44. FAULT ROCKS FROM AN EXHUMED, INTRACRUSTAL, EXTENSIONAL DETACHMENT

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The samples pictured in Plates 44A–44F come from the Pogallo ductile fault zone (PDFZ), a low-angle normal fault that exhumed lower continental crust during early Mesozoic time. The PDFZ presently forms part of the subvertical contact between the Ivrea and Strona-Ceneri units in the westernmost part of the southern Alps, northern Italy (Figure 44.1). Together, these units make up an eroded cross section of intermediate to lower continental crust. This crustal section underwent repeated uplift during Paleozoic and early Mesozoic time. However, its emplacement near the surface in a subvertical orientation resulted from late Cretaceous to Tertiary thrusting and folding during the Alpine orogeny (Zingg and others, 1990; Handy and Zingg, 1991).

Erosion has exposed the PDFZ in a profile nearly perpendicular to its mylonitic foliation and slightly oblique to its stretching lineation. This affords a rare glimpse of the anatomy of a low-angle normal fault. In map view, the PDFZ is about 30 km long and at least 2 to 3 km wide. Syntectonic metamorphism and deformational style vary both across and along strike of the PDFZ, suggesting that prior to subvertical emplacement the PDFZ was a gently to moderately dipping, intracrustal extensional shear zone. At the originally shallower southwest end of the PDFZ, cataclasites grade into greenschist-facies mylonites, which in turn splay into a zone of diffuse, predominantly crystal-plastic, amphibolite-facies deformation at the originally deeper northeast end of the PDFZ. The steep metamorphic gradient from northwest to southeast across the PDFZ reflects rapid, asymmetrical cooling of the shear zone as the hot, uplifting Ivrea footwall was juxtaposed against cooler parts of the Strona-Ceneri hanging wall. There, cataclasites and greenschist-facies mylonites overprint amphibolite-facies mylonites, as depicted on the plates in the following spreads.

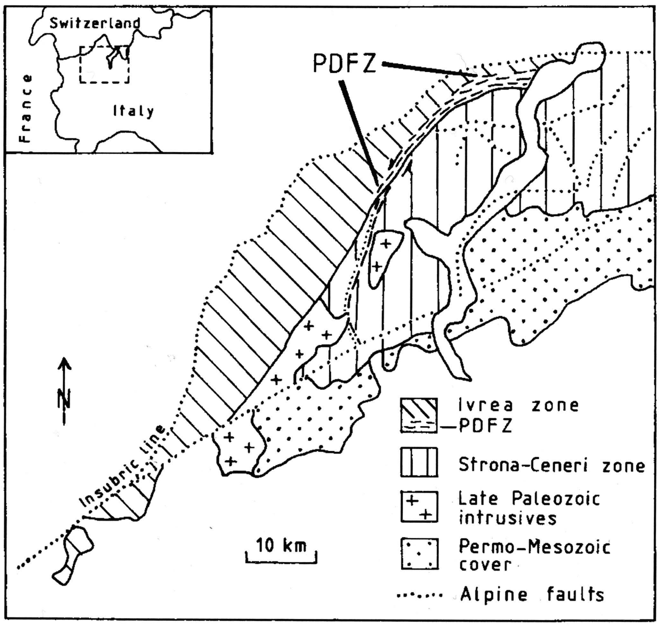
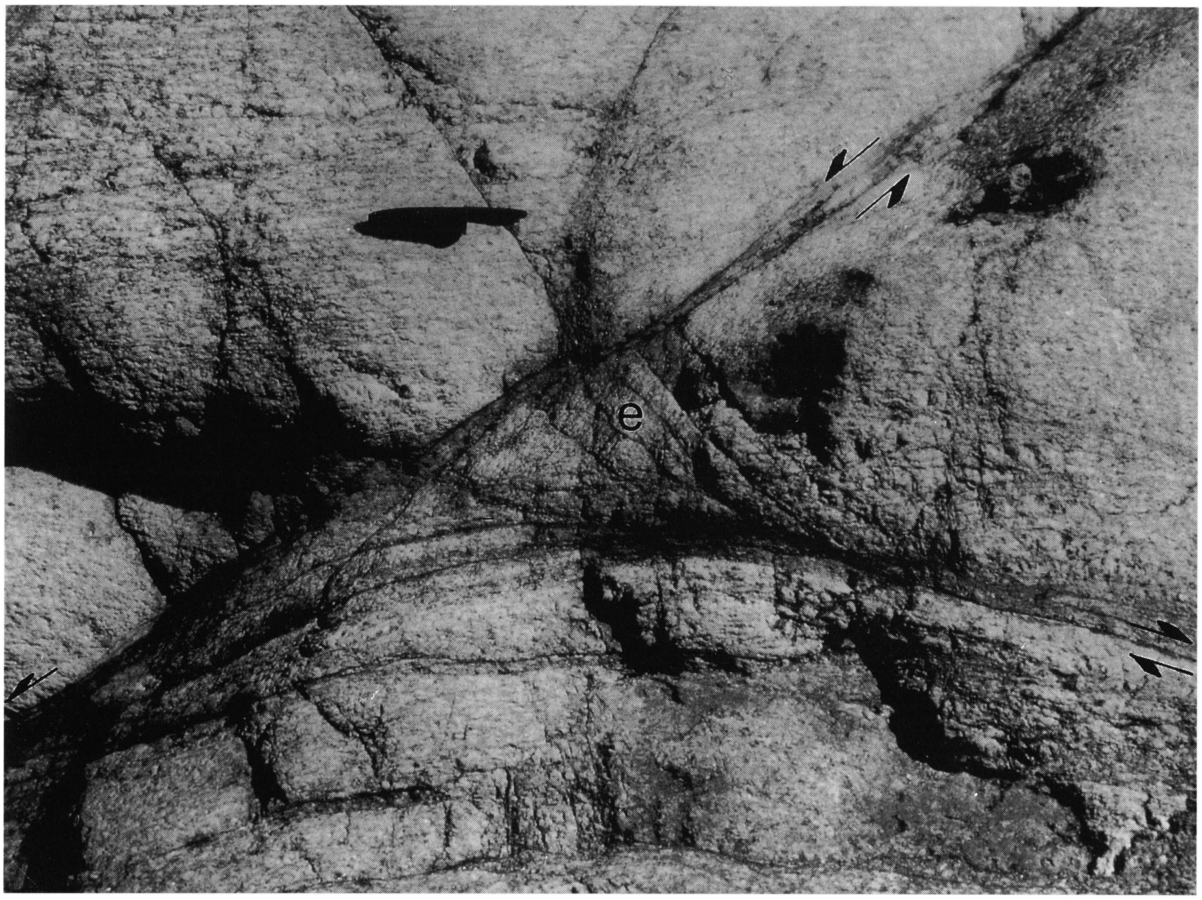


Figure 44.1. Map of the Ivrea crustal cross section showing location of the Pogallo ductile fault zone, PDFZ (see text).

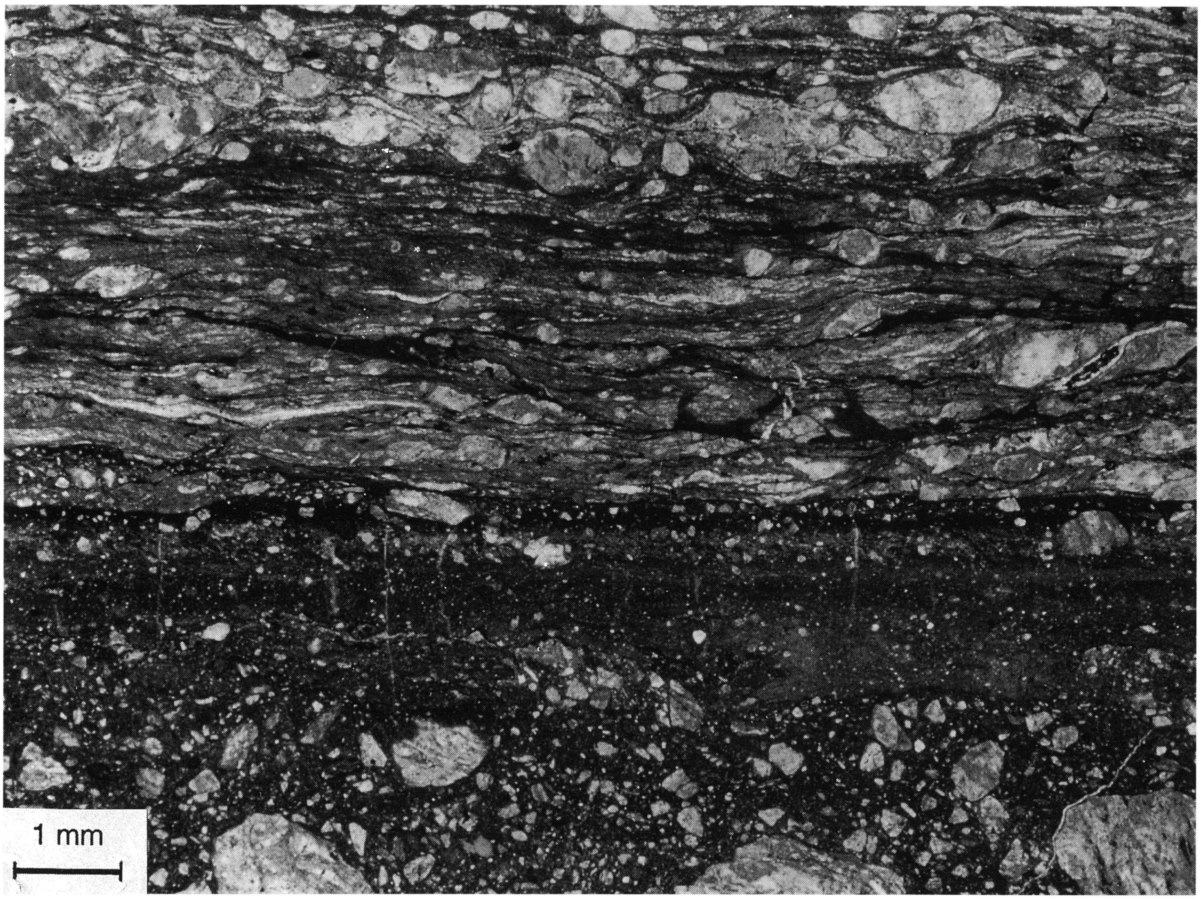
The transition from mylonitic creep to cataclastic flow

44A. Cracks at intersection of conjugate mylonitic shear zones. Anastomosing, greenschist-facies mylonitic shear zones truncate the amphibolite-facies mylonitic foliation of granitoid gneiss. The outcrop surface is perpendicular to foliation and subparallel to the stretching lineation. Sinistral, greenschist-facies shear zones are synthetic with respect to the overall sinistral sense-of-shear within the Pogallo ductile fault zone. Where conjugate shear zones meet, the dextral shear zone becomes narrower and bends into concordance with its sinistral partner. Arcuate extensional cracks (labeled e) emanate from the top of the antithetic shear zone. Conjugate high-angle extensional cracks (indicated with pen cap) form mutually cross-cutting relationships with the mylonitic shear zones, suggesting that brittle deformation was contemporaneous with the final stages of greenschist-facies mylonitization. Pen cap for scale is 6 cm long. Photo from figure 1c in Handy (1994b).

44B. Gradation from mylonite to cataclasite. Retrograde, greenschist-facies mylonite (top) grades to a brecciated cataclasite (bottom) within the dextral shear zone in the lower right-hand part of 44A. Dark bands within, and especially between, the mylonitic and brecciated domains are weakly foliated. They contain small clasts of mylonite and very fine-grained trains of opaque minerals, epidote, and occasionally quartz. The dominant deformation mechanism in such bands could not be identified, but may have involved some kind of (viscous or frictional?) grain-boundary sliding. Note that both mylonitic and cataclastic domains accommodated ductile (i.e., distributed) flow on the scale of this micrograph. NX, section parallel to the XZ fabric plane. Micrograph from figure 10b in Handy (1987).



44 A



44 B

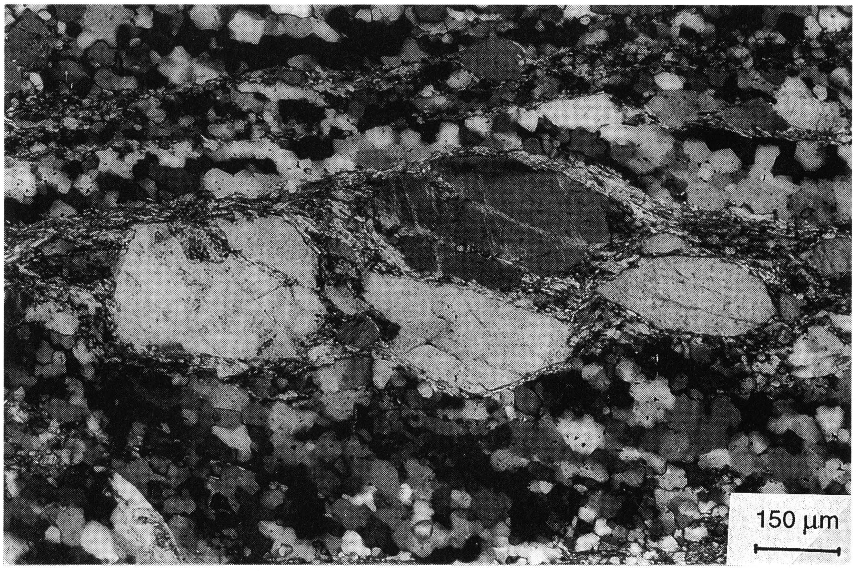
Reaction-enhanced changes in microstructure and deformation mechanism

44C. Strain localization. Thin bands of retrograde, greenschist-facies mylonite (top, parallel to print length) discordantly overprint amphibolite-facies mylonitic foliation (middle and bottom) at the border of a sinistral shear zone along the cool margin of the PDFZ. Note the strain-dependent change in mineralogy from a quartz-plagioclase-white mica-biotite mylonite below to a fine-grained chlorite-white mica-clinozoisite-albite-quartz mylonite above. NX, section parallel to the XZ fabric plane. Photo from figure 10a in Handy (1987).

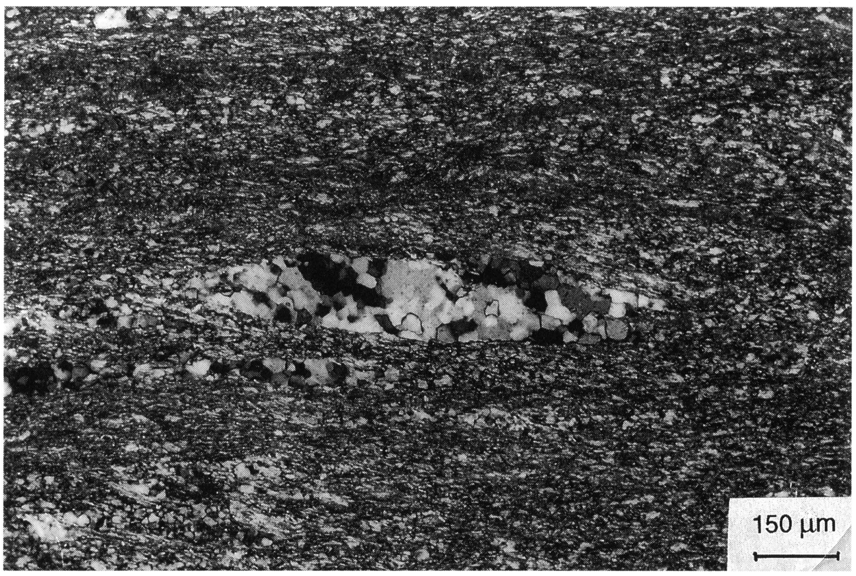
44D. Syntectonic breakdown of plagioclase. Close-up of plagioclase clast within a weak matrix of dynamically recrystallized quartz in the lower mylonitic domain of 43C. The clast is undergoing incipient reaction to fine-grained white mica, clinozoisite, albite, and quartz. Note the nucleation of these reaction products along the boundaries and fractures of the clast. Strain compatibility between clast and matrix is maintained by the nucleation and growth of reaction products in the strain shadows of the clasts. The rheology of the rock is inferred to be governed by dislocation creep of the quartz matrix. NX, section parallel to the XZ fabric plane. Photo from figure 5a in Handy (1990).

44E. Viscous creep in fine-grained micaceous mylonite. Close-up of fine-grained, micaceous foliation in upper mylonitic domain of 44C. Micaceous reaction products comprise a weak, fine-grained matrix that surrounds elongate boudins of fine, dynamically recrystallized quartz. The initially weaker quartz in 44D is now inferred to be slightly stronger than the micaceous reaction products. The dominant deformation mechanism in this mylonitic domain is inferred to be dislocation- and/or diffusion-accommodated, grain-boundary sliding in the fine-grained, micaceous matrix. NX, section parallel to the XZ fabric plane. Photo from figure 5b in Handy (1990).

44 C



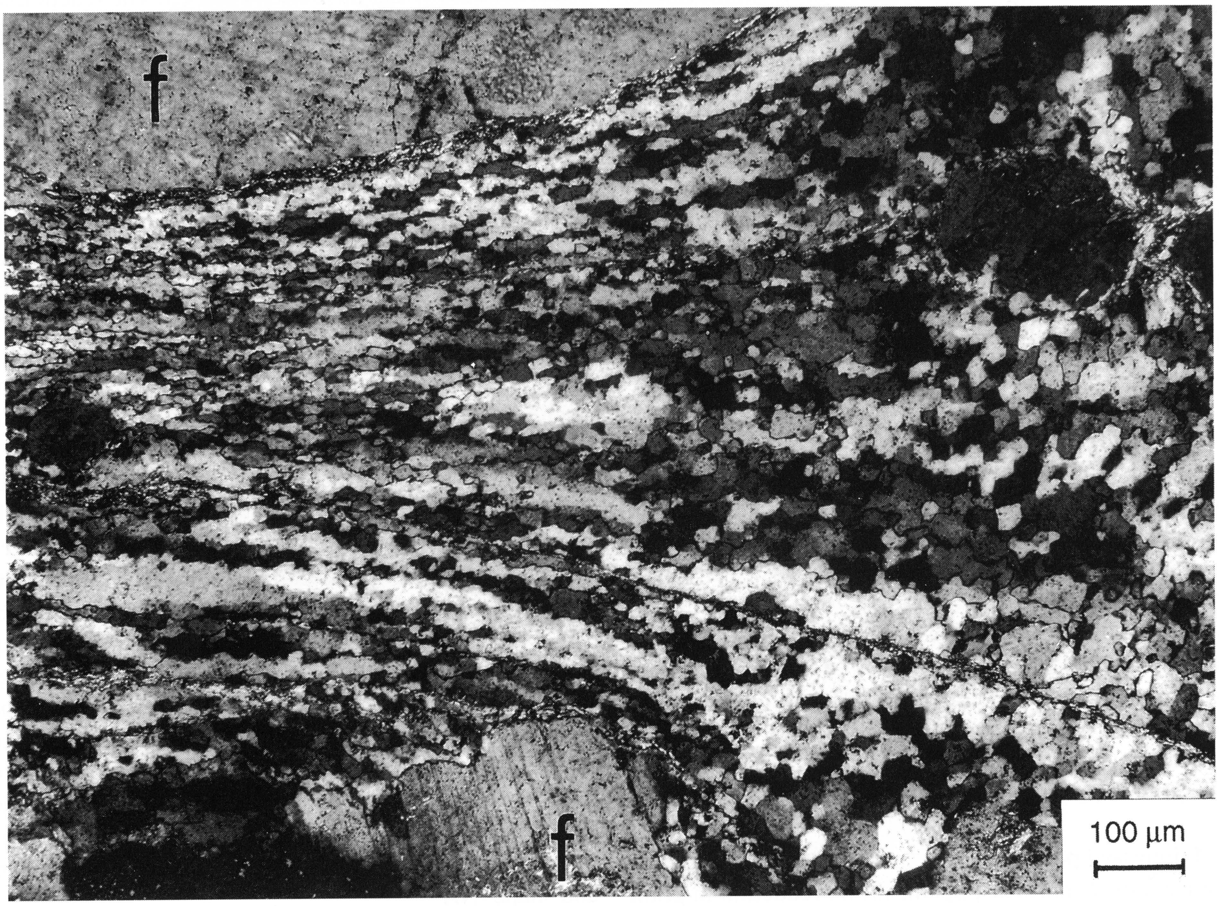
44 D



44 E

Contrasting deformation of minerals in a mylonite

44F. Viscous flow of quartz between feldspar clasts. Dynamically recrystallized quartz between two feldspar grains (labeled f) in greenschist-facies, granitoid mylonite. Note that directly between the impinging feldspar clasts, quartz grains are both smaller and more elongate than where the feldspars are further apart. Dynamically recrystallized grain size is inversely and nonlinearly proportional to creep stress (e.g., Etheridge and Wilkie, 1981). Therefore, the gradients in grain size and shape within the quartz matrix confirm previous inferences that stress, strain, and strain rate were locally much higher between the feldspar grains than elsewhere (Lister and Price, 1978). Numerical models of two-phase aggregates predict a similar concentration of stress and strain in a weak, viscous matrix flowing around rigid bodies (Masuda and Ando, 1988). The preservation in quartz of arcuate grain boundaries and grain triple junctions with unequal angles suggests that recrystallization was dynamic. Evidently, decreases in differential stress and temperature during extensional exhumation were fast enough to freeze in stress-dependent grain size on a very small scale (Handy, 1990; Prior and others, 1990). NX, section parallel to the XZ fabric plane. Micrograph published as figure 3 in Handy (1994a).



44 F