Journal of Structural Geology, Vol. 4, No. 2, pp. 231 to 235, 1982.
Printed in Great Britain

0191-8141/82/020231-05 $03.00/0
Pergamon Press Ltd.

Report on the inaugural meeting of the Canadian Tectonics Group held on 16–18 October 1981 at the University of New Brunswick, Fredericton

PAUL F. WILLIAMS

Department of Geology, University of New Brunswick, Fredericton, New Brunswick, Canada E3B 5A3

(*Received and accepted* 17 *December* 1981)

THE FIRST meeting of the newly formed Tectonics Group was held at the University of New Brunswick at Fredericton on 16–18 October 1981. This informal group is the outcome of a specialist section of a workshop held in Ottawa in January 1981. The Ottawa workshop was organized by Drs W. S. Fyfe and B. R. Rust under the auspices of the Council of Chairman of Canadian Earth Science Departments for the purpose of planning the next decade of research in Canadian Earth Sciences.

This initial meeting was intentionally kept small and all participants were required to read a paper or present a poster. Nineteen papers and five posters were presented by researchers from as far afield as Newfoundland and Alberta and the standard was excellent.

The meeting had no special theme other than rock deformation but the papers presented fell into four natural groups so that sessions were held on Precambrian, Appalachian and Cordilleran Provinces and on fundamental aspects of rock deformation.

On the second full day of the meeting (18 October) a field trip was lead to the southwest coast of New Brunswick by Dr Peter Stringer. Structures attributed to Taconic, Acadian, Variscan and Palisades deformational episodes were visited.

The Canadian Tectonics Group plans to meet on an annual basis with all participants contributing either a paper or a poster. The next meeting is being organized by the University of Toronto for the fall of 1982.

ABSTRACTS OF PAPERS PRESENTED

Particulate flow, folds, cleavage and magnetic fabrics. Graham J. Borradaile, Department of Geology, Lakehead University, Thunder Bay, Ontario, Canada P7B 5E1.

Particulate flow (p.f.) is the rearrangement of grain centres in a rock during deformation. The rearrangement may occur independently of grain deformation (independent p.f.), rate-controlled by grain deformation (controlled p.f.) or it may be restricted to the minimal readjustments of grain position required by incompatible grain deformation (dependent p.f.).

The influence of fluids (fluid pressure, and Rehbinder effect) may enhance the role of particulate flow beyond that required by incompatible grain deformation. During non-coaxial strain histories this can explain transected folds and non-XY, primary cleavage. Application to work on magnetic susceptibility anistropy (m.s.a.) shows that only a penetrative particulate flow ('March model' in terms of grain alignment) produces a m.s.a. ellipsoid congruent with a strain ellipsoid. Where pressure solution is dominant the m.s.a. ellipsoid may not be directly related to bulk strain.

Thrust-faults in Mesozoic strata of the Rocky Mountain Foothills at latitude 53°N. H. A. K. Charlesworth and L. G. Gagnon, Department of Geology, University of Alberta, Edmonton, Alberta, Canada T6G 2E3.

The clastic-wedge sequence in the Rocky Mountain Foothills southwest of Edmonton is divisible into Lower and Upper Molasse Units separated by a marine Shale Unit. During orogenesis the sequence deformed mainly by movement along thrust-faults.

Most thrust-faults in the Lower Molasse Unit cut up section to the NE at angles averaging less than 5°, although flats and ramps where they are parallel and oblique to bedding in the footwall are present. Bending folds in the hanging walls of faults with flats and ramps, although gentle to begin with, may subsequently be tightened. Thrust-faults in the Lower Molasse Unit in the inner Foothills flatten upwards and merge to form a detachment zone at the base of the Shale Unit. This detachment zone with over 15 km of displacement extends northeastwards into the middle Foothills where it gives rise to splays cutting up at low angles through the remainder of the Shale Unit and the overlying Upper Molasse Unit. The detachment zone and associated thrust faults are cut by younger, more steeply dipping thrust-faults.

Thrust-faults in the Upper Molasse Unit of the outer Foothills form flats 10 km or more wide. The duplexes which overlie these flats are commonly located in coal seams, each floor and roof thrust coinciding with the base and roof of a seam, and seam thicknesses up to 15 times normal have been recorded. Duplexes are cut by thrust-faults that cut up section to the NE and SW and in places end along strike against tear faults with displacements of 10 km or more. The thrust-faults cutting up section to the SW, dip under the SW-limb of the Alberta Syncline and are the youngest structures present.

Grenville L–S *tectonites, Bancroft, Ontario: petrofabrics and tectonics.* N. G. Culshaw, Department of Geology, University of Ottawa, Ottawa, Ontario, Canada K1N 6N5.

A moderately SE-plunging L–S fabric, similar to that found in many localities in the western Grenville Province, is a fundamental feature of the structural pattern of an amphibolite-facies gneiss complex which straddles the northern boundary of the western end of the Central Metasedimentary Belt of the Grenville Province. Domal plutonic bodies are overturned to the NW such that basement gneiss overlies its cover. A locally NW-directed ductile thrusting is suggested.

Quartz microstructures and c-axis fabrics show a two-stage history. In the first, most widespread, stage exaggerated grain-growth occurred in quartzites and polycrystalline quartz ribbons developed in granite gneiss. The ribbons are made up of unequal proportions of equidimensional and elongate grains which are preferentially sampled, respectively, in the XZ and YZ planes. Characteristic c-axis fabrics are found for each sample plane: girdles perpendicular to the lineation with Y maxima for YZ samples and more diffuse patterns, tending to cross girdles with wide opening angles for the XZ samples. A synoptic diagram of 3% contours from 9 specimens sampled in the XZ plane shows a NW-leaning girdle interpreted as reflecting NW-directed ductile shearing.

Second-stage finer grained microstructures locally destroy those of the first stage in planar concordant zones approximately 2 cm to 50 m wide. The asymmetric microstructure indicates that the shear sense was precisely reversed from the first stage. Sharp c-axis girdles are perpendicular to the shear direction and inclined to the second foliation.

The two-stage microstructural history is interpreted as resulting from a single kinematic episode during which there was a switch, possibly temperature controlled, from penetrative to locally concentrated deformation with shear opposite to, but compatible with, the regional shear sense, in a manner analogous to the shear between individual volumes in a sheared row of books.

Puzzling arrangements of structures in sediments of the Slave Province. W. K. Fyson, Department of Geology, University of Ottawa, Ottawa, Ontario, Canada K1N 6N5.

Supracrustal terrains bordered by granitoid rocks in the Slave Province are commonly rectilinear and angular, the outlines possibly reflecting graben-like sites of sedimentation and marginal volcanism. With respect to this setting, folds and foliations in the sedimentary rocks form two groups: conformable structures (group A), readily related in development to the suggested graben, and cross structures (group B) which are not readily related. Group A include tight folds and several sets of later cleavages with traces in some areas oblique to marginal plutons, but overall near parallel to axes of the proposed graben. Group A folds in the southern part of the province dominantly verge westward, an arrangement consistent with deformation during westward tilting of down-faulted crustal blocks. Group B include folds and cleavages of similar morphology to group A, but aligned across graben terrains at high angles to the margins.

Structures sequentially alternate in orientation between the A and B groupings. For example, in the best known terrain near Yellowknife, major cross-synclines and subsidiary folds (B) were succeeded by approximately conformable folds (A), the resultant pattern of trend lines forming map-scape 'refolds'. The fold pattern was cross-cut by early-phase foliations (B), then conformable cleavages (A), which on average lie axial planar to the previously developed 'refolds'.

The puzzle is to find a mechanism that plausibly explains the spatial and temporal arrangements of the conformable and cross-structures.

Microstructure and geochemistry of plagioclase and microcline in naturally deformed granite. Simon Hanmer, Department of Geology, Carleton University, Ottawa, Ontario, Canada K1S 5B6.

Naturally deformed feldspars from foliated granites in a shear zone in Newfoundland exhibit transitional brittle–ductile behaviour. Brittle failure is subordinate to dynamic recrystallization, microcracking, strain-enhanced diffusion and reaction-enhanced ductility during the deformation. Both plagioclase (An_{28}) and K-feldspar are transformed to albite with increasing strain. Interaction of metamorphic and structural processes at the grain scale is emphasised. This is illustrated with examples of quartz-filled veins (segregation bands) in plagioclase and recrystallized polycrystalline aggregates in plagioclase and K-feldspar. The role of microcracking in plagioclase and of pre-existing internal growth structures in the formation of initially coarse grained recrystallized aggregates from large single crystals is suggested.

Kinematic interpretation of sheath-fold nappes in the Hudsonian Orogen of northeast Canada (poster). J. R. Henderson, Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, Canada K1A 0E8.

In southern Melville Peninsula the first-order structures are fold and thrust nappes which are revealed within extensive areas containing an Archaean-on-Aphebian sequence. An Upper Nappe of Archaean basement gneisses apparently covered most of the Aphebian supracrustal gneisses exposed in the NE–SW striking Foxe Fold Belt. Isoclinal sheath folds have been documented at many scales, and their stretching axes (X-axes) are oriented parallel to the strike of the fold belt. A late-stage mineral stretching lineation defined mainly by aligned scapolite porphyroblasts in calcite marbles also is aligned parallel to the strike of the belt. The flattening plane of the sheath folds (XY-plane) is mainly horizontal, but broad warps about NE–SW axes in the eastern Melville Peninsula reveal an asymmetry of macroscopic sheath folds in the XZ-plane, indicating that the Upper Nappe moved southwestwards relative to the underlying rocks. A sheaf-like convergence of folds (syntaxis) at the southwest end of the Foxe Fold Belt is due to a progressive convergence of the extension axes in the direction of displacement of the Upper Nappe. The penetrative movements were complete before the rocks were annealed 1804 ± 16 Ma ago under amphibolite facies conditions.

Regional asymmetrical folding in Ordovician and Silurian rocks of northeastern Newfoundland. K. E. Karlstrom, B. A. van der Pluijm and P. F. Williams, Department of Geology, University of New Brunswick, Fredericton, New Brunswick, Canada E3B 5A3.

Structural studies in Ordovician and Silurian rocks in northeastern Newfoundland define regional-scale, open to isoclinal, asymmetrical folds (F_2) with axial surfaces which dip 30–85° southeast. Regional NE-trending penetrative cleavage (S_2) is axial planar to these folds. Structural profiles show a change of asymmetry of upward facing F_2 macroscopic folds between southern New World Island and the Port Albert Peninsula indicating a NE-trending F_2 anticlinorium more than 30 km wide cored by the Dunnage Melange. A 50-km wide synclinorium immediately to the southeast, cored by Silurian sandstones on the Port Albert Peninsula, is indicated by repetition of stratigraphy and change of asymmetry.

F_2 folds overprint earlier F_1 folds producing type II and III interference patterns (Ramsay 1967). This, combined with the sub-horizontal enveloping surface of F_2 folds, suggests that F_1 folds had gently-dipping axial surfaces. Localization of F_1 folds along the contact between marine turbidites of the Change Islands Formation and subaerial volcanics of the North End Formation suggests F_1 may have been related to thrust faulting. F_2 folds are overprinted by F_3 chevron folds, box folds, and kink bands, and local S_3 crenulation cleavage.

Contrary to prevailing interpretations of a structural setting involving fault-bounded tectonostratigraphic zones in eastern Notre Dame Bay (Williams *et al.* 1972, Kay 1976, McKerrow & Cocks 1977), we emphasize F_2 asymmetric folds as the dominant structural features in the northeastern Dunnage Zone. We conclude: (1) the Reach Fault is a post-F_2 high-angle fault which does not separate different structural sequences; (2) the Indian Islands fault (Eastler 1971, Williams 1964) marks a zone of intense F_2 folding, not a fault boundary between the Botwood and Indian Islands Groups (which we equate in part) and (3) F_1, F_2, and F_3 all post-date deposition of Silurian rocks and we see no direct evidence for penetrative Ordovician (Taconic) deformation.

Tectonic significance of Tibbit Hill Volcanics. P. S. Kumarapeli, Geology Department, Concordia University, Montreal, Canada H3G 1M8.

Late Precambrian/Early Cambrian volcanic sequences such as the Catoctin lavas of central Virginia and southern Pennsylvania and the Light House Cove formation of Western Newfoundland are generally regarded as rift volcanics related to continental separation which led to the formation of Iapetus and eventually the Appalachian fold-belt. This idea is based on their setting in the overall Appalachian tectonic/stratigraphic picture and on their petrochemistry. Another volcanic unit which has similar tectonic and stratigraphic relations is the Tibbit Hill formation in the Sutton Mountains region of Quebec and Vermont. Analysis of gravity and magnetic anomalies in the Sutton Mountains region shows that this seemingly-minor belt of volcanic rocks constitutes the surface expression of a thick (maximum thickness about 8 km) pile of dominantly-mafic volcanics which is only slightly exposed at the present level of erosion (Kumarapeli *et al.* 1981).

Any model incorporating the tectonic significance of the Tibbit Hill Volcanics must provide a coherent rationale for the following aspects of the volcanics: (i) the Oak Hill sequence whose basal unit comprises the Tibbit Hill Volcanics has the petrotectonic character of a rift facies assemblage, which accumulated on the late Precambrian–Early Cambrian continental margin of ancient North America; (ii) the presence of minor amounts of rhyolite suggests that the Tibbit Hill volcanics are bimodal and are probably rift-related; (iii) the boomerang-shaped mass of Tibbit Hill Volcanics occurs in the apical area of the Sutton Mountains salient and has a symmetrical disposition with respect to the apex of the salient; (iv) the Ottawa graben, whose initial development probably took place in late Precambrian to Early Cambrian times, if projected eastwards will meet the 'boomerang' as its apex and (v) the Grenville dike swarm (tholeiitic diabase) of possible late Precambrian age also, if projected eastwards, appears to converge on the apex of the boomerang.

A model consistent with the above aspects is that the Tibbit Hill Volcanics formed at an *rrr* triple junction. Two arms of this triple junction went through a Wilson cycle whereas the other arm continued as an aulacogen which is the Ottawa graben.

Deformation behaviour of two Grenville gneisses. C. K. Mawer, Department of Geology, University of Toronto, Toronto, Ontario, Canada M5S 1A1.

Two suites of gneisses from outcrops in the Grenville Structural Province of central Ontario have been studied, with the object of determining their deformational behaviour during mylonitization. The suites comprise specimens of anorthositic gabbro and gneiss of approximately granodiorite composition.

The anorthositic gabbro is composed of approximately 75% plagioclase (An_{55-65}), 20% clinopyroxene and amphibole, and minor amounts of biotite, orthopyroxene and oxides. The samples exhibit a continuum of foliation development and deformation from undeformed rock with primary igneous textures, through foliated rock enclosing pods of essentially undeformed rock to foliated rock which may be folded (sheath folds). The most obvious textural changes in the samples during this progression are a decrease in grain size of all minerals and an increase in perfection of the foliation. Chemical changes (if any) have not as yet been determined.

The granodioritic gneiss is composed of approximately 40% plagioclase (An_{35-40}), 25% quartz, 15% amphibole, 10% K-feldspar, 5% biotite, and minor amounts of clinopyroxene, garnet, sphene and oxides. The samples again show a continuum of foliation development and deformation from weakly-foliated rock, through well-foliated rock with feldspar 'porphyroblasts' to very well foliated rock. The observed textural changes are similar to the anorthositic gabbro.

The deformation behaviour in both suites of gneisses is determined by ductile mechanisms, and dynamic recovery and dynamic recrystallization are ubiquitous. In the granodioritic gneiss, brittle behaviour is observed in the feldspar and garnet grains; no evidence for brittle behaviour is observed in the anorthositic gabbro. The end products in both cases are totally recrystallized, and the granodioritic gneiss at this stage may have deformed in a superplastic manner. The difference in deformation behaviour between the two rock types is due to presence or absence of quartz.

Deformation maps in grain size–stress space and their use in the study of high p,T rock deformation. G. Ranalli, Department of Geology, Carleton University, Ottawa, Ontario, Canada K1S 5B6.

The creep properties of polycrystals depend on several variables, prominent among which are stress, temperature, pressure, and grain size. Even when the pressure effect is incorporated into the temperature effect, the study of the relative importance of different flow mechanisms under various conditions must deal with at least three variables, namely, stress, grain size, and temperature. It is of course possible to construct three-dimensional 'deformation spaces' in which the boundaries between creep mechanisms are surfaces; however, since the representation of such surfaces is not immediate, it is usually preferred to construct 'deformation maps', that is two-dimensional sections in deformation space, with one variable taken as constant. Most commonly, stress and temperature are chosen as coordinates, with a fixed grain size.

An alternative choice, that of taking stress and grain size as coordinates, with fixed temperature, has not found widespread use thus far: it has, however, considerable advantages over stress–temperature maps. For the rather large class of rheological laws in which the strain rate can be expressed in terms of a stress-independent diffusion coefficient, and of a power dependence (which may be zero) on grain size and stress, the features of these maps are remarkably simple. Under rather general assumptions, creep field boundaries, constant strain rate, and constant viscosity contours are straight lines on log–log coordinates, with slopes depending only on the stress- and grain size-exponent in the creep law, and not on the particular temperature for which the map is constructed. When the three most common flow mechanisms are considered (Nabarro–Herring, Coble and power-law creep), the position of the 'triple point' at which the boundaries meet in stress–grain size space is a very simple function of temperature. This makes it possible to project on a single map data for various temperatures: the coordinates of the triple point contain all the necessary information for a synoptic representation of the rheology under different temperature (and pressure) conditions.

Examples of deformation maps in stress–grain size space are given for olivine under laboratory and upper mantle conditions. The maps reproduce well the commonly inferred strain rates and viscosities, and allow prediction of the transition stress (a function of grain size) below which diffusion creep should be observed in the laboratory. Accepting the current estimates for the grain sizes and stresses in the upper mantle and in lithospheric shear zones, it is found that the upper mantle should flow by power-law creep unless the grain size is less than a few tens of microns, whereas shear zones are likely to flow by Coble creep, possibly enhanced by superplasticity.

The influence of deforming stress on diagenetic and metamorphic reactions and on partial melting. Pierre-Yves F. Robin, J. Tuzo Wilson Research Laboratories, Erindale Campus, University of Toronto, Mississauga, Ontario, Canada L5L 1C6.

Finding out the thermodynamic driving force for reactions in systems under stress requires a specific study of its 'reaction type'. A 'reaction type' is characterized by a sufficient description of the states of all product and reactant phases involved in the reaction. Such description, in turn implies definite knowledge or assumptions concerning the possible transfers of chemical components between sites within the system. Among the reaction types examined are: (i) migration and equilibrium of coherent interfaces within stressed crystals; (ii) pressure solution (which is the simplest case of an incoherent reaction); (iii) 'no evasion' reactions, in which the products grow between parallel interfaces of their source reactants, without bulk movement of any chemical component, parallel to the interface; (iv) 'fluid invasion/evasion' reactions, where only one volatile chemical component, having its chemical potential set by the existence of a free fluid phase, can migrate toward/away from the reaction interfaces while the other components cannot migrate; (v) 'evasion reactions', in which the reactants are consumed along an interface at a given pressure, and products grow along interfaces at different (presumably lower) pressure and (vi) partial melting within rocks under homogeneous stress, with magma forming or collecting in fissures (or dykes) perpendicular to the least compressive stress. In each case the thermodynamic driving force for the reaction is given by a definite expression. However, for a given rock, under a given applied stress, such driving force has no unique value because of variations in orientation of the reaction interfaces with respect to the applied stress. The recognition of the appropriate 'reaction type' in any particular situation should require careful petrographic work.

Strain patterns of oval gneiss domains in the Superior and Grenville Provinces of Ontario. W. M. Schwerdtner, Department of Geology, University of Toronto, Toronto, Ontario, Canada M5S 1A1.

In the peneplain terrain of the southern Canadian Shield, gneiss domes are usually identified by means of outward-dipping strain fabrics at the horizontal contact between the oval granitoid cores and their supracrustal envelopes. Using this criterion alone, it becomes difficult to discriminate between (1) mushroom-shaped antiforms exposed at their overhanging contact, and (2) circular synforms cored by an overthrust slice of basement gneiss. Many oval gneiss domains exhibit inward-dipping fabrics along part of their contact, and cannot be readily interpreted. The problem may be overcome by means of way-up determinations in the supracrustal rocks, provided the structure of the envelope is relatively simple.

Deformation patterns observed in the granitoid cores of several Archaean and Proterozoic structures indicate that a significant component of the total strain predates the doming (either horizontal cross folding or single-order diapirism). In analogy with typical salt stocks, the patterns of total strain and superimposed deformation can be explained by multi-order diapirism. Accordingly, parasitic gneiss domes would emerge with some delay from initial diapiric ridges thereby leading to a superposition of large finite strains in the granitoid gneiss. More complicated scenarios involving several tectonic episodes and different structural mechanisms cannot be ruled out.

F_1, F_2, F_3 *and all that; an upward and outward progression in the Columbian Orogen.* P. Simony, Department of Geology, University of Calgary, Calgary, Alberta, Canada T2P 1N4.

Detailed structural investigations in the western Rocky Mountains and the adjacent northern Purcell, Selkirk and Monashee Mountains between latitude 51° north have demonstrated three distinct and widespread deformation episodes, in the inner tectonic zones of the Columbian Orogen. In a first phase of deformation, F_1, two or three southwest-verging fold nappes were formed with limb lengths of the order of 50 km. This deformation, restricted to the western side of the belt, involved the Proterozoic and lower Palaeozoic continental terrace wedge as well as the upper two kilometres or so of the gneissic basement. The stack of F_1 nappes constitutes a lower tectonic level. The second episode of deformation, F_2, formed a compound fan structure with southwest-verging folds and thrusts on the southwest side and northeast-verging folds and thrusts on the northeast side. Tight and complex F_2 folds formed at depth while upright open folds formed at higher tectonic levels in association with thrust faults. F_2 refolded the earlier formed nappe stack but it also extended northeastward, beyond the zone deformed in F_1, into the west flank of the Rocky Mountains. It is outlasted by the major late Jurassic metamorphic episode of the Columbian Orogeny. The third phase of deformation, F_3, postdates the metamorphism and is marked by major buckle folds and associated thrust faults in the western half of the Rocky Mountains and a narrow belt west of the Rocky Mountains where phase 2 folds are refolded. The polydeformed edifice formed by F_1, F_2 and F_3 was passively transported northeastward during the thin-skinned deformation of the eastern Rocky Mountains thrust and fold belt on an array of thrusts which merge with a basal detachment that must extend under the polydeformed edifice. No doubt each phase was diachronous across the wide belt it affected but the arrangement of phases is not chaotic. Instead we see a systematic progression in space and time of discrete pulses, with deformation beginning at depth in the western part of the core zone and systematically progressing eastward (outward) and upward.

On the calculation of pole figures, inverse pole figures and the crystal orientation matrix directly from measured orientation data. J. Starkey, Department of Geology, University of Western Ontario, London, Ontario, Canada N6A 3B7.

Measured pole figures can be used directly to calculate pole figures, inverse pole figures and the crystal orientation matrix; this latter is a frequency distribution of the Euler rotations which relate the crystal orientations in a polycrystalline aggregate to a standard crystallographic orientation. When the data from measured pole figures of crystal forms with different crystallographic multiplicities are to be combined or compared, they must be modified by the appropriate crystallographic multiplicity factor.

To calculate pole figures, the normal to the face for which the orientation pattern is to be predicted is located sequentially at each node of a 51 × 51 grid representing a Lambert equal area projection of the upper reference hemisphere. The corresponding positions of the measured crystal forms on the projection are calculated for incremental rotations around the face normal. For each crystal orientation thus defined, the concentrations of poles at the calculated positions in the appropriate measured pole figures are compared and the minimum is selected. The minimum concentration represents the maximum concentration of crystals consistent with that particular orientation. These minima are summed in the matrix element corresponding to the position of the normal to the face being predicted. The data of the predicted matrix are normalized and expressed as an orientation diagram contoured in multiples of a uniform distribution.

Inverse pole figures are calculated by deriving profiles which represent the concentration of poles in the measured pole figures as a function of the angular distance from the specimen direction for which the inverse pole figure is being prepared. The appropriate frequency profile is rotated around the position of each face normal of the measured crystal forms and the frequency data are summed into matrices corresponding to each form. The final matrix, representing the inverse pole figure, is obtained by multiplying together the matrices corresponding to each form, element by element.

The crystal orientation matrix is calculated in a manner analogous to that used to predict pole figures. The locations of the measured crystal faces on the surface of the reference sphere are calculated, the three Euler rotations are applied to them incrementally and the rotated positions are projected onto the appropriate measured pole figure. The minimum concentration at these projected positions is located. This represents the maximum concentration of crystals consistent with this orientation. These minima are stored in a three-dimensional matrix with orthogonal axes corresponding to the three Euler angles. The data in the matrix are normalized and expressed in multiples of a uniform distribution. Sections are drawn through the matrix to illustrate the fabric.

The orientation diagrams obtained using these techniques have been compared with orientation diagrams derived via the orientation distribution function. For the purposes of these comparisons computer-generated fabrics were used so that the actual crystal orientations were precisely defined. The data derived directly from the measured pole figures more closely represent the actual data. In the case of inverse pole figures the procedures based on the orientation distribution function yield results which are of doubtful geological significance because they relate the specimen directions to a specific crystal direction instead of to a set of crystallographically equivalent directions.

The Wathaman batholith and closure of the Aphebian ocean in northern Saskatchewan. Mel R. Stauffer, Department of Geology, University of Saskatchewan, Saskatoon, Saskatchewan, Canada S7N 0W0.

The south-central Churchill Province of the Canadian Shield in Saskatchewan and Manitoba contains a 450 × 900 km, NE–SW trending, belt of Aphebian meta-supracrustal and batholithic rocks that may represent the evolution of an Aphebian ocean from an early opening stage on through to its final orogenic closure.

At least two volcanic island-arcs are represented by thick sequences of mafic volcanic rocks in the Flin Flon and Western La Ronge domains. These and other parts of the area, notably the Kisseynew domain, contain metasedimentary rocks, most of which probably represent back-arc, fore-arc, and inter-arc clastic sedimentation though some are synorogenic molasse deposits. These are metamorphosed to various degrees from lower-greenschist facies in the southeast to amphibolite grade in the northwest, and have undergone polyphase deformation.

A wide range of plutonic rocks intrude all types of supracrustal rocks, though synorogenic (Hudsonian orogeny) grandiorite to granite is the most common, occurring in numerous batholithic to sub-batholithic bodies, the largest of which is the Wathaman batholith.

The Wathaman batholith runs along the northwestern margin of the area discussed and is approximately 50 × 900 km, though it varies markedly in width, making it one of the largest batholiths in the world. It is rather remarkable in having a fairly consistent composition throughout though it does vary locally (and irregularly) between quartz-monzodiorite and granite. Most outcrops contain numerous K-feldspar megacrysts, some of which may be phenocrysts but others of which are late-tectonic porphyroblasts. The former are highly deformed in many places along the borders of the pluton, whereas the latter are larger and little deformed.

Several major mylonite zones up to 5 × 400 km run NE–SW through the northwestern part of the area, cutting many of the rock types, but generally they are roughly parallel to the overall structural grain.

Deformation of Ordovician and Silurian rocks at Oak Bay and Cookson Island, St. Stephen, New Brunswick. P. Stringer, Department of Geology, University of New Brunswick, Fredericton, New Brunswick, Canada E3B 5A3 and G. E. Pajari, Jr., Pajari Instruments, 1 Shouldice Court, Willowdale, Ontario, Canada M2L 2S3.

Penetrative deformation of Ordovician rocks in southwestern New Brunswick has been ascribed to the combined effects of the Taconic (Ordovician) and Acadian (Devonian) orogenies (e.g. Cumming 1966), or solely to the Acadian orogeny (e.g. Ruitenberg 1967, Brown & Helmstaedt 1970), with the Ordovician/Silurian hiatus interpreted accordingly as an angular unconformity or a disconformity. Our preliminary investigation in the Oak Bay area indicates that the deformation of the Ordovician rocks occurred during both orogenies; similar deformation is shown by probable Ordovician rocks on Grand Manan Island 60 km southeast of Oak Bay (Stringer & Pajari 1981).

In Lower Ordovician pelites of the Cookson Formation at Oak Bay and on Cookson Island, subvertical N- to NW-trending S_1 foliation and intrafolial F_1 minor folds are deformed by subparallel S_2, gently-dipping S_3 and subvertical E-trending S_4 crenulation cleavages and associated F_2–F_4 minor folds. S_1 is a strong alignment of fine-grained phyllosilicates and elongate quartz grains mostly parallel to bedding, and displays compositional layering up to 5 mm in width oblique to bedding in F_1 folds.

In a *c.* 3000 m-thick homoclinal sequence of Upper Silurian fine-grained greywacke sandstones, siltstones and mudstones of the Waweig Formation, dipping 50–75°SE at Oak Bay and on Cookson Island, a single subvertical NE-trending cleavage persistently strikes slightly clockwise of bedding. Minor folds are restricted to a small area at the southeast end of Cookson Island. The cleavage is a weak to moderate alignment of very fine-grained phyllosilicates and elongate quartz grains oblique to bedding. Sporadic retrograde cordierite(?) spots elongate parallel to both cleavage and bedding, fine-grained biotite laths parallel to the cleavage and incipient alignment of phyllosilicates parallel to bedding are interpreted as post-tectonic mimetic recrystallization related to Devonian intrusions.

The contact between the Cookson Formation and massive conglomerates of the Oak Bay Formation which conformably underlie the Waweig Formation on Cookson Island, although sheared and faulted, appears in part to be an original erosion surface at which S_1 foliation in the Cookson Formation is truncated. A weak subvertical NE-trending cleavage in unfolded mudstone beds dipping 65°SE near the base of the Oak Bay Formation is coplanar with a crenulation cleavage associated with tight upright SW-plunging folds which overprint the S_1 foliation and F_2 minor folds within the Cookson Formation for 100 m northwest of the contact with the conglomerate.

Structural analysis of Ordovician and Silurian rocks of New World Island, NE Newfoundland. Ben van der Pluijm, Geology Department, University of New Brunswick, Fredericton, New Brunswick, Canada E3B 5A3.

Structural mapping on New World Island, northeast Newfoundland, shows three generations of folding. The first generation folds are tight to isoclinal and are assumed originally to have had gently dipping axial planes. Second generation folds are large and asymmetrical and have an axial plane cleavage (S_2) which is the dominant cleavage throughout the area. The third generation folds are fault-related and locally develop an axial plane cleavage (S_3). All recognized faulting is post-F_2 and master joints are very well developed. Evidence for presently proposed tectonostratigraphic zones (Kay 1976) is questionable and the proposed (McKerrow & Cocks 1978, 1981) homoclinal, north-younging succession on New World Island is incorrect.

An investigation of the deformation and metamorphism of the Tetagouche Group (Ordovician) rocks in a zone between Brunswick No. 12 and Austin Brook Open Pit (Map 1); (poster). Cees van Staal, Department of Geology, University of New Brunswick, Fredericton, New Brunswick, Canada E3B 5A3.

The dominant macrostructures in the area of investigation are: (1) an isoclinal anticlinorium, namely the Brunswick anticline, in the southern part of the area; and (2) a broad, S-shaped, flexure between Brunswick No. 12 and No. 6 mine (Map 1). Economically important massive sulphide deposits are closely related to macroscopic folds.

The research has been limited so far to structural fieldwork on the surface around Brunswick No. 6 mine and Austin Brook open pit and underground work in Brunswick No. 12 mine. Four generations of folds have been demonstrated.

The first generation folds have a roughly N–S trend, are tight to isoclinal, and are responsible for transposition of bedding. The plunges of F_1 fold axes vary from almost horizontal to moderately steep (40–50°), both in a northerly or southerly direction, which together with other field observations and diamond drill-hole data points to double-plunging macroscopic F_1 folds.

F_2 is characterized by N–S trending, tight, asymmetrical, Z-shaped folds plunging steeply to the SW in the Brunswick No. 6 mine. S_2 overprints S_1 and is 'refracted' as it crosses S_1 in such a way that it appears to be folded with S_1 as axial plane foliation. Previous workers have interpreted S_2 as the older foliation of the two. However, good overprinting of folds shows that S_1 is older than S_2. The trend of S_2 relative to the Brunswick anticline is such that the foliation can be said to overprint the fold. The Brunswick anticline is therefore interpreted as an F_1 fold.

The third generation folds are relatively open, moderate to steep west plunging. They are commonly accompanied by an axial plane fracture cleavage, along which shear may have occurred. The symmetries and orientation of mesoscopic F_3 folds fit well with the broad flexure between Brunswick No. 12 and No. 6 mine, indicating that this might well be a macroscopic F_3 fold.

The fourth generation of folds is commonly represented by Z-shaped kink folds, although some box folds have been developed. This generation of folds seems to have no important influence on the overall distribution of the rocks in the area.

Relative timing of folding and development of axial plane foliations. P. F. Williams, Department of Geology, University of New Brunswick, Fredericton, New Brunswick, Canada E3B 5A3.

Natural folds can be grouped in various ways and two groups are recognized here that may be of genetic significance. One group is characterized by tight to isoclinal folds that commonly are markedly asymmetrical and that lack an axial plane foliation in layer-silicate rich layers or have such an axial plane foliation that is only, very locally developed. These folds tend to be recumbent or reclined unless reoriented by later folding. The second group is characterized by close to tight folds that are commonly symmetrical and that have a well developed axial plane foliation in layer-silicate rich layers. Such folds are typical of slate belts and they tend to have steeply dipping axial surfaces.

Experiments with 'salt/mica schist' that produced folds are described. Some have an axial plane foliation and some do not. The difference can be explained in terms of the relative timing of large and parasitic fold development. Understanding of these experiments leads to an explanation for the differences between the two natural groups. It is suggested that early, pre-large fold, microfolding is generally necessary for the development of a good pervasive axial plane cleavage in pelitic rocks. Where such folding does not occur cleavage will generally be absent or localized. The timing of the folding reflects the deformation environment. Consequently the groups may be indicative of a specific environment; they are not however diagnostic.

The first group is believed to be characteristic of markedly non-coaxial deformation environments and therefore characteristic for example of phyllonites associated with thrusting. The second group is believed to be associated with deformation environments in which the bulk deformation picture is more coaxial.

CONSOLIDATED REFERENCES

Brown, R. L. & Helmstaedt, H. 1970. Deformation history in part of the Lubec–Belleisle zone of southern New Brunswick. *Can. J. Earth Sci.* **7**, 748–767.

Cumming, L. M. 1966. Geology of the Passamaquoddy Bay region, Charlotte County, New Brunswick. *Geol. Surv. Can. Pap.* **65–29** 1–36.

Eastler, T. E. 1971. Geology of Silurian rocks, Change Islands and easternmost Notre Dame Bay, Newfoundland. Unpublished Ph.D. thesis, Columbia University, New York.

Kay, M. 1976. Dunnage Melange and subduction of the Protacadic Ocean, northeast Newfoundland. *Spec. Pap. geol. Soc. Am.* **175**, 1–49.

Kumarapeli, P. S., Goodacre, A. K. & Thomas, M. D. 1981. Gravity and magnetic anomalies of the Sutton Mountains region, Quebec and Vermont: expressions of rift volcanics related to the opening of Iapetus. *Can. J. Earth Sci.* **18**, 680–692.

McKerrow, W. S. & Cocks, L. R. M. 1977. The location of the Iapetus Ocean suture in Newfoundland. *Can. J. Earth Sci.* **14**, 488–495.

McKerrow, W. S. & Cocks, L. R. M. 1978. A lower Paleozoic trench-fill sequence, New World Island, Newfoundland. *Bull. geol. Soc. Am.* **89**, 1121–1132.

McKerrow, W. S. & Cocks, L. R. M. 1981. Stratigraphy of eastern Bay of Exploits, Newfoundland. *Can. J. Earth Sci.* **18**, 751–764.

Ramsay, J. G. 1967. *Folding and Fracturing of Rocks.* McGraw-Hill, New York.

Ruitenberg, A. A. 1967. Stratigraphy, structure and metallization Piskahegan–Rolling Dam area (northern Appalachaians, New Brunswick, Canada). *Leid. geol. Meded.* **40**, 79–120.

Stringer, P. & Pajari, G. E., Jr. 1981. Deformation of pre-Triassic rocks of Grand Manan, New Brunswick. In: *Current Research, Part C, Geol. Surv. Can. Pap.* **81-1C**, 9–15.

Williams, H. 1964. Botwood map-area, Newfoundland. *Prelim. Series Map Geol. Surv. Can.* **60–1963.**

Williams, H., Kennedy, M. J. & Neale, E. R. W. 1972. The Appalachian structural province. In: *Variations in Tectonic Styles in Canada* (edited by Price, R. A. & Douglas, R. J. W.). *Spec. Pap. geol. Ass. Can.* **11**, 1–184.