[AMERICAN JOURNAL OF SCIENCE, VOL. 286, SEPTEMBER, 1986, P. 576-589]

# DUCTILE TO BRITTLE STRAIN HISTORY OF THE McGREGOR FAULT, EAST-CENTRAL NEW YORK

WILLIAM BOSWORTH* and G. W. PUTMAN**

**ABSTRACT. The McGregor Fault forms one of the main bounding faults of the Adirondack Precambrian Massif in east-central New York. Microstructural and field evidence indicates that fault rocks exposed along the present fault trace have experienced a complex strain history involving early periods of high-temperature, ductile deformation followed by later brecciation. Present-day scarp morphology and fault-throw relationships suggest that the McGregor and related faults have experienced several periods of movement between Precambrian and Recent times, with the largest displacement prior to deposition of lower Paleozoic shelf rocks. This lends support to models that geometrically relate the Adirondack bounding faults to structures formed during the initial opening of the Iapetus Ocean in latest Precambrian times. These faults and associated deep shear zones (listric detachment zones) appear to remain as persistent, active tectonic features through repetitive cycles of divergent and convergent tectonism.**

## INTRODUCTION

The eastern margin of the Adirondack Mountains of New York consists of a series of faults, or a fault complex, that juxtapose uplifted Middle Proterozoic basement rocks of Grenville metamorphic age (~ 1.1 by) against lower Paleozoic sedimentary rocks of the Champlain and upper Hudson valleys (fig. 1). A prominent north-northeast-striking strand of this fault complex forms the southeast margin from Saratoga Springs to north of Glens Falls; it was termed the McGregor Fault by Cushing and Ruedemann (1914) (fig. 2). Actually an array of several fault segments, this fault extends southward of Saratoga Springs within the lower Paleozoic rocks (Cushing and Ruedemann, 1914; Ruedemann, 1930) to reach a total length of approx 85 km. It was called the McGregor–Saratoga–Ballston Lake fault system by Geraghty and Isachsen (1981) after the three principal segments (fig. 1). At least seven other major north-northeast- to northeast-striking faults, or fault arrays, extend from the southern Adirondacks across the Mohawk Valley as far west as Little Falls and form a series of strips along each of which the exposed basement rocks are unconformably overlain by gently south-dipping Paleozoic rocks (Darton, 1894; Megathlin, 1938; Fisher, 1980).

Although several of these fault arrays contain graben, or asymmetric half-graben, the prevailing displacements are eastward downstepping with total displacement increasing to the north. The pattern of increasing fault displacement northward has been suggested by Geraghty and Isachsen (1981) as reflecting the apparent and continuing regional doming of the Adirondack Massif (Isachsen, 1975; Barnett and Isachsen, 1980). North- to northeast-trending lineaments as defined by faults and closely

* Department of Geology, Colgate University, Hamilton, New York 13346. Present address: Marathon International Oil Company, P.O. Box 3128, Houston, Texas 77253
** Department of Geological Sciences, SUNY at Albany, Albany, New York 12222

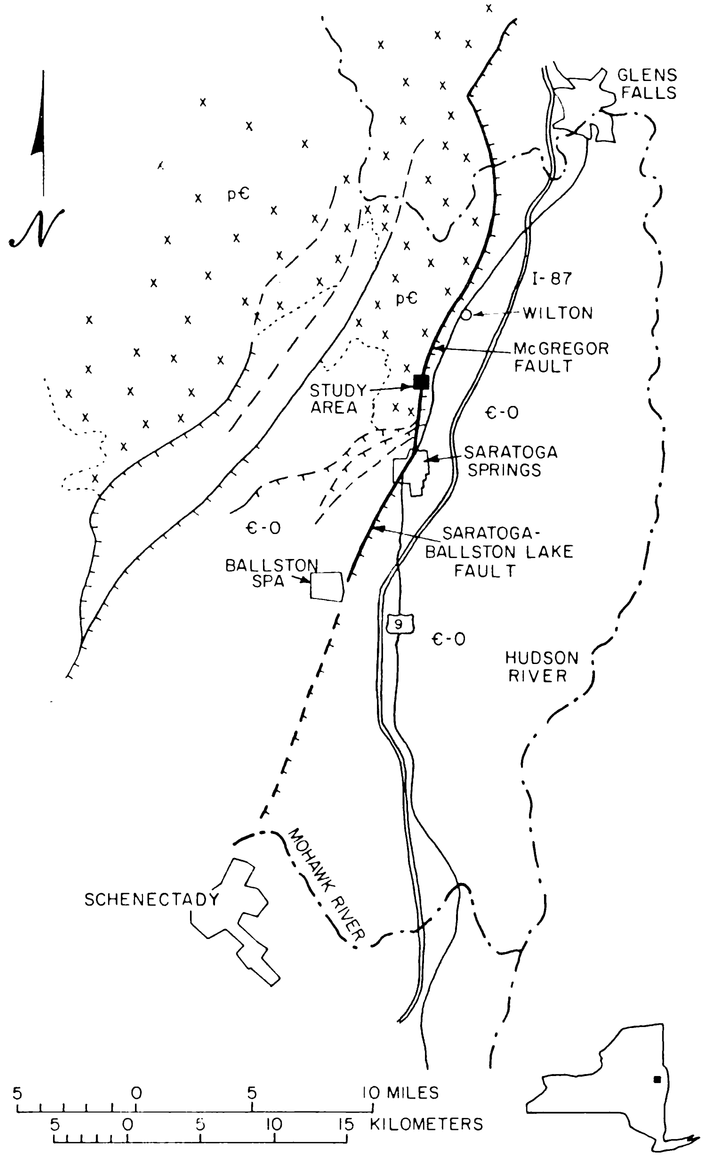



Fig. 1. Geologic map of the southeastern Adirondacks and adjacent Hudson and Mohawk River Lowlands. Location of detailed field map at King's Station is given by small box. Regional geology from Fisher and others (1970). Fault segment names from Geraghty and Isachsen (1981). pЄ and X's = Middle Proterozoic basement rock; Є-0 = lower Paleozoic sedimentary rocks.

spaced fracture sets are common throughout the Adirondacks (Isachsen and McKendree, 1977). The Schroon Lake and Lake George graben are two such prominent fault-defined features of the eastern Adirondacks; the latter intersects the north end of the McGregor Fault. Other sub-parallel eastward-downstepping faults of comparable displacement are likely within the Paleozoic rocks east of the Adirondack margin (Young and Putman, 1979) but are concealed beneath glacial deposits.

Fault attitudes inferred from surface traces, subsidiary fractures in adjacent rocks, adjacent drag folds, and exposed faults of much smaller displacement in the Paleozoic carbonate rocks (Young and Putman, 1979) are commonly high-angle (> 60° dip); actual exposures of the fault zones

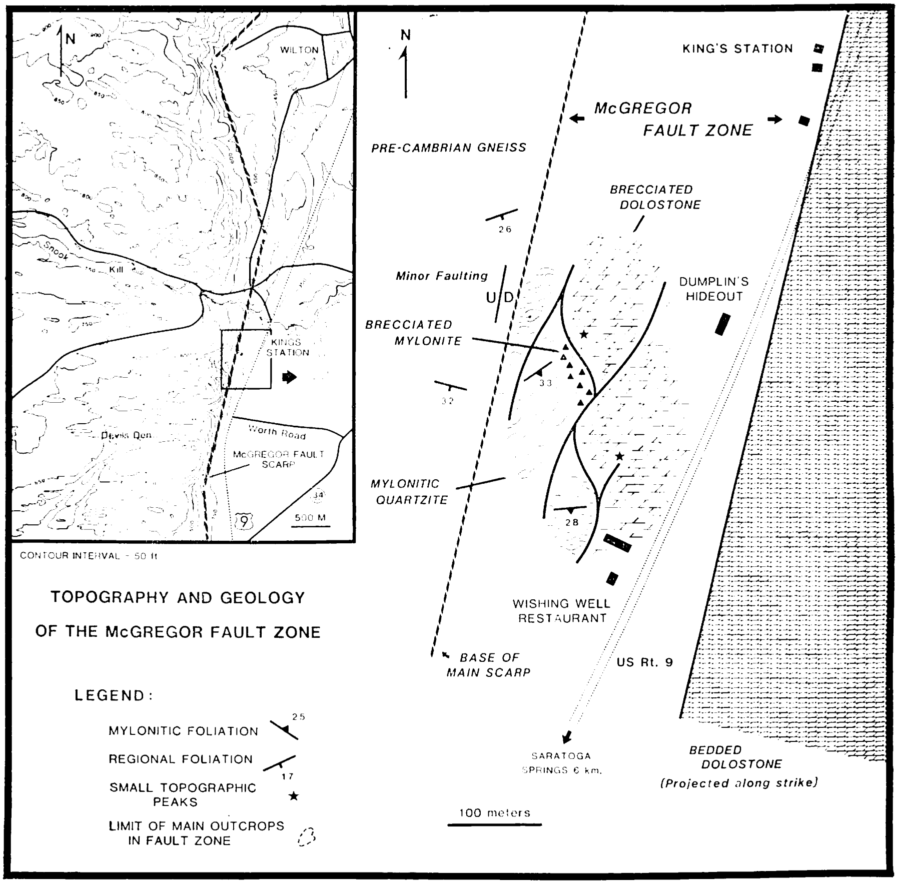
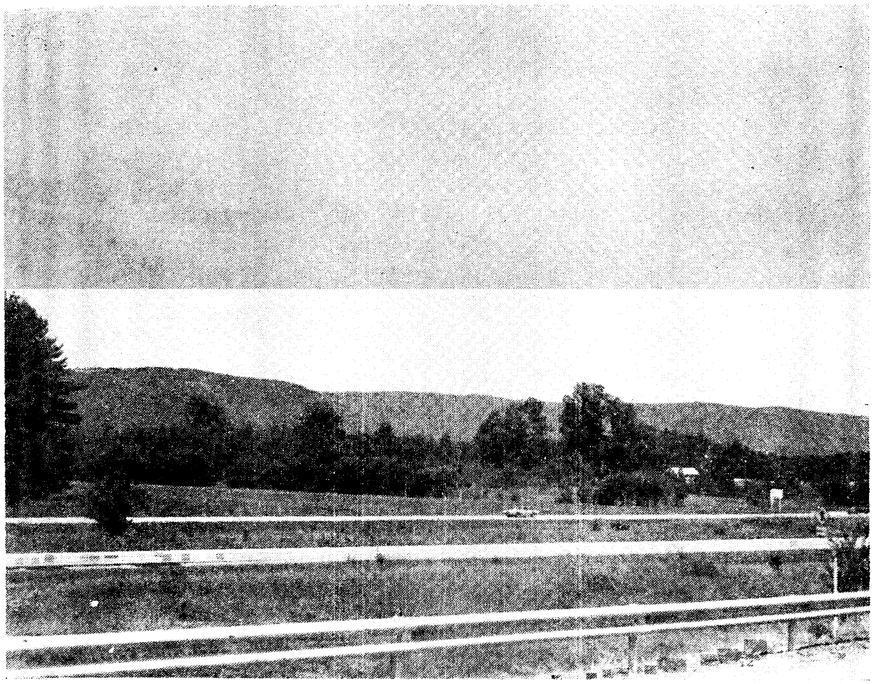



Fig. 2. Detailed geologic map of the McGregor Fault zone at King's Station, New York and adjacent topography (see fig. 1 for location). Three hundred m-wide fault zone contains blocks of dolostone and mylonitic quartzite surrounded by quartzite and dolostone breccia. Minor normal faults in Precambrian gneisses near the McGregor Fault scarp dip approx 70° east and strike north-northeast. East-side down movements in minor faults are typically 1 to 10 cm. Dotted lines indicate extent of outcrop in the fault zone.

PLATE 1



View of the McGregor Fault scarp as seen looking west from near Wilton, N.Y. (see fig. 1 for location of Wilton). Higher ground (Palmertown Range) is underlain by Proterozoic gneisses of the Adirondack Massif. Lowlands consist predominantly of glacially derived alluvium. Relief at the scarp is about 300 m.

of the major faults are very rare, however. Unfortunately, the McGregor Fault zone outcrops described here contained no structural features from which an inference of exact attitude could be made.

The McGregor Fault is marked by a prominent, generally east-facing, scarp with greater relief than occurs along any of the other southern Adirondack margin faults noted above (fig. 2 and pl. 1). If the scarp height is added to the stratigraphic thickness of the approximately flat-lying Paleozoic rocks at any point on the down-thrown block, the minimum vertical fault displacement can be estimated. Such estimates are less than total displacement, because proceeding northward from Saratoga Springs an unknown thickness of basement has been removed on the upthrown block beneath the now exhumed and eroded Proterozoic-Paleozoic unconformity. Relief along the McGregor Fault scarp increases from 100 to 115 m just north of Saratoga Springs to 290 m at Mt. McGregor, 14.5 km to the north, and to 355 m west of Glens Falls. Minimum fault displacements at the same localities are $>$ 440, 600, and 730 m, respectively (Geraghty and Isachsen, 1981).

Isachsen, Geraghty, and Wiener (1983) suggested that the topographic scarp may be the direct result of fault displacement, rather than a faultline erosional scarp, for the following reasons: (A) the sharp relief, (B) the proximity or restriction of the fault zone, where known, to the scarp, (C) the presence of easily eroded fault slivers of Middle Ordovician shale and thin-bedded siltstone exposed in the scarp (for example, just north of Mt. McGregor in the scarp of the Palmertown Range; H. Willems, unpub. data) and (D) the absence of appreciable drainage dissection of the uplifted terrane west of the scarp. Streams flowing over the scarp have steep gradients and have not incised deeply into the scarp. The upland surface adjoining the scarp is relatively flat and suggestive of a prior erosion surface (fig. 2 and pl. 1). These features plus the presence of a number of ~ 90° fault intersections with topographic expression, particularly in Paleozoic carbonates adjacent to the Adirondack margin, which are counter to ice flow direction and not beveled by erosion, and the lack of any observed relation between scarp relief and Proterozoic rock types, argue against Pleistocene differential erosion as a significant factor in the development of Adirondack-margin fault scarps (see also Geraghty and Isachsen, 1981).

These observations suggest that the McGregor Fault has a geologically recent component of displacement consistent with the topography, whereas the difference in scarp height and minimum fault displacement, plus the presence of the uplifted erosion surface, suggest a post-Ordovician history of cumulative fault motion with at least two stages of major movement separated by one of relative inactivity. Timing of fault initiation, however, is not well-constrained by the field data; the youngest Paleozoic sedimentary rocks cut by the fault are Middle Ordovician Snake Hill to Canajoharie Shale equivalents, and the lack of Paleozoic rocks west of the fault prevents any study of possible synsedimentary fault control or growth such as has been documented for some of the Mohawk Valley faults mentioned above (Fisher, 1977, 1980; Fisher and Hanson, 1951).

## MC GREGOR FAULT ZONE EXPOSURE

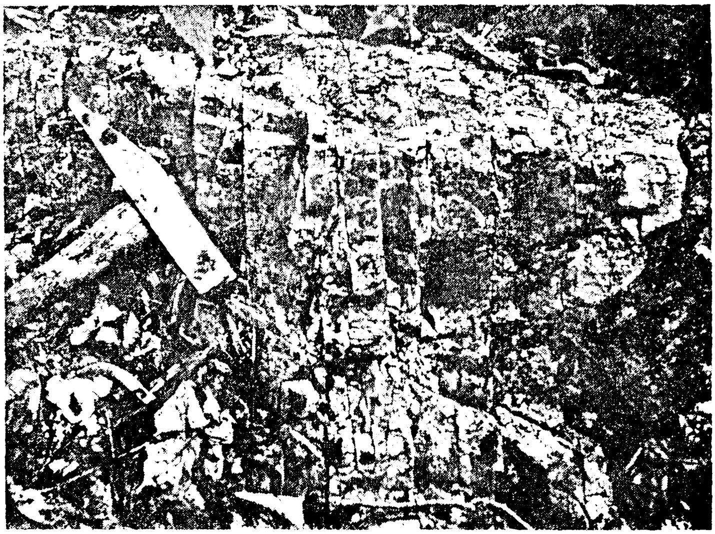
Most of the McGregor Fault scarp is developed on Proterozoic basement rocks without any exposure of the actual fault zone. A rare series of outcrops (Geraghty and Isachsen, 1981) of what can best be described as a fault megabreccia occurs at the base of the scarp, 7.5 km north of Saratoga Springs and west of U.S. Route 9 at the King's Station locality (fig. 2). Here the fault zone is ~ 300 m in width and contains blocks or horses of Paleozoic (Beekmantown) Gailor Dolostone and Proterozoic quartzite up to at least 50 m in long dimension, amid local exposures of quartzite and dolostone breccia which form a matrix between blocks (pl. 2). Unbrecciated Proterozoic quartzite forms the main scarp to the west, and nearly flat- lying dolostone is exposed in the bed of Snook Creek, 1 km to the north along U.S. Route 9.

### *A. Petrology*

Quartzite is prominent among Proterozoic basement rocks of the southeastern Adirondacks from Saratoga Springs to the vicinity of Wilton and consists of interfoliated units varying from > 99 percent quartz to garnetiferous and sillimanitic quartzofeldspathic gneisses. The prevailing

PLATE 2

A.



B.

Field photographs of fractured quartz mylonite (A) and brecciated quartz mylonite (B) in King's Station fault zone. The fracture fabric changes abruptly into breccia in less than 1 m distance. Mylonite foliation in (A) is horizontal. Hammer head is 19 cm long.

mineral assemblage is quartz, microcline, almanditic garnet, sillimanite, and graphite, with muscovite occurring in some gneisses. Modal variations among the subordinate minerals determine local gneiss facies; for example, graphitic "schists" with up to 15 percent graphite were once mined at Porterville, 15 km northwest of Saratoga Springs. Non-carbonate breccia clasts and blocks of the fault zone outcrops are virtually all > 95 percent quartz and, with the exception of graphite, contain the above mineral assemblage. This assemblage indicates moderately high temperatures during Grenville metamorphism but is not particularly diagnostic as to pressure (Miyashiro, 1973). If a normal crustal geotherm is assumed, then crustal thicknesses of 25 to 30 km are consistent with other P,T estimates for the Adirondacks (for example, Putman and Sullivan, 1979).

Down-faulted rocks in the block east of the McGregor Fault comprise the lower Paleozoic stratigraphy of the "New York Standard" or autochthonous sequence. In the vicinity of Saratoga Springs, these units were deposited from late Cambrian through Middle Ordovician times, beginning with quartz pebble conglomerates and sandstones (Potsdam Sandstone) unconformably overlying Proterozoic basement (Fisher, 1977). The bulk of the Paleozoic section consists of thick-bedded Ordovician dolostones and limestones, topped by a transition from thin-bedded limestones and shales (Glens Falls Limestone) to Middle Ordovician black shales with minor siltstones (Snake Hill and Canajoharie Shales). At King's Station, only blocks of Gailor Dolostone (Fisher, 1977) have been recognized in the fault zone. The rock is fine-grained (average crystal size is typically 0.1-0.3 mm) and generally greater than 95 percent dolomite. Accessory mineral phases include quartz, pyrite, hematite, and calcite. Equigranular hypidiotopic fabrics (Friedman and Sanders, 1978) are normally observed, with no metamorphic overprints. Outside the fault zone, deformation is apparent only as hematite-stained joint surfaces and rare carbonate-filled extension fractures. The reader is referred to Fisher (1977) for further discussion of the stratigraphy, lithology, and petrogenesis of the Paleozoic rocks of eastern New York.

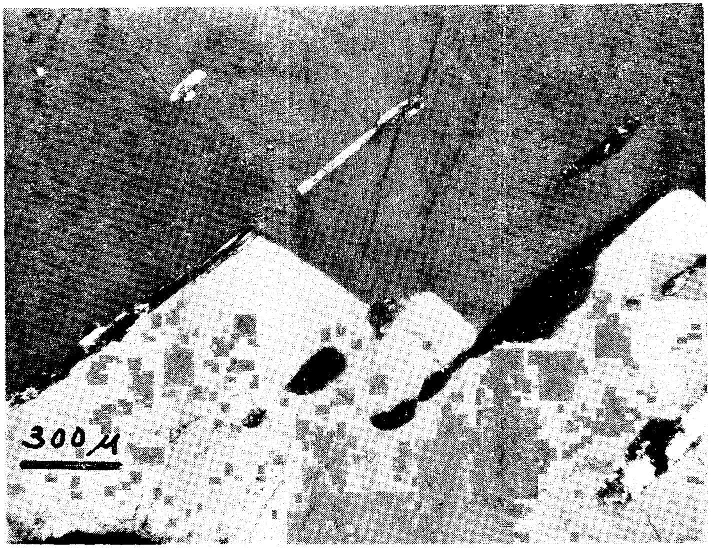
### *B. Microstructures*

The microstructures of rocks exposed at the King's station fault zone locality are described from each of the following structural positions: (1) Proterozoic basement rocks forming the main fault scarp at the western boundary of the fault zone; (2) large blocks within the fault zone proper; and (3) breccia forming the matrix between the large blocks. The margins of several blocks preserve the transition from block to matrix (described more fully below), and hence the tectonic origin of the megabreccia can be reasonably demonstrated. A sedimentary origin (fault scarp talus deposit) is extremely unlikely.

*1. Basement rocks.*—The microstructures observed wtihin the various quartzite and quartzo-feldspathic gneisses of the main fault scarp are dominantly of high-temperature origin. Brittle structures within the gneisses are restricted to joints (see Geraghty and Isachsen, 1981, for details) and rare small-scale east-side down, normal faults (fig. 2). The rocks are variably foliated, with foliation defined by parallel alignment of elongate sillimanite, feldspar, and quartz grains, alternating bands of garnet/sillimanite-rich and poor material, and aligned quartz aggregates (pl. 3-A). Grains show very little undulose extinction, serrated grain boundaries, or

PLATE 3

Photomicrographs of annealed Proterozoic quartzite in upthrown block west of King's Station fault zone. With the exception of brittle structures, the quartz grains are nearly strain free. Crossed-nicols.




A.

A. Regional foliation (pre-dating annealing) is defined by aligned muscovite and sillimanite crystals.


B.

B. Near fault zone, partially healed fractures decorated with inclusions ("type 1" fractures of text) are abundant, they are also present within blocks and breccia clasts of the fault zone itself.

petrographically visible sub-grain boundary structure. The majority of angles at grain boundary triple junctions approach 120°. The texture of these gneisses is essentially granoblastic or weakly nematoblastic in sillimanite-rich layers (Williams, Turner, and Gilbert, 1954) and is inferred to have developed through extensive recovery and recrystallization subsequent to the main high-temperature deformational event(s) of the Adirondack gneiss massif. Isotopic dating elsewhere in the Adirondacks (Hills and Gast, 1964; Silver, 1968; Bickford and Turner, 1971) places the age of metamorphism associated with this deformation at between 1.0 and 1.2 by, the "Grenville Orogeny".

2. *Large blocks.*—The structural fabric within the fault zone blocks is more diverse than in the adjacent country rocks, but it shows two dominant characteristics: (A) quartz within the quartzite blocks has generally undergone extensive grain-size reduction, and (B) small-scale brittle structures are more abundant, particularly at the margins of blocks.

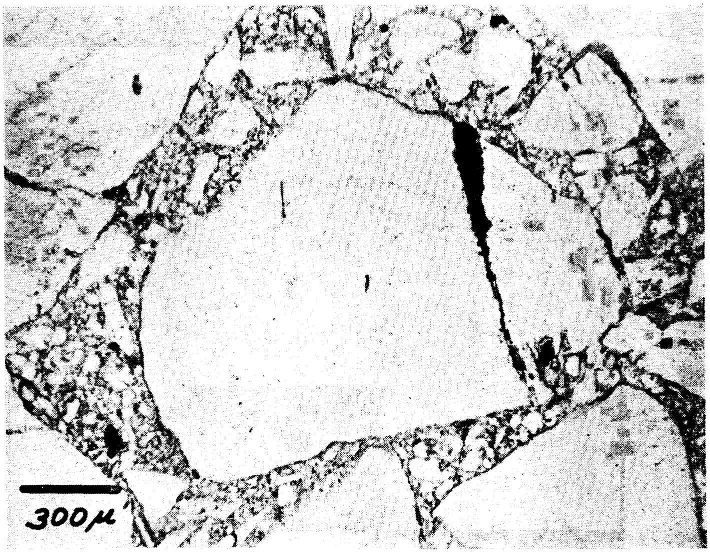
The quartzites composing most of the blocks are also intensely foliated, but the foliation is of a very different character than that formed in the nearby Proterozoic country rock. Bands of fine-grained quartz ($< 20$ to $\sim 200\mu$ diam) anastomose through lens-shaped pods of large, serrated quartz grains (0.3-1.5 mm long axes; compare pls. 3 and 4). Plate 4-B is an example of fabric within clasts of quartzite breccia but is also illustrative of that within blocks such as of pl. 2-A. Finer quartz grains are commonly subequant, whereas the large grains typically have axial ratios of about 2 or 3 to 1. Grains are generaly undulose in extinction, and pronounced subgrain structure is present in most of the large grains. This fabric is characteristic of a quartz mylonite, in which grain size has been reduced by dynamic recrystallization and associated intragranular deformation (Bell and Etheridge, 1973). In some places the large relict grains have been reduced to a few isolated tectonic fish; in others, a mortar texture has developed.

Superimposed on the ductile, mylonitic fabrics of the quartzite fault blocks are varying amounts of brittle deformation, commonly in the form of one or more joint or fracture sets, in places very closely spaced. Near block margins fractures are typically quite pervasive and in at least one case pass progressively into the breccia fabric described below (pl. 2).

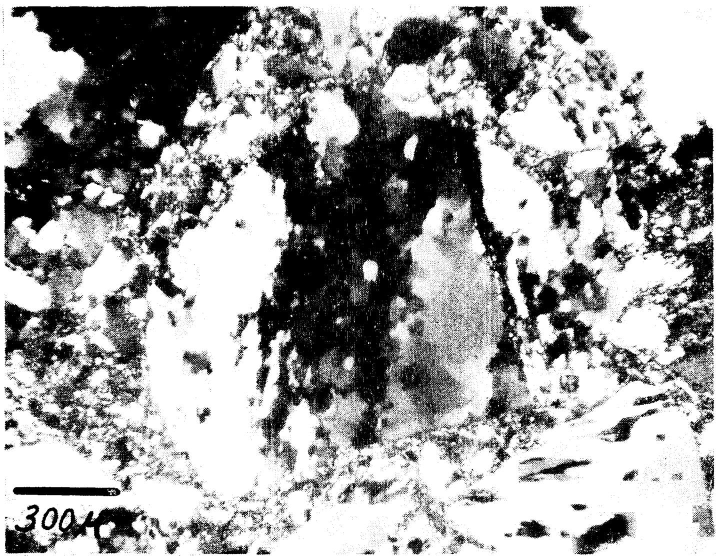
The Gailor Dolostone blocks at King's Station contain a brittle fabric similar to, but more intense than, that present in the quartzite blocks. Irregular joint surfaces and extension fractures are abundant, and throughgoing shear fractures are locally observed. The dolostone blocks, unlike the quartzite blocks, however, contain no evidence of an earlier ductile strain history. The transition from dolostone block to dolostone breccia described below is a cataclastic continuum. Bedding is seldom recognizable within blocks of the fault zone.

3. *Breccia.*—The material between the larger blocks of quartzite and dolostone is largely a quartzite or dolostone breccia (pls. 2-B and 4). Extensive dolostone breccias have also been identified by the authors at other positions along the McGregor and related faults. Boundaries between the

PLATE 4




A.



B.

Photomicrographs of brecciated quartz mylonite from King's Station fault zone. Hand sample resembles plate 2-B. (A) Plane polarized light; (B) Same view, crossed-nicols.

quartzite and dolostone breccias are sharp ($<$ 1 m width), suggesting that these two rocks have been juxtaposed relatively late within the deformational history of the fault zone.

Within the quartzite breccia, clasts are generally less than 5 cm in length and roughly equiaxial. Comminuted material between clasts is largely composed of smaller and smaller fragments of quartzite but also contains small quantities of unresolvable (at 400X) orange-red stained or black gouge, particularly along major fracture surfaces. At least three generations or types of fractures can be identified at any locality within this fault breccia: (1) fractures within clasts truncated by the margins of individual quartzite clasts; (2) fractures defining the margins of the clasts themselves; and (3) through-going fractures that pass from clast to clast through the intervening matrix. Fractures of type 1 are commonly decorated with a profusion of small inclusions and appear in places to be partially or completely healed (Lemmlein and Kliya, 1960; Roedder, 1981) (pl. 3-B). These clast-confined fractures are of a very different appearance than those of types 2 and 3 and are inferred to have developed prior to the major brecciation event(s). However, later fracture orientations may have in part been controlled by the orientations of type 1 fractures. Clast edges and through-going fractures may be clean, distinct surfaces, but commonly they contain a thin layer of the unresolvable material found throughout the breccia matrix, suggesting a movement of fluids or extreme granulation along type 2 and 3 fractures that did not occur along the earlier inclusion-decorated fractures. Inclusion-decorated fractures are also observed within the basement rock gneisses near the main fault scarp (pl. 3-B).

The dolostone breccia at King's Station is largely monolithologic. Clast size, as previously noted, is extremely variable. Much of the breccia, however, consists of 1 to 5 cm clasts surrounded by dolomite gouge. At other localities along strike and locally at King's Station, structurally resistant chert fragments are an important constituent of the clast population, with milled and recrystallized dolomite filling the interstices.

The pre-brittle deformation fabrics of the clasts within the fault breccias at King's Station are in all respects identical to those of the larger blocks of the fault zone described above. The precursors to the McGregor Fault breccias were dominantly pristine dolostone and foliated quartz mylonite, subsequently fractured and eventually broken to the present megabreccia configuration. Truncation of the quartzite mylonitic fabric by clast edges is well-displayed in plate 4-B.

### INTERPRETATION OF THE MC GREGOR FAULT ZONE STRAIN HISTORY: DISCUSSION

Mylonitic textures have not been observed in the quartzites and quartzo-feldspathic gneisses bordering the McGregor Fault Zone to the west. Neither have any breccias been discovered except along the trace of the fault scarp (Geraghty and Isachsen, 1981). These ductile and brittle fabrics therefore are now at least spatially related. Relative age relationships between the mylonitic foliation present only in the McGregor Fault zone and regional late Grenville metamorphic event(s) are critical to the proper interpretation of the strain history of the zone.

While it may be possible for similar mylonite fabrics to be formed, and perhaps even preserved, during near granulite facies metamorphism, the authors know of no such fabrics existing in basement rocks or in high strain zones of demonstrable Grenville age in the southeastern Adirondacks. Even in inferred highly strained rocks with fabrics of reduced grain size, the microstructures are clearly dominated by grain-growth recrystallization and recovery (regional annealing) effects. The presence of a similar K-feldspar–sillimanite-bearing mineral assemblage (high T, P paragenesis) within both the annealed gneisses and the fault breccia (see "Petrology", p. 580-582) argues against any scenario whereby the mylonitic foliation represents an "original" or pre-Grenville tectonic fabric that has escaped annealing conditions at shallower crustal levels.

Alternatively the mylonitic foliation may postdate the regional metamorphism of the Adirondack massif. If so, then either the mylonites are genetically related to motion on the McGregor Fault or the McGregor Fault has fortuitously intercepted an unrelated, post-annealing mylonite zone. Regardless of the timing of mylonitization, the McGregor fault rocks must have been deformed at depths of burial ranging from $> 12$ km (for average geothermal gradient of 25°C/km and a brittle to ductile transition temperature in quartzite of 300°C; Sibson, 1977) to the near surface. Subsequent to mylonitization, ductile conditions were replaced by brittle, and the quartz mylonites described herein were progressively fractured, broken into blocks, and finally disrupted and milled into the present megabreccia. Later, blocks of Ordovician dolostone were worked into the fault zone breccia, but little or no intermixing of dolostone and quartzite breccia has yet occurred.

The simplest interpretation of the relationships observed at the King's Station fault zone locality is that the mylonitic fabric was superimposed on annealed quartzites that were essentially identical to the country rocks now west of the McGregor Fault, and that the association of mylonitic fabrics with the present fault megabreccia is not merely coincidental. We therefore infer that the ductile strain features developed within a deep shear zone produced by crustal faulting in late Proterozoic time during unroofing and rise of the Adirondack basement rock complex. Burial to 12 km is far too much to be accounted for by the known and inferred total displacement of the Precambrian-Paleozoic erosion surface along the McGregor Fault if post-Ordovician faulting alone is assumed.

This timing is consistent with rift development accompanying crustal extension and initial opening of the Iapetus Ocean on the southeastern margin of the North American craton (650-700 my?). Episodic reactivation of old rift-related fault arrays, particularly failed arms, has been a common observation (see Ervin and McGinnis, 1975; Braile and others, 1982), and it is tempting to suggest this mechanism for the bounding fault system of the eastern Adirondacks and upper Hudson-Champlain Valley. Several north-northeast striking mafic dikes are within 3 km of the McGregor Fault (Cushing and Ruedemann, 1914); at least one is truncated by the Paleozoic unconformity (R. Lindemann, personal commun., 1985) and may thus serve to corroborate Late Proterozoic crustal extension. However, other mafic dike sets in the Adirondacks of Cambrian age have a more east-west strike (Isachsen and Seidemann, 1983) and are inconsistent with this trend. Nevertheless, some strongly reactivated faults are not rift related, or only the reactivation stage is associated with known rift features (Ratcliffe, 1971).

Characteristically, persistent reactivated faults respond in subsequent cycles of active tectonism even though the related fault dynamics may be considerably altered (extension versus compression) from the pattern in which faulting was initiated. Topographic features of the McGregor Fault suggest geologically recent activity, and current geodetic changes (Isachsen, 1975; Barnett and Isachsen, 1980) have been used to document the neotectonic uplift geometry. Definitive statements about the early ductile strain history of the McGregor Fault rocks must await radiometric age determinations now in progress. Regardless of the results, the King's Station mylonites are a rare glimpse into an early event in the total tectonic history of the basement rocks of eastern North America.

## ACKNOWLEDGMENTS

The authors wish to thank James McLelland and Yngvar Isachsen for numerous discussions of the geology of the southeastern Adirondacks. Henry Willems, Esperenza Martinez, and Fred Bosworth assisted in mapping the McGregor Fault zone near King's Station. Comments by Ben Page and Douglas Rankin helped improve an earlier version of this paper. All interpretations, however, are solely the responsibility of the authors. Diane Paton and Bonnie DeGroat helped prepare this paper for publication.

## REFERENCES

Barnett, S. G., and Isachsen, Y. W., 1980, The application of Lake Champlain water level studies to the investigation of Adirondack and Lake Champlain crustal movements: Vermont Geology, v. 1, p. 5-11.

Bell, T. H., and Etheridge, M. A., 1973, Microstructure of mylonites and their descriptive terminology: Lithos, v. 6, p. 337-348.

Bickford, M. E., and Turner, B. B., 1971, Age and probable anatectic origin of the Brant Lake Gneiss, southeastern Adirondacks, New York: Geol. Soc. America Bull., v. 82, p. 2333-2342.

Braile, L. W., Keller, G. R., Hinze, W. J., and Lidiak, E. G., 1982, An ancient rift complex and its relation to contemporary seismicity in the New Madrid seismic zone: Tectonics, v. 1, p. 225-237.

Cushing, H. P., and Ruedemann, R., 1914, Geology of Saratoga Springs and vicinity: New York State Mus. Bull. 169, 177 p.

Darton, N. H., 1894, A preliminary description of the faulted region of Herkimer, Fulton, Montgomery and Saratoga Counties: New York State Mus. 48th Ann. Rept. of Regents, v. II, p. 3-56.

Ervin, C. P., and McGinnis, L. D., 1975, Reelfoot rift: Reactivated precursor to the Mississippi embayment: Geol. Soc. America Bull., v. 86, p. 1287-1295.

Fisher, D. W., 1977, Correlation of Hadrynian, Cambrian and Ordovician rocks in New York State: New York State Mus. Map and Chart Ser. 25, 75 p.

———— 1980, Bedrock geology of the central Mohawk Valley, New York: New York State Mus. Map and Chart Ser. 33, 44 p.

Fisher, D. W., and Hanson, G. F., 1951, Revisions in the geology of Saratoga Springs, New York and vicinity: Am. Jour. Sci., v. 249, p. 795-814.

Fisher, D. W., Isachsen, Y. W., and Rickard, L. V., 1970, Geologic map of New York State: New York State Mus. and Sci. Service Map and Chart Ser. no. 15, scale 1:250,000.

Friedman, G. M., and Sanders, J. E., 1978, Principles of Sedimentology: New York, John Wiley & Sons, Inc., 792 p.

Geraghty, E. P., and Isachsen, Y. W., 1981, Investigation of the McGregor-Saratoga-Ballston Lake fault system, east central New York: U.S. Nuclear Regulatory Comm. Rept. NUREG, CR-1866, 44 p.

Hills, F. A., and Gast, P. W., 1964, Age of pyroxene-hornblende granitic gneiss of the eastern Adirondacks by the rubidium-strontium whole rock method: Geol. Soc. America Bull., v. 75, p. 759-766.

Isachsen, Y. W., 1975, Possible evidence for contemporary doming of the Adirondack Mountains, New York, and suggested implications for regional tectonics and seismicity: Tectonophysics, v. 29, p. 169-181.

Isachsen, Y. W., Geraghty, E. P., and Wiener, R. W., 1983, Fracture domains associated with a Neotectonic, basement-cored dome — The Adirondack mountains, New York: Internat. Conf. on Basement Tectonics, 4th, Oslo, Proc., Pub. 4, p. 287-305.

Isachsen, Y. W., and McKendree, W. G., 1977, Preliminary brittle structures map of New York: New York State Mus. Map and Chart Ser. 31.

Isachsen, Y. W., and Seidemann, D., 1983, Dike orientations in basement rocks of the Adirondack dome, New York, and regional paleostrain history as deduced from their K/Ar ages: Internat. Conf. on Basement Tectonics, 5th, Cairo, Egypt, Abs., p. 30; full text in Proc., in press.

Lemmlein, G. G., and Kliya, M. O., 1960, Distinctive features of the healing of a crack in a crystal under conditions of declining temperature: Internat. Geology Review, v. 2, p. 125-218.

Megathlin, G. R., 1938, Faulting in the Mohawk Valley, New York: New York State Mus. Bull. 315, p. 85-122.

Miyashiro, A., 1973, Metamorphism and Metamorphic Belts, London, George Allen and Unwin Ltd., 492 p.

Putman, G. W., and Sullivan, J. W., 1979, Granitic pegmatites as estimators of crustal pressures — A test in the eastern Adirondacks, New York: Geology, v. 7, p. 549-553.

Ratcliffe, N. M., 1971, The Ramapo fault system in New York and adjacent northern New Jersey — A case of tectonic heredity: Geol. Soc. America Bull., v. 82, p. 125-141.

Roedder, E., 1981, Problems in the use of fluid inclusions to investigate fluid-rock interactions in igneous and metamorphic processes: Fortschr. Minereralogie, v. 59, p. 267-302.

Ruedemann, R., 1930, Geology of the capital district, New York: New York State Mus. Bull. 285, 218 p.

Sibson, R. H., 1977, Fault rocks and fault mechanisms: Geol. Soc. London, Jour., v. 133, p. 191-213.

Silver, L. T., 1968, A geochronologic investigation of the anorthosite complex, Adirondack Mountains, New York, *in* Isachsen, Y. W., ed., Origin of anorthosites and related rocks: New York State Mus. and Sci. Service Mem. 18, p. 233-252.

Williams, H., Turner, F. J., and Gilbert, C. M., 1954, Petrography: an introduction to the study of rocks in thin sections: San Francisco, W. H. Freeman and Co., 406 p.

Young, J. R., and Putman, G. W., 1979, Stratigraphy, structure, and the mineral waters of Saratoga Springs — Implications for Neogene rifting, *in* Friedman, G. W., ed., NEIGC-NYSGA Joint Ann. Meeting Guidebook, Troy, N.Y., p. 272-291.