Airborne Geophysics and Geoelectric and Inclinometric Monitoring at the Gschliefgraben Landslide

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Airborne geophysics has recently emerged as an innovative methodology for landslide investigation (SUPPER et al., 2007). By the end of September 2009, a complex airborne geophysical survey was performed in a large complex of geologically controlled landslides and earth flows in the Gschliefgraben valley in Upper Austria (municipality Gmunden) east of the lake Traunsee. Simultaneously, the GEOMON^{4D} and DMS automated monitoring systems were installed to obtain the information on ground resistivity temporal change, displacement and ground water level changes.

The area of Gschliefgraben is a 2.85 km long and 0.85 km wide valley along the foot of the Northern Calcareous Alps. The front of the Northern Calcareous Alps forms a steep cuesta there with the summit at Mt. Traunstein (1691 m a.s.l.; Figure 1). The catchment is divided into small subparallel channels and subsequent catchments; its topography is strongly controlled by the mass wasting that has developed since the end of the last glacial period. In late November 2007, probably triggered by a rock fall in April 2006, an earth flow of about 3.8 million m^3 of colluvial mass was reactivated. Displacement velocity was up to 4.7 m/day at the beginning (MARSCHALLINGER et al., 2009). The main mass wasting processes are represented by sliding and flowing in the central part (Figure 2), which is built mostly of Ultrahelvetic marls and shale. These incompetent, soft rocks are intensively fragmented with relatively high content of swelling clay minerals. They emerge here in the form of a tectonic window below the Rhenodanubian Flysch and the overlying Northern Calcareous Alps. On the other hand falling, toppling, and spreading are the most characteristic types of movement in the eastern and southern marginal areas of the Gschliefgraben where mostly hard rock occurs (Northern Calcareous Alps, Pleistocene talus breccias).

Fig. 1: Airborne photograph of the Gschliefgraben area from the West (Photo by R. SUPPER, 2009).

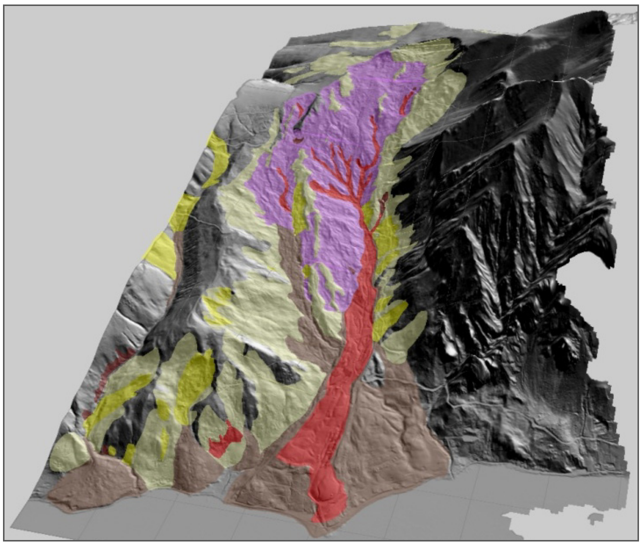


Fig. 2: 3D visualization of the slope-failure inventory map of the Gschliefgraben area: red – active landslides and earthflows, purple – area of active and suspended small scale shallow landslides and earthflows, brown – inactive earthflow accumulations, yellow – suspended landslides, light yellow – dormant and relict landslides.

Airborne Geophysics

Airborne geophysics is now a promising method for landslide investigation. Therefore, it was tested in the well-documented and investigated site of Gschliefgraben. One of the big advantages of this approach is surveying of large areas within relatively short time, while the internal structure can be derived. The airborne geophysical survey consisted of the frequency domain electromagnetic, gamma-ray spectroscopy, and magnetic and passive microwave survey.

The frequency domain electromagnetic method is intended to determine the distribution of the specific ground electrical resistivity, giving information mainly on porosity, water saturation, conductivity of the pore fluid and clay content. Variable frequencies and different geometric arrangements of the coils were used in order to allow depth-specific sounding of the subsurface. The lowest frequency determines the total penetration depth of the method, i.e. approximately 120 m below the ground surface. The registered lowest resistivity is related generally to areas most susceptible to mass wasting (Figs. 3 and 4).

Another approach (gamma-ray spectroscopy) determines the natural and artificial radioactivity, which depends on the content of radioactive minerals within the first decimeters of the subsurface. Natural gamma radiation is essentially derived from three sources: the radioactive elements thorium (energy peak: 2.62 MeV), uranium (energy peak: 1.76 MeV) and potassium (energy peak: 1.46 MeV). These elements occur in different rocks and soils at various concentration levels. The content of those radioactive elements was explicitly related to the original geological structure: the highest content was registered in areas of shale, claystone and sandstone, while the lowest content along limestone and breccias (Figure 5). The relation of the radioactive contents to landslide bodies will be a task for further research.

The airborne magnetic survey defines the total intensity of the earth's magnetic field. Deviations from a reference earth magnetic field are considered as anomalies and assist e.g. in the discovery of differently magnetized bodies (i.e. ore bodies, young volcanic rocks, metallic contents of waste repositories) or fracture zones. The relation of the magnetic field anomalies and mass wasting also remains a task for further research.

The last tested parameter, the passive microwave, is used for estimating soil moisture (in water content percentage) within the first centimetres of the subsurface by a passive L-band antenna (1400 to 1427 MHz). The intensity of this radiation correlates to the water content in the soil and is influenced by the surface temperature, surface roughness as well as vegetation; the "penetration" depth of this method is 5–10 cm. The highest soil water content was registered within the zone of the active earthflow and along a shore line of Traunsee (Figure 6). The soil moisture surveying seems to be a promising indicator of active mass movements.

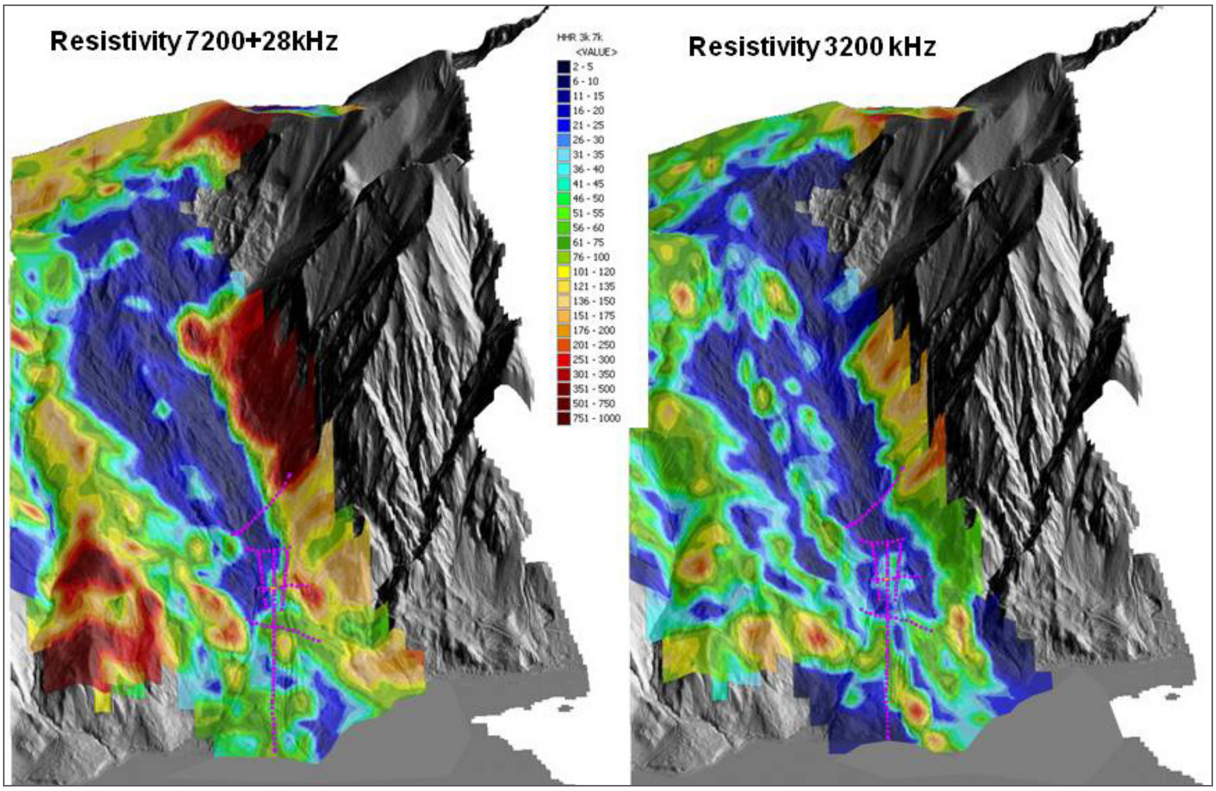


Fig. 3: 3D visualization of the airborne electromagnetic survey of the Gschliefgraben area.

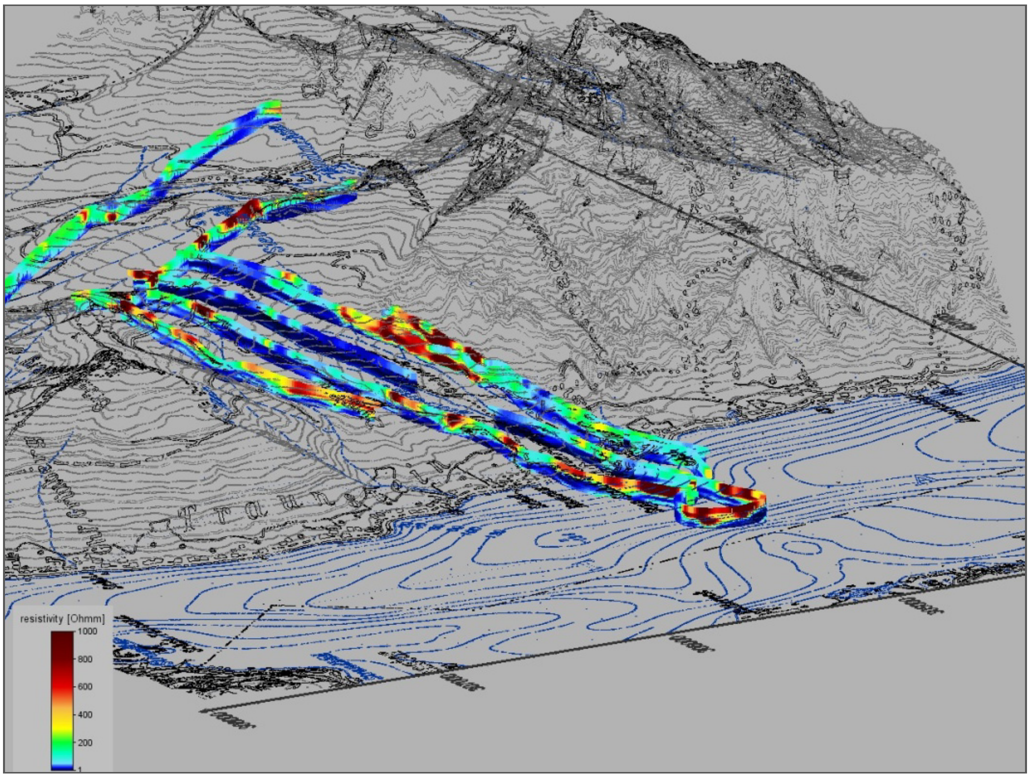
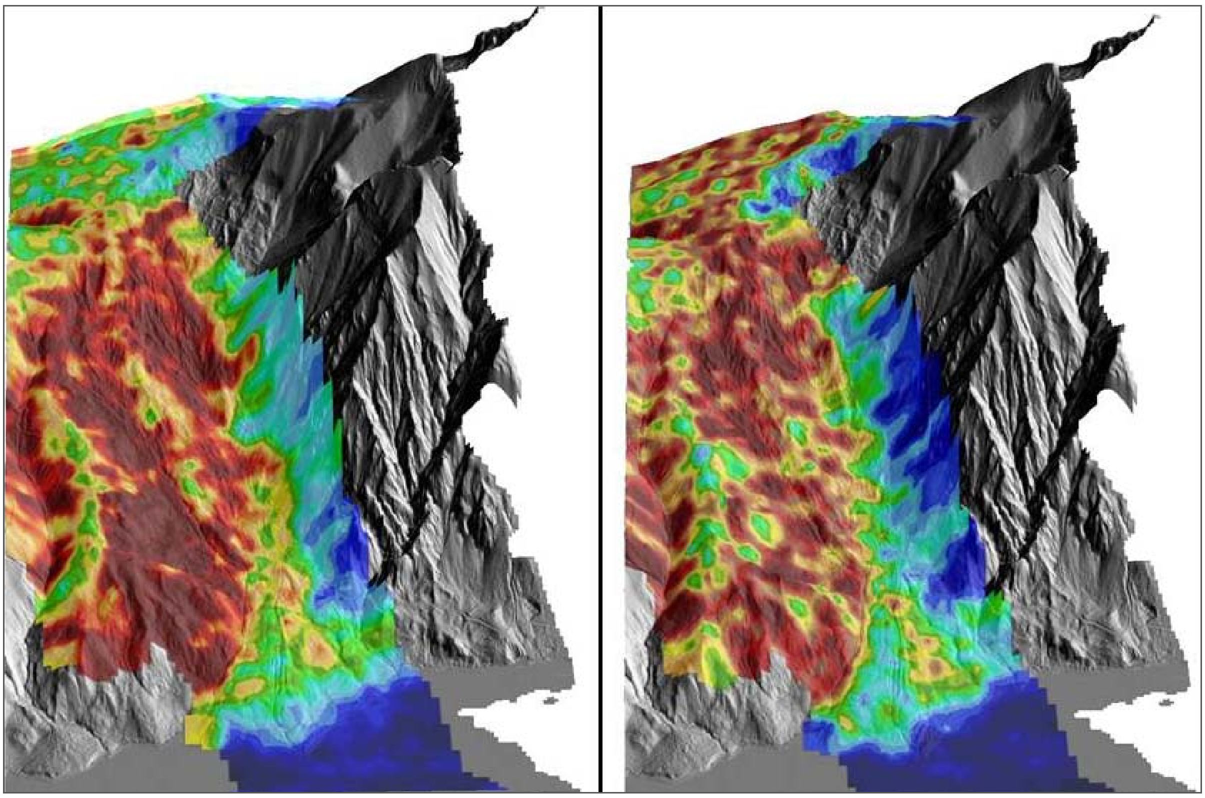


Fig. 4: 3D visualization of the airborne electromagnetic survey of the Gschliefgraben area: ground resistivity profiles are 120 m deep and follow the path of the helicopter.



A) B)

Fig. 5: 3D visualization of the airborne gamma-ray survey of the Gschliefgraben area for: A) Potassium and B) Thorium (high content in red colors, the lowest content is in deep blue).

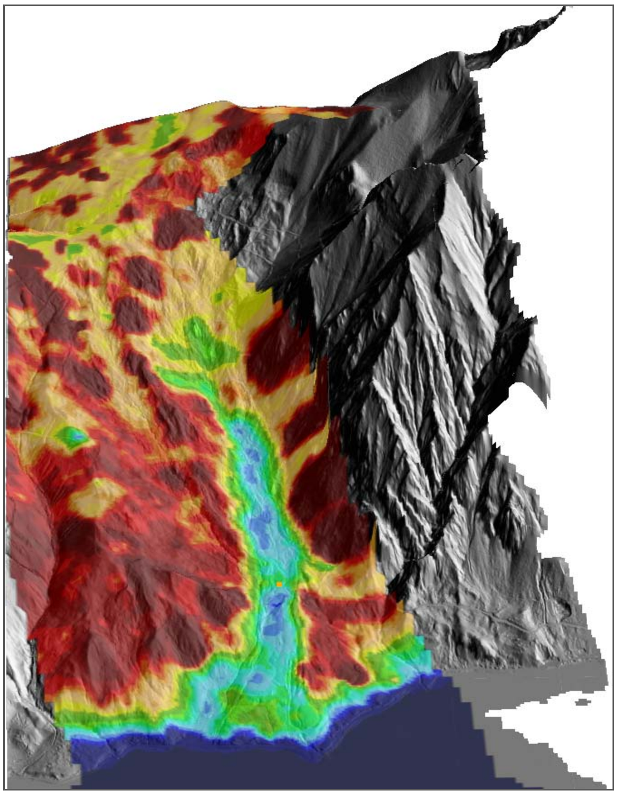


Fig. 6: 3D visualization of soil moisture of the Gschliefgraben area by the airborne survey.

Mass Movement Monitoring

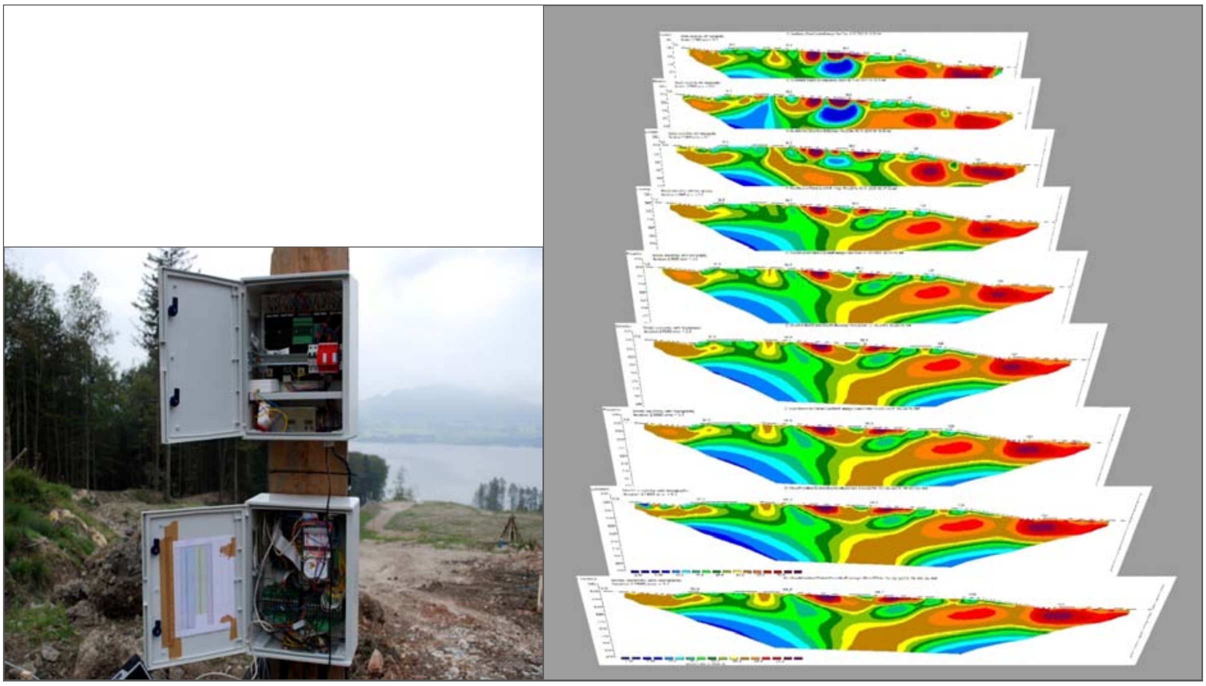
The other aim of our activities at the Gschliefgraben test site was to introduce new techniques for mass movement monitoring and early warning. For this purpose, the GEOMON^{4D} and D.M.S. automated monitoring systems were installed in the lower central part of Gschliefgraben valley.

The GEOMON^{4D} is a new tool for high speed ground resistivity and self-potential measurement. Data acquisition of about 3000 measurements/hour in single channel mode and usually 1000 samples per single configuration (including recording of the full signal) enable effective noise analysis and filtering. Moreover, a completely open architecture allows installation of any number of current or potential electrodes by adding parallel or serial cards. The GPRS (General Packet Radio Service) data transfer allows the maintenance to be performed fully remote-controlled. Data, such as measurement results, test sequences and log files, containing information about system and GPRS connection status are sent automatically via email to the data processing centre at GSA. Consequently, immediate availability of information for local stakeholders could be guaranteed.

In the centre of the landslide of Gschliefgraben, two monitoring profiles were installed. The central control unit and preliminary results from one profile are presented in Figure 7.

To define correlation between geoelectric anomalies and the triggering of movements, an innovative multiparametric monitoring system of stability D.M.S. (**D**ifferential **M**onitoring of **S**tability; Centro Servizi di Geoingegneria, Italy) was implemented in the crossing of the GEOMON^{4D} profiles. The D.M.S. tool measures high accuracy displacements in 2 or 3 directions (both horizontal and vertical at all the prefixed depths), piezometric ground-water level and soil temperature up to depths of 26 m below the ground-surface. Thus it allows the complex analysis of the dynamics of mass movement, e.g. deformation analysis, displacement, velocity, acceleration, and depth of failure or piezometric variations (FOGLINO et al., 2006).

As the preliminary results show, the monitored earthflow at Gschliefgraben undergoes continuous movement since the installation of D.M.S. (24th September, 2009) with a few smooth acceleration phases only (Fig. 8). The correlation of displacement and precipitation is not very clear. The correlation of the ground resistivity and the mass movement is a task for further research.



A) B)

Fig. 7: Geomon^{4D}: a tool for continuous, automatic and remotely-managed monitoring of ground resistivity changes. A) a photo of the central part of the Geomon^{4D}, B) set of result images of the longitudinal profile registered between September 2009 and February 2010 with a 14-day separation.

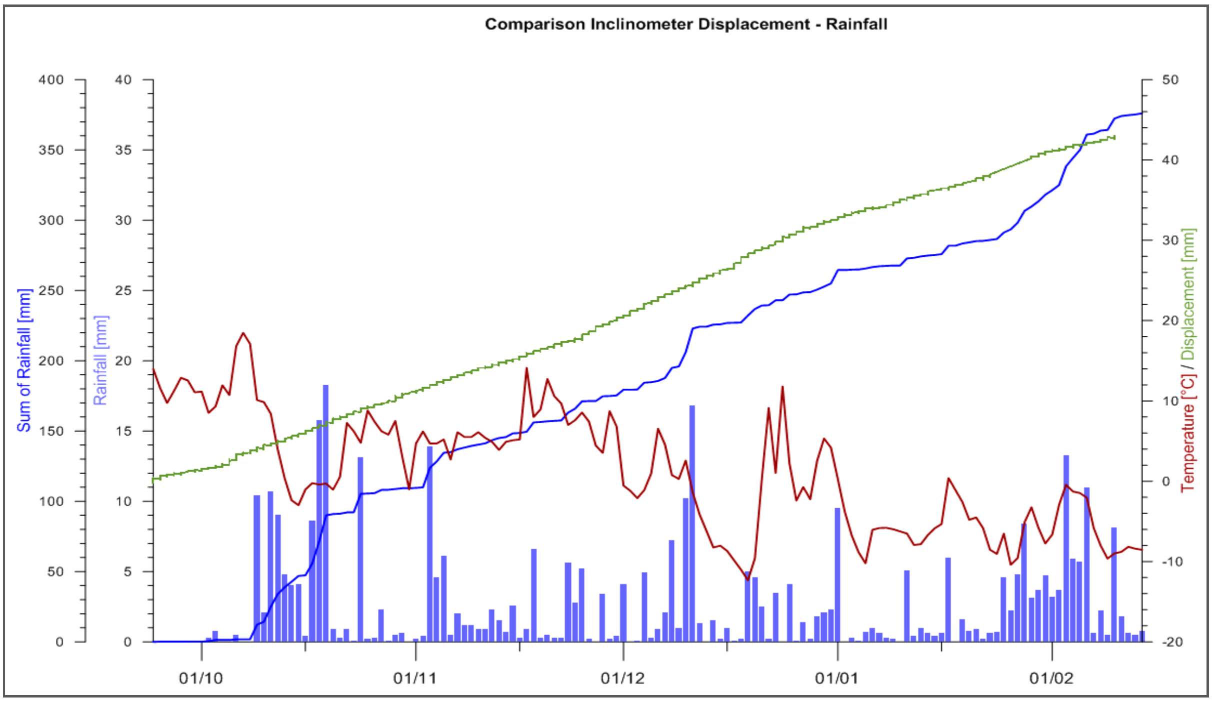


Fig. 8: Results of DMS monitoring of cumulative displacement correlated with air temperature, ground water level and mean day precipitation registered between September 2009 and February 2010 in the central part of Gschliefgraben.

Acknowledgement

The authors would like to acknowledge the excellent close cooperation with **Torrent and Avalanche Control (WLV), Section Upper Austria, Centro Servizi di Geoingegneria, Ricaldone (Italy), and ZT Büro Moser/Jaritz, Gmunden (Austria).** The study was supported by the 7^{th} FP project "SafeLand – Living with the landslide risk in Europe".

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