Excellent exposures along the Burdekin River and its tributaries provide special opportunities to detect controls upon the many styles and generations of veins of a major gold and mineral field. Well-defined unconformities help appreciation of the role of older structures in deducing tectonic chronologies from fabrics.

Reference exposures of Middle Devonian limestone between 'Fletcher View' and the Big Bend north of Charters Towers illustrate different types of en échelon vein arrangements and variations in the styles of veins of different ages and compositions. A sheet of limestone rests unconformably upon a pre-Devonian granodiorite basement dissected by older dykes, veins and a NW-trending foliation. Vein fabrics differ markedly from outcrop to outcrop. Patterns emerge in more extensive vein fabrics. These patterns indicate correspondence between younger vein fabrics and complex basement fabrics dominated by NW-trending foliation. A plot of en échelon vein directions reveals that those to the left of the foliation direction are dominantly sinistral and that those to the right are dominantly dextral. These relationships and a range of angular relationships point to a complex model for en échelon arrangements in which Riedel 1 and 2 fractures, as well as tensional fractures are influenced by older basement structures.

An early generation of limestone veins is darkened by inclusions of sulphuretted hydrocarbons. The terminations of these veins are distinctively 'horsetailed' unlike the simple terminations of later, white carbonate veins. A hypothesis for these style differences is that they are responses to changes in pore-fluid pressures and compositions.

Another reference area for veins lies along the Broken River, a tributary of the Burdekin River 150 km west of the Big Bend area. En échelon veins have formed in a quite different tectonic environment within a thick folded sequence of Silurian limestones. Stylolites indicate far greater volume changes than in the Big Bend reference area and also indicate systematic refraction of stress trajectories towards the normals to en échelon arrangements. Contrary refraction about conjugate en échelon arrangements is commonly sufficient to bring gash veins of one arrangement into close parallelism with the en échelon direction of a conjugate set.

Structural analysis of the Broken Hill Block. B. E. Hobbs* N. Archibald,* M. A. Etheridge† and V. J. Wall,* * Department of Earth Sciences, Monash University, Clayton, Victoria, Australia, 3168, † Bureau of Mineral Resources, P.O. Box 378, Canberra, A.C.T., Australia, 2601.

The aim of this paper is to discuss the philosophies involved in the interpretation of multiply deformed terrains with special emphasis, as an example, on the Broken Hill Block. A structural interpretation of the area is presented involving four periods of deformation each associated with the development of macroscopic folds. In addition, later structures associated with retrograde schist zones are developed. Earlier workers have used a classical (Weissian) approach employing mesoscopic fabric elements which have been assembled into a chronological scheme and then used to interpret the macroscopic structure. This led to a macroscopic picture of essentially upright folds superposed coaxially on earlier nappe-like folds. The present study employs the mapped outcrop patterns combined with the spatial distribution of structural facings to identify the macroscopic structure. A step is then made backwards in scale from the macroscopic to mesoscopic to discuss the significance of the mesoscopic fabric elements. On this basis, the regional structure consists essentially of early, inclined to recumbent folds with later upright folds superposed almost at right angles to the trend of the earlier axes. This leads not only to a difference in macroscopic structure between the two approaches but important differences in mesoscopic interpretations arise as well.

Multiple deformation in the Dales Gorge Member of the Lower Precambrian Hamersley Group, Western Australia. R. C. Horwitz, C.S.I.R.O., Division of Mineralogy, Floreat Park, Western Australia, Australia, 6014.

Analyses of structures in the Hamersley Province indicate the existence of several directions of folds and faults. The WNW-oriented Hamersley Synclinorium is parallel to smaller en échelon folds. A conspicuous E–W trend is outlined by axial culminations of anticlines and two complementary en échelon sets strike NE and NW.

Two complementary fault or joint systems, largely restricted to the Archaean group are known to have acted during the transgression of the Fortescue Group. One strikes E–W, the other is arcuate, striking generally N in the south and swinging to NNE in the north. Another set of complementary faults essentially frame the Province to the southwest and southeast; one swings from NW in the south to N in the west; the other strikes about NE.

Isopach maps, compiled for each of the alternating 33 macrobands of the Dales Gorge Member of the Brockman Iron Formation and for groupings of them, were analysed and are interpreted as interference patterns of multiple axes of thickening and thinning. Despite an apparent haphazard distribution of thicknesses in the successive macrobands, most thickness axes are only displaced in a minor way from one to the next. The trends of thickness parallel and follow the distributional biases of the WNW (regional fold) the E–W (fold and fault) and the N to NNE (fault in basement) structural trends. The distribution and dominance in BIF or S macrobands indicate that thickness variations in the Dales Gorge Member result from several features with a contribution from a form of compaction of slumping during sedimentation engendered by faults in the basement.

Tectonic evolution and fabric development of the Arunta Complex in the Harts Range, Central Australia. P. R. James, P. Ding, R. W. Lawrence, A. R. Martin, L. Rankin and G. P. Scales, Department of Geology and Mineralogy, The University of Adelaide, Adelaide, South Australia, Australia, 5000.

High-grade metamorphic rocks of the Arunta Block in the Harts Range Area have been divided into two major groups according to lithology and structure. An underlying crystalline basement has been recognized as having a more complex tectonothermal evolution than its structurally overlying supracrustal cover sequence. The basement is comprised predominantly of layered felsic and mafic gneisses which have a complex history of three isoclinal fold events, BD_1, BD_2 and BD_3, followed by tight inclined to upright folds (BD_4) trending in a NE direction. All folds deform a high-grade, layer-parallel fabric which is intensified by the folding. Included with the basement is the Entia gneiss complex (an inlier with the Entia Dome), the Oonagalabi gneiss complex (an isoclinal fold of remobilized basement represented by the Oonagalabi Tongue) and undifferentiated gneisses in the south of the area. Basement thrusts (BT) are confined to the western portion of the Oonagalabi Tongue.

Structurally overlying the basement are the cover rocks of the Irindina supracrustal assemblage (predominantly pelitic gneisses, but including calcareous rocks and quartzites) and of the Harts Range meta-igneous complex (predominantly mafic amphibolites, but including the Entia anorthosite). Both units are complexly folded by three isoclinal events CD_1, CD_2 and CD_3. A thrusting event CT, responsible for décollement surfaces along many of the lithological contacts within the cover sequence, occurred between the last two of these ductile events, and stacked the cover sequence into a series of nappes.

Basement and cover were juxtaposed by a major semi-ductile thrusting event, HRT_1, and then both cover and basement were isoclinally folded during HRD_1 at the commencement of the Harts Range orogenic event. Two thrusting events HRT_2 and HRT_3 were responsible for the tectonic emplacement of the megacrystic Bruna granitic gneiss, which now separates basement and cover throughout much of the Harts Range Area. HRT_2 was isoclinally folded during HRD_2 and HRT_3 during HRD_3. Subsequently the area was deformed by less intense open folds which resulted in the complex major basin-and-dome outcrop style.

Microstructures and sequence of deformation along the Norumbega Fault Zone, Eastern Maine, U.S.A. T. D. Johnson and D. R. Wones, Department of Geological Sciences, 4044 Derring Hall, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 24061, U.S.A.

The Norumbega Fault Zone, a NE-trending zone of ductile and brittle deformation (Devonian or younger), consists of about five distinct fault traces. All lines of evidence suggest dextral and south-up oblique shear in the major vertical NE-trending shears, with associated conjugate sinistral shears in some areas. The affected lithologies are phyllite, schist, felsic gneiss, felsic granite, mafic granite and syenite.

The style of deformation depends both on mineralogy and pre-shear fabric and on the apparent extent of shearing. In particular: phyllite and schist responded to the shear stress with asymmetric kink folds; gneiss, with proto- to ultramylonite development and fabric rotation; quartz-poor igneous rocks, cataclastically; and quartz-rich granite has a widespread flattening fabric locally overprinted by shear zones of proto- to ultramylonite, producing a *C–S* fabric, and in locations of intense shearing the ultramylonite was refolded as a layered rock.

Quartz, where present, absorbed most of the bulk strain by development of ribbon texture in the quartz-rich granites and gneiss, with feldspar deforming brittly. In the massive quartz-poor rocks there developed narrow zones of intense cataclasis in which all minerals underwent similar comminution followed by alteration; outside of these zones the feldspars experienced extensive intragranular deformation, primarily microcracking and subgrain development.

Why unconformity-related U deposits are unconformity-related. J. D. Johnston, V. J. Wall, 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.

Although unconformity-related U deposits constitute a significant portion of the world's economic uranium mineralization, the role of the unconformity, until now, has been little understood. High-grade uranium mineralization in the East Alligator River uranium field is localized in reverse faults and associated zones of kinking, chevron folding and brecciation in schistose basement. The reverse faults have non-planar geometries controlled by the mechanical anisotropy of the basement schists and their contrast with the unconformably overlying, gently dipping cover of massive quartz sandstones. Preferentially following schistose basement units, the faults transform along the unconformity forming flats, and ramp steeply through the overlying massive sandstone, forming discrete narrow zones within it.

Breccia zones, initiated by hydraulic fracturing, are best developed where faults are slightly oblique to the basement foliation and in kink hinges. Chloritic alteration is most strongly developed in such zones of brittle–ductile deformation. The vast mass-transfer required to effect this alteration illustrates the vast volumes of fluid focused through these zones and hence their structurally enhanced permeability. We present geometrical and mechanical models which explain these features.

The essential role of the unconformity results from the cover/basement rheology and permeability contrasts: (a) the former controls the geometry of fault zones and related dilatant regions which enhance permeability and provide space for mineral deposition and (b) fault-focused fluid migration patterns, developed on local and regional scales, reflect the diagenetically reduced permeability of the sandstone relative to that of the hydrofractured basement.

Concentric, ellipsoidal, compositional, shell (C.E.C.S.) development around nodules associated with solution transfer during crenulation-cleavage development. P. A. Jones, Department of Geology, James Cook University P.O., Queensland, Australia, 4811.

Two outcrops of the Robertson River formation, both within 10 m of mafic intrusions contain unusual nodules. These consist of a central pre-D_1 core surrounded by several syn-D_2 concentric, ellipsoidal, compositional shells (C.E.C.S.) of varying phyllosilicate content with an albite groundmass. During the D_2 crenulation-cleavage formation event, incremental effects of the deformation were preserved as shells of modified host rock by progressive albitization outwards from the rigid core.

In the ZY plane of the local strain ellipsoid, coaxial and noncoaxial C.E.C.S. were developed in hinge and limb regions of folds, respectively. The geometrical relationships of noncoaxial shells to other structures indicate that no rigid-body rotation occurred during their development and that the D_2 event involved progressive, bulk, inhomogeneous shortening. The shape and orientation of each successive C.E.C.S. was controlled by the perturbation in the strain field generated by the rigid nodule. With the development of each additional shell the orientation of the whole nodule became more coincident with the local strain ellipsoid.

The D_2 event appears to have been locally episodic and the strain rate and rate of solution transfer varied with the waxing and waning of each pulse, producing three distinct types of C.E.C.S. around a central core.

Slaty cleavage generation during deformation of synthetic mica-quartz rocks in a high pore-fluid pressure environment. P. G. Lennox, Department of Earth Sciences, Monash University, Clayton, Victoria, Australia, 3168.

Specimens consisting of synthetic mica and quartz have been shortened up to 60% in a Heard gas apparatus in the presence of high pore-fluid pressures at temperatures up to 550°C, fluid and confining pressures up to 300 MPa, and at strain rates of 10^{-4} to 10^{-5} sec^{-1}. These experiments provide constraints on the deformation mechanisms operative during the generation and modification of deformation microfabrics in low-grade metamorphic rocks.

Deformation mechanisms which are important in these experiments include oriented growth and grain-rotation mechanisms in micas plus solution transfer and quartz-grain translation processes. Synthetic phlogopite–quartz mixtures yield numerous deformation microfabrics similar to those observed in rocks from low-grade metamorphic terrains. Microstructures developed experimentally during the operation of these processes include well-developed slaty cleavage, kink bands in oriented micas, scalloped quartz grains, strain shadows, mica fringe structures and conjugate shear zones (generated at >50% shortening). Vug-filling fibrous micas form when the pore-fluid pressure exceeds the confining pressure.

Experiments are proceeding in a re-designed assembly which assists the permeation of water at high fluid pressures through specimens during their deformation. The aim of these new experiments is to generate deformation microfabrics similar to those observed in low-grade metamorphic terrains in which there was a high water–rock ratio during deformation.

The relation between quartz-vein geometry and folding in a low-grade flysch sequence, Cape Liptrap, Australia. P. G. Lennox, Department of Earth Sciences, Monash University, Clayton, Victoria, 3168.

The Fold Stack area at Cape Liptrap provides an excellent exposure of a quartz-veined, simple buckle-folded sequence of low-grade metamorphosed arenites and mudstones. The quartz veins formed dominantly in hydraulic extension fractures. The quartz veins, measured from the fold-defining one-metre-thick arenite beds, form sets of consistent orientation and dimension. These quartz veins define three major quartz-vein sets; oblique, subparallel or subnormal with respect to the fold axis. They are exposed in unique, overlapping sequential patterns which change around the fold-defining arenite bed and from inner to outer arcs of this bed.

The observed sequence of quartz-vein sets from the outer hinge zone blocks is generally consistent with the theoretical pattern of quartz-vein formation derived from the finite-element model of a buckling competent bed in a thick incompetent matrix. In contrast, the limb block theoretical and observed sequence of quartz-vein sets is not consistent with this model. Derivation of the minimum principal compressive stress path in the limb blocks from the sequence of quartz-vein sets does not accord with the theoretical predictions. Both these discrepancies, for the limb block reflect in part, the effect of the mechanical anisotropy of the arenite bed on the initiation/propagation of quartz veins, the complexity of the limb-block stress history or other unknown factors.

Comparison of the observed sequence of quartz-vein sets with a simplified four-stage model of a stress-field changes during folding indicates that sets must have formed at discrete overlapping intervals within the fold-forming deformation and that some quartz-vein sets must have formed during shear failure.

Implications of the low-angle normal (evolving) crustal shear-zone model for metamorphic core complexes of Cordilleran type, and the origin of the 'accretionary wedge' of the Hellenic arc. G. S. Lister, Bureau of Mineral Resources, P.O. Box 378, Canberra, A.C.T., Australia, 2601.