University of Anbar

College of Science

Department of Applied Geology

Advanced Structural Geology

Title of the lecture

Joints

Assistant Prof. Dr. Abdulkhaleq A. Alhadithi

2022

Joints

Joint A natural, unfilled, planar or curviplanar fracture which forms by tensile loading. The walls of a joint move apart very slightly as the joint develops. Joint formation does not involve shear displacement.

Systematic versus Nonsystematic Joints

Systematic joints are planar joints that comprise a family in which all the joints are parallel or subparallel to one another, and maintain roughly the same average spacing over the region of observation (Figure 1). Systematic joints may cut through many layers of strata, or be confined to a single layer. **Nonsystematic joints** have an irregular spatial distribution, they do not parallel neighboring joints, and they tend to be nonplanar (Figure 1). Nonsystematic joints may terminate at other joints. You will often find both systematic and nonsystematic joints in the same outcrop.

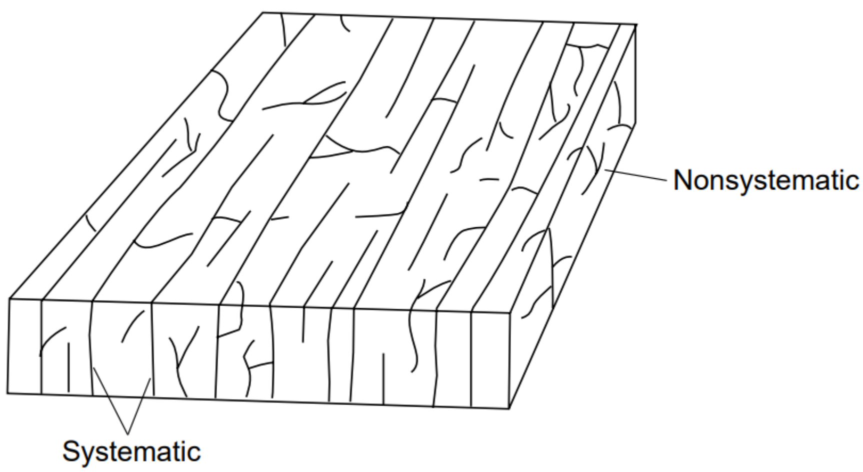

Figure 1 Block diagram showing occurrence of both systematic and nonsystematic joints in a body of rock.

Joint Sets and Joint Systems

We'll describe joint patterns here and give the explanations of why various different groups of joints form. A **joint set** is a group of systematic joints. Two or more joint sets that intersect at fairly constant angles comprise a joint system, and the angle between two joint sets in a **joint system** is the **dihedral angle**. If the two sets in a system are mutually perpendicular (i.e., the dihedral angle is ∼90°), we call the pair an **orthogonal system**, and if the two sets intersect with a dihedral angle significantly less than 90° (e.g., a dihedral angle of 30° to 60°), we call the pair a **conjugate system**. Many geologists use the terms "orthogonal" or "conjugate" to imply that the pair of joint sets formed at the same time. However, nonparallel joint sets typically form at different times. So, we use the terms merely to denote a geometry, not a mode or timing of origin.

Many different configurations of joint systems occur, which are distinguished from one another by the nature of the intersections between sets and by the relative lengths of the joints in the different sets. In joint systems where one set consists of relatively long joints that cut across the outcrop whereas the other set consists of relatively short joints that terminate at the long joints, the throughgoing joints are master joints, and the short joints that occur between the continuous joints are cross joints. In the flat-lying sedimentary rocks that occur in continental interior basins and platforms, joint sets are perpendicular to the ground surface (and, therefore, to bedding) and orthogonal systems are common. In gently folded sedimentary rocks, such as along the foreland margin of a mountain range, strata contain both vertical joint sets that cut across the folded layers, and joints that are at a high angle to bedding and fan around the folds (Figure 2). Both orthogonal and conjugate systems occur in such gently folded strata. The joint sets of an orthogonal system in folded sedimentary rocks commonly have a spatial relationship to folds of the region, so we can distinguish between **strike-parallel joints**, which parallel the general strike of bedding (roughly parallel to regional fold hinges), and **cross-strike joints**, which trend at high angles (~60° to 90°) to the regional bedding strike (Figure 2). Conjugate systems in gently folded rocks consist of two cross-strike sets with their acute bisector at a high angle to the fold hinge. Because both sets of joint systems need not form at the same time, a conjugate geometry of a system of joints does not require that they are conjugate shear ruptures. In the internal portions of mountain belts, where rocks have been intensely deformed and metamorphosed, outcrops may contain so many joints that joint systems may be difficult to recognize or simply do not exist.

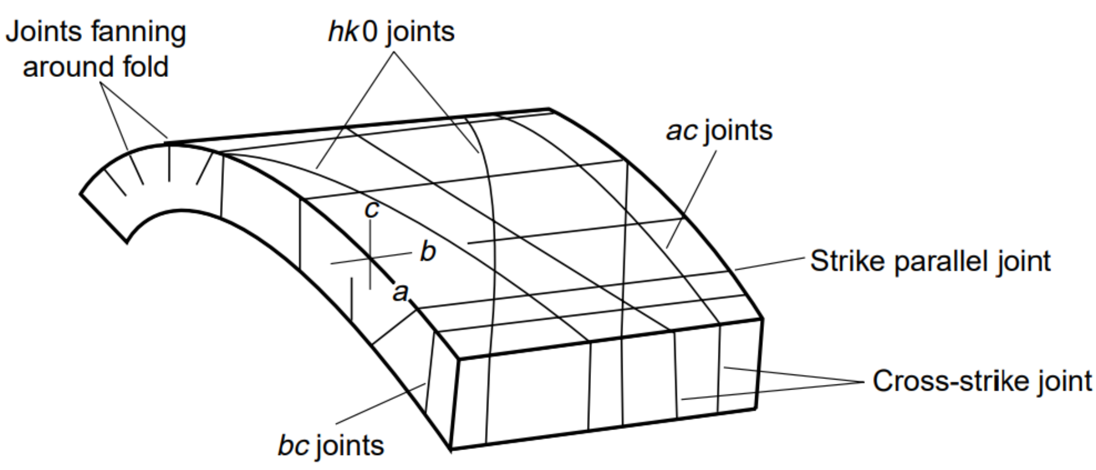

Figure 2 Idealized arrangement of joint arrays with respect to fold symmetry axes. The "hk0" label for joints that cut diagonally across the fold-hinge is based on the Miller indices from mineralogy; they refer to the intersections of the joints with the symmetry axes of the fold

In such regions, joints formed prior to deformation and metamorphism have been partly erased. New joints then form at different times during deformation, during subsequent uplift, or even in response to recent stress fields. Rocks in such regions are so heterogeneous that the stress field varies locally, and thus joints occur in a wide range of orientations. Nevertheless, in some cases, younger joints, meaning those formed during uplift or due to recent stress fields, may stand out as distinct sets.

Intrusive and metamorphic rocks without a strong schistosity commonly contain a set of joints that roughly parallels ground surface topography, and whose spacing decreases progressively toward the surface. Such joints are called **sheeting joints** or **exfoliation joints** (Figure 3). If the ground surface is not horizontal, as is the case on the sloping side of a mountain, sheeting joints curve and follow the face of the mountain, thus giving the mountain the appearance of a partially peeled onion. Rock sheets detach off the mountain along these joints, thereby creating smooth dome-shaped structures known as **exfoliation domes**. Shallow intrusive igneous rock bodies (dikes and sills) and lava flows in many localities display **columnar jointing**, meaning that they have been broken into joint-bounded columns which, when viewed end-on, have roughly hexagonal cross sections. However, in some bodies the columns curve.

Figure 3 Sheeting joints (or exfoliation) in granite

Joints Related to Regional Deformation

During a convergent or collisional orogenic event, compressive tectonic stress affects rocks over a broad region, including the continental interior. Joints form within the foreland of orogens during tectonism for a number of reasons. Joints from natural hydrofracturing often form on the foreland margins of orogens during orogeny. The conclusion that the joints are syntectonic is based on two observations. First, the joints parallel the σ_1 direction associated with the development of tectonic structures like folds. Second, the joints locally contain mineral fill which formed at temperatures and fluid pressures found at a depth of several kilometers; thus, they are not a consequence of the recent cracking of rocks in the near surface. The origin of such joints may reflect increases in fluid pressure within confined rock layers due to the increase in overburden resulting from thrust-sheet emplacement, or from the deposition of sediment eroded from the interior of the orogen.

During an orogenic event, the maximum horizontal stress is approximately perpendicular to the trend of the orogen. As a consequence, the joints that form by syn-tectonic natural hydraulic fracturing are roughly perpendicular to the trend of the orogen. Because the stress state may change with time in an orogen, later-formed joints may have a different strike than earlierformed joints, and the joints formed during a given event might not be exactly perpendicular to the fold trends where they form. Such joint patterns are typical of orogenic foreland regions, but may also occur in continental interiors.

Joints are commonly related to faulting, and these fall into three basic classes. The first class is composed of regional joints that develop in the country rock due to the stress field that is also responsible for generation and/or movement on the fault itself. Since faults are usually inclined to the remote σ_1 direction, the joints that form in the stress field that cause a fault to move will not be parallel to the fault (Figure 4a). The second class includes joints that develop due to the distortion of a moving fault block. For example, the hanging wall of a normal fault bock may undergo some extension, resulting in the development of joints, or the hanging block of a thrust fault may be warped as it moves over the fault, if the underlying fault surface is not planar, and thus may locally develop tensile stresses sufficient to crack the rock (Figure 4b). The third class includes joints that form immediately adjacent to a fault in response to tensile stresses created in the wall rock while the fault moves. Specifically, during the development of a shear rupture (i.e., a fault), an en echelon array of short joints forms in the rock adjacent to the rupture. These joints merge with the fault and are inclined at an angle of around 30° to 45° to the fault surface; they are called **pinnate joints** (Figure 4c). The acute angle between a pinnate joint and the fault indicates the sense of shear on the fault.

When the stress acting on a region of crust is released, the crust elastically relaxes to attain a different shape. This change in shape may create tensile stresses within the region that are sufficient to create **release joints**, such as occurs in relation to folding. Folded rocks may be cut by syn-tectonic natural hydrofractures, a process manifested by joints oriented at a high angle to the fold-hinge, (Figure 5). In addition, during the development of folds in non-metamorphic conditions, joints often develop because of local tensile stresses associated with bending of the layers (Figure 5). Joints resulting from this process of outer-arc extension have a strike that is parallel to the trend of the fold-hinge, and may converge toward the core of the fold. If development of folds results in stretching of the rock layer parallel to the hinge of the fold, then cross-strike joints may develop. Finally, joints may develop in a region of crust that has been subjected to broad regional warping, perhaps due to **flexural loading** of the crust. Like folding, joint formation reflects tensile stresses that develop when the radius of curvature of a rock layer changes.

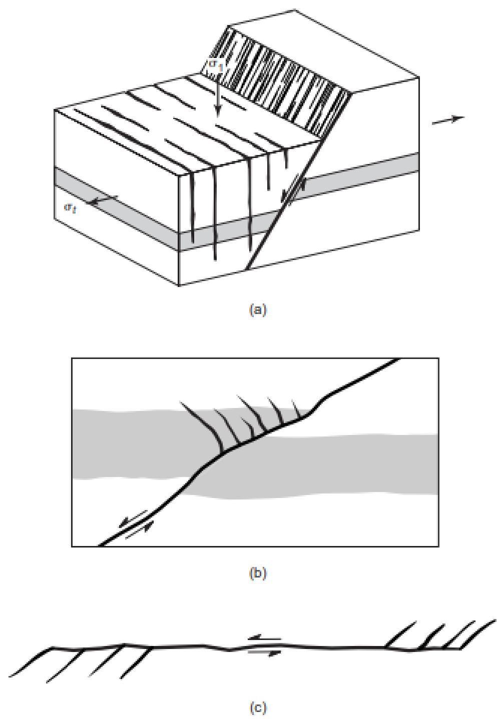

Figure 4 (a) Formation of joints in the hanging-wall block of a region in which normal faulting is taking place. (b) Formation of joints above an irregularity in a (reverse) fault surface. (c) Pinnate joints along a fault.

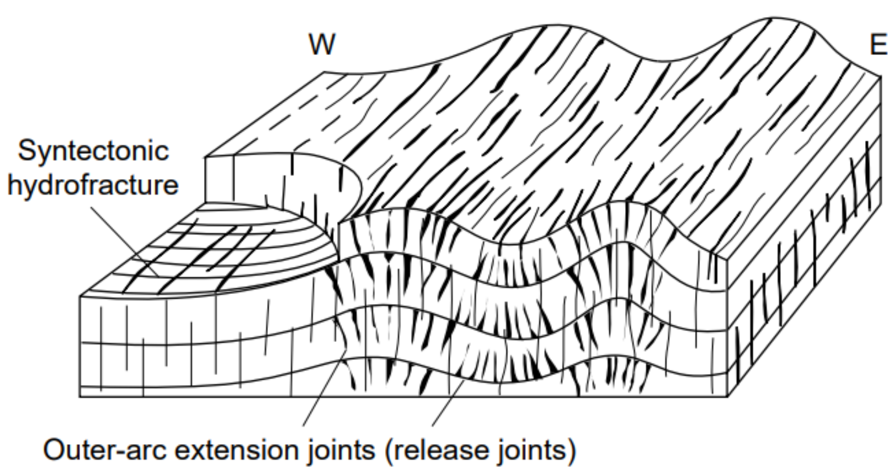

Figure 5 Block diagram showing outer-arc extension joints whose strike is parallel to the hinge of folds.

Orthogonal Joint Systems

In orogenic forelands and in continental interiors, you will commonly find two systematic joint sets that are mutually perpendicular. In some cases, the joints define a **ladder pattern** (Figure 6a), in which the joints of one set are relatively long, whereas the joints of the other are relatively short cross joints which terminate at the long joints. In other cases, the joints define a **grid pattern** (Figure 6b), in which the two sets appear to be mutually cross cutting. The existence of such orthogonal systems has perplexed geologists for decades, because at first glance it seems impossible for two sets of tensile fractures to form at 90° to one another in the same regional stress field. Recent field and laboratory studies suggest a number of possible ways in which orthogonal systems develop, though their application to specific regions remains controversial.

In orogenic forelands, an orthogonal joint system typically consists of a strike-parallel and a cross-strike set, defining a ladder pattern. The two sets may have quite different origins. Cross-strike joints parallel the regional maximum horizontal stress trajectory associated with folding, and thus may have formed as syntectonic natural hydrofractures, whereas strike-parallel joints could reflect outer-arc extension of folded layers. Alternatively, the strike-parallel joints could be release joints formed when orogenic stresses relaxed.

Orthogonal joint systems may develop in regions that were subjected to a regional tensile stress that was later relaxed. During the initial stretching of the region, a set of joints develops perpendicular to the regional tensile stress. When the stress is released, the region rebounds elastically, and expands slightly in the direction perpendicular to the original stretching. A new set of joints therefore develops perpendicular to the first.

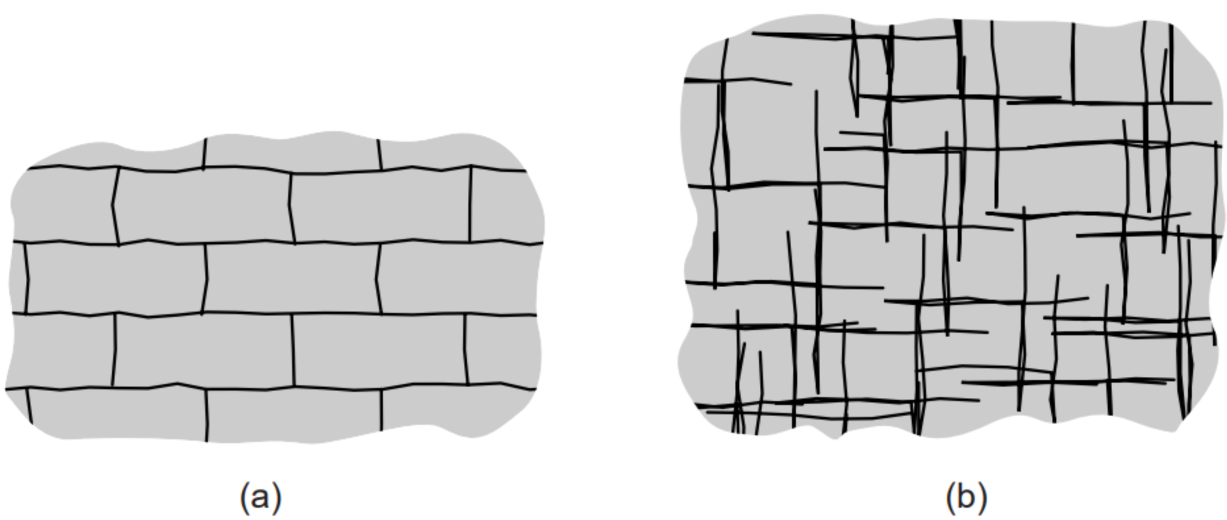

Figure 6 Two patterns of orthogonal joint systems. (a) Traces of joints defining a ladder pattern. (b) Traces of joints defining a grid pattern.

Orthogonal joint systems may also develop during uplift. Imagine that a rock layer is unloaded when the overburden erodes away. As a result, a joint set perpendicular to the regional σ_3 develops. With continued uplift and expansion, the tensile stress that develops in the layer can be relieved easily in the direction perpendicular to the existing joints; that is, they just open up. But tensile stresses cannot be relieved in the direction parallel to the existing joints, so new cross joints form, creating a ladder pattern. Grid patterns (Figure 6b) suggest that the two joint sets initiated at roughly the same time, or that cracking episodes alternated between forming members of one set and then the other. If we assume that both joint sets form in the principal plane that is perpendicular to σ_3, we can interpret such occurrences as being related to the back-and-forth interchange of σ_2 and σ_3 during uplift, when σ_2 and σ_3 are similar in magnitude. To see what we mean, imagine a region where σ_1 is vertical, and σ_3 is initially north–south. When σ_3 is north–south, east–west trending joints develop. But if σ_3 switches with σ_2 and becomes east–west, then north–south trending joints develop.

Conjugate Joint Systems

At some localities in orogenic forelands, we find that joint sets define a conjugate system in which the bisector of the dihedral angle is perpendicular to the axis of folds. The origin of such fracture systems remains one of the most controversial aspects of joint interpretation. Based on their geometry, it was traditionally assumed that conjugate joints are either shear fractures, formed at about 30° to σ_1 (representing failure when the Mohr circle touches the Coulomb failure envelope), or so-called transitional-tensile fractures that are thought to form at angles less than 30° to σ_1 (representing failure when the Mohr circle touches the steep part of the failure envelope). Yet, if you examine the surfaces of the joints in these conjugate systems, you find in many cases that they display plumose structure, confirming that they formed as Mode I (extension) fractures. Further, as we noted earlier, transitional-tensile fractures have never been created in the lab, so their very existence remains suspect. The only type of crack that is known to propagate for long distances in its own plane is a Mode I crack; shear fractures form by linkage of microcracks, not by propagation of a single shear surface in its own plane. But if the members of conjugate joint systems are not shear fractures, how do they form? Many researchers now believe that both of the two nonparallel sets in the conjugate system are cross-strike joints that initially formed perpendicular to σ_3. Thus, to explain the contrast in orientation between the two sets, they suggest that the two sets formed at different times in response to different stress fields.

References

Ben A. van der Pluijm, and Stephen Marshak. (2004) EARTH STRUCTURE AN INTRODUCTION TO STRUCTURAL GEOLOGY AND TECTONICS. Second edition.