Alois Zátopek

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Microseisms and the Importance of their World-Wide Study*)

ALOIS ZÁTOPEK

Geophysical Institute of the Charles University, Prague

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The so-called microseisms represent the most regular, quasi-periodic kind of ground unrest. They may be originated in different ways and their spectre of periods is distributed from some hundredths of a second to some tens of seconds. For example, local microseisms with periods of 0.07 sec and 0.3 sec, respectively, were observed in Prague, in 1940, in connection with favourable physical conditions which occurred by random during the repair of a dam, damaged before by ice and high water. On the other hand, there exist observations of periods longer than 10 seconds and even over 20 seconds.

This communication will deal with microseisms in the period range from 3 to 10 sec. These ground oscillations, appearing most frequently during the winter

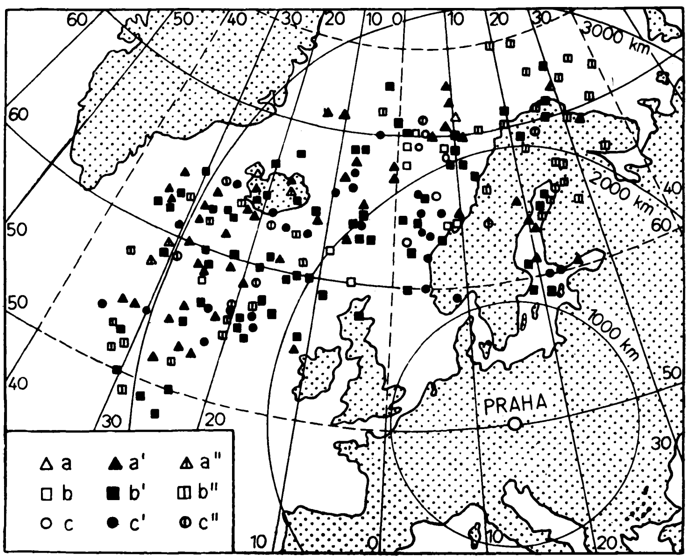

Fig. 1. Relation between the position of cyclonic centres and the amplitudes of microseisms at Praha during the active period 1948-49. Pressure in the cyclonic centre a) ≦ 965 mb, b) 970–980 mb, c) ≧ 985 mb; a, b, c strong microseims, a″, b″, c″ medium microseims.

*) Presented at the Xth Symposium, Soc. Hungarian Geophysicists, Budapest, September, 1964.

season on the seismograms over great parts of continents, are due, in general, to rapid changes of atmospheric pressure pattern over seas and oceans.

The main subject of this contribution are the microseisms originated in the north-eastern part of the Atlantic frontal zone (Fig. 1) as observed on the European continent, and especially in the central part of Europe.

This investigation of European microseisms covers the period from 1948 until 1963 and was carried out at the seismological station of Prague. Its aim was to establish a more exact relation between the circulation in the Atlantic frontal zone, extending between the east coast of North America and the west coast of the European continent, and to ascertain the influence of other regimes of circulation which cannot be a priori eliminated.

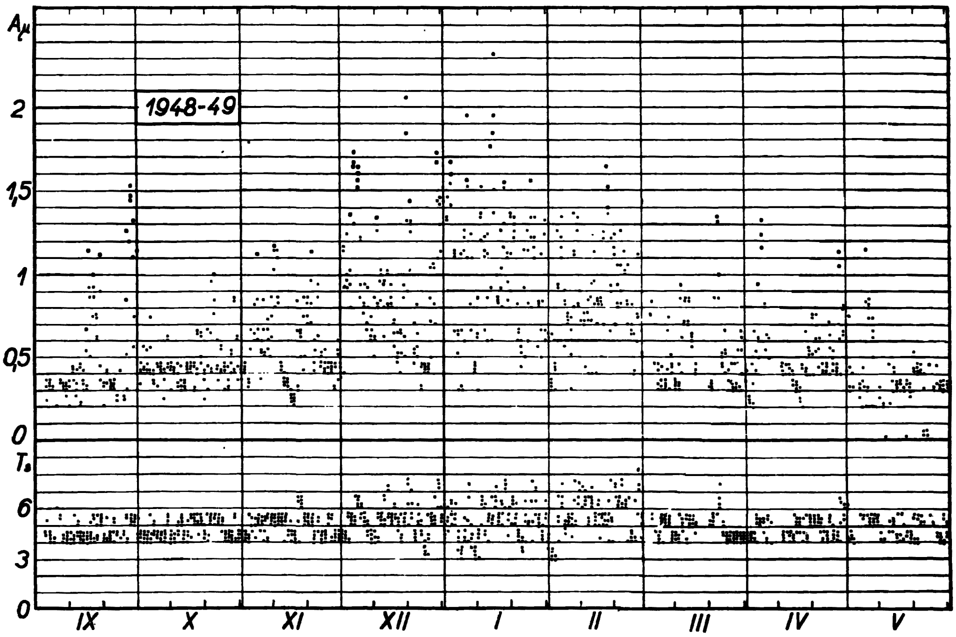

Fig. 2. Horizontal amplitudes $A = (A_N^2 + A_E^2)^{1/2}$ *and periods* $T = \frac{1}{2}(T_N + T_E)$ *of microseisms recorded at Praha 1948/49 (near a maximum of the solar activity).*

In the first stage of our study, the respective correlations between the amplitudes and periods of microseisms, recorded at the station of Prague, with the position and depth of barometric lows, with velocity and evolution of their centres, with the character and movement of fronts, with wind direction and velocity, with the sea depth in the origin area, and with other factors have been established and studied.

The results of this study of oceanic effects observed at a continental station, i.e. that of Prague, have been obtained by means of a continuous graphical representation of the time course of amplitudes and periods of microseisms, taken throughout the whole annual period of microseismic activity. This representation uses four parallel time axes, corresponding to the principal meteorological terms at 0 h, 6 h, 12 h, and 18 h GMT, respectively. In this way, one normalized millimetre paper was sufficient for representing the time course of the periods and amplitudes for one whole active period from September to May of each year (Figs. 2–4). Even auxiliary

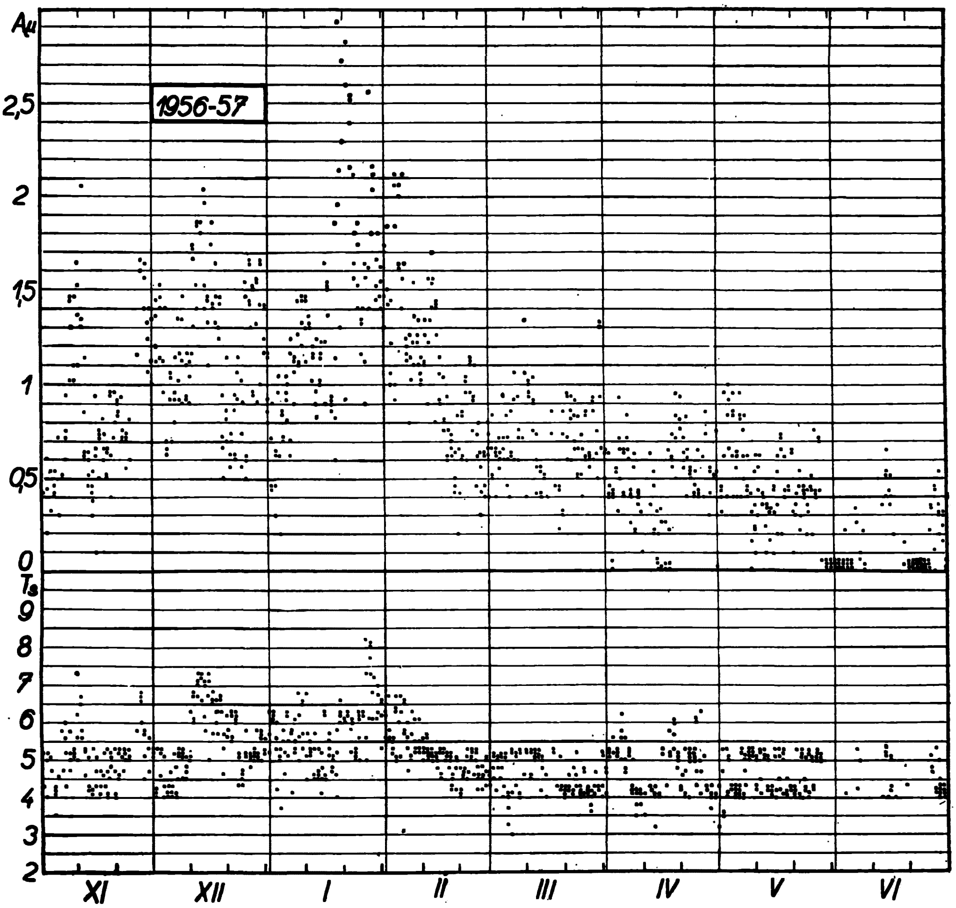

Fig. 3. Amplitudes A and periods T recorded at Praha 1956/57 (near another solar activity maximum).

data, necessary for obtaining relations between microseisms and other investigated factors, may be plotted into the same diagram. Active periods of different years can be compared very easily for the same or for different stations, and more general time and space characteristics can be derived by means of this method.

It must be underlined that not only microseismic storms, as it is normally the case, but also the "usual" microseims were included into the analysis. This happened by means of the idealized summation curves of periods and amplitudes constructed for the active period in question, and represented as smooth curves. Differentiating them, the idealized smoothed course of periods and amplitudes during the period considered was obtained. These curves can also be compared for various active periods and for different stations; by means of them a comparative study of individual active periods, and longer time intervals, for one or for many stations was possible during the second stage of the analysis (Fig. 5). The IGY and the YIGC intervals, naturally, were subjected to a more detailed study.

Throughout the period of investigations, the corresponding synoptic maps were studied from day to day simultaneously with the course of microseisms. It was

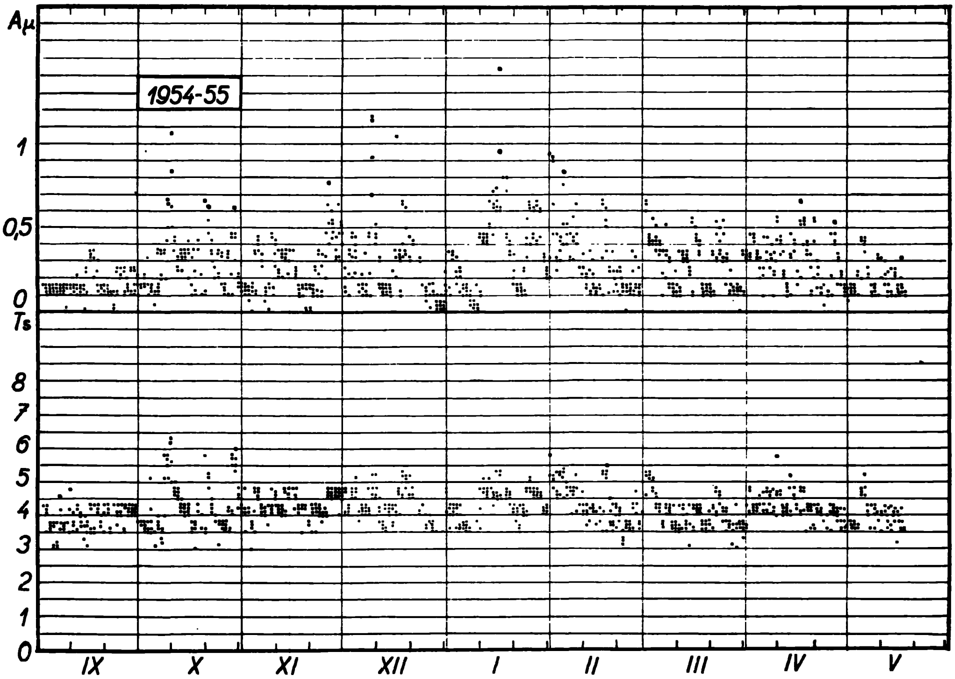

Fig. 4. Microseisms of Praha 1954/55 (solar activity minimum).

proved that for Prague the microseisms are closely connected with cyclonic activity in the eastern part of the Atlantic frontal zone, i.e. in a belt running to the north-east, east of the meridian 40°W and north of the parallel 50°N (see Fig. 1). Particularly important regions for the generation of microseisms—as observed at the station of Prague—proved to be the part of the Atlantic Ocean situated to the west, south-west and south of Iceland, the region of Jan Mayen Island, the region west of the coast of central Norway, the northern Norwegian coast, and the northern part of the Baltic Sea (Figs. 6, 7).

The generation of microseisms in these regions has been found to be closely connected with the origin, development and motion of pronounced barometric lows. It was found that stationary cyclones do not exhibit noticeable effects on the amplitudes of microseisms as observed in Prague. No clear effects of the cyclones occurring over the shallows off the coast of Greenland, over the North Sea, and in the English

Channel or in the Bay of Biscay were stated. Similarly, no traces of the effect of the Mediterranean regime, this being in many cases distinctly expressed in meteorological factors over Bohemia, were found in the Prague microseisms. Many of the effects observed show, apart from the effects of distance from the place of origin of the microseisms, also an influence of geological structure.

During the second stage of research the method described was applied to periods and amplitudes of 18 following European seismological stations: Athens, Belgrade, Bratislava, Bucarest, Collm, Copenhagen, De Bilt, Halle, Hurbanovo, Jena, Kiruna, Nord, Potsdam, Skalnaté Pleso, Strasbourg, Stuttgart, Triest, Warsaw. In this way the results obtained for Prague could be generalized for the whole central Europe. It was found that the known similarity in the course of microseismic amplitudes at different stations in the case of individual storms is valid also for the generalized smoothed amplitude curves derived for the respective active periods. The conservation of the type of these curves for a number of stations situated along the profile Kiruna-Triest (Fig. 5) is seen as a demonstration of the predominating effect of the Atlantic zone in the global regime of the European microseisms.

However, it was stated that the regions, mentioned above as the main origin areas of microseisms for central Europe, appear to be less important for the propagation of microseisms through the Scandinavian shield and Russian platform. For the last two regions the most important origin area seems to be the part of the Atlantic Ocean which is situated off the western coast of Scandinavia.

As it concerns the mechanism of European microseisms, these are originated by barometric effects as well as by coastal effects, especially by the surf effect. One can attribute the parallel effects of continental dimensions, which determine the general common character of microseismic activity of individual active periods, to the "first order" sources, while the differences, which are characteristic for various regions, may be explained as effects of the "second order" sources. In the first

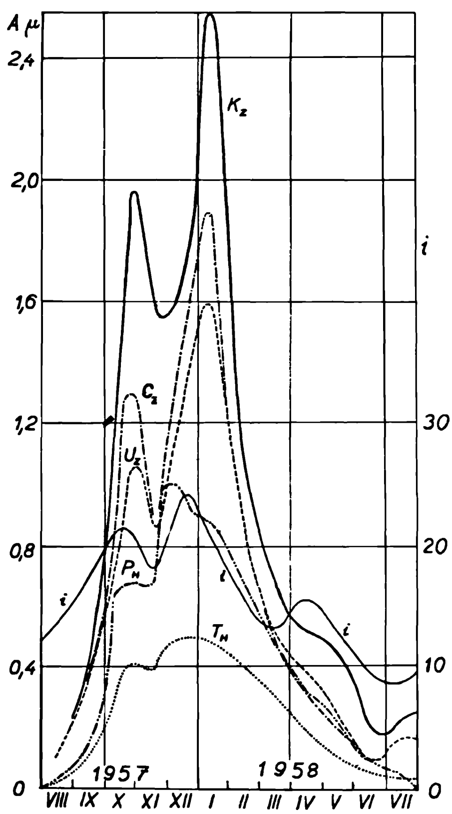

Fig. 5. Smoothed amplitude curves 1957/58 along a N-S profile; decrease of amplitudes from N to S (K_Z vertical component at Kiruna, U_Z vertical component at Uppsala, C_Z vertical component at Copenhagen, P_H horizontal component at Prague, T_H horizontal component at Trieste. Curve i represents smoothed indices for 500 mb.

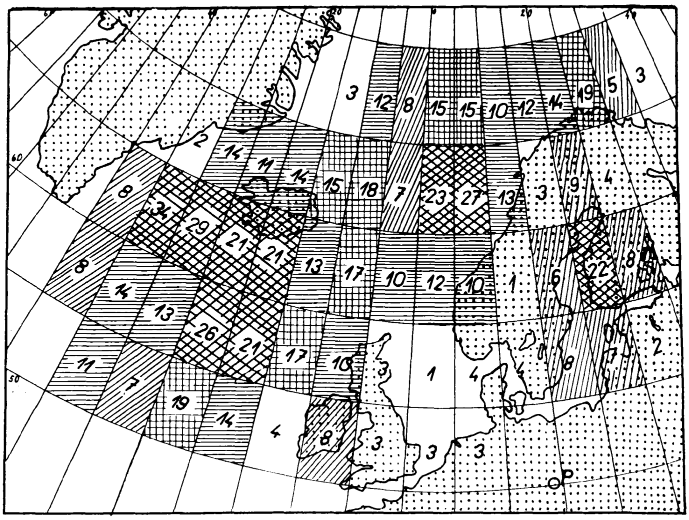

Fig. 6. Origin areas of microseisms derived by superposition of maps similar to that given in Fig. 1 for the period 1948–49 and 1956–57).

case, the sources are of considerable dimensions involving large oceanic masses of water which participate in generating microseisms. In the second case, the sources are of only regional dimensions, e.g. centres of secondary barometric lows, winds, cold front passages from the sea to the continent, surf, etc., generally acting in the neighbourhood of the coast. The dimensions of the sources are naturally connected with the period of microseisms: long period microseisms, in general, are to be ascribed to more extended sources than the short period ones. Here, under the term "source" we understand the "effective" source, i.e. a complex of "elementar" sources responsible for the generation of microseisms in the origin areas. It is clear that, in real conditions, no universal mechanism and no universal theory may be suggested which would be able to describe the generation and propagation of microseisms.

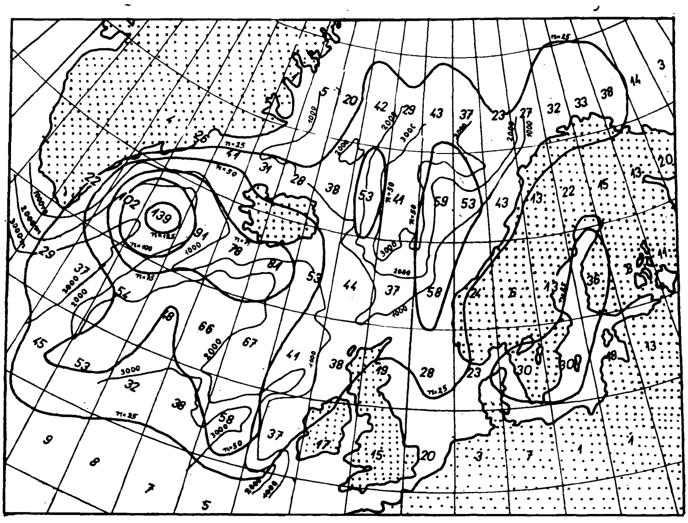

Fig. 7. Origin areas indicated by maximum isolines of statistical weights (1948–1960).

These also depend greatly on the geological and tectonical structure of the area in question. Our present knowledge of these relations is very unsatisfactory; for Europe it would require a detailed study, covering, if realized, the whole European area and the western part of the Asiatic continent.

The immediate relation of microseisms, generated in the Atlantic frontal zone, with atmospheric circulation was studied by correlating the course of microseismic amplitudes with an index number, roughly proportional to the west-east component of the geostrophic wind velocity in the 500 millibar level. An obvious qualitative correspondence was found for the winter period (see Fig. 5, curve "i"); for the warmer period of the year it appeared to be less satisfactory. The explanation of this observa-

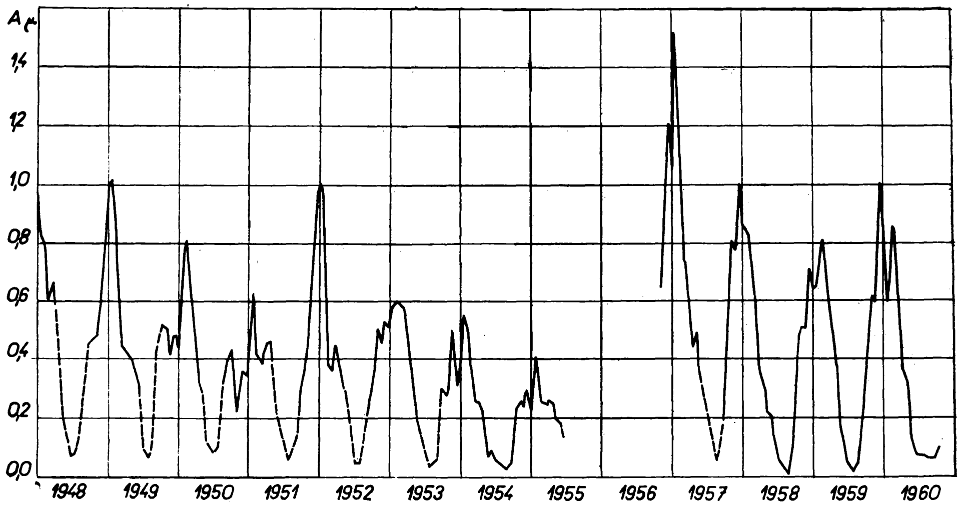

Fig. 8. Smoothed amplitude curves 1948–1960 (the lack 1955/56 caused by a water calamity); solar activity maxima: 1947 and 1956, respectively.

tion by a smaller effect of warmer turbulent air layer on the formation of water waves over the ocean seems to be obvious.

In order to see how the effect of the solar activity is, which influences the atmospheric circulation, on microseisms, the time course of smoothed microseismic amplitude curves (plotted for Prague) was pursued during the period 1948–1960. This period covers the time interval from the maximum of solar activity in 1947 over the following maximum in 1957. It was found that, on the whole, the maxima formed a wave with the highest peaks corresponding to the maxima just mentioned of the solar activity (Fig. 8). A comparison of the course of the mean relative sunspot numbers during the period considered with the course of the maximum smoothed amplitude values shows roughly the same trend of both curves (Fig. 9).

The third stage of research into microseisms in Prague was a statistical investigation of periods of European microseisms; especially the cases with periods over 6 seconds were studied. Periods of microseisms are a very sensitive and reliable parameter. It was found that the well known parallelism in the course of periods

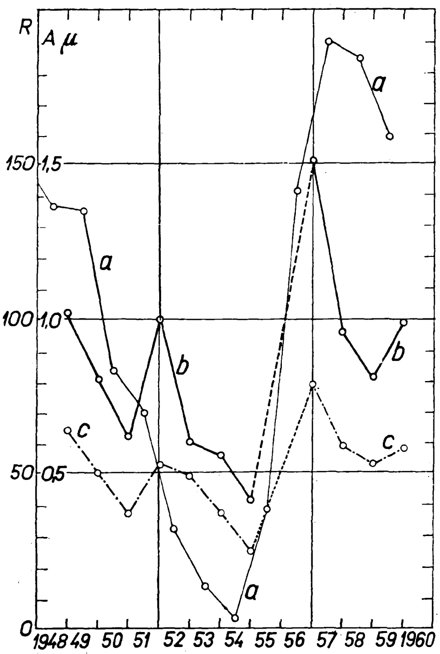

Fig. 9. Mean relative sunspot numbers R (after Waldmeier) a) plotted against maximal and mean smoothed amplitudes of microseisms, curves b) and c) respectively.

and amplitudes of microseisms is only a very rough statistical characteristic. A more detailed study shows certain systematic differences of periods at various stations, and reveals microseisms as a "polychromatic" movement, the periods of which are strongly influenced not only by the origin mechanism, but also by the geological structure. The long-period microseisms, as observed in Prague, are originated mostly in the region of Iceland; the regions of Jan Mayen, of the northern Norwegian coast and Baltic Sea, respectively, are of primary importance for Scandinavia and for the Russian platform. It was generally stated that long-period microseisms appear, when extended pressure patterns with pronounced lows are present. If these are storm cyclones, then long period microseisms are observed as longperiodic microseismic storms; if the cyclones are stationary (Fig. 10), only a very small rise of amplitudes (or none at all), but always a considerable increase of periods are observed. For the rise of long-period microseisms, the development of cyclonic features of great dimensions, extending mostly in the SW-NE, and less frequently in the NW-SE, directions and their rebuilding were found as characteristic. A comparison of similar phenomena at different stations of Europe leads to a conclusion that such a study, extended to as many stations as possible, would be very useful in a wide scale research into the structure of the Earth's crust, and the mechanism of origin and propagation of microseisms as well.

A number of authors studied microseisms from different points of view in all parts of the world. They discovered very interesting regimes which often differ considerably from each other, but there is practically no knowledge of the system as a whole, and of the connections between the various regimes and the prevailing mechanisms. In order to penetrate into

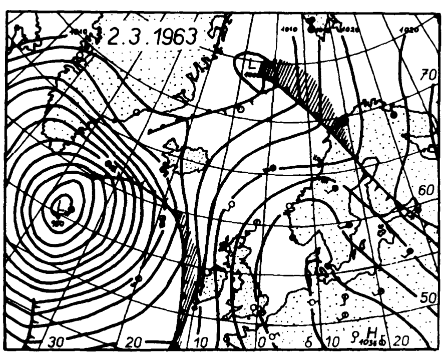

Fig. 10. Synoptic chart at 6.00 GMT on March 2, 1963 (stationary low).

these problems, very important for the study of the general atmospheric circulation and for the structural study of the Earth's crust, it would be necessary to organize a simultaneous world-wide research into the complex of phenomena and relations, connected with microseisms. A group of problems could be attacked as a seismological contribution to the International Quiet Sun Year. These investigations would indirectly stimulate the progress in standardization and homogeneization of seismic instruments and methods of mechanization and automatization of evaluating data from long observational series.

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Mikroseismy a důležitost jejich celosvětového studia

(Souhrn)

Na seismické stanici Praha jsou od r. 1948 soustavně studovány mikroseismy s periodami od 3 do 10 sekund.

V první etapě, věnované mikroseismům registrovaným stanicí Praha, byla zjištěna jejich těsná souvislost s cyklonální činností v sv. části tzv. atlantické frontální zóny na východ od 40° z. d. a sev. od 50° š. Byly nepřetržitě sledovány korelace amplitud a period mikroseismů se synoptickými faktory zmíněné zóny. Statistické zpracování je vázáno na hlavní meteorologické termíny a vychází z grafického znázornění chodu period a amplitud v soustavě o čtyřech časových osách, odpovídajících meteorologickým termínům. Je rozsáhle používáno grafických metod kolektivního počtu, zejména vyhlazených součtových křivek amplitud a period a z nich odvozených derivačních křivek, zachycujících celkový charakter jednotlivých aktivních období. Studiem korelací byly získány základní zákonitosti průběhu pražských mikroseismů a odvozeny hlavní oblasti jejich vzniku: okolí Islandu, oblast Jan Mayena, sz. a sev. část norského pobřeží a Botnický záliv.

V druhé etapě toto studium bylo rozšířeno na 18 dalších evropských stanic, rozšířena platnost pražských závěrů na oblast střední Evropy a sledován celkový úbytek amplitud ve směru S-J a Z-V. Zjištěno, že šíření mikroseismů je silně ovlivňováno geologicko-tektonickou stavbou velkých bloků evropského kontinentu. Základní rysy evropské mikroseismické činnosti byly přisouzeny zdrojům „prvního řádu", působícím na širém Atlantickém oceánu. Základní rysy jsou pak v různé míře ovlivňovány zdroji „druhého řádu", vázanými spíše k pobřeží.

Ve studovaném období se jeví jisté zesílení mikroseismické činnosti (amplitud) v období sle-

dujícím sluneční maxima 1947 resp. 1957, a naopak zeslabení v období slunečních minim 1955 resp. 1963.

Třetí etapa byla věnována výzkumu period, zejména delších než 6 sekund. Bylo zjištěno, že dlouhoperiodické mikroseismy jsou spojeny s výskytem rozsáhlých a hlubokých tlakových depresí, zejména v oblasti Islandu.

Srovnávací studie mikroseismů ukazují, že buzení mikroseismů v různých oblastech světa podléhá různým cirkulačním režimům, jejichž dosud velmi málo známé souvislosti vyžadují, aby dlouhodobé, soustavné a nepřetržité studium mikroseismů bylo zahájeno v celozemském měřítku.

Микросейсмы и значение их исследований в мировом масштабе

Резюме

На сейсмической станции Прага систематически изучаются с 1948 г. микросейсмы с периодами от 3 до 10 секунд.

В первом этапе исследований, когда уделялось внимание микросейсмам, регистрированным лишь станцией Прага, была найдена их тесная связь с циклональной деятельностью в северной части атлантической фронтальной зоны восточнее 40° западной долготы и 50° северной широты. Непрерывно исследовались корреляции амплитуд и периодов микросейсм относительно синоптических факторов названной зоны. Статистическа обработка результатов обусловлена стандартными метеорологическими сроками и исходит из графического представления смещений нулей и амплитуд в системе с четырьмя осями времени, соответствующими метеорологическим срокам. В большой мере применяются графические методы обработки больших совокупностей данных, особенно сглаженные суммарные кривые амплитуд и периодов, также как и по ним построенные производные кривые, предствляющие общий характер отдельных активных интеревалов. В результате изучения корреляций были получены основные закономерности в пражских микросейсмах и даны главные области их возникновения: окрестность Исландии, область остора Ян-Майен, северо-западная и северная части норвежского побережья и Ботнический залив.

Во втором этапе эти исследования были распространены и на дальнейшие 18 европейских станций, обобщена справедливость пражских заключений на область средней Европы, исследовалось общее убывание амплитуд в направлениях север–юг и запад–восток. Было обнаружено, что распространение микросейсм значительно обусловлено геологическо-тектонической структурой больших блоков европейского континента. Основные черты европейской микросейсмической деятельности считаются происходящими от источников «первого порядка», имеющихся в области Атлантического океана. Эти основные черты дальше обусловлены в разной мере источниками «второго порядка» относяшимися более к береговым зонам.

В интервале исследований обнаруживается некоторое увеличение микросейсмической деятельности (амлитуд) в периоды, следующие за солнечными максимумами 1947 или 1957 гг., и наоборот некоторое уменьшение в периоды солнечных минимумов 1955 или 1963 гг.

Третий этап был посвящен исследованиям периодов, особенно большей величины чем 6 секунд. Было обнаружено, что длиннопериодические микросейсмы связаны с происхождениями обширных и глубоких депрессий (давления), особенно в области Исландии.

В результате сравнительных исследований микросейсм оказывается, что происхождение микросейсм в разных областях мира обусловлено разными режимами циркуляции, взаимоотношения которых до сих пор весьма мало изученные, требуют, чтобы систематические и непрерывные исследования микросейсм в течение длинного периода были начаты в мировых масштабах.