Time Dependencies Between Tectonic Activity of Świebodzice Depression (SW Poland) and Seismic Activity in Poland and Czech Mining Regions

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Abstract. Since the 1970-ties, large azimuth changes in the equilibrium of quartz horizontal pendulums have been irregularly registered in the Geodynamic Laboratory in Książ. However, azimuth changes of the pendulums did not correlate with meteorological phenomena and the compensation phases of these changes excluded processes of gravitational creep of the rock massif. It was assumed that changes of these azimuths result from tectonic tilt of the rock massif. These were the first observations of contemporary tectonic activity in the Świebodzice Depression (SW Poland). Multiannual observations have allowed for determining temporal and amplitude characteristics of such tectonic activity. Intervals of tectonic activity last from several days to two weeks and are separated by periods of low activity or even no activity. During tectonic events, amplitudes of rock massif deformation reach values of several tens of tidal amplitudes. The distinguished characteristics of tectonic effects and their incidental character have been confirmed by water-tube tiltmeters (WT) activated in the Geodynamic Laboratory in the early 2000s. Unique conditions of the rock massif cause that the WTs, in connection with blocks of the rock massif separated by faults, are natural detectors of tectonic activity, allowing to determine the function of tectonic activity and its derivatives in the surrounding areas.

1 Introduction

In 2016–2018 the principal research topic in the Geodynamic Laboratory in Książ (GL) included studies on the changes of kinematic activity in the Świebodzice Depression rock massif (the Sudetes, SW Poland) in the context of their correlation with intervals of seismic activity in mining areas [1]. The first comparative studies between functions of tectonic activity (TAF) and seismic activity of mining areas in the Fore-Sudetic Monocline, Upper Silesian Basin and Bohemian Massif began in 2016. These investigations show that strong

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seismic shocks (>3 Mag) occur in mining areas only in specific phases of kinematic activity in the Świebodzice Depression rock massif. Discovery of coincidence between seismic phenomena and tectonic activity confirms the hypothesis on the existence of a large scale and generally uniform tectonic force field covering the mentioned geological units.

2 Description of the phenomenon

Over 40-year clinometric observations in the Geodynamic Laboratory in Książ have allowed for distinguishing local temporal and amplitude characteristics of contemporary tectonic activity in the vicinity of the Świebodzice Depression. Phases of tectonic activity in the Świebodzice Depression rock massif last from several to over ten days, as evidenced by observations made by the GL instruments indicating rock massif tilt and vertical movements [2-7]. The amplitude of deformations during a single tectonic event reaches from over ten to several tens of tidal amplitudes. The measurement systems of water-tube tiltmeters, the main measurement instruments linked with the rock massif, supply information on the kinematic activity of the massif with nanometre precision. The system of dense tectonic faults in the surroundings of GL instruments [8-15] assures large freedom of block translocation and shock-less stress release, which results in lack of seismic activity in the Świebodzice Depression.

Fig. 1. Vectors of horizontal velocity plotted from GNSS data [33].

Earth's tectonic activity is strictly connected with geodynamic activity of rift and subduction zones [16-24]. In the case of the western part of the Eurasian Plate (area of the Świebodzice Depression), its motion depends on the activity of the north-central part of the Atlantic rift through the convergence of the African Plate. This is confirmed by the results of multiannual measurements by satellite and space techniques, indicating the largely uniform velocity field for the central part of the Eurasian Plate (Fig. 1) [25-34].

2.1 Rules governing massif transition into seismic states

Results of comparative studies indicate that the rock massif near Książ reaches states corresponding to seismic states in mining areas according to strictly determined, repetitive rules. This is a fundamental observation, which opens new possibilities for discussing deformations in the Świebodzice Depression rock massif, preceding seismic states in neighbouring geological units, i.e., the Fore-Sudetic Monocline, Upper Silesian Basin and Bohemian Massif. Discovery of these rules has allowed to define temporal (T) and amplitude (A) rules in the description of the process, at which the Świebodzice Depression rock massif reaches a state corresponding to the seismic state in the mentioned regions. Each rule comprises 5 precedents, graphically presented in Fig. 2.

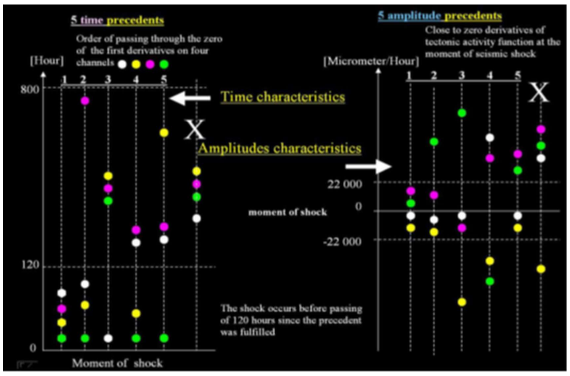

Fig. 2. Definitions of five temporal and five amplitude precedents, in course of which the Świebodzice Depression rock massif reaches a state corresponding to seismic states in the mining areas of Lower and Upper Silesia (SW Poland) and the Czech Republic (NE part).

Temporal precedents T determine the time expressed in hours from the moment of the last passage through zero, i.e. change of TAF derivative sign in each measurement channel of water-tube tiltmeters (4 channels), to the occurrence of a seismic shock. For all cases of strong seismic events (>= 3.5 Mag) in 2006–2016 (ca. 140 cases), the temporal role was realised by one of the model temporal precedents presented in Fig. 2.

Amplitude precedents A determine the values of TAF derivatives in four WT channels during a seismic shock. For strong shocks (>= 3.5 Mag), values of derivatives during the shock are concentrated around zero in the interval from <-22000 to 22000> [μm/h]. Numerical intervals used in Fig. 2 for amplitude precedents have been empirically determined, and their values result from application of multiplier 10^3 [μm/h]. Comparison of TAF and their derivatives with the temporal distribution of strong seismic events in the Fore-Sudetic Monocline shows that a condition crucial for the occurrence of a seismic shock is the realisation of one temporal precedent and one amplitude precedent.

2.2 Realisation of temporal and amplitude precedents in 2016 – selected examples

Fig. 3 presents the concentration of moments of passage through zero of TAF derivatives (change of sign) at about 100 h before a strong seismic shock in 2016, which took place in the Fore-Sudetic Monocline (Legnica-Głogów Copper District mining area). This rule (T) is repeated annually since 2004. The numbers of shocks in each year are marked on the horizontal axis. Fig. 4 presents the concentrations of TAF derivative values around zero during a seismic shock. Similarly, as for temporal precedents, this rule (A) is repeated annually since 2004. The numbers of shocks in each year are marked on the horizontal axis.

Analysis of the charts (Figs. 3 and 4) indicates that strong seismic shocks (>= 3.6 Mag) and gentle shocks in the range of 3.0 to 3.6 Mag were preceded in 2016 by the realisation of temporal and amplitude precedents of TAF derivatives except single cases of gentle shocks (most probably caused by mining activities). Only one strong shock at 3.8 Mag (event no. 13) from 2016 does not have well determined temporal and amplitude precedents.

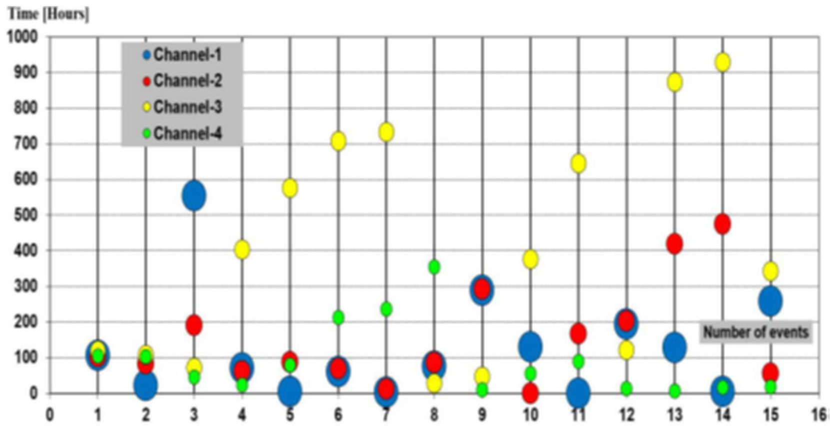

Fig. 3. Realisation of temporal precedents for 15 strong seismic shocks in 2016.

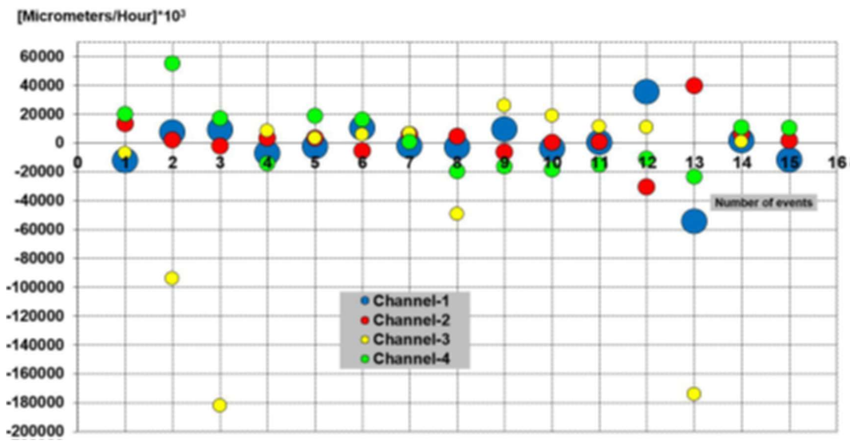

Fig. 4. Realisation of amplitude precedents for 15 strong seismic shocks in 2016.

Comparative studies have shown that the basic condition, which must be absolutely fulfilled before a seismic shock, is change of sign of TAF derivatives in four measurement channels of WT in a period not longer than 600 h before a seismic event and not later than 1 h after a seismic event. Graphs of amplitude precedents (Fig. 4) show four cases of symmetry of derivative values during a shock. Symmetry states of TAF values during shocks are seismogenic.

3 Selected examples of TAF plots during very strong seismic events causing tragic accidents in underground mines

A strong seismic shock in Lower Silesia on 29th November 2016 (Fig. 5) caused 8 casualties and 21 injured. The shock took place in the KGHM Polska Miedź S.A. Rudna mine. The shock was independent with a magnitude of 4.4 in the Richter scale at a small depth of 1 km. The destruction zone encompassed 5 km of mining excavations on an area of 90 km^2 and the shock was recorded within a diameter of 40 km from the mine.

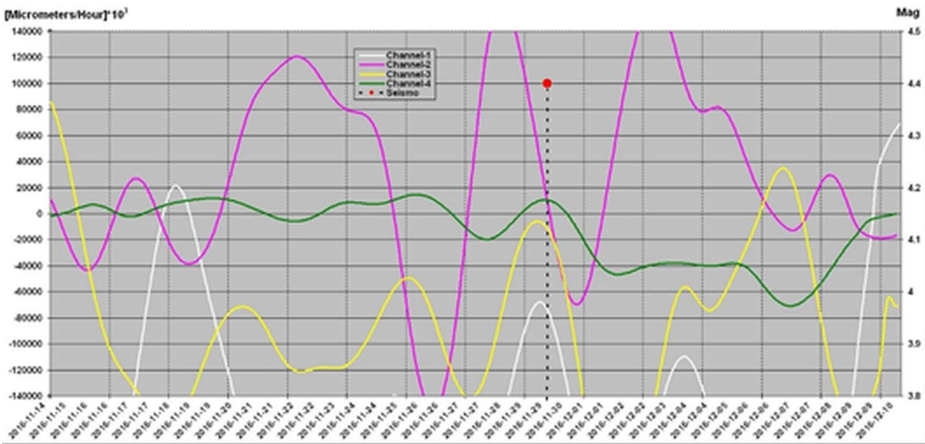

Fig. 5. 2016 – plots of TAF derivatives and the main shock: 2016-11-29, 4.4 Mag.

Results presented in Fig. 6 confirm that the presented method encompasses the area of the Fore-Sudetic Monocline, Upper Silesian Basin and Bohemian Massif. Shocks in Upper Silesia and in the Czech Republic also occur in windows with low deformation velocities (during small values of TAF derivatives – extension phases). During strong seismic events, deformation velocities (TAF derivatives) attained low values from the reference area <-22000, +22000>. Three strongest seismic events took place in the Fore-Sudetic Monocline. On 8th and 17th November there were no seismic events in the Fore-Sudetic Monocline despite fulfilment of precedents – low velocities of rock massif deformation (Fig. 7). On these days, seismic shocks were noted in the Czech Republic (8th November) and in Upper Silesia (17th November; Fig. 6). Significantly, the interval of seismic quietness occurred simultaneously in all three mining areas, between 11th and 16th November 2016, caused by high kinematic activity, i.e. high values of TAF derivatives.

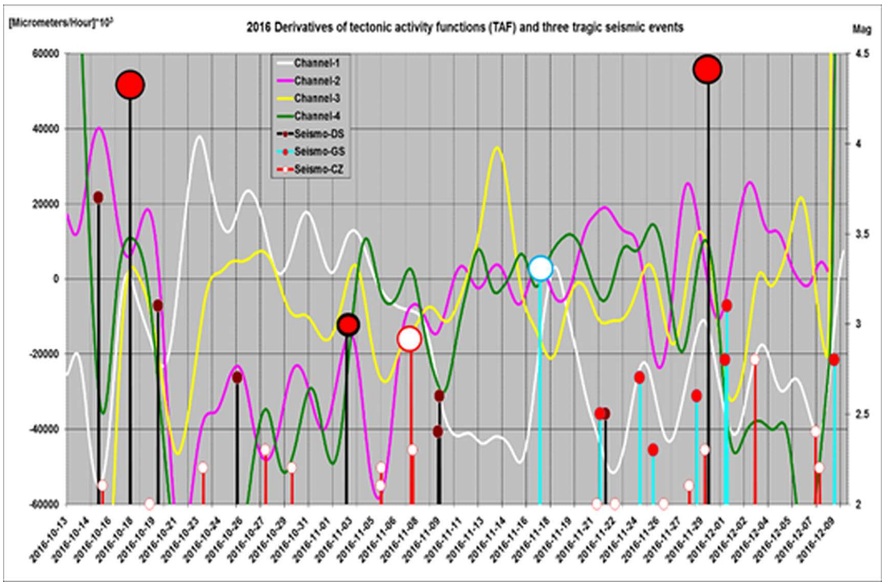

Fig. 6. Plots of TAF derivatives (4 channels) and seismic activity in 2016 in the Fore-Sudetic Monocline (Seismo-DS), Upper Silesian Basin (Seismo-GS) and Bohemian Massif (Seismo-CZ) with specification of three tragic seismic events in mines: OZG Rudna Główna, 4.3 Mag (17th October), OZG Lubin, 3.1 Mag (3rd November) and OZG Rudna Główna, 4.4 Mag (29th November).

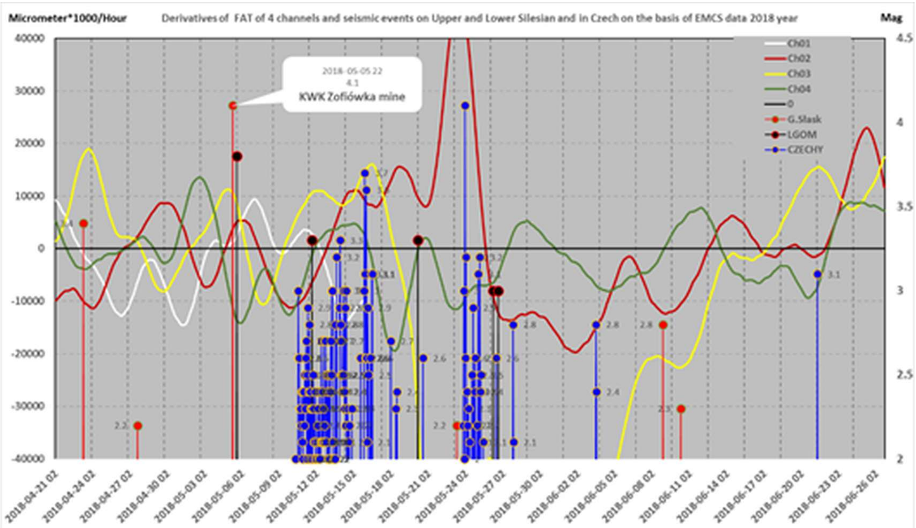

Fig. 7. Tragic seismic event in the KWK Borynia-Zofiówka-Jastrzębie coal mine, 4.1 Mag (5th May 2018) in the context of tectonic activity of the rock massif expressed by 4 plots of TAF derivatives.

Following a tragic seismic shock in the KWK Borynia-Zofiówka-Jastrzębie coal mine on 5th May 2018, there were 5 casualties and 7 injured miners. The shock was commonly experienced by residents in the surrounding area. During about 3 weeks preceding the tragic phenomenon, TAF derivatives attained low or very low values, fulfilling temporal and amplitude precedents and indicating large susceptibility of the rock massif to destruction (extension phase). Conditions for shock occurrence were fulfilled from 10th April. Two shocks occurred at this time: in the KGHM on 14th April, 3.7 Mag and 4.2 Mag, and in the Upper Silesian Basin on 23rd April, 3.2 Mag. The event in the KWK Borynia-Zofiówka-Jastrzębie coal mine on 5th May was the next shock. Lasting from 10th April till 12th May 2018, the period of small deformation velocities is one of the longest registered (low values of TAF derivatives).

4 Summary

Comparative analysis of tectonic activity in the Świebodzice Depression rock massif with seismic phenomena in 2006–2016 has indicated that almost all (>95%) high-energy seismic shocks occurred in intervals with low values of TAF derivatives, i.e. low velocities of rock massif deformation (which may be referred to extension intervals) and in TAF derivatives symmetry state (several percent of shocks). It was observed that fulfilment of this relationship improves with increase of shock energy. During epochs of high values of TAF derivatives, i.e. high velocities of rock massif deformations (compression intervals), there were no high-energy seismic shocks in mining areas. Recognition of high compliance of intervals with low velocities of the Świebodzice Depression rock massif deformation with intervals of seismic events for a representative sample (ca. 140) of strong seismic phenomena in 2006–2016 supports the concept of a large-scale tectonic force field, which source area is the Atlantic rift system. This field covers areas of the Świebodzice Depression (GL in Książ), Fore-Sudetic Monocline, Upper Silesian Basin and Bohemian Massif, which explains the cause of the observed coincidence between seismic activity in these areas and phases of tectonic activity in the Świebodzice Depression (compression and extension phases) recorded by GL instruments. Practical application of the TAF method allows for determining the so-called PGZ parameter – momentary susceptibility of rock massif to destruction. The PGZ parameter allows for assessing the momentary level of seismic shock threat at a several level scale.

The TAF method may be applied to determine intervals of increased seismic shock threat almost in real time after modernisation of the registration process and compilation of WT results. To achieve this, analogous modules should be replaced by digital measurement systems. Application of new instruments in WT will cause increase of WT measurement precision by about 1.5 order of magnitude and supply numerical measurement sequences in real time. Application of digital extensometers will considerably shorten compilation of the observations, due to which it will be possible to determine the plot of TAF derivatives and PGZ parameter for each subsequent hourly epoch. Application of the TAF method should improve exploitation safety in underground mines and selection of optimal moments for rock massif release (with application of blasting method) in intervals of high PGZ values, i.e. large susceptibility of rock mass to destruction (extension phase).

Taking into account the social and economic aspects related with mining accidents resulting from tectonic activity of the rock mass, the presented method may find practical application in the existing system of hazard monitoring. Using actual TAF derivative values, the increase of seismic hazards in exploitation areas should be known from a few to several tens of hours before a potential, high-energy seismic shock.

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