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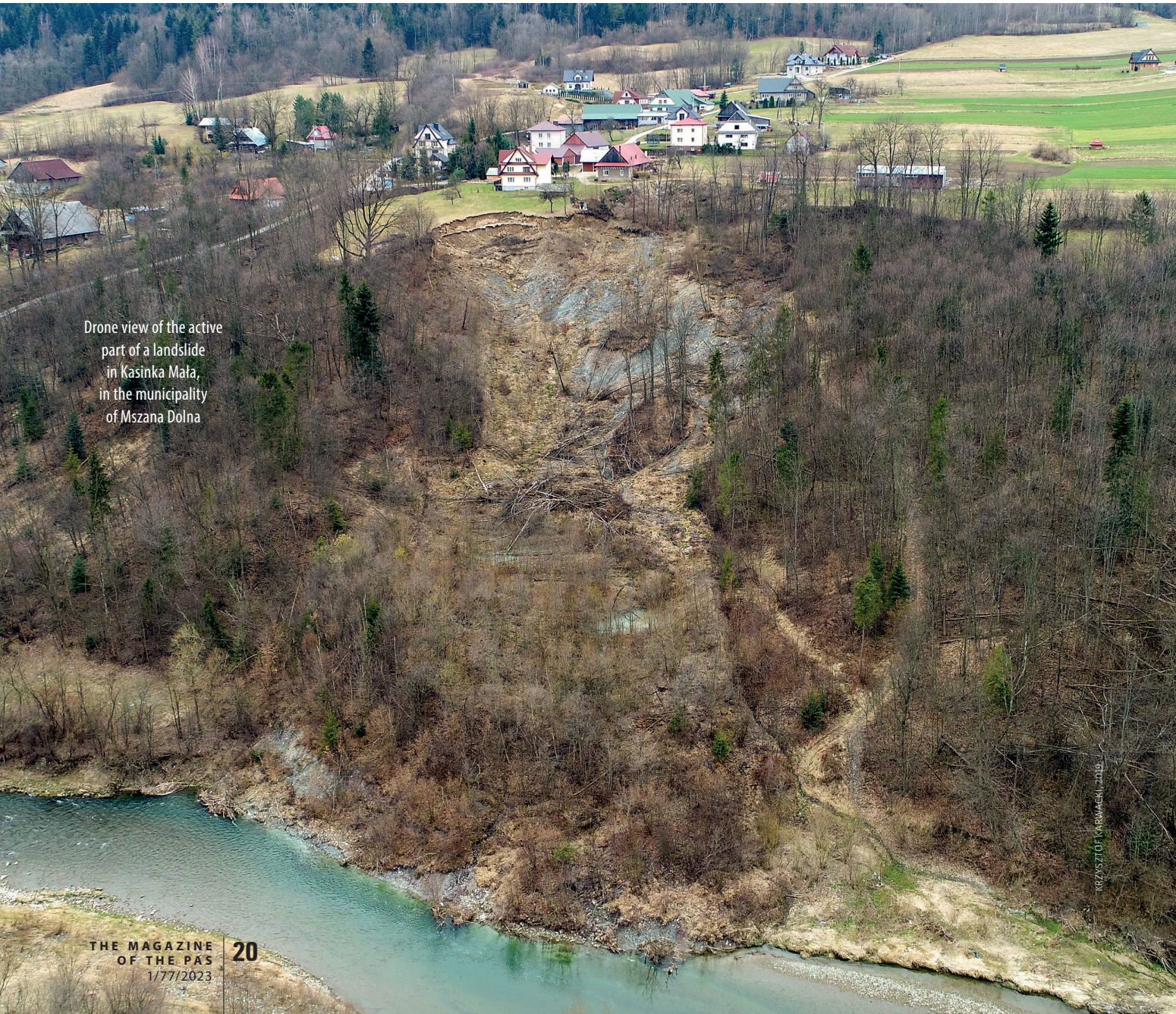
Adam Karol Chaszczewicz, ME

is a specialist at the Geohazards Center of the Polish Geological Institute – National Research Institute (PGI-NRI). He works to identify and record mass movements in Poland.

acha@pgi.gov.pl

Losing the Ground Beneath Your Feet

Any insufficiently understood dynamic geological process can be potentially dangerous.



Drone view of the active part of a landslide in Kasinka Mała, in the municipality of Mszana Dolna

KRZYSZTOF KARWACKI, 2019

Adam Karol Chaszczewicz

Polish Geological Institute
– National Research Institute (PGI-NRI) in Warsaw

ADAM CHASZCZEWICZ, 2023

Cracks forming in the walls of a residential building built on landslide colluvium – Dąbrówka Starzeńska, Dynów municipality

The theme of a natural disaster destroying homes, villages, or even whole cities has captured people's imaginations since the dawn of civilization. Ancient texts are replete with the stories of such events. The Epic of Gilgamesh tells the age-old tale of a devastating flood. The story of the annihilation of Sodom and Gomorrah in the Bible may be linked to the seismic activity of the Dead Sea rift. Letters written by Roman officials and intellectuals provide us with accounts of the eruption of Mount Vesuvius and the destruction of Pompeii. Later medieval and modern texts also bear testimony to natural disasters. One example is the mention of a rockfall on 24 August 1598 near Bardo Śląskie, which, briefly blocking the channel of the Nysa Kłodzka River, almost led to the flooding of the entire town. These days, we are not helpless in the face of such violent natural phenomena. They are the subject of intensive research, helping us to try to anticipate them and prevent their disastrous aftermath.

Underestimated Dangers

The term "geological hazards" (or "geohazards" for short) refers to various dynamic processes whose impact on the Earth's surface poses, or could potentially pose, a danger to people's lives or wellbeing, to infrastructure or property, or to the natural environment. Apart from earthquakes, floods, landslides, and volcanic eruptions, the category "geohazards" also includes hurricanes, tsunamis, meteorite impacts, weather anomalies, and even major shifts of the Earth's magnetic poles. The term is therefore not a synonym for natural disasters, but rather draws attention to how any insufficiently understood dynamic process affecting the Earth could prove dangerous to people and might cause damage on a hard-to-anticipate scale.

Poland enjoys a seismically relatively stable location, situated far from the edges of tectonic plates and volcanically active zones. It is also quite distant from warm tropical waters. As a result, an incorrect conviction long prevailed that the country did not have to be very worried about geohazards. Although newly occurring landslides had been noted regularly in the Carpathian Mountains since the eighteenth century, for quite a long time it was still not realized how significant a problem they actually represented. In the twentieth century, as wetter periods occurred every few years, or every decade or two, intense precipitation increased the occurrence of downslope movements of large amounts of rock and soil ("mass movements"). Major incidents of this sort are referred to as "landslide disasters". After each such disaster, the public takes a greater interest in the issue, but only briefly so. This situation continued essentially through most of the twentieth century. Although several regional studies were carried out in Poland in the decades after WWII, and in the late 1960s the first nationwide survey was undertaken, the available data remained insufficient to fully evaluate the scale of the danger. It is now estimated that, by the beginning of the twenty-first century, nearly 10,000 individual landslides had been identified in Poland's segment of the Carpathian Mountains alone, plus 2000–3000 more in other parts of the country.

A major turning point in the history of landslide research in Poland came in 1997–2001. Heavy precipitation and rapid thawing, flooding, and waterlogging occurred repeatedly over that period, leading in certain places to subsequent landslide disasters. Influenced by these tragic events, the Landslide Counteracting System (LCS, also known by its Polish acronym SOPO) was launched in 2006. It was originally intended that nationwide mapping work would lead to some 20,000–30,000 landslides being inventoried. However, the results exceeded expectations. Currently, after the SOPO project's more than 16 years of operation (as of May 2023), more than 70,000 landslides are registered in the project's database. However, the mapping work has still not been completed, so the number continues to grow. The true value of the Landslide Counteracting System became clear in 2010. When another landslide disaster struck, specialists were able to provide ongoing support to local authorities in countering the impact.

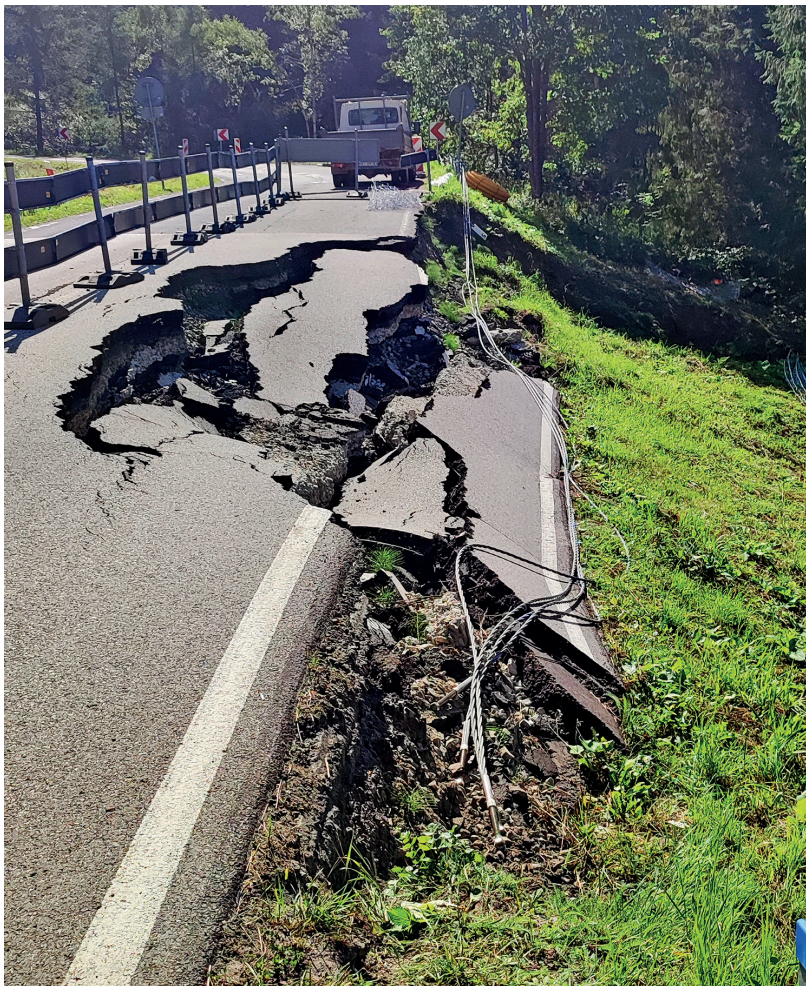
Reactivated after long years

Landslides are geological formations that occur in the near-surface zone of the Earth's crust as a result of gravitational displacement of rock material, shifting

along the surface of a rupture, slip, or flow. A landslide is a type of mass movement. It occurs due to the discharging of stresses present in unstable slopes or hillsides. The effect is to break the continuity of the rock masses, forming a shear plane, along which gravitational sliding of material occurs. This surface generally takes the form of a shallowly situated fault, with a mostly cylindrical, sometimes rectilinear shape. The displaced rock formations, referred to as colluvium, usually form characteristic landforms such as scarps, toes, ridges, grabens, and depressions.

The factors leading to the activation of mass movements are numerous. In most cases, slopes and hillsides become unstable after periods of intense rainfall, snowmelt, or flooding. Water reduces the angle of internal friction within the rock medium and acts as a lubricant for discontinuities existing in the ground. The geological structure of the area is also an important factor. The arrangement of rock layers, their compactness and permeability parameters have a considerable influence on the stability of slopes. The role of the land relief and the undercutting of slopes by watercourses should not be overlooked either. Importantly, human activity can also be a factor triggering the activation of mass movements – overburdening a slope by constructing buildings on it, undercutting a slope by digging trenches, or following improper cultivation and land reclamation practices can all be conducive to them.

Landslide-damaged fragment of road between Wetlina and Brzegi Górne



KRZYSZTOF KARWACKI, 2022

The sliding of rock masses usually leads to the formation of characteristic relief elements. Their presence is so indicative that they are one of the criteria used in geological mapping work to determine the presence of a landslide at a given site. However, the typical colluvium surface relief becomes obscured over time. Partial or full leveling of the landslide surface, however, does not mean that the discontinuity within the ground ceases to exist. Once established, the discontinuous form may be inactive for hundreds or thousands of years until, under favorable conditions, the stability of the slope again becomes breached. The same is true of landslides that have been deliberately covered over as a result of various earthworks. The only fully effective practice for eliminating a landslide is to remove the colluvium all the way below the slip surface. However, this is only possible for small forms. If this cannot be done, landslide stabilization measures need to be taken. This is a complicated operation, usually involving major financial outlays. Therefore, the most common and simplest practice is to exclude areas affected by mass movements from use.

Unfortunately, due to relatively low public awareness of the threat of landslides, the ad hoc refilling and leveling out of their characteristic relief features is a common practice in Poland. In such cases, the memories associated with mass movements in that location quickly become forgotten or deemed no longer relevant. A decade or two later, the area in question may even come to be considered stable and attractive as a location for investment. Such a process of forgetting is referred to as "landslide amnesia" and, unfortunately, can lead to tragedy if a leveled landslide becomes active.

The SOPO project

Most of the landslides identified so far in Poland are located in the Carpathian Mountains, running across the southeast of the country. Particular ranges such as the Beskids, Bieszczady, and Carpathian Foothills are most threatened by mass movements, mainly due to their characteristic geological structure. They are dominated by successive layers of sandstone and shale, comprising a system particularly susceptible to landslides. It is estimated that mass movements in the area affect the living conditions of several hundred thousand residents of communities in the Carpathians. Sometimes farms, hamlets, or almost entire villages and settlements turn out to be situated on landslide areas. Sections of local roads, public utility networks, and telecommunications infrastructure are regularly

PIOTR NESCIERUK, 2010 (4)

Devastation caused by a landslide in Kłodne, Limanowa municipality

destroyed there. Landslides also occur in large numbers in the intensively expanding urban agglomerations of Rzeszów and Kraków, and in the foundations of national roads, expressways, and highways. Geological formations located on the slopes of artificial reservoirs also pose a great threat: a sudden slide can give rise to a huge wave on the lake, forcing water to overflow the crown of the dam. One reservoir known to be at such risk is Lake Międzybrodzkie in Silesia. Landslide formations have also been a major problem in the design of natural gas pipelines linking Poland and Slovakia.

However, numerous landslides can also be found in Poland outside the Carpathian Mountains, although they are much more dispersed and the danger they pose is generally local. For instance, they can be found in the Sudetes, as well as in other mountainous and highland areas of southern Poland. They are observed within the loess covers of the Lublin region and in karst areas. They also occur in post-glacial formations in northern Poland – including in the slopes of lake troughs and moraine hills. They are commonly identified in the slopes of river valleys and their headwaters. Particularly distinct forms are found in the Vistula River valley on the banks of the Włocławek Reservoir. The coastal strip along the north of the country is also not free of them, as they occur in large numbers in cliff-like areas.

Extensive research on landslides and areas threatened by mass movements in Poland (which is among the tasks of the Polish Geological Survey) is pursued by by the Geohazards Center of the Polish Geological Institute – National Research Institute (PGI-NRI). The maps of landslides and terrains prone to mass movements developed under the Landslide Counteracting System (SOPO) project are now being used by many public and private entities. The results and progress of the ongoing landslide inventory can be viewed via a web application (available only in Polish) available under the link given at the end of this article. The project also monitors selected formations using drones, laser scanners, satellite technology, borehole surveys, and GPS measurements. The SOPO project is divided into stages. During the current third stage, ending in 2024, plans call for mapping work in the Carpathian region to be completed. In the next stage, we will then intensify our efforts in the rest of the country, already started in previous years. ■

Further reading:

Landslide FAQ by the US Geological Service: https://www.usgs.gov/faqs/what-landslide-and-what-causes-one

The research journal *Landslides* https://www.springer.com/journal/10346/

The SOPO project application: https://www.pgi.gov.pl/osuwiska/123/aplikacja.html