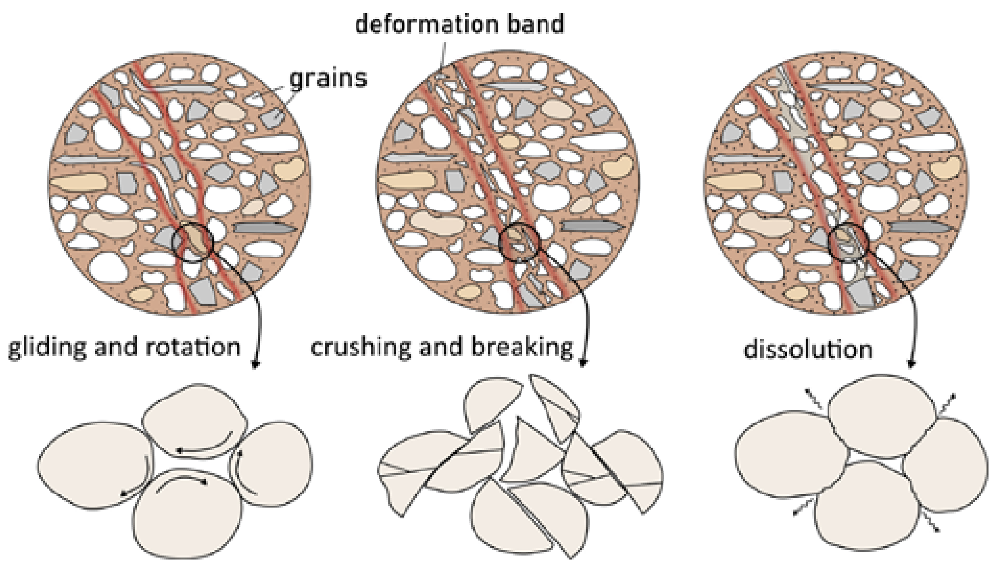
 DOI: 10.24425/academiaPAS.2021.139449

Microscopic Boundaries in Rock: Deformation Bands

Westward view from Tarnica; sandstone layers with deformation bands visible in the foreground

1



Piotr Strzelecki, MSc
a geologist, is a research assistant and lecturer at the AGH University of Science and Technology. He specializes in structural geology, tectonics, and petrophysics. He leads a project implemented as part of a Preludium grant, entitled "The origin of deformation bands in the Silesian Nappe (Bieszczady Mountains) and a novel, microtectonic approach to paleostress reconstruction" and financed by the National Science Centre (2018/31/N/ST10/02486).
piotr.strzelecki@agh.edu.pl

Piotr Strzelecki

Faculty of Geology, Geophysics and Environmental Protection
AGH University of Science and Technology, Kraków

There are many types of boundaries to be found in geological science. One particularly intriguing kind is known as "dislocations" – deformation structures which can occur on varying scales and can assume different forms, such as faults. Dislocations originate as a result of the displacement of rock masses against each other and form surfaces or zones along which such displacement has taken place. Examples of large-scale dislocations include boundaries of tectonic plates, along which fault systems stretching as far as several hundred kilometers can be found. Dislocations on a lesser scale can also occur within lithospheric plates, in the form of faults several meters wide or wider, which can be traced over distances running tens of kilometers. Large-scale processes can also be manifested in the form of micro-deformations visible under a microscope. Among deformations of the latter type are those known as deformation bands.

Under pressure

Deformation bands are deformational microstructures which form in rock made up of grains, e.g. in sandstone, originating as a result of the accumulation of mineral and rock clasts. These microstructures owe their name to their distinctive appearance: they resemble extensive, albeit narrow stripes and can run for quite a few meters while being only several centimeters, or in many cases even as little as several millimeters thick. The formation of a deformation band does not involve significant displacement, only several centimeters or even millimeters, and the continuity of the rock's is preserved. In effect, there is no distinct boundary in the form of a fissility surface, as occurs in the case of faults. However, following the displacement a narrow zone of changes does appear within the deformation band; it also determines the thickness of the microstructure and can be examined via microscope analysis. Based on the nature of the microstructure, we can identify different features of deformation bands and mechanisms underlying their formation.

Strength in numbers

At first sight, it could seem that deformation bands are small and insignificant structures. Nothing could

2

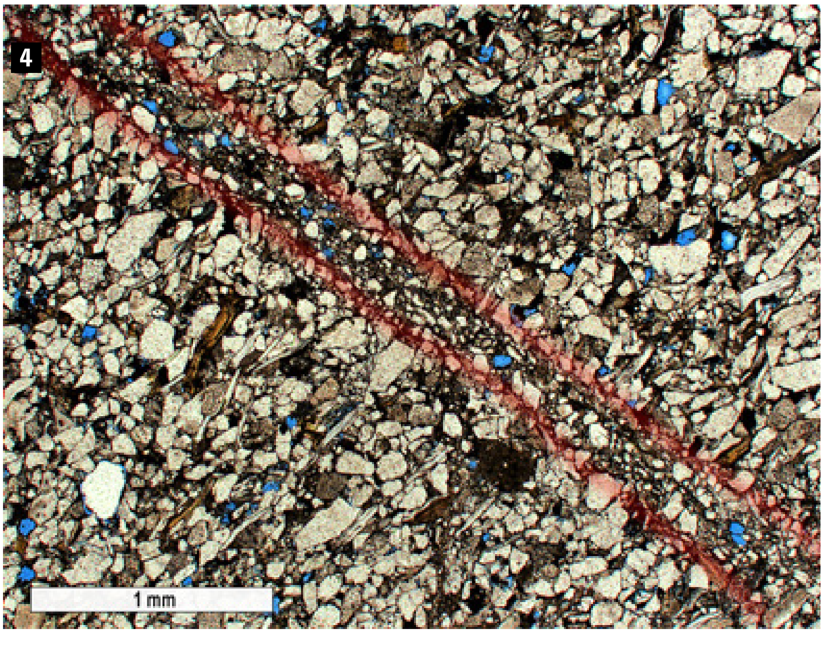
Fig. 1
Types of deformation bands based on their kinematic features

Fig. 2
Deformation bands visible on a rock surface, forming distinctly parallel lines

Fig. 3
Sandstone surface showing multiple deformation bands

Fig. 4
Microscope view of deformation bands in sandstone. The direction of the deformation bands is marked in red. Smaller grain size than in the remaining part of rock is visible within the deformation band. Porous spaces in the rock are marked in blue

be further from the truth. As a rule, they occur in extensive clusters. Due to the fact that a single band has a limited potential for accommodating displacement, deformation bands are formed sequentially, at close distances from one another. This is the reason why they occur in extensive clusters, with subsequent bands found every few millimeters or centimeters. In effect, as many as a hundred or so can be found along just a one-meter section of rock. Zones with deformation bands can be local or regional in scope. In the latter case, such zones can stretch over distances spanning from tens to hundreds of kilometers. These are associated with regional tectonic processes such as folding or faulting of rocks. Deformation bands can also form as fault damage zones. In many cases, their presence is a sign of larger-scale dislocations, or may presage them.



Each band tells its own story

Several types of deformation bands can be distinguished depending on their microstructure and kinematic features. Their simplest division is based on two criteria: (1) kinematics, i.e. the way in which two rock fragments shifted in relation to one another, and (2) the deformation mechanism, i.e. the way in which the grains interacted in the process of the band formation. With respect to the kinematic factor, we can distinguish dilatant bands, i.e. bands which form as a result of rock expansion, moving of rock fragments away from each other and filling the resultant space with smaller, more loosely packed grains. In turn, compaction, the reverse of dilatation, leads to a reduction in the volume of rock and coming closer of its fragments. As a result of this process, the material within such a deformation band is densified. The third and most widespread type includes deformation bands formed as a result of shearing, i.e. displacement of rock fragments along specific plane or surface. The actual emergence and orientation of a given type of deformation band is associated with the type of stress affecting the rock.

On the other hand, the microstructure of a band is dependent on the mechanism of its formation. We can distinguish three basic mechanisms which occur within a deformation band during the process of its formation: (1) grain gliding and rotation, (2) crushing and breaking, and (3) dissolution. Whether a specific deformation mechanism occurs depends on the conditions in which the deformation took place, e.g. the depth of the rock or how it is solidified. In the case of loose rock such as sand, grains will glide and rotate. In the case of hardened rock such as sandstone, grains will crush and break and in effect reduce their size. For rocks situated at considerable depths, the process of grain dissolution may be initiated due to increased temperature and pressure. For this reason, deformation bands may reveal different features, and their examination may provide information on the conditions in which the deformation occurred.

Sources of information

Scientists regard deformation bands as crucial sources of information about the geological history of areas under study. Based on analysis of their microstructure and spatial orientation, they draw conclusions concerning the conditions in which the deformation occurred; this is particularly useful in the work on tectonic reconstructions. Studies of the properties of deformation bands are also of considerable significance for the mining industry. Deformation bands can often be found in sandstone, a major reservoir rock accumulating fluid resources such as oil, natural gas, or geothermal water. Therefore, prospecting engineers find it useful to understand the distribution and nature of deformation bands when extracting such resources and planning boreholes. The presence of deformation bands may improve or hamper the efficiency of extraction. Depending on the nature of their microstructure, deformation bands may improve filtration properties of rock and form pathays for the migration of fluids within the rock or, conversely, they may impede the flow of liquids and pose a barrier to their migration.

Moreover, the study of "earthly" deformation bands can sometimes even advance our understanding of the geological structure and processes which occur on other planets. Some zones resembling deformation band clusters have been observed in satellite images of the Martian surface. In the deposits inside a crater in the Arabia Terra region, areas exhibiting deformation bands form extensive networks several hundred meters long. Perhaps, in the future, more detailed data supplied by subsequent research missions may bring more specific information on such structures, and they themselves might prove useful in solving problems and issues such as presence of water on Mars or the identification of Martian tectonic processes?

Where can we see them with our own eyes?

Due to their unique appearance, deformation bands can undoubtedly serve as a kind of geo-tourist attraction. Already now, their presence has already been confirmed in several national parks across the world. One of the first ever descriptions of deformation bands came from the Navajo sandstones in Utah, where they can be admired at Arches National Park. Fortunately, citizens of Poland do not need to travel so far to see them. The most numerous deformation band clusters documented so far in Poland can be found in the Bieszczady Mountains, in the Bieszczady National Park. We can encounter them while hiking across polonynas (*połoniny*), i.e. montane meadows of the Bieszczady Mountains. They are easy to spot, being particularly well visible in thick sandstone layers which are often exposed on tourist trails. With their deformation bands, such sandstones stand out among the surrounding rocks and draw the tourists' attention with their linear patterns formed on the surface. Numerous deformation bands can also be found on Tarnica, the highest peak in the Polish part of the Bieszczady Mountains. Their presence here is due to mountain formation processes during the Alpine orogeny. Following a collision of tectonic plates, the area underwent deformation processes involving intensive shortening of rock layers. Deformation bands are among the telltale signs of this ancient process, which are still surviving in the rock today. ■

5

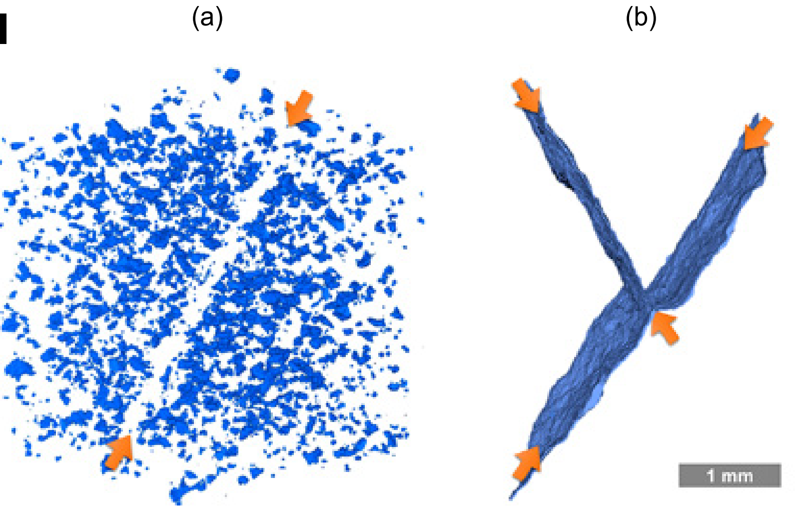


Fig. 5
Three-dimensional images of porous rock surface (in blue), with marked directions of deformation bands (orange arrows). Water and other fluids such as oil and natural gas flow through empty (porous) spaces in the rock. The direction and features of the deformation band may pose a barrier to (a) or offer a passage for fluid migration (b)

6

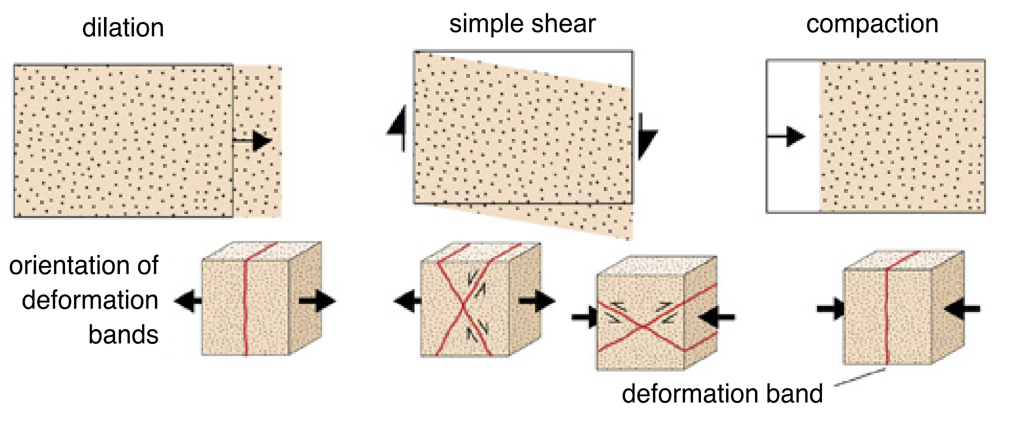


Fig. 6
Types of deformation band microstructure depending on the deformation mechanism

Further reading:

Fossen H., Schultz R.A., Shipton Z.K., Mair K., Deformation bands in sandstone: a review, *Journal of the Geological Society* 2007, 164, 755–769.

Fossen H., Bale A., Deformation bands and their influence on fluid flow, *AAPG Bulletin 2007*, 91, 1685–1700.

Sikora R., Strzelecki P., Radzik N. et al. Wybrane problemy geologii strukturalnej w południowo-wschodniej części polskiego segmentu Karpat zewnętrznych [Selected problems of structural geology in the southeastern portion of the Polish segment of the outer Carpathians]. In: Peryt T. *LXXXVII zjazd naukowy Polskiego Towarzystwa Geologicznego* 2019, 61–73.