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Low-temperature, fluid-assisted joint reactivation and 'diffuse faulting' in the Machu Picchu granitoid pluton, Eastern Cordillera, Peru

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A series of batholiths, forming part of the 'roots' of a Permo-Liassic rift system, are exposed in the high Eastern Cordillera of central Peru as a result of tectonic inversion. Shortening of the Machu Picchu granitoid pluton is accommodated by widespread shear reactivation of primary (cooling) joints, by a process that might be termed 'diffuse faulting'. Fault-like reactivation of pre-existing joint surfaces is marked by quartz shear fibres, epidote and chlorite occurring along slip planes displaying minor (few cm) offsets within apparently undeformed granite. Analysis of fault slip data indicates that shear reactivation of different joint sets is kinematically consistent with NE oriented shortening. Wall-rock granite shows no major differences, in terms of alteration and fabric development, with respect to country rock granite. Only in the immediate vicinity (i.e., few mm) of the slip plane, the break down of plagioclase and of Fe–Mg-bearing minerals becomes more intense. This appears to represent an incipient stage of reaction softening and development of phyllosilicate-rich assemblages that are very important in more evolved shear zones. These latter consist of several cm to tens of cm thick bands of sigmoidally shaped foliation flanking the brittle precursor fracture. Ductile bands show a mylonitic fabric, including typical S-C structures and shear bands, and dynamic recrystallisation of quartz dominated by subgrain rotation recrystallisation. Several tens of cm thick phyllonites also occur within the study area, although they are less common ($<$ 1% of the total N. of shear zones). They show a mylonitic fabric, whereby the original mineral assemblage of the granite, dominated by quartz and plagioclase, has been replaced by one consisting of quartz, epidote-sericite and chlorite. These phyllonitic levels appear to represent even more evolved

shear zones that nucleated along the common brittle precursors, but underwent more intense reaction softening, allowing more substantial strain localisation. Pluton deformation is controlled by the degree of fluid-rock interaction occurring along the brittle precursors – which in turn controls shear zone development – and by the geometry and distribution of precursor joints. Three main sets can be recognised, characterised by oblique-slip reactivation with variable reverse and strike-slip components of motion. These main joint sets are characterised by spacing values ranging from a few to 150 cm and showing typical exponential frequency distributions. Assuming an average slip value of 1 cm, each of the three reactivated main joint systems may be able to produce cumulative shear displacements of $\sim$ 3 km at the pluton scale. Therefore, the reactivation of differently oriented sets of precursor joints allowed the granite to deform effectively by a form of ‘distributed shear’ involving relatively small displacements occurring over a very large number of primary fractures, which form a pervasive network. Although fluid-assisted strain localisation is fundamental at the meter scale, at the km (or pluton) scale strain can be considered as essentially distributed. Relatively small finite strains, integrated over the size of the pluton, may result in substantial amounts of crustal deformation.