GEOPHYSICS

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EMERGENCE OF EARTHQUAKES FOOTPRINT IN NATURAL ELECTROMAGNETIC FIELD VARIATIONS

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Purpose. It is well-known that strong earthquakes are typically accompanied by some phenomena which relate to variations of natural electromagnetic fields. Based on the idea about the mechanism of lithosphere–atmosphere–ionosphere coupling we expect to detect some precursors of strong natural earthquakes in electromagnetic data sets recorded by magnetotelluric instruments far enough from epicenters. **Methodology.** The temporal changes of power spectral density in the natural electromagnetic field components were analyzed with respect to the earthquakes with a magnitude greater than 5 (M5+) occuring in Europe as well as worldwide. **Results.** Electrical and magnetic field variations were recorded at three sites located at two lines. The first line was placed along the Tesseyre-Tornquist Zone in Poland and the second one was perpendicular to the first. The observations have been carried out from September 2015 to April 2018. The data were recorded by standard five channels magnetotelluric instruments. The magnetic field components were measured in three orthogonal directions and electrical ones in two horizontal orthogonal directions. The spectra of the electromagnetic field components have been analyzed with respect to earthquakes with M5+ in Europe as well as around the globe. The changes in the intensity of the spectra which can be treated as earthquake precursors have been detected from 24 to 32 hours before the seismic events. The reasons for such effects are also discussed. **Originality.** The electromagnetic monitoring is typically carried out next to seismically active regions but according to theoretical explanations some of the phenomena are of global origin. We used ordinary magnetotelluric data recorded at mid latitude sites placed far enough from the seismically active regions and we show that a global relationship exists between seismic and electromagnetic events with high probability. **Practical significance.** Such results can accomplish the information about earthquake precursors.

Key words: natural electromagnetic field; spectra; earthquake; precursors.

Introduction

It is well-known that strong earthquakes are typically preceded by some phenomena in natural electromagnetic (EM) fields variations. Both precursors as well as post-seismic events were observed in a wide frequency (period) band of EM variations and many attempts to explain them have been undertaken. An electrokinetic effects under the ground is considered as one of possible explanation of such anomalous signals [Takahashi et al., 2007; Bordes et al., 2008]. An interrelation between the tectonic activity and the anomalous changes of the geophysical parameters characterizing the Earth's lithosphere have been noticed also in [Moldovan et al., 2009]. Micro-crackings located in an earthquake preparation zone are also considered as the possible source of electromagnetic radiation in VLF and ULF band [Teisseyre & Ernst, 2002]. Most probably similar effects were the cause of temporal changes in apparent resistivity which related to the 2010–2011 seismo-volcanic crisis at Taal volcano [Ladanivskyy et al., 2018].

The correlation between the earthquakes and EM events is often explained by the electric field variations which are generated within the upper atmosphere due to seismo-ionospheric coupling phenomena [Hayakawa & Hobara, 2010]. On the basis of correlation study Straser et al., [2016] concluded that practically all natural M6+ and even M5+ earthquakes are preceded by increased solar activity, which causes the appropriate disturbance in the Earth's geomagnetic field. They explain this correlation by a proton flow emitted by the Sun. The overview of earthquakes which were accomplished by some well distinguished footprints in different bands of the EM field spectra can also be found in [Straser et al. 2016]. As an opposite, they showed, as on the basis of their own data as well as on the data from other observatories around the globe, that man-made earthquake such as, for example, devastating earthquake that occurred near the Koyna Dam in India in 1967, extraction of oil, gas, and minerals, several nuclear tests have not been preceded by geomagnetic activity. So, such effects can be used as indirect proof of close ionosphere–tectonosphere coupling.

Two horizontal electrical and three magnetic fields components were recorded at three sites placed at two lines: one along the Tesseyre-Tornquist Zone in Poland and the second one was placed perpendicular to the them. The duration of observation was from September 2015 to April 2018 year. Several strong earthquakes (M5+) have occurred for this time as in Europe (Italy and Romania) as well as around the globe.

In this paper, some effects in the recorded EM field which correlate to significant seismic events (to the Italian strong earthquakes which happened in 2016) are represented.

Purpose

It is well-known that strong earthquakes are typically accompanied by some phenomena which relate to variations of natural electromagnetic fields. Based on the idea of about the mechanism of lithosphere–atmosphere–ionosphere coupling we expect to detect some precursors of strong natural earthquake in electromagnetic datasets recorded by magnetotelluric instruments far enough from epicenters.

Methodology

The temporal changes of power spectral density in the natural electromagnetic field components were analyzed with respect to the M5+ earthquakes occuring in Europe as well as worldwide.

Results

Experimental data

Three magnetotelluric instruments (PSM) were installed in three different locations in Poland and have operated simultaneously since September 2015 until April 2018 with several unexpected gaps. Two of three stations (Grabnik - GRB and Kozieniec - KZN were installed over the belt of well-known Tesseyre-Tornquist Zone (TTZ) and the last one (Suwalki, SUW) was shifted to the side of Precambrian East European Craton (EEC). The pattern of measuring sites forms a rectangular angle on the map (see Fig. 1). Such a configuration have been chosen to allow us to apply the Generalized Magneto Variation Soundings method [Semenov et al., 2011] to the data but it is not the foccus of the current article. TTZ is a strip of well conducting sedimentary rocks tens of kilometers wide and up to 7 km deep. Their slopes are composed of high-resistance crystal rocks. If we added a conductivity cross section across the TTZ, we would see the complexity of its structure.

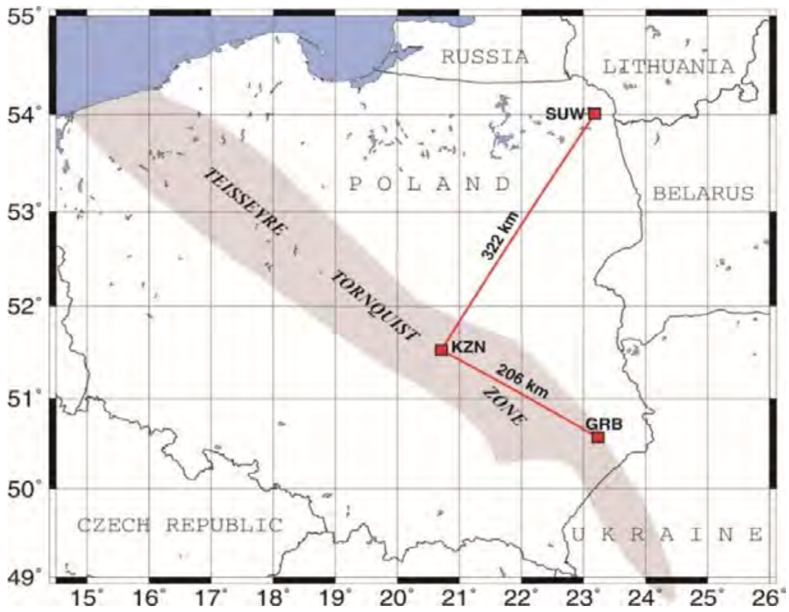

Fig. 1. Location of measuring sites in Poland: Suwalki (SUW), Kozieniec (KZN) and Grabnik (GRB)

Unfortunately our data set is not continuous. It was broken several times due to equipment factors. Among three measuring sites, KZN was noisier in comparison to the GRB at TTZ and SUW at EEC.

Several significant earthquakes have occurred on the European continent during the mentioned period of data acquisition. Among them the catastrophic Italian earthquakes of 2016 can be mentioned. The information about earthquakes were taken from the USGS catalogue [https://earthquake.usgs.gov/earthquakes/map]. The data were analyzed to detect the strong seismic events caused signals in the EM parameters onto our data acquisition placement.

Analyzed events

Since the sources of long period magnetotelluric variations are the currents in the ionosphere and magnetosphere and based on the seismo-ionospheric coupling phenomena we tried to see the effects of strong earthquakes (M5+ and M6 +) onto our data. During the data collection, such events on the Polish territory were not registered, but such earthquakes were fixed on the territory of Italy and Romania. Figure 2 shows the dynamic spectra of the 5 components of the EM field in the period range 500-10,000 s for October 2016 at site GRB. That month two earthquakes M6.1 (2016-10-26) and M6.6 (2016-10-30) occurred in Italy, and their hypocenters were fixed at a distance of ~ 15 km from each other. Before these events, an increase in the spectral density of the EM field variations was fixed about 30 hours prior the first earthquake. Even more clear this effect can be seen before the earthquake M6.2 (2016-08-24), recorded in the same region in Italy. Figure 3 shows variability of magnetic and electric spectra at the same site GRB for the same period band. What can be seen on both figures the vertical Bz component is less sensitive to seismic events than horizontal ones. Similar pattern is also present on the dynamic spectra plots at sites KZN and SUW except the electrical channels at KZN because they are influenced by a moderate level of artificial noises at this site. We also analyzed the EM spectra around the December 27 (2016) earthquake in Romania (M5.6). The plots also highlight some activation in geomagnetic field approximately 30 hours before seismic event as in previous cases.

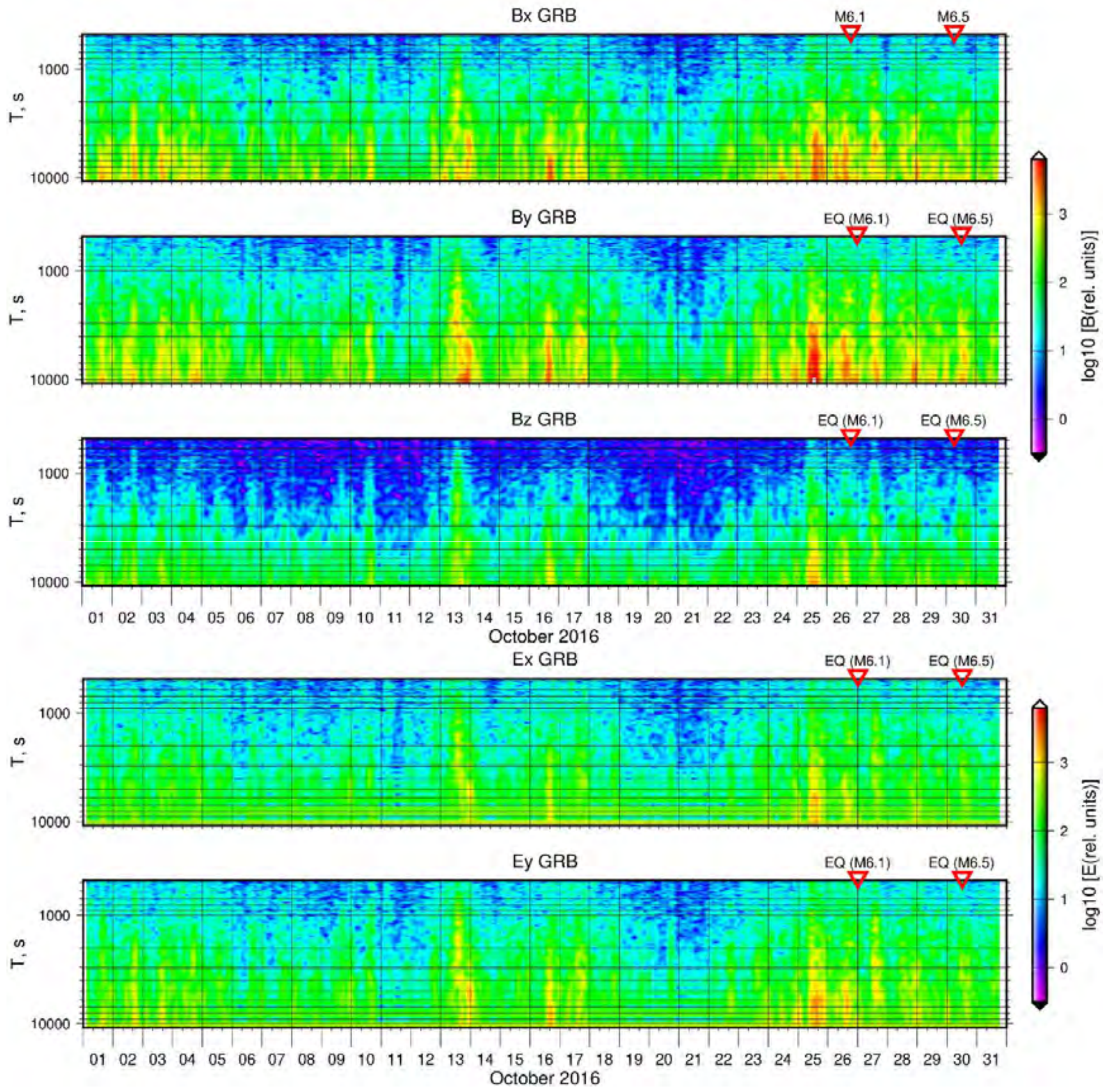

Fig. 2. Variability of EM spectra with time at point GRB on October 2016. Red triangles mark the earthquakes in Italy mentioned in text

Originality

The electromagnetic monitoring is typically carried out next to seismically active regions but according to theoretical explanations some of the phenomena are of global origin. We used ordinary magnetotelluric data recorded at mid latitude sites placed far enough from the seismically active regions and we show that such a global relationship exists between seismic and electromagnetic events with high probability.

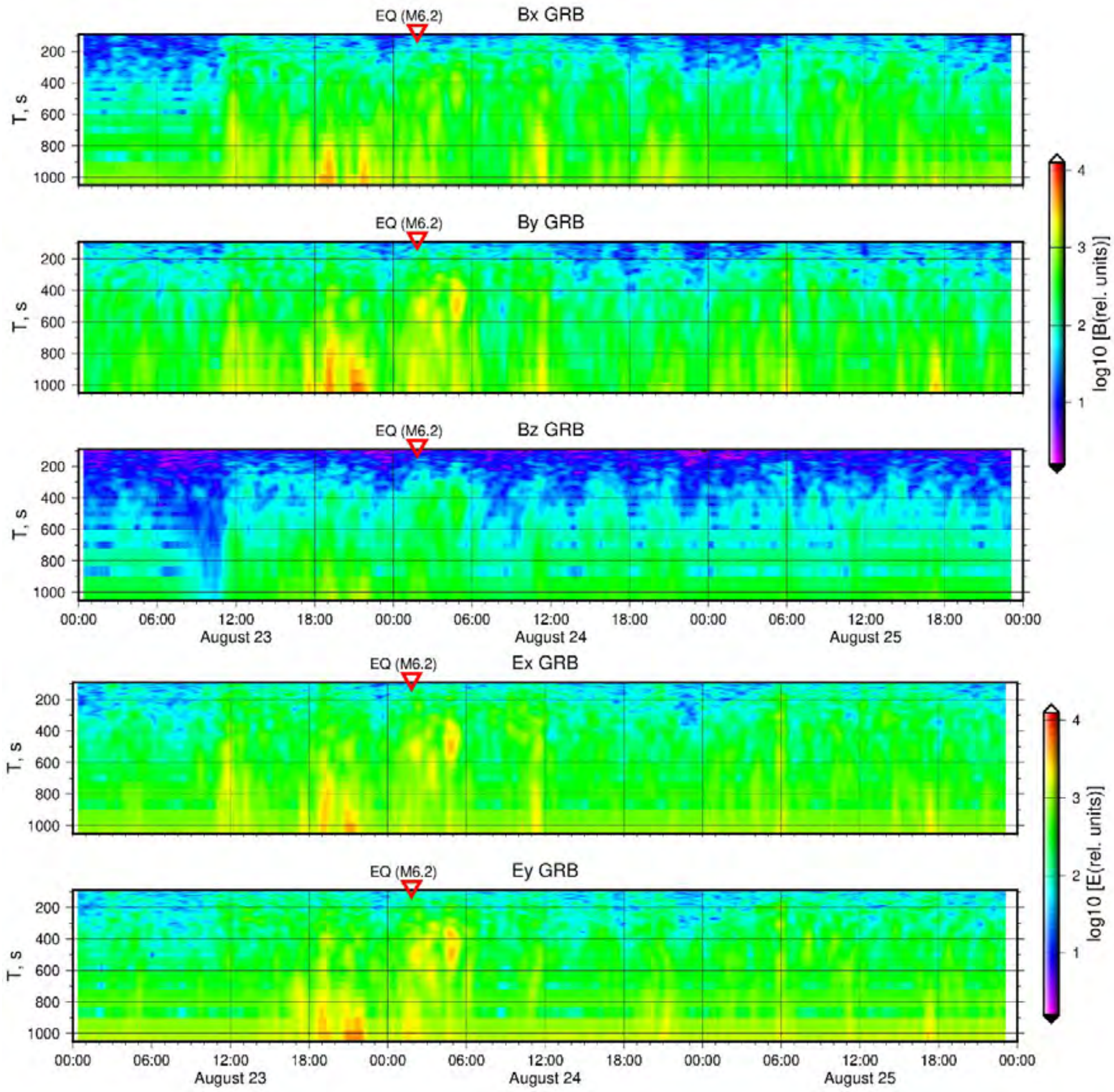

Fig. 3. Variability of EM spectra with time at point GRB for the August 24, 2016 earthquake

Practical significance

Obviously the considered effects in the natural EM field spectra cannot serve as 100% precursors of strong earthquakes, but such results can supplement the information about them.

Discussion and conclusions

Correlation between earthquakes and electromagnetic field variations is a background for suggesting the piezoelectric and seismo-electro-kinetic phenomena [Guglielmi, 2008] in weakened zones and during stresses caused by seismic waves [Jarosinski, 2012] from rather powerful earthquakes [Neishtadt et al., 2006; Kurtz and Nibbled, 1978]. The first one is the variation of the magnetic field due to elastic stresses, while the second is the variations of media conductivity due to dynamics of fluids in the Earth's crust caused by its stress strain state. The latter effect is characterized by inertia [Svetov, 2007]. Both effects cannot be described by the Maxwell's equations alone. So a task for future study is to separate the induction effect from other kinds of phenomena.

In the present paper it was demonstrated that the detectable changes in the EM spectra were recorded in the frequency band from a few hundreds up to a few thousands seconds for strong earthquakes (M6+) that occurred at a great distance from the registration sites. An increase in the spectral density of the EM field variations was observed about 30 hours before these events (Fig. 2, Fig. 3). In addition, Figure 2 shows an increasing intensity in the spectra from 13 to 18 October, 2016. What is further-interesting, at the same time the world network also recorded series of earthquakes M6+. The first was recorded in Papua New Guinea on 15 October, 2016 with a magnitude of M6.3. Thus, the time lag in the change of the intensity of the spectra is commensurate with those analyzed in the work.

Perhaps the observed effects can be explained by increases of the proton density of the solar wind [Straser et al., 2016. Cataldi et al., 2016]. There are many data suggesting a potential relationship between the potentially destructive earthquakes at a global scale and the solar activity. Therefore, it is imperative to understand how this happens. Straser et al. [2016] and Cataldi et al. [2016] confirmed that the seismic events of strong intensity (M6+) that occur at a global scale are always preceded by an increase of the proton density of the solar wind. The same anomalies appear as intense variations in the geomagnetic field following an increase in solar activity if they are observed using a fluxgate magnetometer that produces magnetograms. They reported [Cataldi et al., 2016] that considering the time intervals recorded from January 1, 2012 to April 30, 2016 the 604 seismic events, (USGS data), whereby an average 140.9 hours elapsed between the beginning of the solar wind proton density increase and the earthquake. The average temporal difference reported by Straser et al. [2016] between the maximum intensity of the electromagnetic anomaly recorded and an M6+ seism was ~9 hours, while the minimum difference was 1 minute and maximum one was ~37 hours. This well corresponds to results detected in this research.

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ВИЯВЛЕННЯ ПРОЯВІВ ЗЕМЛЕТРУСІВ У ВАРІАЦІЯХ ПРИРОДНОГО ЕЛЕКТРОМАГНІТНОГО ПОЛЯ

Мета. Загальновідомо, що сильні землетруси типово супроводжуються певними явищами, що належать до варіацій природного електромагнітного поля. Ґрунтуючись на ідеї про механізм літосферноатмосферно-іоносферної взаємодії, ми сподіваємось виявити деякі передвісники сильних природних землетрусів у наборах електромагнітних даних, котрі реєструвались магнітотелуричними станціями досить далеко від епіцентрів. **Методика.** Аналізувались часові зміни спектральної густини енергії в компонентах природного електромагнітного поля відносно землетрусів магнітудою більше ніж 5 (M5+), котрі траплялись і у Європі, і по всьому світу. **Результати.** Варіації електричного і магнітного полів реєструвались у трьох точках встановлених на двох лініях: перша була розташована вздовж зони Тесера-Торнквіста в Польщі, а друга була перпендикулярно до неї. Спостереження проводились з вересня 2015 р до квітня 2018 р. Дані реєструвались за допомогою стандартних п'яти канальних магнітотелуричних станцій, а саме компоненти магнітного поля вимірювались в трьох ортогональних напрямках а електричного лише в двох ортогональних горизонтальних. Аналізувались спектри компонент електромагнітного поля відносно землетрусів з магнітудою M5+, які траплялись як у Європі так і по всій планеті. Зміни в інтенсивності спектрів, котрі можуть бути трактовані як передвісники землетрусів були виділені від 24 до 32 годин перед сейсмічною подією. Причини таких ефектів у статті теж обговорюються. **Наукова новизна.** Електромагнітний моніторинг типово проводиться поряд із сейсмічно активними регіонами, але згідно теоретичних трактувань, деякі явища мають глобальне походження. Ми використали звичайні магнітотелуричні дані, записані в точках розташованих в середніх широтах досить далеко від сейсмічно активних регіонів але ми продемонстрували, що такі глобальні зв'язки між сейсмічними і електромагнітними подіями з високою ймовірністю існують. **Практичне значення.** Подібні результати можуть доповнювати інформацію про передвісники землетрусів.

Ключові слова: природне електромагнітне поле; спектри; землетрус; передвісники

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ВЫЯВЛЕНИЕ ОТПЕЧАТКОВ ЗЕМЛЕТРЯСЕНИЙ В ВАРИАЦИЯХ ЕСТЕСТВЕННОГО ЭЛЕКТРОМАГНИТНОГО ПОЛЯ

Цель. Общеизвестно, что мощные землетрясения типично сопровождаются соответствующими явлениями, относящимися к вариациям естественного электромагнитного поля. Базируясь на идеи об механизме литосферно-атмосферно-ионосферного взаимодействия, мы намереваемся выделить некоторые предвестники сильных натуральных землетрясений в наборах электромагнитных данных, зарегистрированных магнитотеллурическими станциями на достаточно большом растоянии от эпицентров. **Методика.** Анализировались временные изменения спектральной плотности мощности в компонентах естественного электромагнитного поля по отношению к землетрясениям с магнитудой больше 5 (M5+), которые имели место в Европе, а также по всему миру. **Результаты.** Вариации электрического и магнитного полей регистрировались в трех точках, установленных на двух линиях: первая линия проходила вдоль зоны Тесера-Торнквиста в Польше, а вторая – перпендикулярно к первой. Наблюдения проводились с сентября 2015 г по апрель 2018 г. Данные регистрировались при помощи стандартных пяти канальных магнитотеллурических станций, а именно компоненты магнитного поля измерялись в трех ортогональных направлениях, а электрического – в двух ортогоныльных горизонтальных. Анализировались спектры компонент электромагнитного поля по отношению к землетрясениям с магнитудой M5+, которые имели место как в Европе, так и по всей планете. Изменения в интенсивности спектров, которые можно интерпретировать как предвестники землетрясений, виявлены от 24 до 32 часов перед сейсмическими событиями. Причины этих эффектов также обсуждаются в статье. **Научная новизна.** Электромагнитный мониторинг типично проводится вблизи сейсмически активных регионов, но согласно теоретических толкований некоторые явления имеют глобальное происхождение. Мы использовали обыкновенные магнитотеллурические данные, зарегистрированные в точках, расположеных в средних широтах, достаточно далеко от сейсмически активных регионов, но мы продемонстрировали, что такие глобальные связи между сейсмическими и электромагнитными событиями с большой вероятностью имеют место быть. **Практическое значение.** Такие результаты могут дополнить информацию о предвестниках землетрясений.

Ключевые слова: естественное электромагнитное поле; спектры; землетрясение; предвестники.

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