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Abstracts of other papers presented at the conference on 'Multiple Deformation and Foliation Development'

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Problems in structural correlation from low to high metamorphic grade: examples from the Halls Creek Mobile Zone, East Kimberleys, and the Adelaide Fold Belt. R. Allen, Department of Geology and Mineralogy, The University of Adelaide, Adelaide, South Australia, Australia, 5000.

In the Halls Creek Mobile Zone, deposition, deformation and metamorphism occurred in the Proterozoic whereas orogenic activity in the Adelaide Fold Belt commenced in the Early Palaeozoic, although both fold belts have an initial history of Proterozoic rifting. In both, D_1 folds are the most obvious structural elements at low metamorphic grades. In areas of high-grade rocks, D_2 overprints D_1 and earlier structures and fabrics are difficult to identify. D_1 folds are inclined to recumbent, tight to isoclinal, with penetrative axial-plane slaty cleavage. A near-coaxial D_2 event modified these folds at high grade. In the Halls Creek Mobile Zone, additional crustal shortening produced 'pinched in' synclines, folds with tightly appressed limbs and a strong elongation lineation. In the Adelaide Fold Belt the major component of D_2 appears to be simple shear with little crustal shortening, producing discrete zones of D_2 crenulation, shallowing of D_1 fold limbs and transposition. However, while fold style can in places serve to discriminate between D_1 and D_2, the crucial observation needed is the sense of bedding/cleavage relationships around folds. This is critically dependent on the ability to distinguish S_1 from S_0 and S_2. This is a function of their relative development and retention (itself a function of lithology), fold geometry, and the nature of the layer-parallel fabric. Some lithologies are unsuitable (e.g. basalts and ignimbrites in the Kimberleys), and in others, prograde S_2 obliterates S_1 except in fold hinges and porphyroblasts. Thus, structural correlation from low to high grade in these two fold belts is generally problematical.

Structural geometry of the Chewings Range, Central Australia. C. Amri,* B. E. Hobbs,* C. K. Mawer,† C. Teyssier* and J. C. Wilkie,‡ *Department of Earth Sciences, Monash University, Clayton, Victoria, Australia, 3168, †Department of Geology, University of New Brunswick, Fredericton, New Brunswick, Canada, E3B 5A3, ‡Box 123, Gundaroo, New South Wales, Australia, 2620.

The igneous and metamorphic basement complex of the Western Arunta Block is overlain by a sequence of quartz-rich metasediments and thin intercalated basic and acid meta-volcanic horizons which form the Chewings Range layering, S_0. The first recognized deformation, D_{1-2}, is reponsible for a flat-lying composite foliation, S_{1-2}, axial plane to tight to isoclinal F_2 folds and containing a strong L_2 lineation which trends N–S. This lineation is of stretching origin and commonly lies at a small angle (0–45°) to F_2 fold hinges. D_{1-2} was associated with sillimanite-grade metamorphism. The D_3 deformation is characterized by a steep N-dipping axial-plane crenulation cleavage in the most schistose rocks. It is coeval with both prograde and retrograde assemblages. Large-scale F_2 and F_3 structures interfere, resulting locally in complex map patterns. Late-stage mylonite zones commonly occur at the contact between quartzites and surrounding gneisses.

A Fry-type analysis of the D_{1-2} deformation responsible for the strain recorded in the quartzites was used to determine the finite strain. The results indicated a range from constriction to flattening-type ellipsoids. Quartz commonly forms up to 100% of the Chewings Range quartzites and its microscopic substructures can be readily related to the macroscopic structural features. Crystallographic preferred orientations of quartz c-axes have been correlated with strain at a number of localities and appear to be consistent with predicted theoretical patterns. They show a girdle at a high angle to the linear fabric of the tectonites, with maxima regularly distributed; this suggests that in each grain one of the crystallographic planes became parallel to the foliation.

Foliation development in the Cannibal Creek Granite and its aureole: heterogeneous shortening around a ballooning diapir. R. Bateman, Department of Geology, James Cook University, Townsville, Queensland, Australia, 4811.

Several features indicate that the Cannibal Creek Granite was emplaced as a ballooning diapir: (1) its aureole was intensely deformed in an event, the effects of which die out within 5 km of the pluton; (2) the granitoid is less dense than the rocks of its aureole; (3) the aureole foliation is parallel to and continuous with the granitoid foliation, and forms closed, elliptical trend lines and (4) contact-metamorphic porphyroblasts grew synkinematically with regard to the aureole foliation.

The foliation in the granitoid is commonly formed by an alignment of microcline megacrysts and mica. In more gneissic rocks around the contact, feldspars have recrystallized and quartz forms intensely deformed ribbons. Where the granitoid foliation strikes obliquely to the contact, it is continuous with that of the aureole. This obliquity occurs where the contact is less regular in trend than the foliation on a scale of a few kilometres, and indicates that the rocks of the aureole and the pluton were rheologically similar during the deformation of the aureole.

The aureole foliation is penetrative within 500 m of the contact, and occurs further out as a crenulation cleavage, weakening outwards. 'Millipede' microstructures, the large-scale geometry of the aureole folds and foliation, and the absence of lineations in the foliation indicate that the deformation had a strain history of heterogeneous bulk shortening. There is no record of progressive bulk shear, indicating that this deformation took place by ballooning *in situ*, after the pluton had ascended to its present position. Kinking and stoping evidently preceded ballooning, and may have resulted from the ascent of the magma. The aureole deformation was followed by the injection of ring dykes and collapse of the central block.

Foliation development, porphyroblast nucleation and growth and deformation history. T. H. Bell, Department of Geology, James Cook University, Queensland, Australia, 4811, and P. D. Fleming, Department of Geology, La Trobe University, Bundoora, Victoria, Australia, 3083.

Syntectonic porphyroblast nucleation and growth is controlled by deformation partitioning on a microscopic scale. Dissolution occurs in operating zones of high shearing strain and some of this dissolved material transfers in solution to sites of low shearing strain where reaction, precipitation and replacement sometimes generates porphyroblastic minerals. Syntectonic porphyroblasts cannot grow across operating zones of high shearing strain. However, shifting patterns of deformation partitioning causes some formerly operative zones of high shearing strain to cease operating or become dominated by shortening

shortening strain alone; porphyroblasts can readily nucleate in and overgrow these sites. Therefore porphyroblasts commonly nucleate in crenulation hinges or any microlithon dominated by a shortening-strain history because these zones provide numerous microfracture sites and hence ready access to ions by fluid flow and diffusion. They also provide strain energy from within crenulated micas, the removal of which enables the nucleating porphyroblast to overcome its activation energy barrier.

Many if not all supposedly pre- and post-tectonic porphyroblasts in regional metamorphic rocks are possibly syntectonic. Strain distribution and partitioning is particularly inhomogeneous in the early and late stages of a deformation sequence. Consequently, zones of shear-dominated strain are widely and variably dispersed as the rock inhomogeneously begins to take up or lose the strain. Hence, porphyroblast growth both early and late during deformation will commonly occur in zones, which as a result of deformation partitioning, are undergoing very little or no strain. As a consequence porphyroblast growth will appear rapid relative to strain rate.

We suggest all porphyroblasts may be syntectonic including those associated with contact metamorphism. In the latter case the emplacement of a granite provides the source of fracturing and fluid access necessary for porphyroblast growth in such an environment.

Transposition and interference patterns in the Apuan Alps, Northern Apennines, Italy. M. Boccaletti,* S. Capitani,* M. Coli,* G. Fornace,† G. Gosso,† G. Grandini,* F. Milano,† G. Moratti,‡ P. Nafissi* and F. Sani,* * Department of Earth Science, University of Florence, 50121 Italy, † Geological Institute, University of Turin, 10123 Italy, ‡ Unit of Appennio Geology, University of Florence, 50121 Italy.

The Apuan Alps represent the main outcrop of metamorphic units in the Northern Apennines, Italy. They constitute the lowermost-known unit throughout the belt, cropping out in a tectonic window beneath three nappes on the inner side of the orogenic belt. During the Tertiary, the Apuan Unit was affected by the Northern Apennine orogeny. In recent years detailed structural field work has been carried out in northern areas in the Apuan Alps. The whole map area shows a remarkable consistency of structural data: an interference pattern results from the overprinting of three schistogenic and synmetamorphic fold generations, B_1, B_2 and B_3. B_1 and B_2 are isoclinal and transpositional and interfere at every scale, whereas B_3 is very gentle and does not significantly change the structural pattern defined by the overprint of B_2 on B_1. The oldest geometric elements of the tectonic fabric give rise to a new sequence, which has been successively deformed by the youngest fabric elements. During folding the Apuan Unit was affected by greenschist-facies metamorphism, an event whose relationship with the deformational history is explained here: the metamorphic grade was almost the same during B_1 and B_2, and decreased during B_3.

A microstructural and microchemical study of reticulate, spaced and slaty cleavage developed in rocks at Hallett Cove, South Australia. I. F. Clark and P. R. James, Department of Geology and Mineralogy, The University of Adelaide, Adelaide, South Australia, Australia, 5000.

The rocks of the Brachina Formation throughout the Adelaide Fold Belt show a variable development of cleavage. Fanned reticulate cleavage is developed at Hallet Cove in quartzite horizons and grades from a spaced cleavage to a slaty cleavage in purple siltstones. The cleavage is generally parallel to the axial plane of a major S-plunging fold. Minor folds on the limb of a major anticline are well exposed in both a cliff section and a wave-cut platform at Black Cliff.

A microstructural and microchemical study of selected specimens was carried out using an optical microscope, a scanning electron microscope and a microprobe chemical analyser. The topic of particular interest is the variation in cleavage development and spacing and its relationship to lithology, strain and position within larger-scale structures in the area.

Optical-microscope studies showed the layer-silicate minerals that were deposited parallel to sedimentary layering have been deformed by kinking. The axes of the kink bands are parallel to the direction of the cleavage. There is also evidence of stylolitic residues in zones parallel to the cleavage and in small rounded clumps. A microchemical study of selected specimens was carried out using a JEOL 733 microprobe. This made it possible to identify chemically distinct small zones displaying different structural features. It is also possible to analyse individual minerals in these fine-grained rocks and to analyse small zones within the kinked minerals. Combining data from individual mineral analyses of small zones makes it possible to calculate and compare mineral percentages for the different zones.

The structural evolution of a profile through the Narooma area, New South Wales, Australia. J. Cole, School of Earth Sciences, Macquarie University, North Ryde, New South Wales, Australia 2113.

Three sedimentary successions are present in the Narooma area on the South Coast of New South Wales. The lowermost, the Wagonga Beds, consisting of slate, chert, pillow lava and volcanic breccia, probably of Late Ordovician age, is conformably overlain by a deep-water quartzose greywacke-and-slate succession. Both of these are unconformably overlain by the Upper Devonian Merrimbula Group which is a dominantly fluvial unit, 1.5 km thick.

Three phases of deformation are recognised in both the Wagonga Beds and the greywacke-and-slate succession. Mesoscopic F_1 folds are tight to isoclinal, and upright to recumbent, in both the greywacke-and-slate succession and the Wagonga Beds. The F_1 folds have a northerly trend. In the greywacke-and-slate succession the S_1 axial-plane cleavage is a crenulation cleavage that becomes progressively more differentiated westward toward the Budawang Synclinorium. S_1 in the Wagonga Beds is a weak, axial-plane slaty cleavage. Mesoscopic F_2 folds are rare in the greywacke-and-slate succession in the east, but become more common towards the Budawang Synclinorium. Mesoscopic F_2 folds are very common in the Wagonga Beds. They generally plunge to the NNW congruent with the outcrop of the Wagonga Beds which defines a large macroscopic F_2 fold closure. D_3 involved N–S compression, which on the macroscopic scale resulted in a regional kink structure. On the mesoscopic scale, D_3 is represented by E–W trending folds and conjugate kinks, both of which possess an axial-plane crenulation cleavage. Both D_2 and D_3 post-dated the Upper Devonian Merrimbula Group with D_1 predating the intrusion of the Early Devonian Bodalla adamellite. The Budawang Synclinorium consists of two synclines and one anticline which have an open fold style and an axial-plane slaty cleavage in the pelites.

Deformation microfabric development in chalcopyrite in fault zones, Mt. Lyell, Tasmania. S. F. Cox, Department of Earth Sciences, Monash University, Clayton, Victoria, Australia, 3168, and M. A. Etheridge, Bureau of Mineral Resources, P.O. Box 378, Canberra, A.C.T., Australia, 2601.

Deformation of chalcopyrite ($CuFeS_2$) under low-grade metamorphic conditions within fault zones in the Mt. Lyell area of western Tasmania (Australia) has occurred dominantly by a dislocation flow process. Elongate grain fabrics and well-developed crystallographic preferred orientations have developed by $\{112\}\langle 1\bar{1}0\rangle/\langle \bar{2}01\rangle$ dislocation glide. However, the presence of recovered dislocation substructures indicates that dislocation climb has also been important.

At strains greater than about 30% shortening, strain-induced grain-boundary migration and deformation-band boundary migration is associated with the initial development of a dynamically recrystallized microstructure. However, subgrain rotation and subgrain coalescence mechanisms of recrystallization appear to have been important following the initial dynamic recrystallization of the original grain-boundary regions of host grains. In some cases significant grain growth by twin coalescence has followed new grain nucleation.

Deformation by $\{112\}$ twin glide, and, to a lesser extent, brittle failure mechanisms have been significant in some fault zones. The twin-glide formation mechanism is interpreted to have operated in a higher deviatoric stress environment and possibly lower-temperature regime than that in which dislocation glide and climb have been the dominant mechanisms. Brittle failure may have occurred in a still higher deviatoric stress regime, a lower-temperature regime, or perhaps by hydraulic fracturing during periods of locally high fluid pressure in the fault zones.