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Tectonophysics 405 (2005) 77–98

TECTONOPHYSICS

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A statistical procedure for the analysis of seismotectonically induced hydrochemical signals: A case study from the Eastern Carpathians, Romania

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Received 24 May 2004; accepted 18 May 2005
Available online 11 July 2005

Abstract

Changes in the stress field of an aquifer system induced by seismotectonic activity may change the mixing ratio of groundwaters with different compositions in a well, leading to hydrochemical signals which in principle could be related to discrete earthquake events. Due to the complexity of the interactions and the multitude of involved factors the identification of such relationships is a difficult task. In this study we present an empiric statistical approach suitable to analyse if there is an interdependency between changes in the chemical composition of monitoring wells and the regional seismotectonic activity of a considered area. To allow a rigorous comparison with hydrochemistry the regional earthquake time series was aggregated into an univariate time series. This was realized by expressing each earthquake in form of a parameter "*e*", taking into consideration both energetic (magnitude of a seismic event) and spatial parameters (position of epi/hypocentrum relative to the monitoring site). The earthquake and the hydrochemical time-series were synchronised aggregating the *e*-parameters into "earthquake activity" functions *E*, which takes into account the time of sampling relative to the earthquakes which occurred in the considered area. For the definition of the aggregation functions a variety of different "*e*" parameters were considered. The set of earthquake functions *E* was grouped by means of factor analysis to select a limited number of significant and representative earthquake functions *E* to be used further on in the relation analysis with the multivariate hydrochemical data set. From the hydrochemical data a restricted number of hydrochemical factors were extracted. Factor scores allow to represent and analyse the variation of the hydrochemical factors as a function of time. Finally, regression analysis was used to detect those hydrochemical factors which significantly correlate with the aggregated earthquake functions.

This methodological approach was tested with a hydrochemical data set collected from a deep well monitored for two years in the seismically active Vrancea region, Romania. Three of the hydrochemical factors were found to correlate significantly with

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doi:10.1016/j.tecto.2005.05.014

the considered earthquake activities. A screening with different time combinations revealed that correlations are strongest when the cumulative seismicity over several weeks was considered. The case study also showed that the character of the interdependency depends sometimes on the geometrical distribution of the earthquake foci. By using aggregated earthquake information it was possible to detect interrelationships which couldn't have been identified by analysing only relations between single geochemical signals and single earthquake events. Further on, the approach allows to determine the influence of different seismotectonic patterns on the hydrochemical composition of the sampled well. The method is suitable to be used as a decision instrument in assessing if a monitoring site is suitable or not to be included in a monitoring net within a complex earthquake prediction strategy.

Keywords: Earthquake; Relation analysis; Hydrochemistry; Well water; Monitoring

1. Introduction

There is an increasing wealth of publications reporting on earthquake related signals detected within hydrogeological and gas-geochemical time series (e.g., Toutain et al., 1997; Igarashi and Wakita, 1995; Igarashi et al., 1995; Tsunogai and Wakita, 1995; Silver and Valette-Silver, 1990; Zongjin, 1990; Wakita et al., 1980). Gas emanations from the crust, used as indicators for buried active faults, are also well documented (e.g., Wakita et al., 1980; King, 1980). These studies show that tectonic processes may contribute to a significant part of the variance observed in geochemical time series. But additional to tectonic factors, other processes like earth tide, variation in atmospheric pressure, or intensive precipitation may also influence the flux of different gases released from the crust. To correct for these effects different algorithms were elaborated (e.g., Tanamura et al., 1991; Matsumoto, 1992; Finkelstein et al., 1998).

Earthquake related hydrogeochemical signals can be observed up to several hundred kilometres away from the hypocenter of an earthquake (Igarashi and Wakita, 1990; Bella et al., 1998), and multiple signals detected at some monitoring stations sampled for many years indicate a long-lasting or quasi-permanent interaction between the seismicity and hydrogeologic constitution of an area. Even small earthquakes, or a hardly detectable tectonic activity may possibly generate a detectable response in a hydrochemical time series (Bolognesi, 1997; Wakita et al., 1980). Several mechanisms are proposed to explain the occurrence of seismically induced hydrochemical signals. Among these, mixing of different aquifers or changes in permeability due to stress release are the most favoured models (e.g., King, 1986; Roeloffs, 1988; Thomas, 1988; Bolognesi, 1997; Heinicke and Koch, 2000; Hamza, 2001; Montgomery and Manga, 2003).

Hauksson (1981), Toutain and Baubron (1999) and Hartmann and Levy (2005) give an overview of possibly earthquake related gas-geochemical precursors. They analysed the relationship among various descriptive variables such as magnitude, epicentral distance, precursory time and duration of the signal and concluded that, depending on the magnitude of the main event, there is potentially a possible correlation between the maximal epicentral distance and the duration of the gas-geochemical anomaly. More or less similar relationships are reported also for hydrogeological anomalies related to single earthquake events (Montgomery and Manga, 2003; Hartmann and Levy, 2005).

These findings indicate a possible interconnection among four basic categories of variables representing: a) the released seismic energy, expressed basically by the magnitude of the earthquake; b) a geometric component, delineating the spatial relationship between the hypocentral area and the monitoring site; c) a time component which includes the occurrence of the signal relative to the earthquake and the duration of the anomaly, and d) a geochemical component, represented by one or several geochemical variables. Based on a review, Igarashi et al. (1995) concluded that a multiparametric approach is more reliable in detecting seismsotectonically induced hydrogeological or geochemical anomalies than using only single, discrete parameters.

In the case of an "one earthquake–one signal" event, the geochemical anomaly may occur within a relatively large time interval before, simultaneously or after the