different than those shown in Figure 5.

So far we have examined the effect on the MAD signal of the speed of the aircraft, the separation of the aircraft and submarine, and the course of the aircraft as it passes through the submarine's field. Another factor, the effect of the size of the submarine on the signal size should be self evident. The last factor to be examined in this section is the magnetic heading of the submarine at the time of contact.

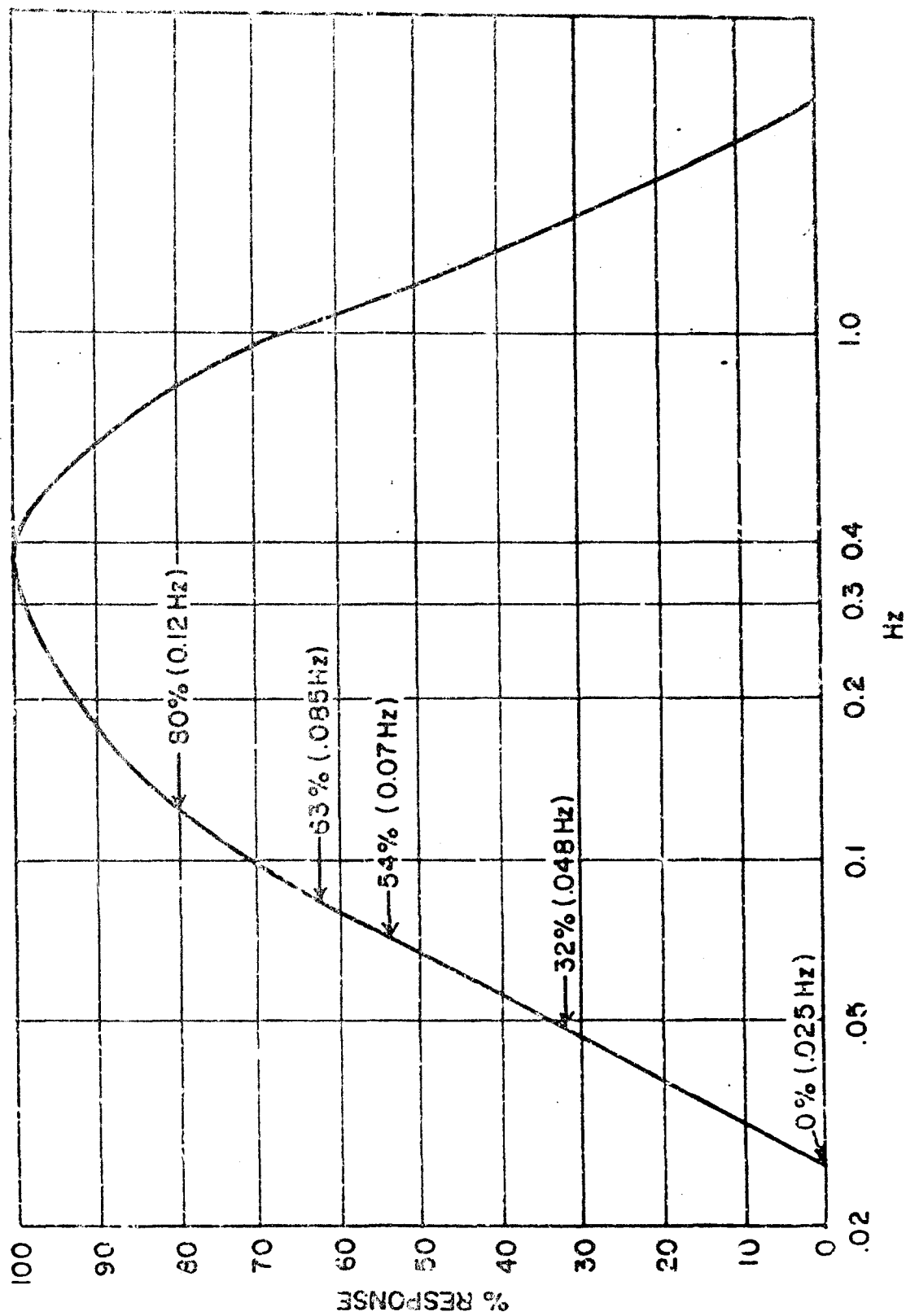
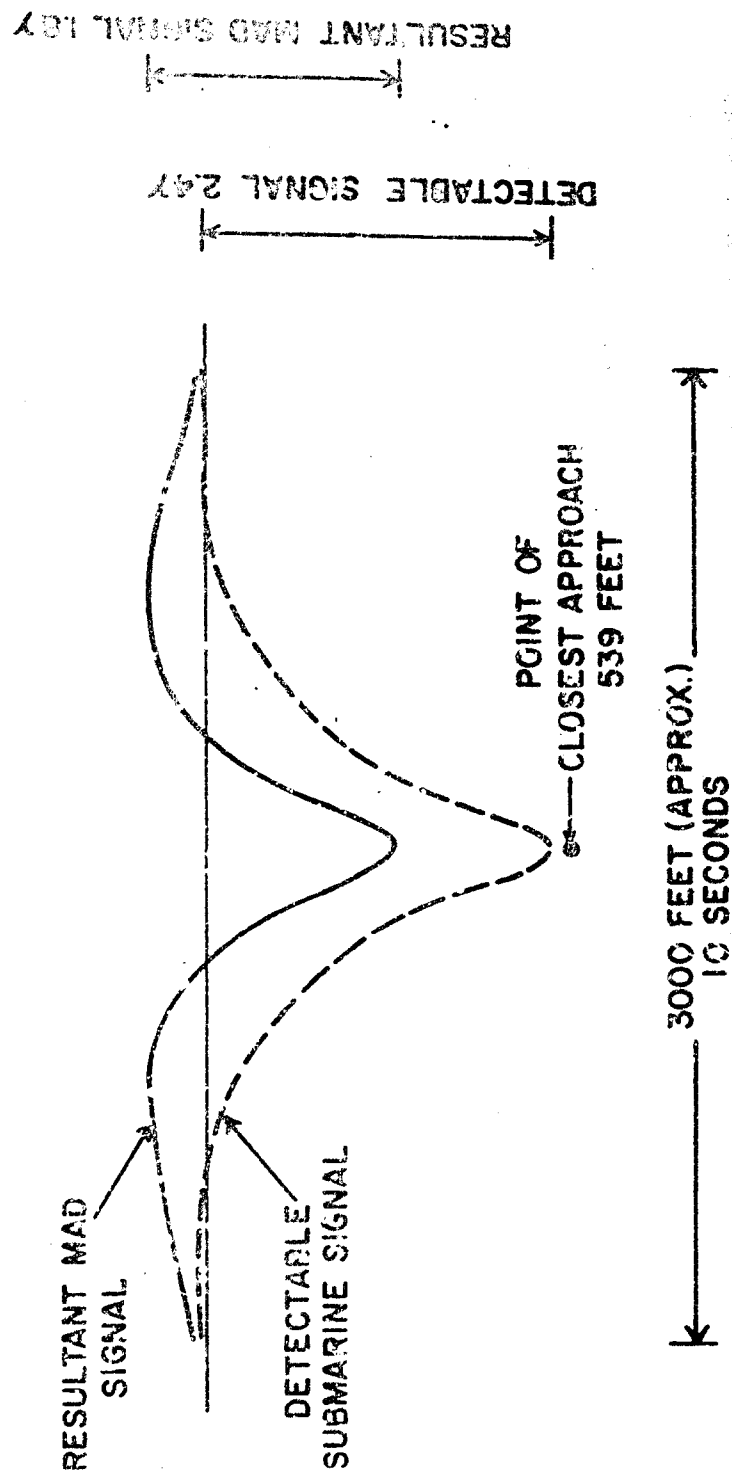


FIGURE 10. AMPLITUDE RESPONSE CURVE FOR A FILTER USED IN AN AN/ASQ-10



AIRCRAFT ALTITUDE 500 FEET
 AIRCRAFT COURSE EAST MAGNETIC
 AIRCRAFT SPEED 180 KNOTS
 HORIZONTAL SEPARATION OF AIRCRAFT AND SUBMARINE 200 FEET

FIGURE 12. COMPARISON OF DETECTABLE SUBMARINE SIGNAL AND RESULTANT MAD SIGNAL

The magnetic signature of a submarine can be said to be composed of permanent magnetism and induced magnetism. The subject of permanent and induced magnetism can be a very complex one, only the essentials will be considered here.

Permanent magnetism is that magnetism which is retained by material over long periods of time without appreciable reduction. Induced magnetism is magnetism acquired by a piece of material while it is under the influence of an external magnetic field. Many types of magnetic material are used in the construction of submarines, and since they operate in the earth's magnetic field, they exhibit the characteristics of both permanent and induced magnetism.

A submarine's magnetic field cannot be adequately represented by any simple form or combination of forms. However, an attempt can be made to illustrate the interaction of the permanent and induced fields of a submarine. In the illustration, Figure 13, a permanent field of one unit of strength is assumed along with an induced field of two units of strength on a north heading. On a north heading the induced component of the submarine's field will add directly to the permanent component and the amplitude of the submarine's signature will be the greatest. When the submarine is headed east or west its induced component is considerably reduced because the magnetic field is no longer aligned with the major axis of the submarine. On a south magnetic heading the permanent and induced fields will be directly opposed and on this heading the magnetic signature will be the least. On the intermediate headings the amplitude of the signature will range between the maximum and minimum values.

This figure is meant only as an illustration and the results shown are true only for the assumptions made. There are in fact a very wide variety of possible relationships of permanent and induced fields.

There are steps that can be taken to reduce the magnetic signature of a submarine. But with time the effectiveness of these procedures diminishes, and the amplitude of the magnetic signature increases once again.

ENVIRONMENTAL FACTORS AFFECTING MAD OPERATIONS

The MAD filter has been designed to pass the frequencies that comprise the submarine's signal while rejecting those frequencies which might interfere with the proper identification of target signals. It is not possible to build a

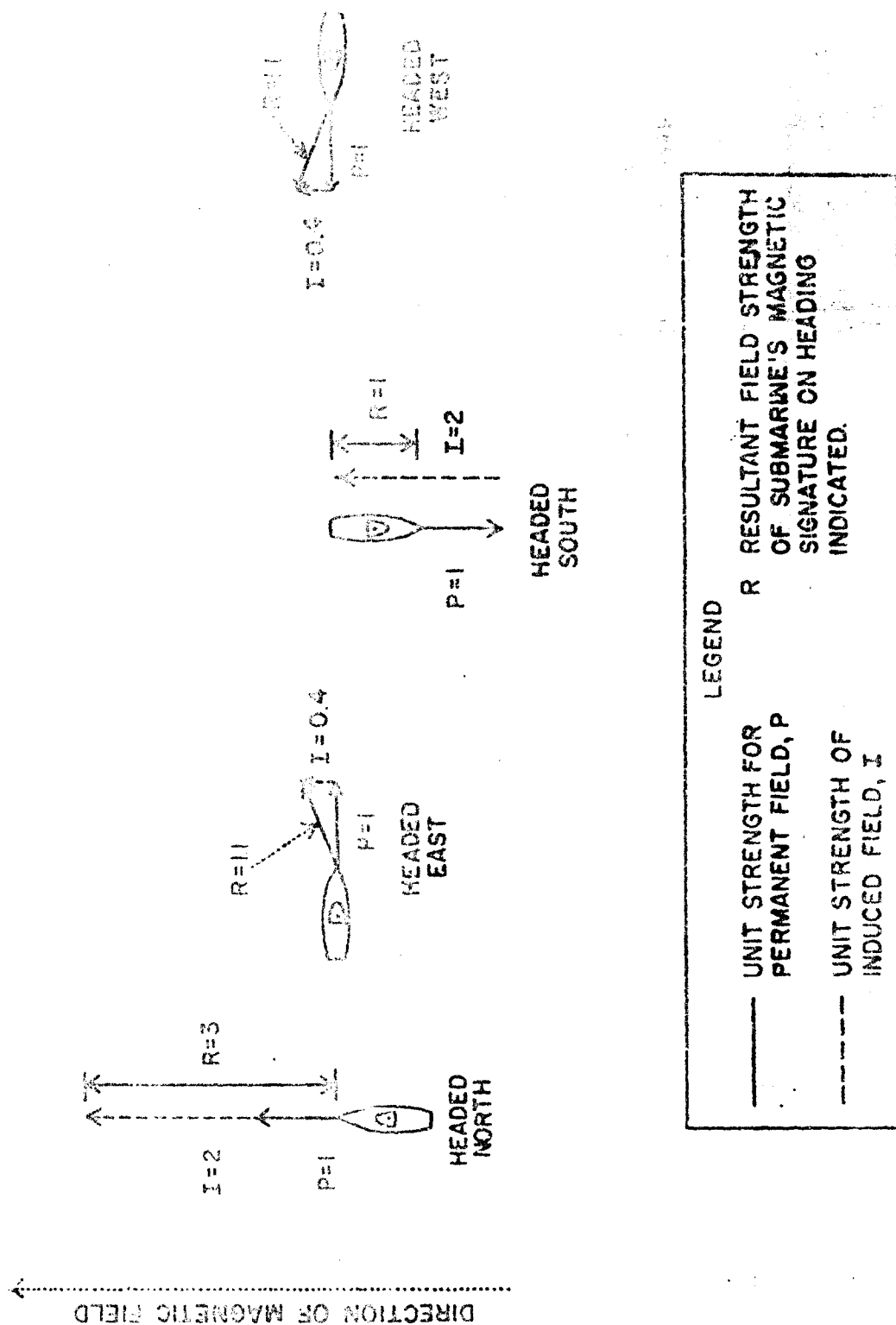


FIGURE 13. ILLUSTRATION OF THE INTERACTION OF THE PERMANENT AND INDUCED MAGNETIC FIELDS OF A SUBMARINE

filter that will completely reject all unwanted frequencies; as a result certain unwanted frequencies appear on the MAD trace as noise. This noise can be classified in two broad categories: on-board noise, and environmental noise. It is seldom that either of these forms of noise will appear on the trace as a target-like signal. However, because of the amplitude and duration of certain types of noise, it is very possible for it to mask a real signal and therefore reduce the effective range of the MAD gear.

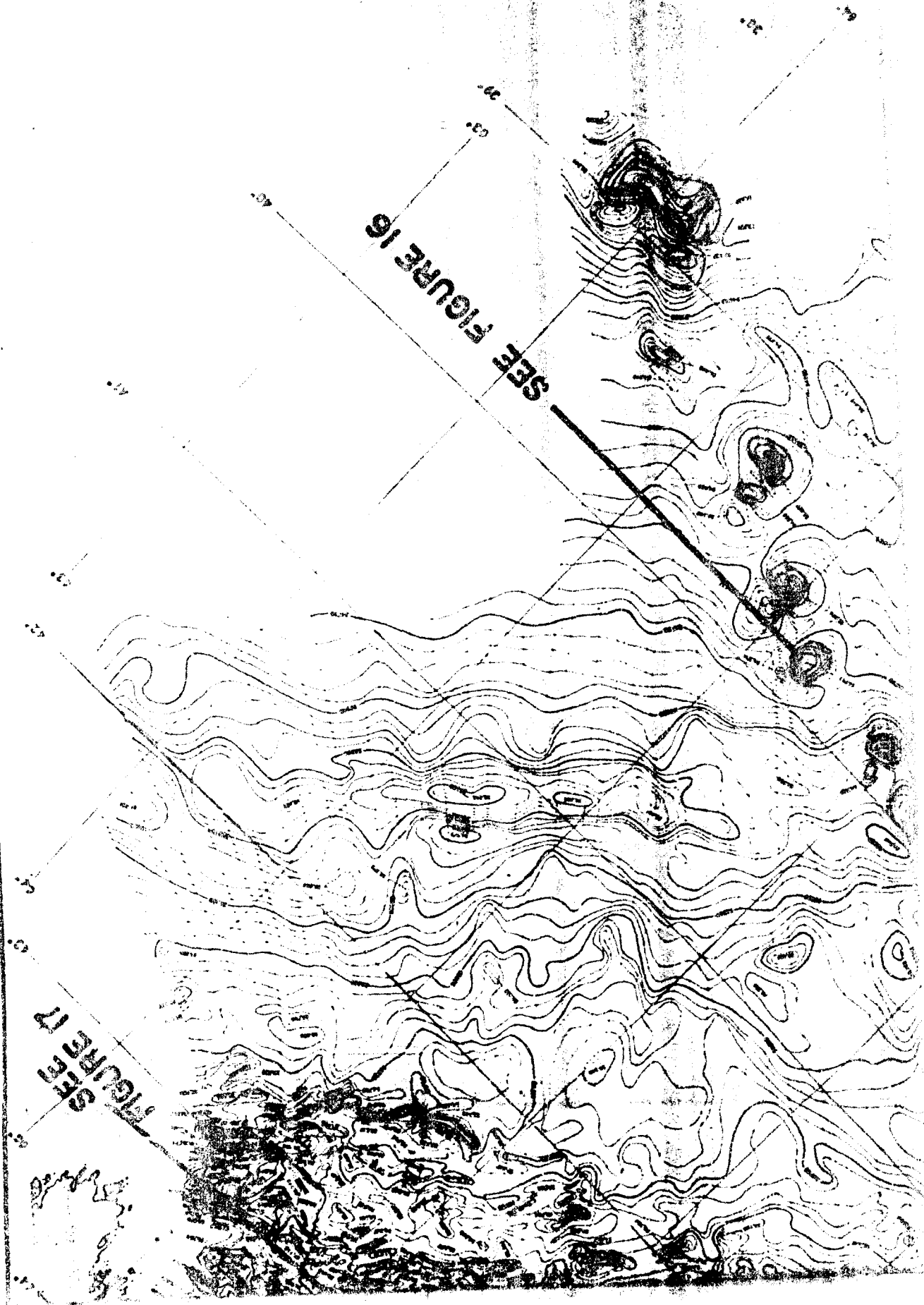
On-board noise has as its source the electronics of the instrument itself, and the various electrical and electronic equipment of the aircraft. On-board noise must be controlled by a conscientious job of compensation and maintenance. This report will not consider the effects of on-board noise but will confine itself to a discussion of environmental noise.

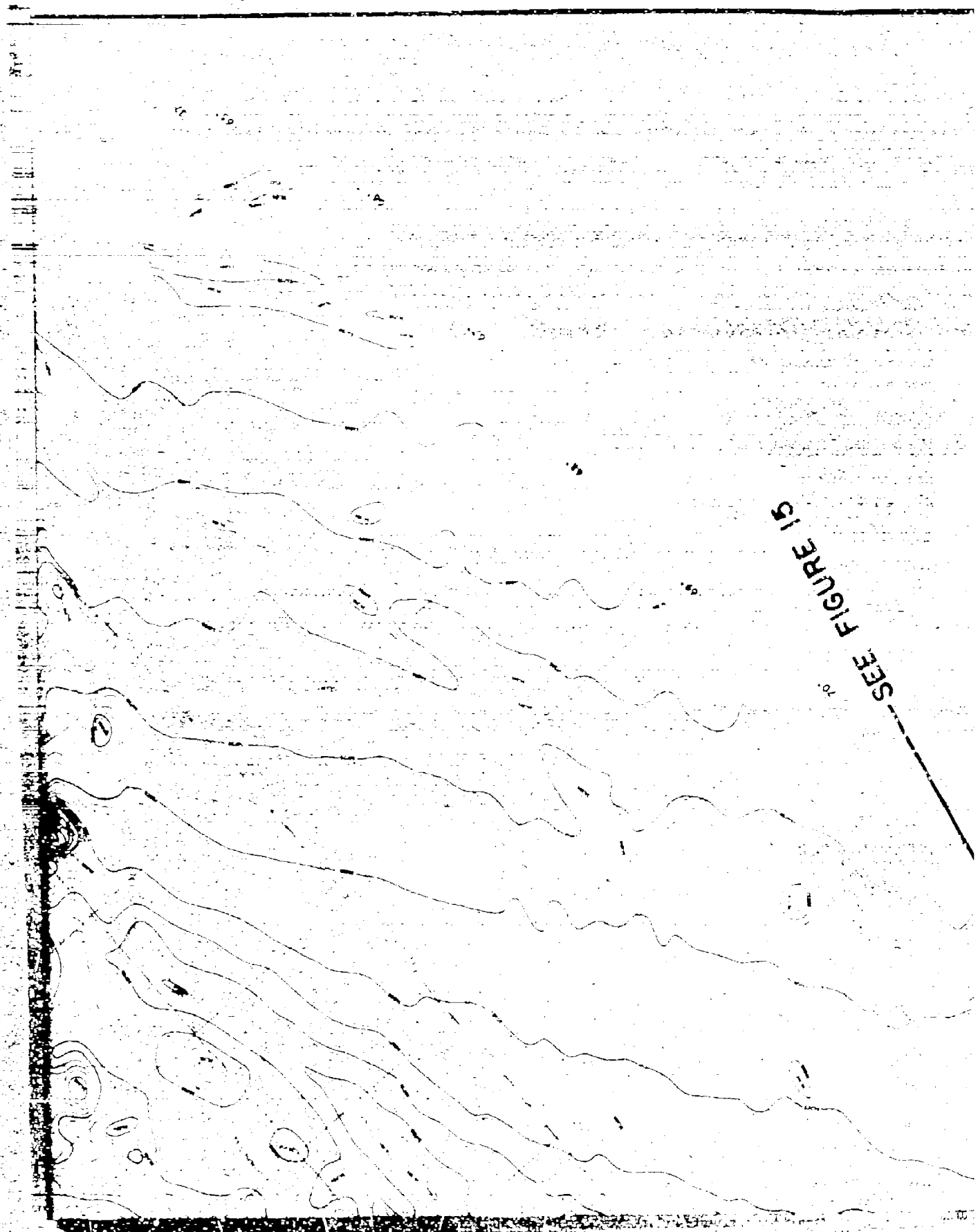
Environmental noise can be sub-divided into two types, geologic and temporal. The term geologic noise is applied to noise which has as its source naturally occurring magnetic anomalies. These anomalies are caused by magnetic material present in the earth's crust. Temporal (time varying) magnetic noise appears in the form of magnetic storms and micropulsations. There is nothing that the MAD operator can do about the problems of geologic and temporal noise at present. However, it is important that he be aware of these sources of noise so that he can better evaluate what is happening on his recorder trace.

Certain general observations can be made about the geologic noise problem. Geologic noise is generally more pronounced in shallow water areas because over those areas the detector is much nearer the source of the anomaly. Magnetic anomalies are often associated with unusual bottom features such as seamounts. Anomalies are "frozen" in the earth's crust and they are very stable over long periods of time. It is true that the absolute value of the field changes with time, but the general shape of the magnetic anomaly changes very little with time. If an operating area has a bad geologic noise problem today, it will be just as bad tomorrow.

A standard method of representing the earth's total magnetic field component, H , is by a contour chart. Figure 14 is a contour chart of H along the United States East Coast. The contours on this chart represent a 50 gamma contour interval. The contours join points of equal magnetic intensity and are called isodynamic lines.

Another type of contour presentation more familiar to Naval Aviators is the weather map. On the weather map isobars connect points of equal barometric pressure at the earth's surface or at some specific altitude. Anomalous features in the pressure pattern are designated as highs or lows. The center of the high or low is usually enclosed by an isobar and a value assigned to the highest or lowest barometric observation. The spacing of the contours around the highs and



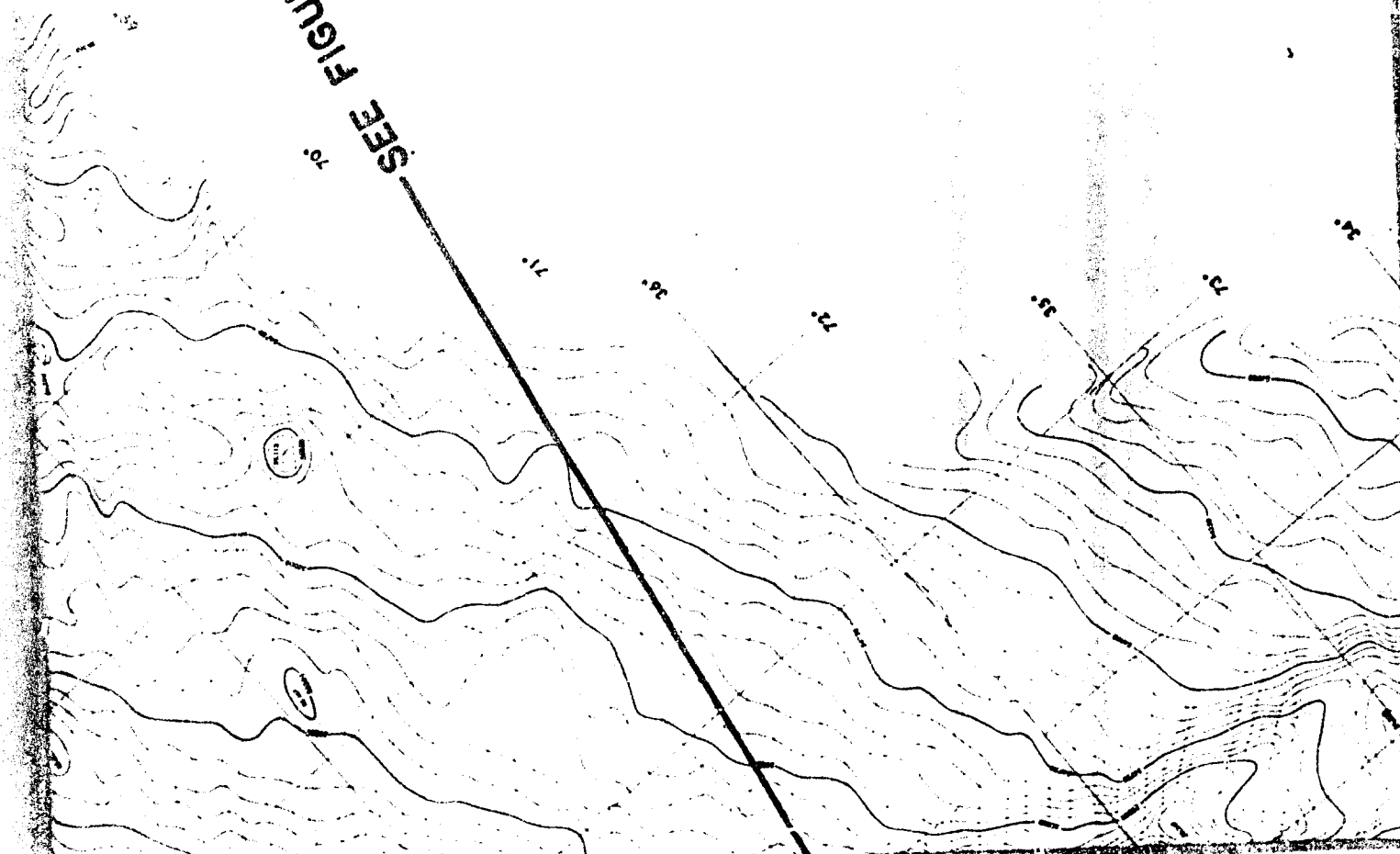


SEE FIGURE 12

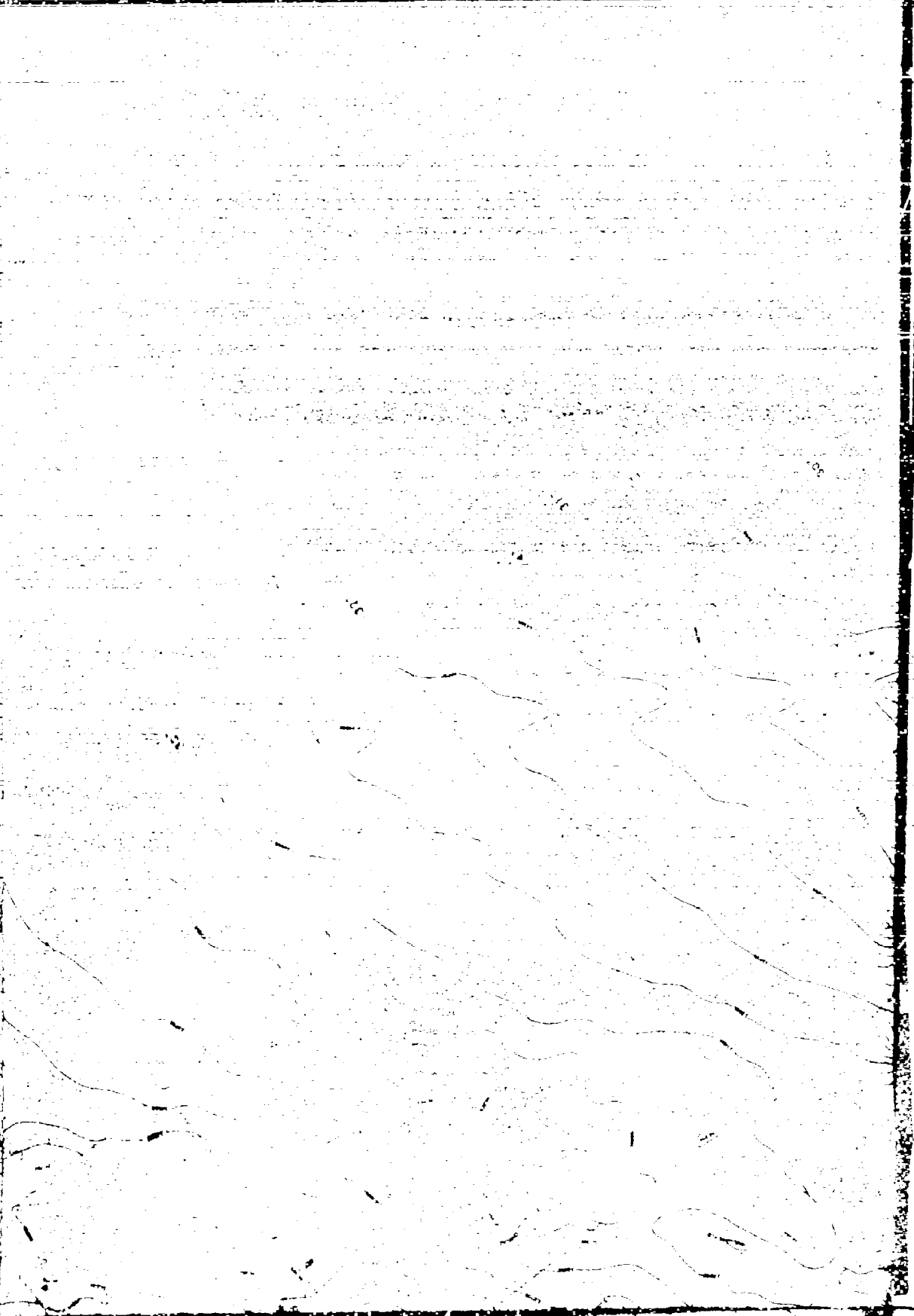
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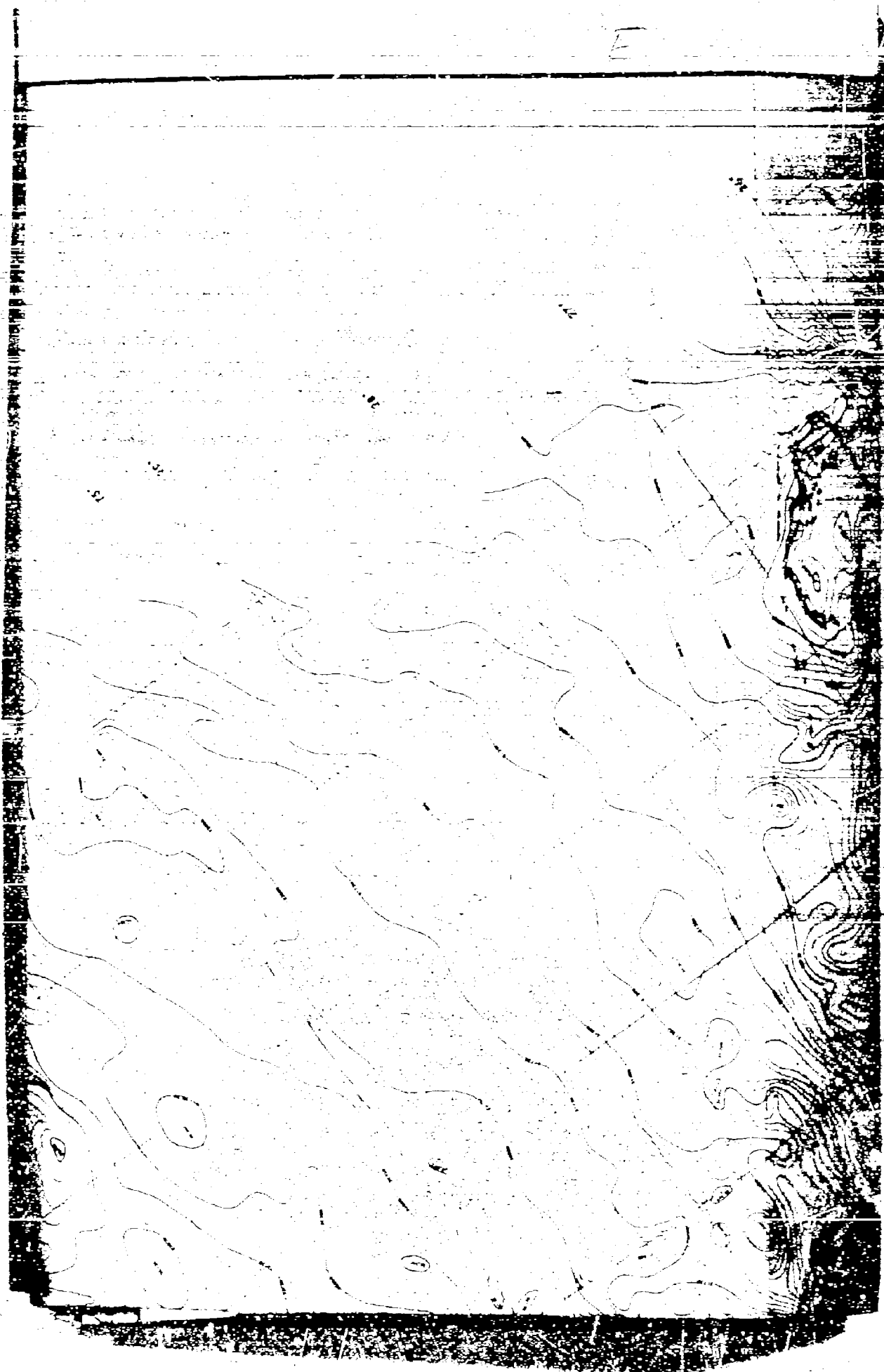
Contour Interval 50 Gammas
Scale: 1:2,500,000
UTM Projection

SEE FIGURE 13



D





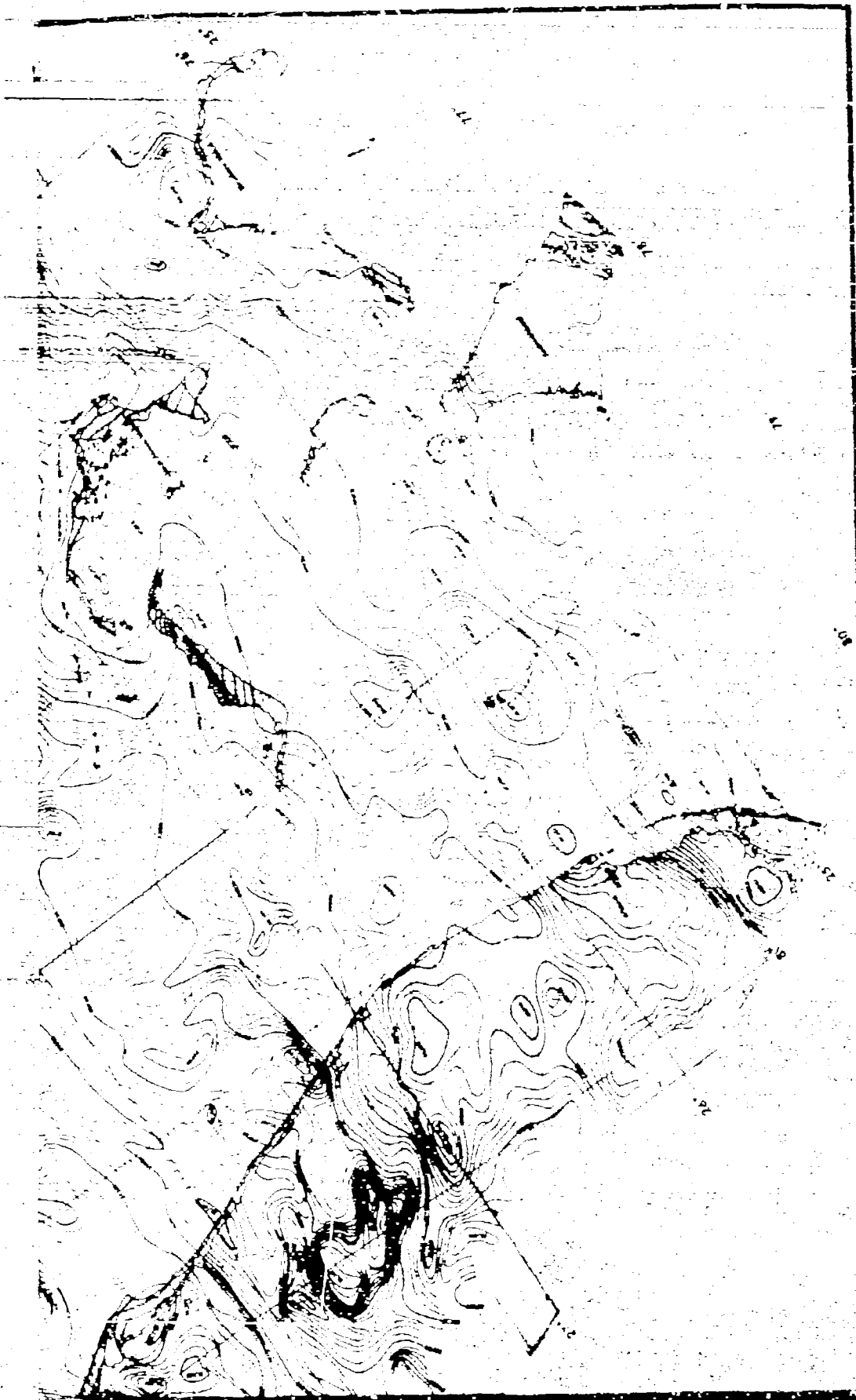
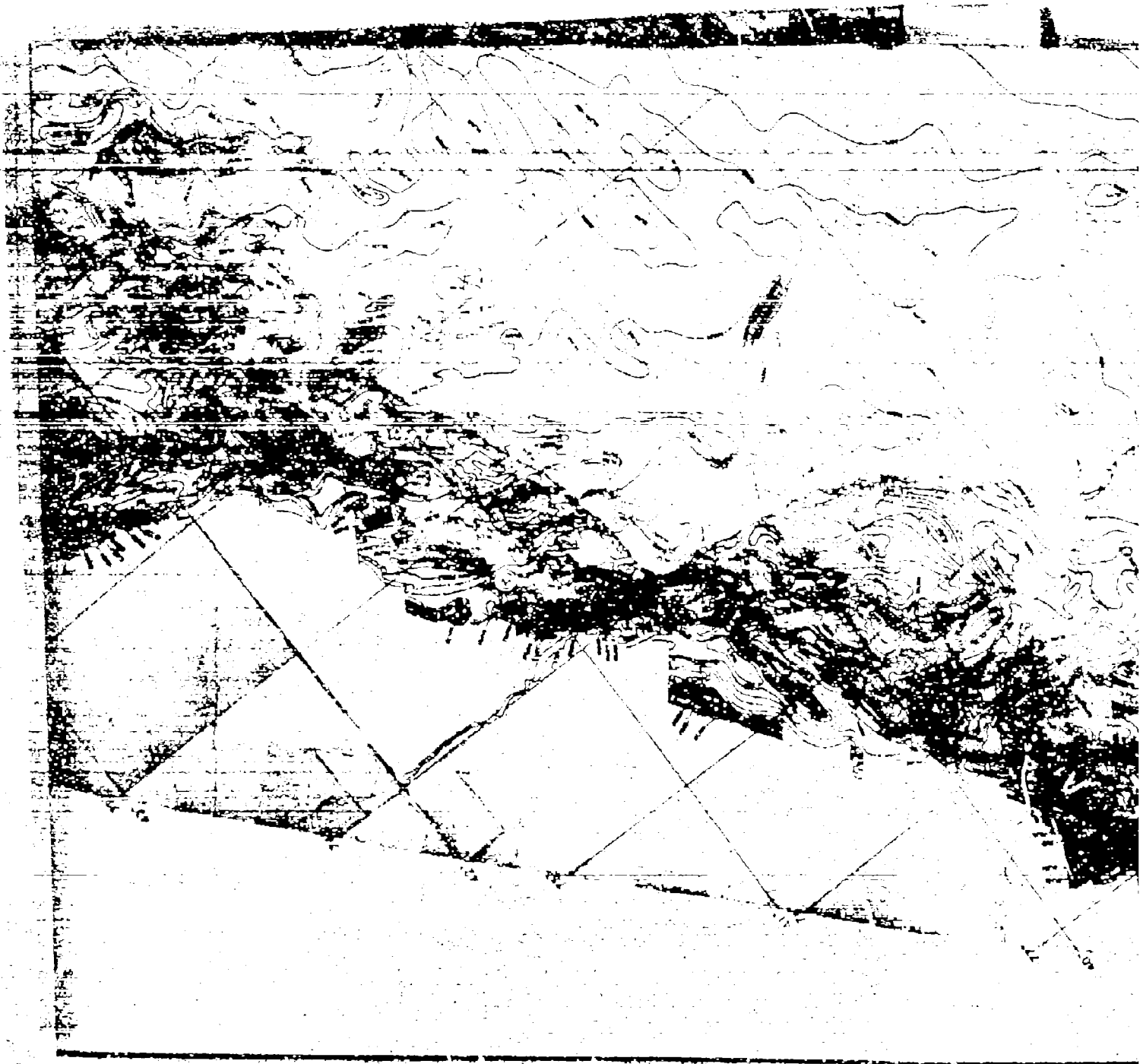
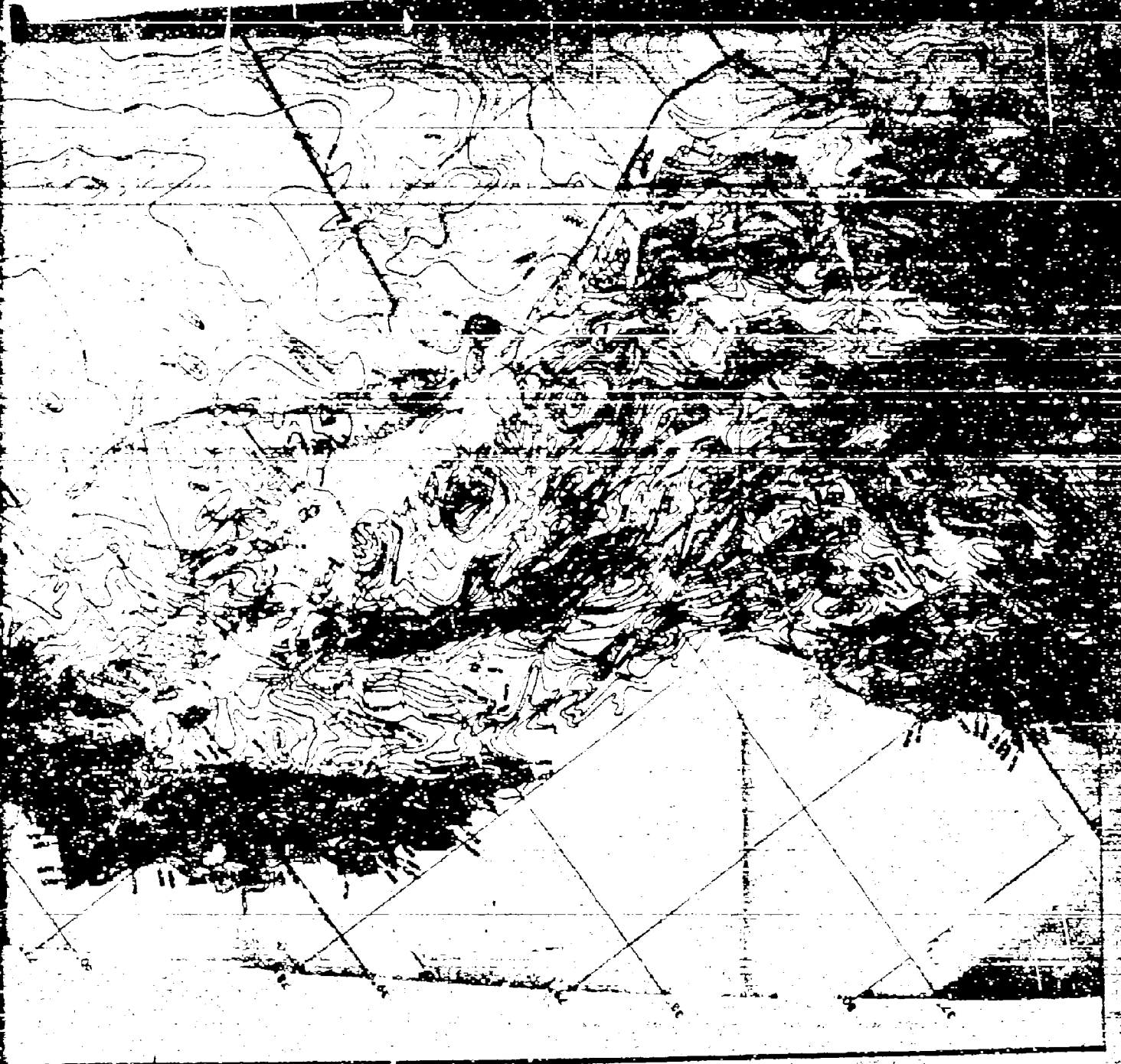


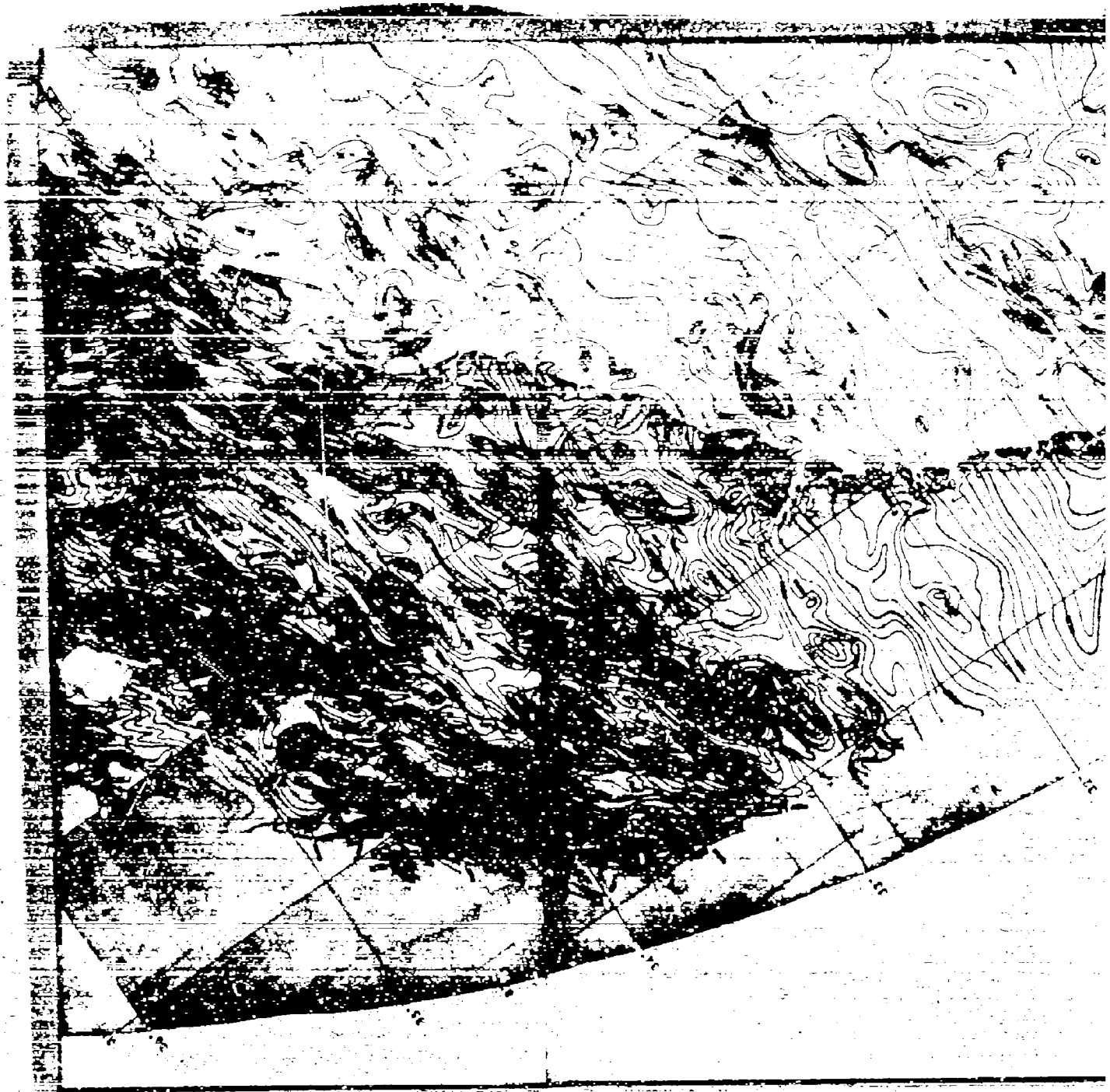


FIGURE 14. TOTAL MAGNETIC INTER

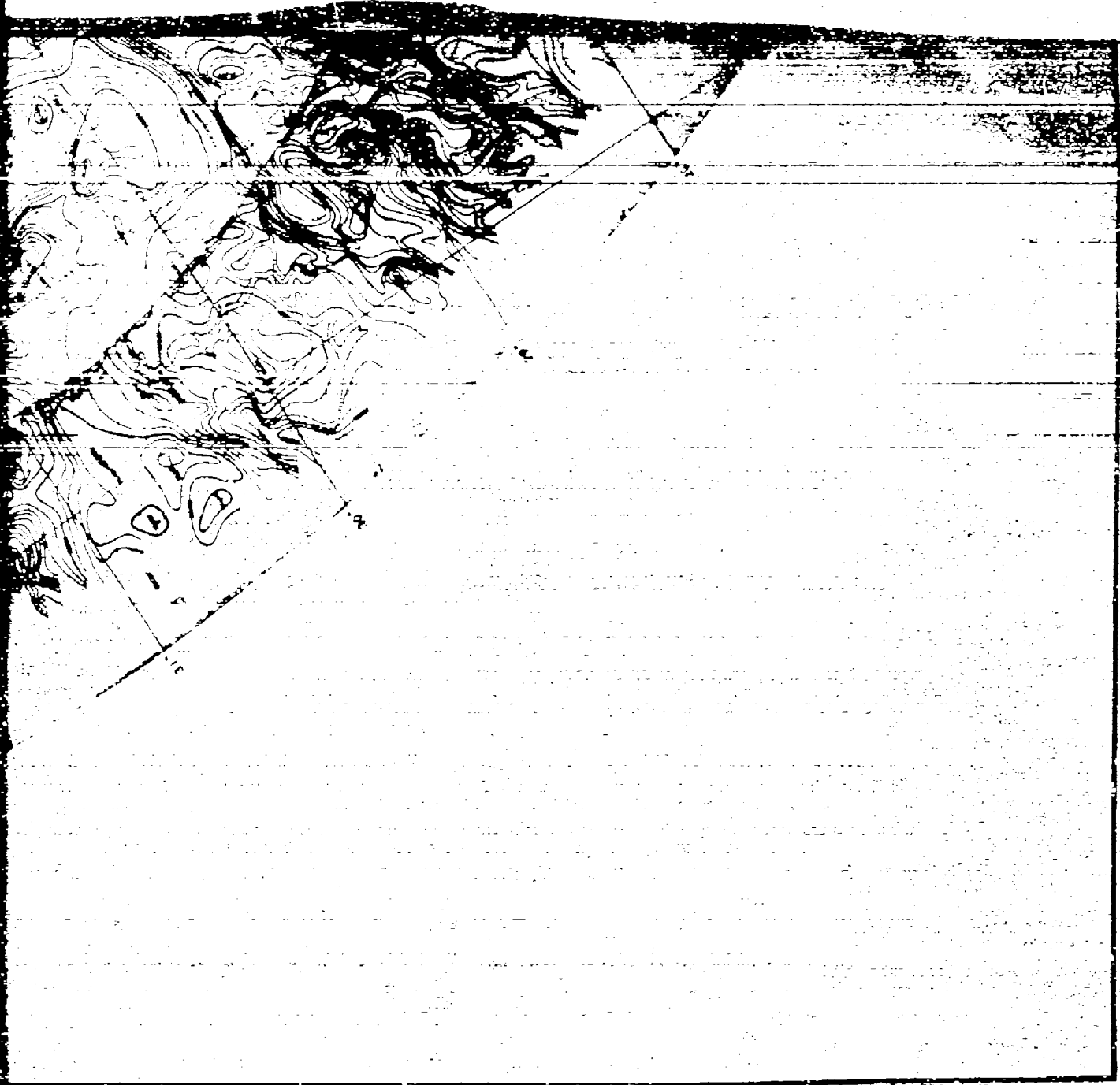


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loves indicates the steepness of the pressure gradient. Similarly, magnetic anomalies may either be highs or lows in the earth's magnetic field, and their relative steepness are also indicated by the spacing of the contours around the high or low point.

On the contour chart of the east coast area, the magnetic field in the Gulf of Maine, north of 42° , stands out as an extremely complex area. The many small anomalies with steep gradients make this the worst operating area for MAD along the east coast. The area between 37° to 39° North, by contrast, has only a few anomalies with very low gradients; in this area MAD performance should be good. Another area of interest is between 39° and 40° North, and 64° to 68° West. The group of large anomalies in this area are associated with the New England Seamount Chain. This seamount chain continues onward to the south-east and each seamount has an anomaly associated with it that will be seen on a MAD trace.

The three areas mentioned are examples of different types of MAD operating areas. The Gulf of Maine is a shallow water area with a complex geologic noise problem; 37° to 39° North is a low geologic noise area in both shallow and deep water; and the seamount area is an example of a deep water area with a noticeable level of geologic noise. In order to take a closer look at these areas Figures 15, 16, and 17 have been prepared.

Figure 15A shows an enlargement of part of Figure 14, the contour chart, in the 37° to 39° latitude band. This enlargement includes a small anomaly. The line across the anomaly marked 1345-1349, represents an aircraft track across the anomaly and part B of the figure shows the resultant MAD trace.

First, a few observations about the contour portion of the figure. Each contour line represents a 50 gamma change in the F component, every fifth contour is made heavier and the gamma value noted. This contour format is widely used in preparing detailed charts of the magnetic field. (The position of the anomaly has been noted so that a cross reference can be made to the large chart.)

The track line across the anomaly shows the aircraft passed the peak of the anomaly at 1347. On the MAD trace the affect of the anomaly can be noted at that time; it appears as a broad signal of about 1 gamma amplitude. A standard method of rating anomalies is by their gradient, that is, their rate of increase or decrease in a given distance. The steepest gradient associated with this anomaly is that part that the aircraft passed over between 1347 and 1349; this gradient was about 80 gammas per mile as compared to the

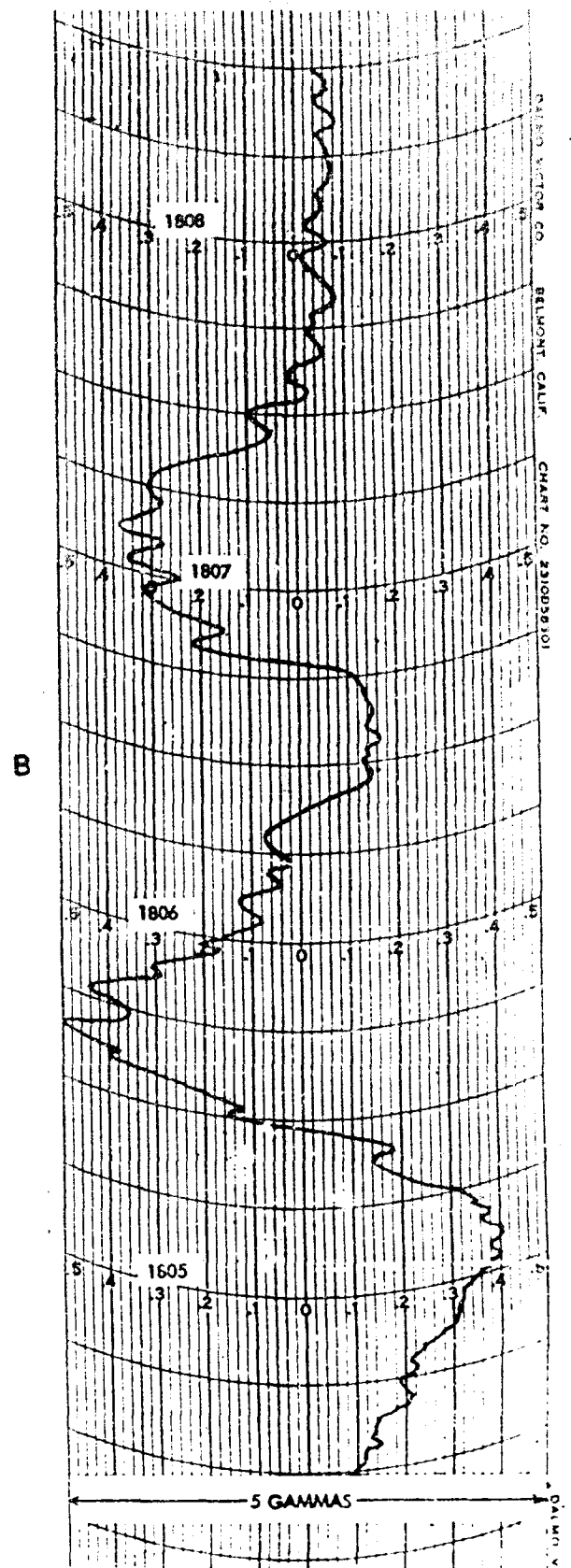
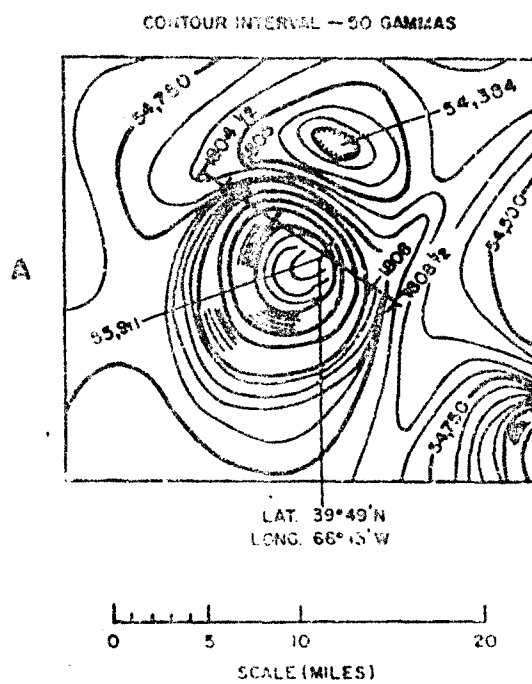


FIGURE 16. MAD RESPONSE OVER A SEAMOUNT IN DEEP WATER
(AIRCRAFT ALTITUDE 500 FT.)

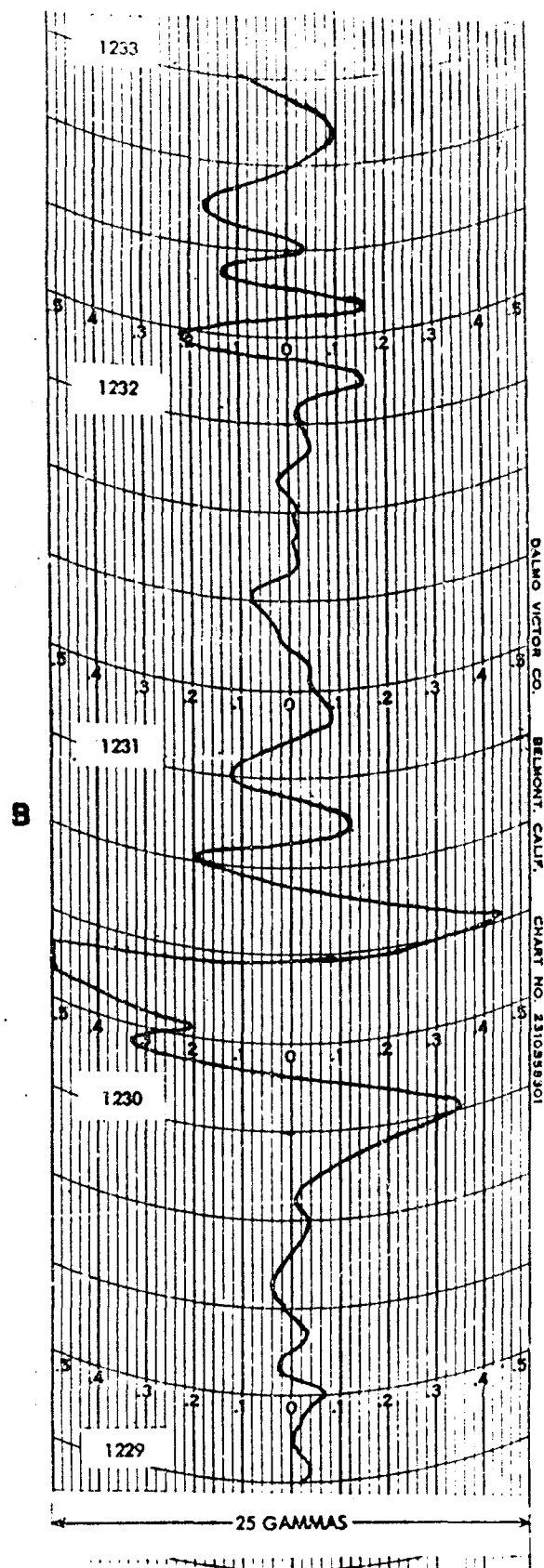
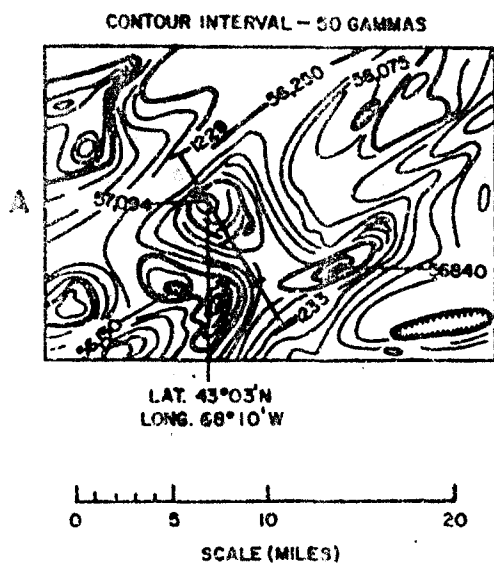


FIGURE 17. MAG RESPONSE IN AN AREA OF HIGH GEOLOGIC NOISE

normal field gradient along the Atlantic Coast of 10 gammas per mile in a north-south direction. This anomaly is located in shallow water and would hardly be noticed on a MAD trace.

Figure 16A shows another enlargement of the contour chart. In this figure one of the anomalies associated with the New England Seamount Chain is presented. The contour format is the same, but it can be noted that when a very steep gradient is depicted, the contour lines between the heavy lines are often dropped so that the presentation will not become illegible. Another detail of the presentation is the method of noting a low in the magnetic field. In the upper portion of the figure the value of 54,384 is noted. The inner contour surrounding this value has several short lines called hachures extending inward from the contour. This hachuring procedure is used to differentiate between an anomaly that represents a low point in the field rather than a high point.

Figure 16B shows how the MAD trace looked as the aircraft passed over the anomaly. This anomaly had a noticeable effect on the MAD trace over about a three minute period during which a signal of up to $4\frac{1}{2}$ gammas peak to peak can be seen. The gradient of this feature runs as high as 290 gammas per mile. Some of the larger magnetic anomalies associated with the other seamounts would drive the pen on the MAD recorder off scale at this 5 gamma setting. There are 2200 fathoms of water over this seamount, so the MAD detector was well separated from the source of the anomaly, yet the frequency content of the anomaly was such that the MAD trace was affected.

Figure 17 presents an example of how geologic noise interferes with MAD operations in the Gulf of Maine. The contour presentation shows an area that includes several small anomalies. In this case the peak values of most of the anomalies have been omitted so that the illustration would not become cluttered.

The small anomaly over which the aircraft track passed is located in about 100 fathoms of water and has a maximum gradient of 400 gammas per mile. The resultant MAD trace shows that this small intense feature caused the MAD recorder pen to go off scale on the 25 gamma setting just after 1230. A second signal can be seen just after 1232 caused by a ridge in the magnetic field over which the aircraft passed. It is quite evident that if a submarine had been located in the area the aircraft passed over between 1230 and 1231 its signal would have been hidden by the signal from the magnetic anomaly. Conversely, it is quite possible that the signal caused by the small anomaly at 1230+ and the signal seen at 1232+ could have been mistaken for target signals.

In studying these examples of geologic noise, it is important to note that in Figures 15 and 16 the ASQ-10 function switch was set on 5 gammas and in Figure 17 the setting was 25 gammas. This switch governs the sensitivity of the data displayed on the MAD trace. In areas where the general level of geologic noise is low the MAD equipment can be operated on a very sensitive setting such as the 5 gamma setting of Figure 15 and 16. Areas in which there is a high level of geologic noise the operator must go to a higher setting in order to keep the recorder pen on scale. Of course at these higher settings it will be difficult, if not impossible, to see a small submarine anomaly.

The function switch does not affect the filter operation. The band-pass of the filter is set and is beyond the operator's control. In general the function switch should be set so that the average level of activity on the trace does not exceed two major divisions.

Detailed magnetic contour charts can be helpful in evaluating MAD performance. The charts alone cannot exactly define how large a signal a specific anomaly will create on a MAD trace. However, the charts can provide an indication of whether to expect good, fair, or poor MAD performance in an area. Three important keys in evaluating an area for MAD performance are the gradients of the anomalies in the area, the size of the anomalies, and the depth of water over the anomalies. Figure 18 makes a general evaluation of MAD along the Atlantic Coast based on the magnetic contour chart of the area.

Figure 14, the contour chart of the Atlantic Coastal Region, is actually a composite of 15 separate charts. The three enlarged contour examples show the scale of the original data, 1:500,000. Copies of the original 15 charts can be obtained from the U. S. Naval Oceanographic Office; they are called the H.O. 17507 series of charts. Other contour charts of the magnetic field covering large areas of the Norwegian Sea and Mediterranean Sea are also available from the Oceanographic Office. The geomagnetic data available from the Oceanographic Office is described in the Oceanographic Office Publication IR 67-52.

In using magnetic contour charts for evaluating MAD performance the track spacing of the survey data must be taken into consideration. Usually, the chart will state track spacing or show tick marks on the contour lines indicating where the tracks passed. In the case of the Atlantic Coast magnetic data the track spacing was about 5 miles. It is likely that certain small features were not shown.

Another type of aid that can be used to evaluate MAD performance is the Bottom Contour Chart (BC Chart). This type of chart presents contoured

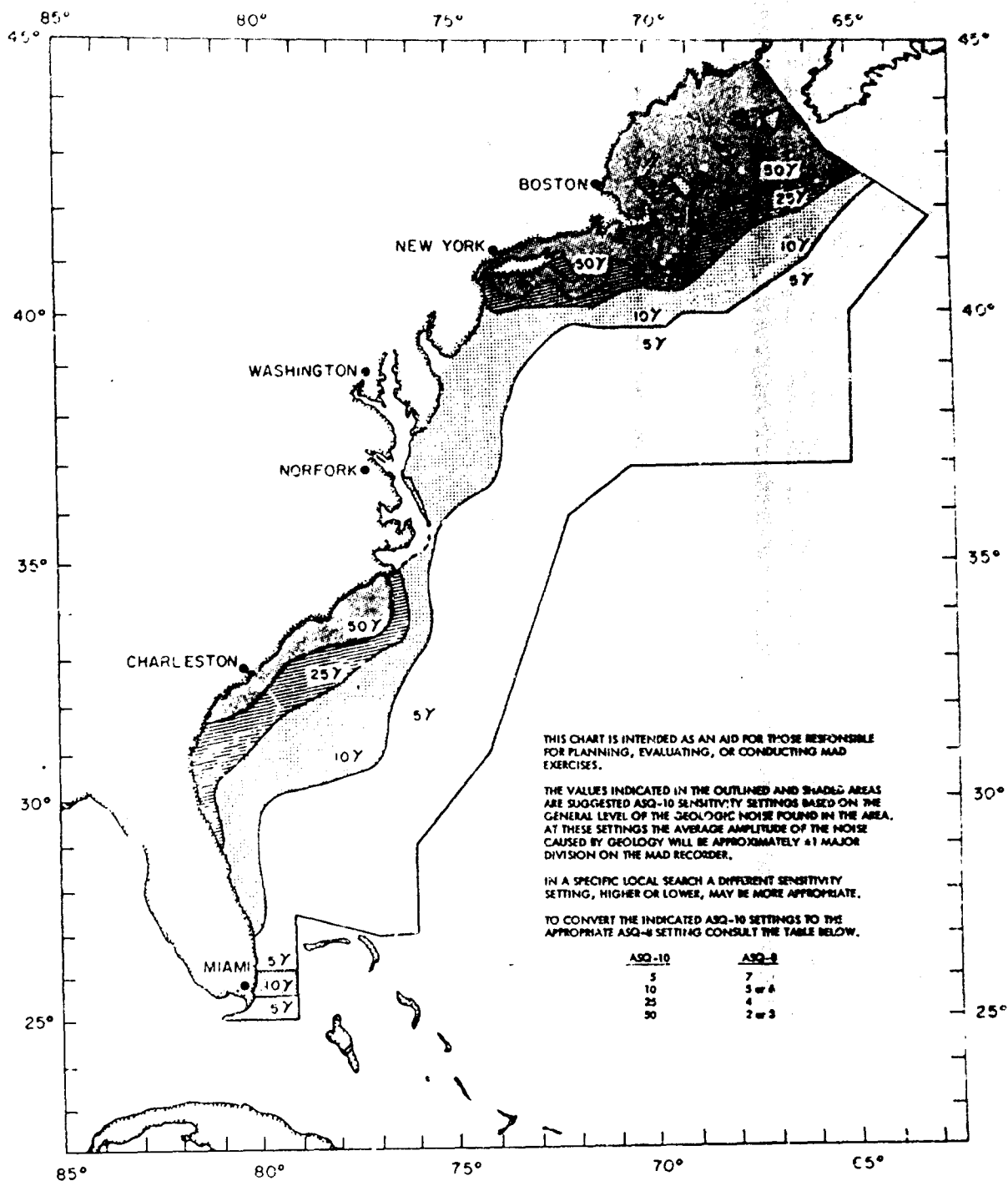


FIGURE 18. MAD GEOLOGIC NOISE CHART FOR U.S. EAST COAST

information on the shape of the ocean bottom. The unusual features on the floor of the ocean such as seamounts and ridges are shown on BC charts in a contour format very similar to the magnetic contour format.

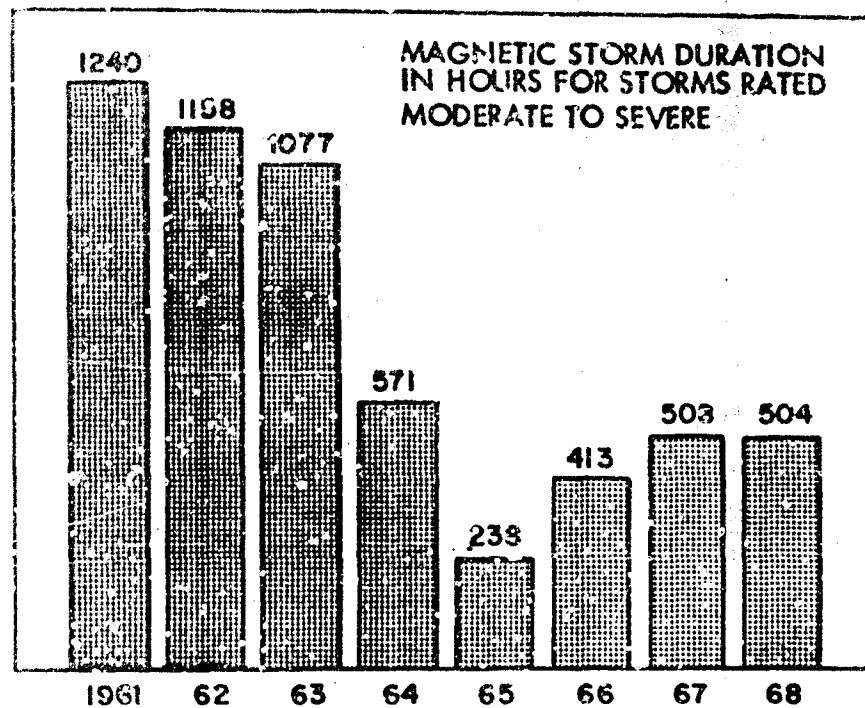
In a previous section of this report the affect on MAD of one of the seamounts in the New England Seamount Chain was examined (Figure 16). It was mentioned that each of the seamounts had a magnetic anomaly associated with it. Not only the New England seamounts but most other seamounts in the Atlantic and Pacific Oceans have a magnetic anomaly associated with them. Some of these anomalies can interfere with MAD operations. If a BC Chart is available for an operating area, it may provide a guide to those places where geologic noise may interfere with MAD operations.

Very large ocean floor features such as the Mid-Atlantic Ridge are known to have many difficult operating areas associated with them. Parts of the Norwegian Sea, the seas around Iceland, areas near the Hawaiian Islands, and off the West Coast of the United States particularly north of 40° latitude, are other areas in which geologic noise can be a problem. Although the exact amount of geologic noise to be experienced in the vicinity of any bottom feature cannot be precisely determined from the BC Charts, they can often provide an explanation of any peculiar patterns seen on the MAD trace.

The U. S. Naval Oceanographic Office Chart Catalog, H.O. Pub. No. 1-N, Introduction Part II, lists the BC Charts currently available.

The second type of environmental noise that can affect MAD equipment is termed temporal magnetic noise. To reiterate, temporal magnetic noise may be defined as such phenomena as the usual daily variation of the field, magnetic storms, and micropulsations. The normal daily field variation is such a long period or low frequency change that it will be excluded by the filter in the MAD equipment.

Any marked degree of disturbance of the earth's magnetic field can be considered a magnetic storm. Figure 19 shows the number of hours per year during the years 1961-1968 that the magnetic field could be considered moderately to severely disturbed. These hours represent the amount of time during the years indicated that the efficiency of MAD gear could have been impaired by storm type activity. This is based on the assumption that when the field reaches the moderately disturbed level some of the activity passes through the filter and appears as noise on the MAD trace. Storm durations of 40 to 50 hours are not uncommon. In the last several years, the longest storm occurred during 1962; it lasted 172 hours.



1961	1962	1963	1964	1965	1966	1967	1968
14%	13%	12%	6%	3%	5%	8%	6%

FIGURE 12. MAGNETIC STORM HOURS PER YEAR, 1961-1968

One of the things that can be seen from Figure 19 is the cyclical natures of the storm activity. In the past the magnetic storm cycle has ranged from 8 to 17 years, with an average of 11.2 years. The magnetic storm cycle is directly related to the sun spot cycle. In the present cycle 1965 was the year of minimum activity.

Within the yearly cycle there is a monthly sub-cycle. Long term studies of magnetic activity have shown that the months nearest the equinoxes are the most active magnetically. The months of September and October are the most active; the next two most active months are March and April.

Just how does storm activity affect MAD operation? As stated previously some of the storm activity does find its way through the filter; it cannot be precisely stated just how large this affect will be. It is known that at times, the amplitude of the noise on the MAD trace caused by storms can be very high. The pattern appearing on the MAD trace can be of such an amplitude and of such an unusual nature as to make the operator doubt his equipment is working properly. In fact, there have been cases where MAD equipment has been shut down and considered out-of-order because of the appearance of intense storm activity.

When pronounced storm activity occurs, it occurs all over the world at the same time. However, there is a definite latitude effect associated with the severity of storm activity. A general statement may be made that storm severity is less at low latitudes than at high latitudes. That means that during the same magnetic storm, aircraft flying out of Puerto Rico might see very little effect, and those flying out of Iceland would be wondering what happened to their equipment.

Storm activity should be suspected as the source of noise when an aircraft is operating in an area which usually could be considered a low level noise area, and unusual activity is seen on the trace. If more than one aircraft is engaged in the operation, all aircraft in the same area would see the same type of noise.

One aid in evaluating any unusual noise seen on the MAD trace is the GEOALERT's broadcast by WWV and WWVH. The times of these broadcasts and the broadcast format is presented in Appendix One.

Both the terms magnetic storms and micropulsations were used in this report at the beginning of the discussion of temporal magnetic noise. It was intended that a distinction be made between marked disturbances of the field

denoted by the term magnetic storms and a lower level of activity denoted by the term micropulsations.

There is, in fact, a wide variety of magnetic pulsation activity. This pulsation activity can take place during both active and quiet magnetic field periods. In order to standardize the nomenclature of pulsation activity the International Association of Geomagnetism and Aeronomy, (IAGA), in 1963, made certain provisional designations for both the pulsations with more regular forms, denoted pc, and the pulsations with more irregular forms, denoted pi. Table I shows the IAGA pulsation classification and typical amplitudes of the various classes of pulsations.

The pulsations designated as pc 1, 2, 3, and pi 1, because of their frequency would be of particular interest to those concerned with MAD operations. The amplitudes listed in Table I are typical for each class of pulsation, but do not represent the maximum amplitude of the pulsations under all circumstances.

Each class of pulsation has certain definable characteristics; for instance, pc 1 are very often observed in bursts that last about 30 minutes, but on rare occasions may last up to 12 hours. Pc 1 activity is more likely to occur during high solar activity in the week following large major magnetic disturbances. Other classes of pulsations show daily and seasonal variation, or variation in amplitude and occurrence frequency as a function of latitude. Unlike major magnetic storm occurrences, pulsation activity may be confined to a small area.

WHERE IS MAD GOING?

The next generation of MAD equipment, the AN/ASQ-81, will be put aboard the P 3-C aircraft during the 1970's. These new magnetometers will operate on an entirely new principle called optical pumping. These new devices are much more sensitive than the older flux-gate magnetometers, and they will provide the means by which MAD detection ranges can be much improved.

The progress represented by this break through in sensitivity brings with it problems. In order to turn this sensitivity into increased detection ranges a better system of dealing with the problems of both on-board and environmental noise must be devised.

There are those who believe that the best way to deal with the on-board noise problem is to enclose the magnetometer in a housing and tow it at the end of a cable. The Project MAGNET aircraft of Oceanographic Development Squadron EIGHT have logged many survey hours with a towed ASQ-81 configuration.

TABLE I
MICROPULSATION CLASSIFICATION

TYPE	FREQUENCY (Hz)	TYPICAL AMPLITUDE (GAMMAS)
pc 1	5.000 - 0.2000	0.02 - 0.1
pc 2	0.200 - 0.1000	0.10 - 0.5
pc 3	0.100 - 0.0200	0.10 - 0.5
pc 4	0.020 - 0.0070	0.50 - 10.0
pc 5	0.007 - 0.0017	10.00 - 75.0
pi 1	1.000 - 0.0250	0.20 - 0.6
pi 2	0.025 - 0.0070	0.20 - 0.6

The U. S. Naval Oceanographic Office has done much work in the field of geologic noise as it effects MAD. From this work it appears that the geologic noise problem can be considerably reduced by new filtering techniques. These new techniques may take the form of developing special filters and charts for areas in which geologic noise is a particular problem. In this system the operator would have a chart to assist him in choosing the proper filter to use in order to get the best MAD performance possible.

The development of what could be termed a real time or self-adjusting filter is also under investigation. This would be a rather sophisticated computerized technique in which the filter band-pass could be altered as necessary to meet the specific problems encountered in an operating area.

The Oceanographic Office has also begun a comprehensive study of the effect of magnetic storms and micropulsation activity on MAD equipment. One of the immediate aims of this program will be acquiring specific examples of temporal noise patterns so that they may be used by those involved in MAD operations in evaluating unusual noise patterns seen on the MAD traces. A long term aim of this study will be the development of a method by which MAD users can be warned of the existence of adverse magnetic conditions as they occur or shortly before they are expected to occur.

APPENDIX A

BROADCASTS OF THE GEOALERTS BY WWV AND WWVH

The GEOALERT for a given day is first broadcast at 0418 UT on station WWV*, Fort Collins, Colorado, then at 0448 UT on station WWVH**, Maui, Hawaii, and at hourly intervals until the next alert is issued. In case of delay in receipt of the daily message, WWV or WWVH will be silent at 18 or 48 minutes after the hour UT, respectively, until the new message is received.

Each message begins with letters GEO in Morse Code and the coded information follows. This coding permits three types of information at each broadcast -- each in the form of letters repeated three times in slow International Morse Code. The first set concerns the forecast of solar or geophysical events or the observation of stratospheric warming (or the observation of a stratospheric warming together with a forecast of either solar or geophysical event). The letters which may occur in the first set and their meaning are as follows:

EEE	(. . .)	No forecast (or STRATWARM observation) statement (NIL)
III	(.. .)	FLARES expected
SSS	(...)	PROTON FLARE expected
TTT	(- - -)	MAGSTORM expected
UUU	(.. -)	FLARES and MAGSTORM expected
VVV	(... -)	PROTON FLARE and MAGSTORM expected
HHH	(....)	STRATWARM observed
DDD	(-..)	STRATWARM observed and FLARES expected
BBB	(-...)	STRATWARM observed and PROTON FLARE expected
MMM	(--)	STRATWARM observed and MAGSTORM expected

The second and third sets of letters refer to the occurrence of observed solar and geophysical events. The time of onset of, or the existence of the phenomenon is included by the letter broadcast. The coding for the time and type of event is shown in the table given below.

	Day before that of issue (hours UT)				Day of issue	IN	
	00-06	06-12	12-18	18-24	00-04	PROGRESS	NIL
2nd letter set:	MMM	TTT	HHH	SSS	III	GGG	EEE
PROTON EVENT	(--)	(-)	(....)	(...)	(..)	(--.)	(.)

* WWV frequencies: 2, 5, 5, 10, 20, 25 MHz

** WWVH frequencies: 2, 5, 5, 10, 15 MHz

	00-06	06-12	12-18	18-24	00-04	PROGRESS	NIL
3rd letter set:	U'JU	AAA	BBB	DDD	NNN	PPP	EEE
GEOMAGNETIC STORM	(..-)	(.-)	(-...)	(-..)	(-.)	(.--.)	(.)

Sample Messages (In International Morse Code):

GEO SSS EEE DDD

signifies: GEO = solar geophysical message

SSS = PROTON FLARE expected

EEE = no PROTON EVENT between 0000 UT yesterday and 0400 UT today

DDD = GEOMAGNETIC STORM occurred (began) between 1800-2400 UT yesterday

GEO III GGG NNN

signifies: GEO = solar geophysical message

III = FLARES expected

GGG = PROTON EVENT in progress

NNN = GEOMAGNETIC STORM began between 0000-0400 UT today

(From National Bureau of Standards Special Pub. 236)

NOTE: The letters T, U, V, and M of the first letter set and the third letter set could be of assistance in evaluating unusual MAD noise patterns.

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<p>During the last several years much has been learned about the natural environmental problems that influence the operation of Magnetic Anomaly Detection (MAD) equipment. The purpose of this report is to pass this information on to those directly involved in MAD operations. The approach is non-mathematical and deals only with the basic principles involved in the detection of a small anomaly in the presence of natural environmental noise.</p>			

