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Exemplary geophysical investigations on coal seam fires in Northern China

A. Lambrecht (1), U. Meyer (1), H. Rüter (2), V. Gundelach (1), H. Lindner (2), G. Schaumann (3), S. Schlömer (1), L. Guangliang (4), K. Bing (4), and W. Jianjun (5)

(1) BGR, Hanover, Germany, (2) HarbourDom GmbH, Cologne, Germany, (3) LIAG, Hanover, Germany, (4) BRSC, Beijing,China, (5) BNU, Beijing,China

Within the framework of the Sino-German research initiative "Innovative technologies for exploration, extinction and monitoring of coal fires in Northern China" different geophysical methods have been applied.

The investigation area was the coal fire district of Wuda, located in the south-central part of the Inner Mongolia Autonomous Region of Northern China. The Wuda coalfield is bordering in southeast with the Helan Shan (Helan Mountains), in the east with the mountains of the Ordos Massif, while in the west and north with the Gobi desert. It is a gentle north-south striking structural syncline with an aerial extent of 40 km2 and with elevations ranging between 1100 and 1300 m above sea level. The survey area is covered mainly by sandstone. Up to 18 mined coal seams extend to greater depths varying from a few metres down to several hundreds of metres below surface.

The objective of subsequent geophysical surveys was to detect areas affected by coal seam fires by means of physical parameters acquired over the burning and burnt coal seams, to find out which methods are useful for fire detection, to accompany the extinguishing process and to control successful extinction. Airborne methods used are helicopter borne electromagnetics (HEM) and magnetics. Ground surveys for measuring transient electromagnetics, magnetics, ground penetrating radar and near surface temperature were carried out in selected parts of the helicopter survey.

Ground penetrating radar (GPR) is an ideal method to detect voids in depth less than 50 m. An important point to extinguish a coal fire is to know the paths of oxygen transport from the surface to the fire. Some crevices which are potential paths for oxygen can be determined by GPR due to the resolution of the chosen frequency. The GPR system applied was built by GSSI and utilized for three different antennae length. The centre frequencies are 40, 80 and 200 MHz. A 200 MHz system was used to get detailed information close to the surface and a 40 MHz antenna was used to get maximum penetration depth.
The heat and fluid transport included in the burning process presumably changes the permittivity of the rock which affects the attenuation of the radar signal and reduces the conductivity of the rock. This enables GPR measurements to discriminate burning zones from intact zones. The border line of the fire zone in the southern and the northern part of the investigated fire zone could be found. At the burning areas it was possible to discriminate different layers in the subsurface. Anywhere else the soil was highly conductive and full of clefts. The clefts were visible in the radar data only close to the surface.

Magnetic was measured area-wide with a QuickTracker (GSM-19T) console from GEM Systems over different fire zones and shows positive anomalies in the coal fire area. The stratigraphy in the area shows no magnetic rocks above the coal seam, which leads to the interpretation that the positive magnetic anomalies are caused through the thermal induced magnetism of the stones lying above the coal seam. Over 100 rock samples (Sandstone, Coal and clinkers) has been taken for in-situ determination of the magnetic susceptibility. The positive magnetic anomaly is distinguished by the high magnetisation of the clinkers and therefore important for the detection of coal fires.

TEM measurements were performed along profile lines across the fire zone or at single localities selected in the actual area. The spacing of the TEM sites was adapted to the terrain. Profiles crossing the area where the hot burning zone can be found, the TEM curves change their shape clearly. The vertical resistivity section shows a highly conductive layer which seems to coincides with the thermally affected coal seam.

Temperature variations are most extreme at the surface of the soil. The peak temperature below the surface occurs about 2 hours after the maximum ambient air temperatures are attained.
Temperature measurements in the gas emanating vents showed intense fluctuations not directly related to meteorological conditions. These variations are a result of the proceeding fire front.
Further on the long-term spatial temperature distribution/variation and the occurring diurnal and seasonal variations of soil temperature above coal fires was elaborated to quantify temperature evolution above the selected coal fire zone based on operation of autonomous data logger.

The electromagnetic methods reveal areas of lower resistivity and the ground magnetic surveys display clearly increased amplitudes of the magnetic field intensity in the areas affected by coal fires. As the effects of coal fires on the geophysical parameters measured are often very small, ground geophysical surveys are more sensitive to locate coal seam fires than airborne geophysical surveys. On the other hand, areas of coal seam fires are not always accessible. In the next field campaign it is contemplated to try to use a UAV (unmanned aircraft vehicle) for local coal fire surveying.