



# Indian Institute of Technology, Kanpur

## Department of Earth Sciences

ESO213A: Fundamentals of Earth Sciences

### Lecture 23. Ductile Shear Zones

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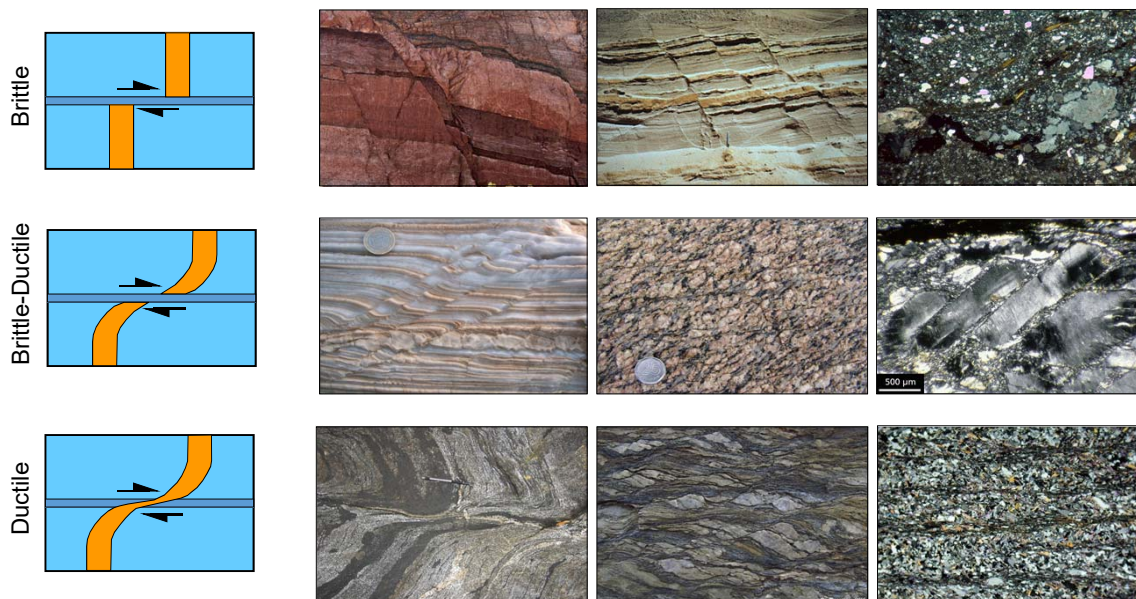


### Aims of this lecture



- Definition and characteristics of Ductile Shear Zones
- Foliations in Ductile Shear Zone
- Kinematics of Ductile Shear Zone

## Review: Basics and Definitions



Photographs from web and other sources

## Review: Basics and Definitions

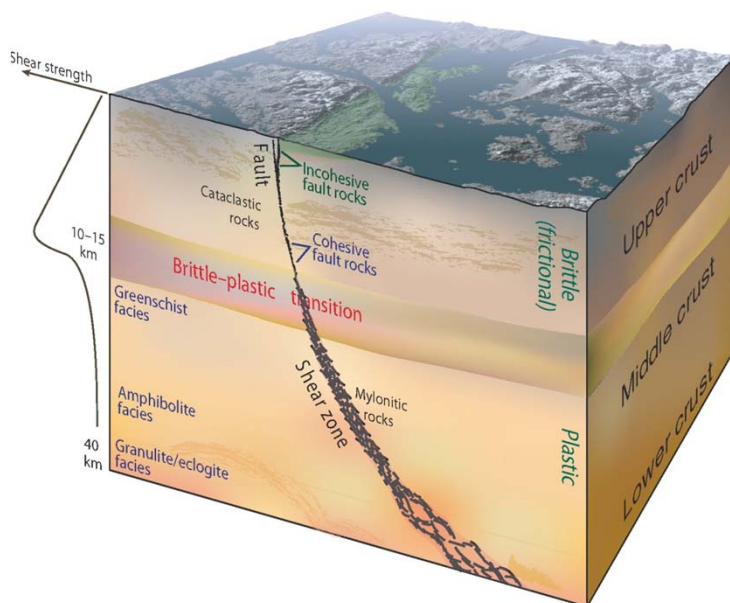


Illustration: Fossen, 2005

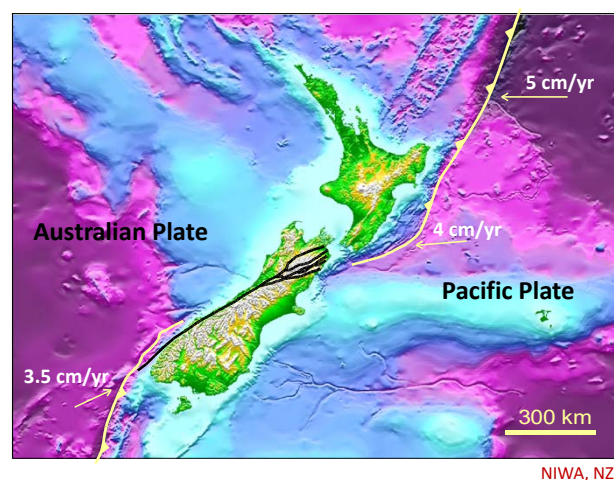
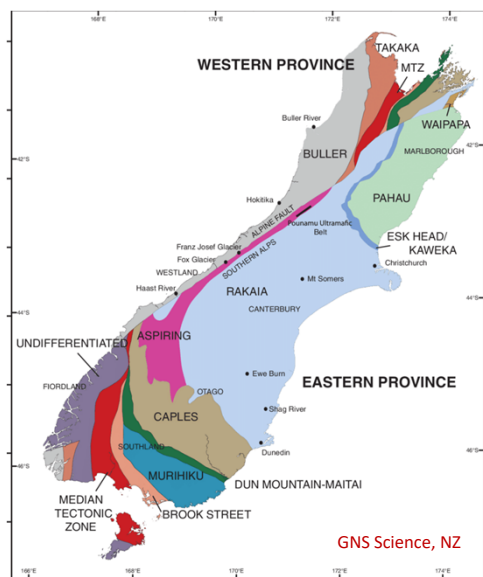
Simplified model of the connection between faults, which normally form in the upper crust, and classic ductile shear zones. The transition is gradual and known as the brittle-ductile transition.

The depth depends on the temperature gradient and the mineralogy of the crust. For granitic rocks it normally occurs in the range of 10–15 km.

## What is a Ductile Shear Zone

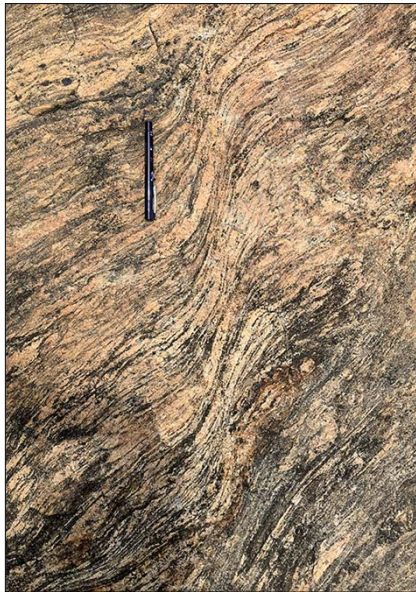
- A ductile shear zone is a long narrow zone within which dominantly ductile deformation has caused a localization of large strain compared to the surrounding regions.
- The formation of a ductile shear zone is commonly associated with a drastic reduction of grain size and the development of an extremely foliated (banded) and lineated rock.
- The rock type within a typical ductile shear zone is known as *mylonite* [*mylonite* designates the texture, not the composition of the rock; *breccia* is the rock type within the brittle shear zone]
- Ductile shear zones may range in scale from the microscopic or grain scale to the scale of a few hundreds of kilometres in length and a few millimetres to a few tens of kilometres in width.

## A typical Ductile Shear Zone – Large scale





## A typical Ductile Shear Zone – Outcrop scale

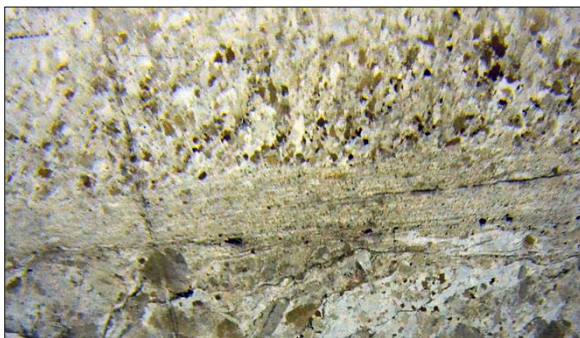


Photographs: Santanu Misra

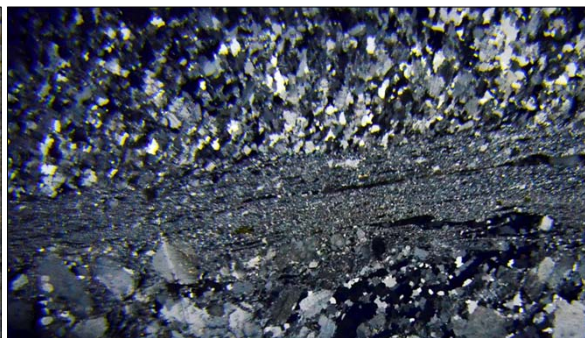


Photographs: Santanu Misra

## A typical Ductile Shear Zone – Micro scale



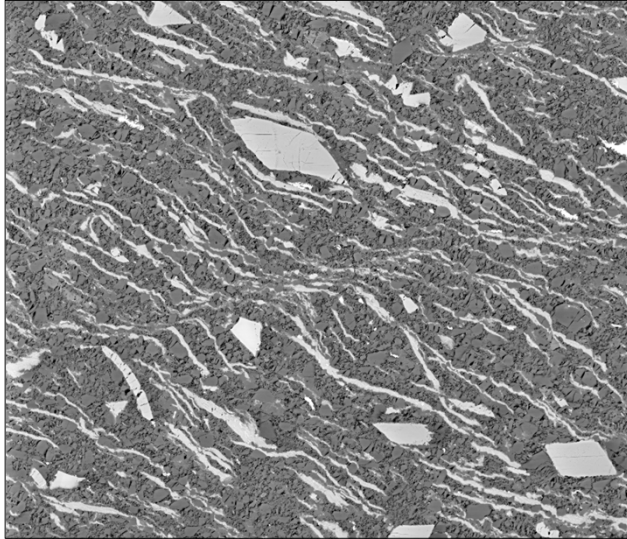
Photograph: Santanu Misra



Photograph: Santanu Misra

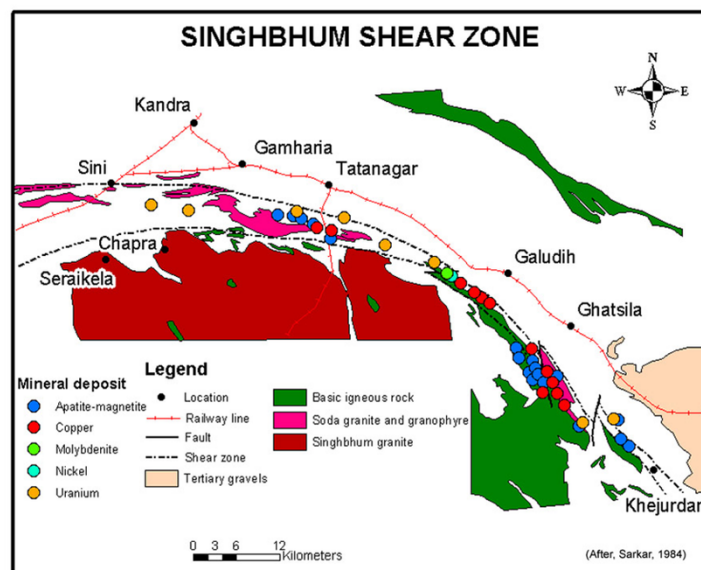
Ductile shear zone in granite. Width of the images 4.2 cm.

## A typical Ductile Shear Zone – Micro scale



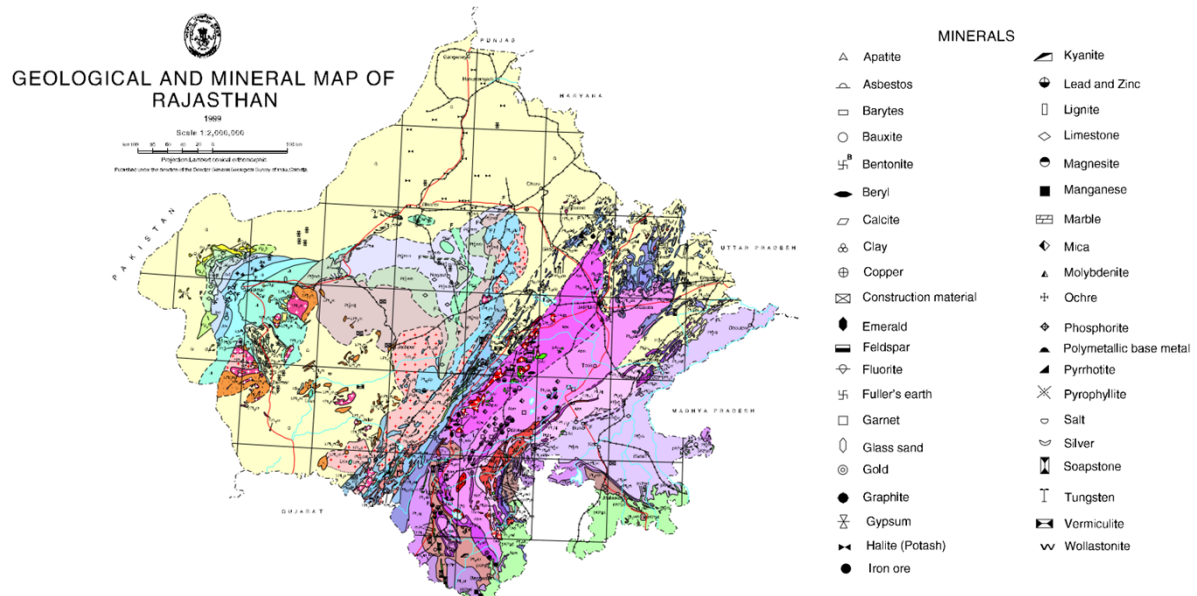
Incipient ductile shear zone in an experimentally deformed quartz (dark)-biotite (bright) aggregate. [Experiment and photo: Santanu Misra; width of the image 400 microns]

## Ductile Shear Zone – why so important?





## Ductile Shear Zone – why so important?



## Ductile Shear Zone – Characteristics

- Strongly foliated (and lineated) rock that has undergone intense ductile deformation (*mylonitization*), with accompanying reduction in grain size.
- Contain fabric elements of monoclinic symmetry.
- Grains, mostly flattened, are much smaller than wall rock.
- Dominantly crystal plastic (intra-crystalline) deformation with/without presence of porphyroclasts.
- Contain planar and linear shape fabric.
- Matured mylonites show two – three *sub-foliations* inclined to each other with certain angles.
- Tight to isoclinal folding, reclined folding, sheath fold.

## Shear Zone Rocks



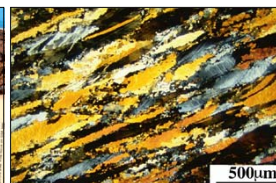
	Random Fabric	Foliated Fabric			
Non-Cohesive	Fault breccia (visible fragments > 30%) Fault gouge (visible fragments < 30%)				Increasing deformation and decreasing grain size
Cohesive	Crush breccia (fragments > 0.5 cm) Fine crush breccia (fragments 0.1-0.5 cm) Crush micro-breccia (fragments < 0.1 cm)		0-10%	Proportion of Matrix	
	Protocataclasite	Protomylonite	15-20%		
	Cataclasite	Mylonite	50-90%		
	Ultracataclasite	Ultramylonite	90-100%		
	BRITTLE	DUCTILE			

## Mylonite



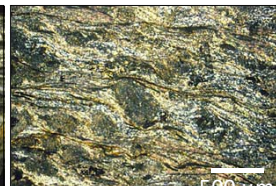
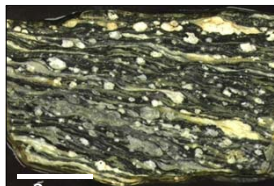
### Protomylonite

- Grain size > 50  $\mu\text{m}$
- Percentage matrix < 50%
- Small recrystallized grains surround large relict grains (mortar texture).



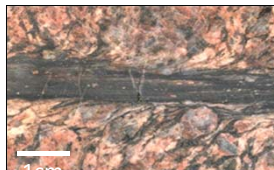
### Mylonite (Orthomylonite)

- Grain size < 50  $\mu\text{m}$
- Percentage matrix 50%-90%
- Strongly foliated with porphyroclasts in fine-grained matrix



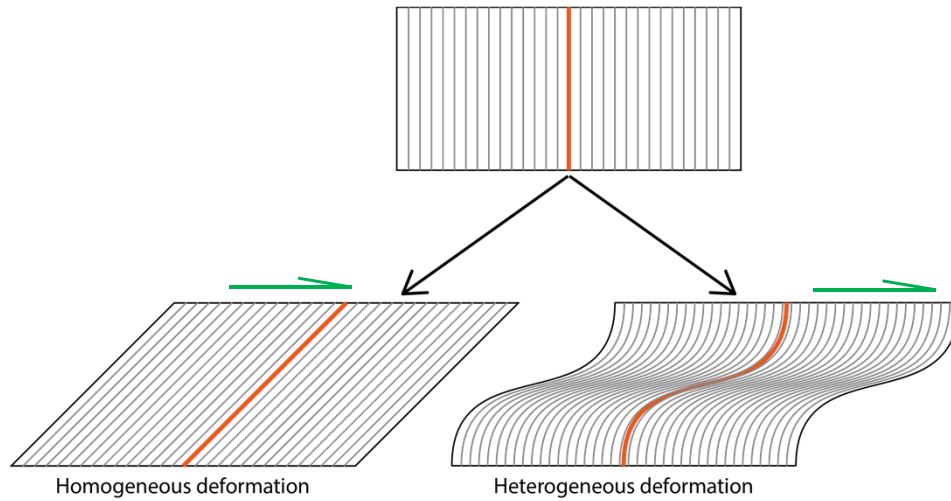
### Ultramylonite

- Grain size < 10  $\mu\text{m}$
- Percentage matrix > 90%
- Thoroughly deformed fine-grained rock

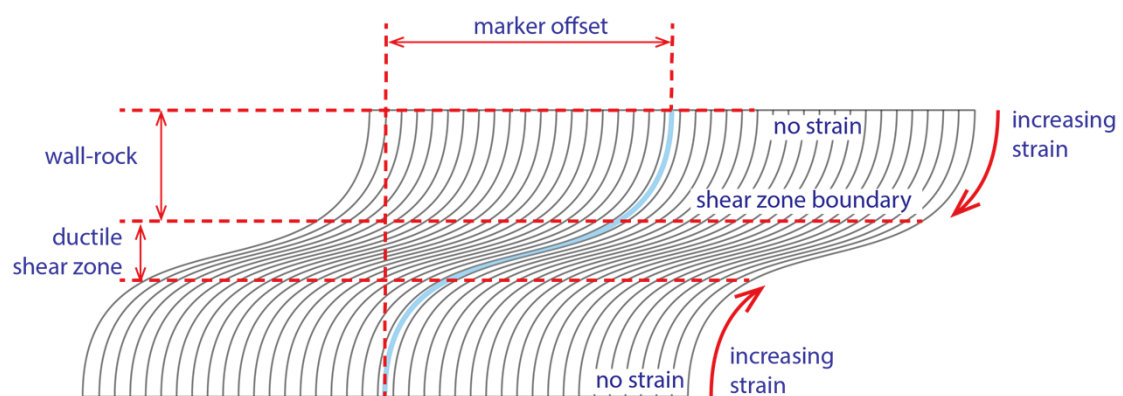


Photographs from various sources and self

## Anatomy of a Ductile Shear Zone



## Anatomy of a Ductile Shear Zone



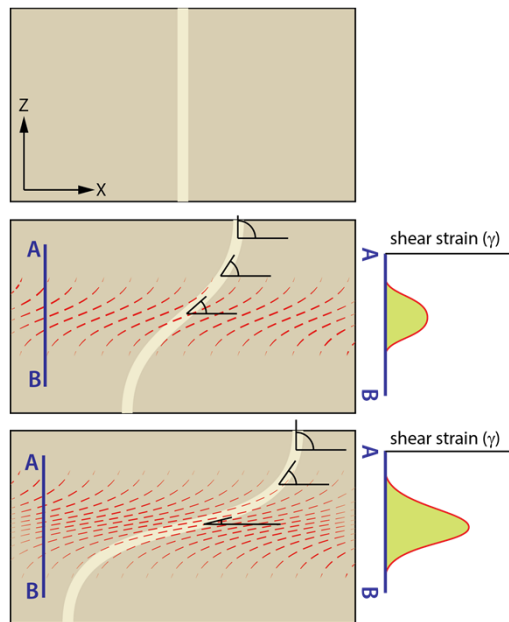


## Foliations in Ductile Shear Zone

Shear zones are with genetically related foliation. The foliation makes 45° with the shear zone along the margins. This angle is reduced as strain increases toward the center of the zone.

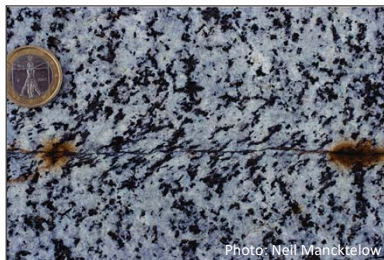
The displacement ( $d$ ) can be found either by measuring or calculating the area under a shear strain profile across the zone if the deformation is simple shear.

$$d = \int_A^B \gamma dy$$



## Foliations in Ductile Shear Zone

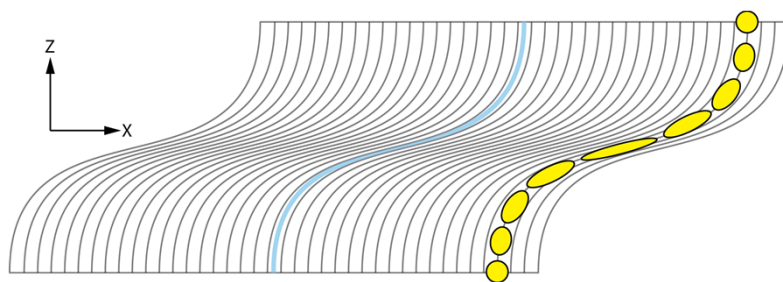
- A typical shear zone is characterized by development of foliation (tracks the XY plane of the strain ellipsoid), orientation of which depends on geometry, nature and strain of the shear zone.
- In a fairly isotropic rock, a faint foliation will appear at low shear strains but intensity increases with larger shear strain.



## Foliations in Ductile Shear Zone



## Kinematics of a Ductile Shear Zone



## Kinematics of a Ductile Shear Zone

In the strongly deformed domains, the stretching lineation can be equated with the shear direction. The curved or **sigmoidal pattern of the foliation** in the XZ sections of rocks defines the **sense of shear**. The bulk acute angle of the foliation to the shear zone walls is always sympathetic to the sense of shear.

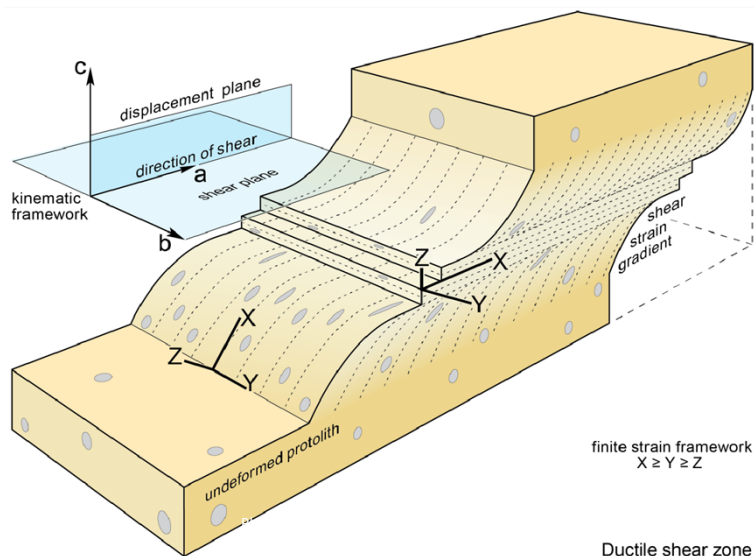


Illustration: Jean Pierre Burg

## Kinematics of a Ductile Shear Zone

- Most the mylonites contain structures that show monoclinic (low) symmetry, simply referred to as *asymmetric structures*. The asymmetry is related to the rotational component or non-coaxiality of the deformation, or the fact that objects rotate in a preferred direction.
- The (a)symmetry of mylonite structures can be used to evaluate the sense of shear and sometimes also the degree of coaxiality of a mylonite zone

### Where to see?

- XZ section of the strain ellipsoid**
- Perpendicular to foliation, parallel to lineation.**

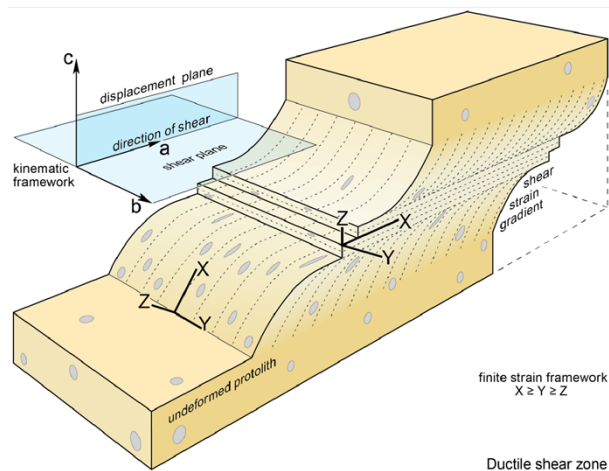


Illustration: Jean Pierre Burg





## Some Typical Shear Zone Structures (on XZ plane)

Foliation Drag; deflected markers

Internal foliations (C, S and C')

Mica Fish

Delta ( $\delta$ ), sigma ( $\sigma$ ) and Phi ( $\phi$ ) structures

Sigmoidal veins

Sheath Folds

Fractured minerals

Asymmetric Folds

Know more here:

[https://youtu.be/EX8oH48hglw?list=PLHyuArGIllyR\\_2mObwQ3yng18LDnDqidp](https://youtu.be/EX8oH48hglw?list=PLHyuArGIllyR_2mObwQ3yng18LDnDqidp)

## Next Lecture



ALL THE BEST FOR THE  
MID-SEMESTER EXAMINATION