STRAIN INDICATED BY CALCITE TWINNING:
IMPLICATIONS FOR DEFORMATION OF THE EARLY MESOZOIC
NORTHERN NEWARK BASIN, NEW YORK. [1]

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ABSTRACT

The Triassic Brunswick Formation, an arkosic sandstone within the northern Newark Basin, New York, is cemented with calcite that has been mechanically twinned during post-cementation deformation. Strain measured from calcite twins decreases from the Ramapo Fault eastward across the central part of the basin. The plunge of the maximum compressive strain varies from 60° adjacent to the Ramapo Fault to less than 20° in the north-south direction in the middle of the basin. A north-south compression within the basin is compatible with several left-lateral strike-slip faults, such as the Rockland Lake Fault, cutting the basin at N40°E. This study demonstrates the effectiveness of twinned calcite as a tectonic strain marker in a terrain developed by extensional tectonics. Other workers have proposed that late Permian to early Jurassic history of central Atlantic rifting includes early dextral, normal and later sinistral faulting. It is suggested that the late sinsitral shear phase, recognized in mechanically twinned calcite, may extend into the latest Jurassic.

INTRODUCTION

One technique for measuring small internal strains within rocks deformed under low temperature and pressure conditions is the calcite strain-gauge method (Groshong, 1972). This technique has provided information on the orientation and magnitude of strain in many different tectonic settings associated with compressional tectonics such as foreland fold and thrust belts (Groshong, 1975; Engelder, 1979; Spang and others, 1981). However, little information is available on its application in tectonic settings where extension appears to be important such as in a Mesozoic graben associated with the opening of an ocean basin. Our study focuses on the measurement of strain from twinned calcite cements and the interpretation of the distribution of strrain in such a graben, the northern Newark Basin in Rockland County, New York (Fig. 1).

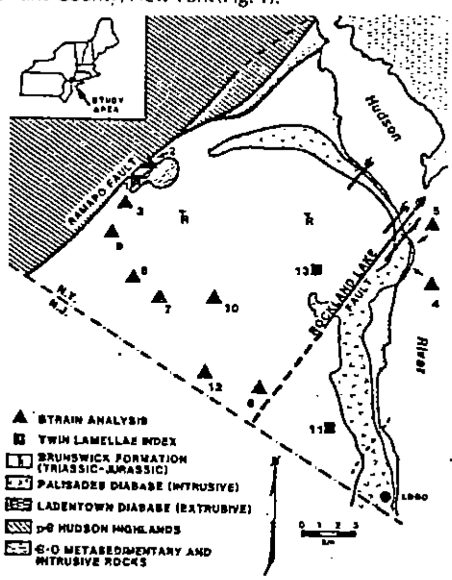

Figure 1. Map of northern Newark Basin (after Ratcliffe, 1971; Dames and Moore, 1977). Triangles and squares – sample localities of the Brunswick Formation.

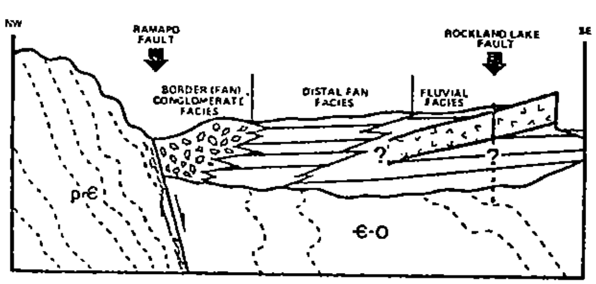

Figure 2. Schematic cross-section across the northern Newark Basin showing the relationship between sediments, faulting and major igneous activity.

THE NEWARK BASIN AND RAMAPO FAULT

The Newark Basin, as exposed in Rockland County, is bordered on the northwest by the Ramapo Fault, which separates the basin from the Precambrian gneisses of the Hudson Highlands, and Cambro-Ordovician metasediments of the New York City Group (Fig. 1). Adjacent metamorphic terrains are the source regions for sediments now seen in the northern part of the basin (Abdel-Monem and Kulp, 1968; Sanders, 1974). Savage (1968) assigned the sedimentary rocks exposed in Rockland County to the Brunswick Formation, however Olsen (1982) assigned these rocks to the Passaic (Brunswick) and Stockton Formations. For the purposes of this paper the locally accepted term, Brunswick Formation, will be used throughout.

Within the eastern part of the basin, the rocks are composed of gray and red arkose, feldspathic sandstones and red shales deposited in a primarily fluvial regime (Fig. 2). Coarser grained components increase westward and the red arkose and shale become interbedded with red-brown feldspathic, gravelly sandstones and conglomerates. This represents the transition from fluvial to alluvial depostional environments of a distal fan facies. The westernmost portion of the Brunswick Formation, bordering the Ramapo Fault, is composed of red-brown bedded cobble conglomerate and boulder-cobble conglomerate of a proximal fan facies. Most of the clastic sedimentary rocks across the Newark Basin contain variable amounts of interparticle and grain replacive calcite cement. During basin formation these sediments were intruded by the Palisades diabase (Erickson and Kulp, 1961, Dallmeyer, 1975), and younger parts of the section were partially covered by the Ladentown basalt of equivalent age (Kodama, 1983).

Sedimentation in the Newark Basin started in late Triassic time (Van Houten, 1977) followed at about 190 m.y. (Erickson and Kulp, 1961) by the intrusion of the Palisades sill (Dallmeyer, 1975). The transition from normal faulting at the edge of the basin to left-lateral strike-slip faulting within the basin occurred after the time of intrusion of the Palisades diabase (190 m.y.). The Ramapo Fault contains horizontal slickensides overprinting former dip-slip fault surfaces (N. Ratcliffe, personal communication). Ages of relatively undeformed hydrothermal minerals found in some fault zones suggests that the last major strike-slip movements occurred prior to 142 ± 8 m.y. (Dames and Moore, 1977).

The role of the boundary faults on the sedimentation pattern along the western border of the entire Newark Basin in the Triassic is in dispute. Normal faulting and sedimentation within a graben may have been contemporaneous (Kummel, 1897; Sanders, 1963, 1974) or normal faulting may postdate sedimentation in a down-warped basin (Faill, 1973).

The Ramapo fault (Fig. 1) is a complex zone that has been demonstrably reactivated since the Precambrian with as many as six stages of displacement inferred either by Ratcliffe (1971) or Dames and Moore (1977). Two stages of Precambrian faulting have caused intense cataclastic effects along the Ramapo fault zone. Similar effets were observed from Ordovician high-angle faulting cross-cut by post-middle Ordovician right-lateral transcurrent faulting. Mesozoic faulting, which formed the Newark Basin, was first normal then over-printed by strike-slip movement. The Ramapo fault is an active tectonic element even today. Aggarwal and Sykes (1978) report several earthquake focal mechanisms in this vicinity. This complex history suggests that the Ramapo fault zone has been periodically reactivated over a time span of 700 m.y. (Ratcliffe, 1971).

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Within the basin several faults cut the Brunswick Formation and the Palisades diabase (Fig. 1). The most prominent is the Rockland Lake Fault which has been mapped as a left-lateral strike-slip fault extending from the Hudson River southwest, where the fault offsets a dike up to 300 meters (Appel and Fenster, 1977). Along strike to the northeast, across the Hudson River is the Croton Falls Fault System cutting the Cambro-Ordovician metasedimentary rocks of the New York City Group. This may be a continuation of the Rockland Lake Fault zone (Appel and Fenster, 1977).

DEFORMED CALCITE

Method

For our strain analysis 10 oriented sandstone samples were collected across the southern (widest) part of the Newark Basin in Rockland County (Fig. 1). Three other samples were collected to determine a twin lamellae index (Friedman, 1964).

Using the calcite strain-gauge technique of Groshong (1972) oriented thin sections were examined under a petrographic microscope equipped with a Universal stage. A single thin section was used for the determination of strain in each sample. The orientation of the twin planes and C-axis were recorded along with the number and thickness of the twin planes and size of the crystal.

A twin lamellae index was determined for 13 samples from the Brunswick Formation. For determining the index all twinned grains in a thin section traverse were analyzed by measuring the thickness of all twins and thicknesses of the grains normal to the twins. All thin twins were assigned a thickness of 0.5 microns (Groshong, 1972). Our index is an average of the percentage of the twinned portion of grains determined by averaging data from 50 or more twinned grains. This serves as a quick determination of the relative differences in strain between samples and is not a substitute for Groshong's (1972) technique for measuring absolute strain.

RESULTS

Calcite occurs in the Brunswick Formation as cement filling pores and is also found replacing plagioclase and well-rounded grains of unknown primary composition. Calcite also replaces quartz in samples 1, 2, 3, and 6 (Fig. 1), located directly below the Palisades diabase and near the Ladentown lava flows. At all locations the calcite is mechanically twinned.

The three-dimensional strain tensor for each of 10 samples is given in Table 1. The principal compressive strain never exceeds more than 3%. The orientations of the maximum compressional and extensional strains using the technique of Groshong (1972) are plotted on a lower-hemisphere projection in Fig. 3. The maximum compressional strains (E_1) show an average northerly trend with plunges that vary from 3° near the eastern edge of the basin to 58° near the Ramapo Fault (Fig. 4). Maximum extensional strains (E_3) plunge at a shallow angle towards the east or west. Strain decreases with increasing distance from the Ramapo Fault except near the Rockland Lake Fault (Samples 4 & 5) (Fig. 5). A comparison of the twin lamellae index with increasing distance from the Ramapo Fault shows the same trend with the more highly twinned samples found near either the Ramapo or Rockland Lake Faults (Fig. 6).

TABLE I

Station	Number of Twin Sets	% Negative Expected Values	Principal* Strain(%)	Estimated Error ± of Maximum Extension	Bearing	Plunge
2	39	33	2.44	1.19	236	25
			1.02		140	14
			-3.47		23	61
3	39	28	1.55	0.57	331	33
			0.55		219	30
			-2.10		97	42
4	27	30	1.13	0.44	287	17
			-0.29		82	71
			-0.83		195	7
5	54	20	1.92	0.44	89	33
			-0.35		203	27
			-1.57		321	43
6	32	47	0.34	0.28	149	6
			0.08		256	68
			-0.42		56	20
7	39	41	0.27	0.24	291	20
			0.12		42	43
			-0.40		183	39
8	26	19	1.55	0.73	63	7
			-0.53		162	49
			-1.01		328	39
9	15	--	1.54	1.24	118	26
			-0.16		234	40
			-1.38		6	38
10	21	10	0.86	0.46	246	12
			-0.28		135	59
			-0.57		343	27
12	12	8	1.08	0.32	117	20
			-0.31		229	45
			-0.76		11	37

* – Compressive strain is negative.

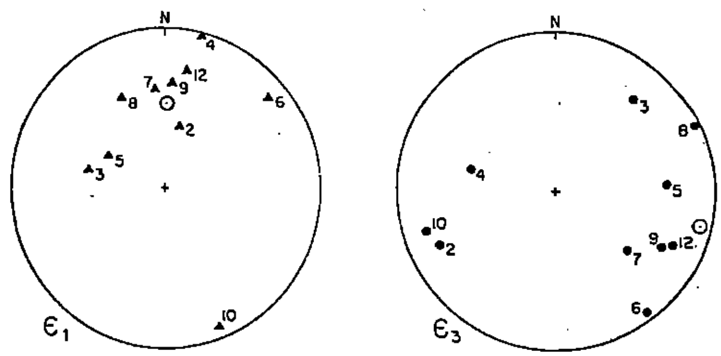

Figure 3. Data from dynamic analysis of calcite strain shown in lower hemisphere equal-area projections. Plotted are orientations of maximum compressive (E_1) and extensional (E_3) strains for each station. The average orientation for each plot is shown by large open circle.

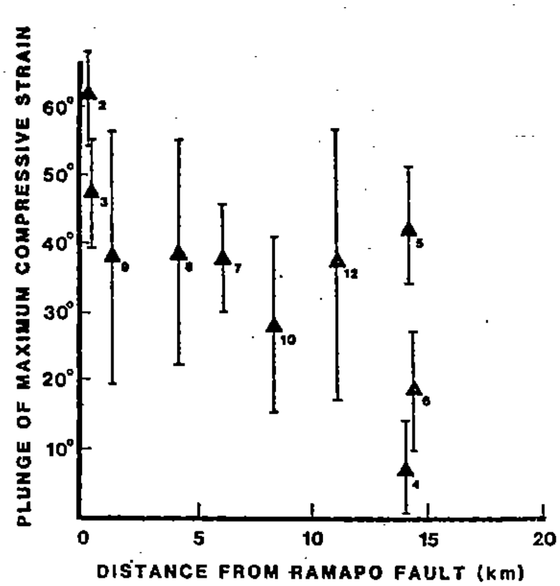

Figure 4. Plot of the plunge of maximum compressional strains (E_1) vs. distance from the Ramapo Fault. Error bars based on an analysis by Groshong, et al (1983).

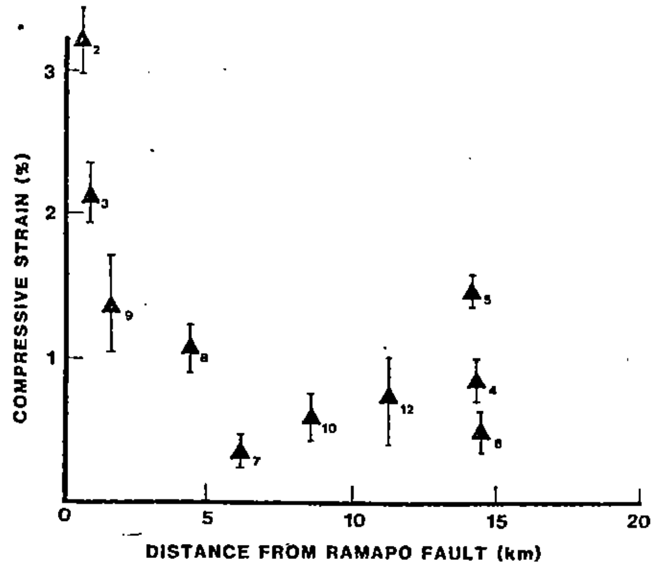

Figure 5. Plot of maximum compressive strain for calcite versus distance from Ramapo Fault. Error bars based on an analysis by Groshong et al (1983).

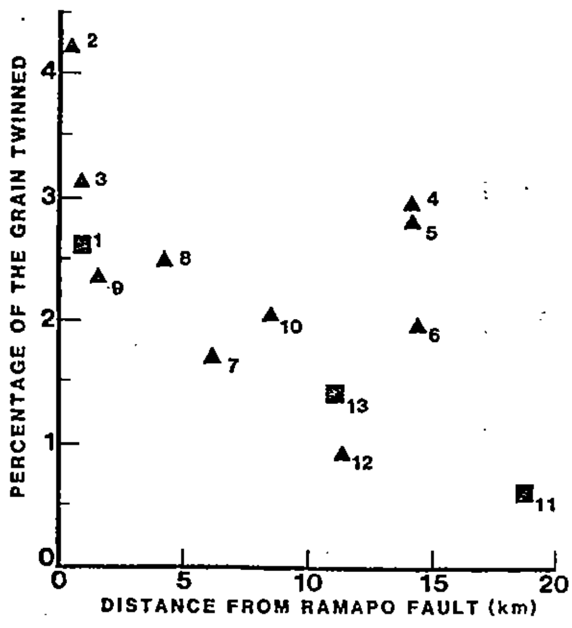

Figure 6. Plot of percentage of the grains twinned versus distance from Ramapo Fault.

Sample 6 has an anomolously high twin lamellae index similar to samples 4 and 5 (Fig. 6) while the plunge of the maximum strain remains at a low angle (Fig. 4). In this area a local offset in the drainage pattern follows a southwest projection of the Rockland Lake fault. Strain relationships and drainage pattern allow us to speculate that the Rockland Lake fault may extend 5 km. southwest of the previously mapped limit.

DISCUSSION

The calcite strain-gauge data reflect part of the Mesozoic history of the northern Newark Basin. Strain was highest near the extensive faults in the vicinity of the northern Newark Basin, the Ramapo and Rockland Lake Faults. The plunge of the maximum compression is between 40 and 60 degrees near the Ramapo Fault. A dip-slip displacement of at least 220 m is known for this fault followed by reactivation with a small amount of horizontal slip (Dames and Moore, 1977). Within the basin all samples but #5 have a maximum compression plunging at less than 40° which is compatible for a stress field with a large component of strike-slip faulting. Likewise, the average azimuth for maximum compression is northerly, an orientation compatible with left-lateral oblique-slip on faults trending about N40°E.

The strain distribution pattern suggests that stress associated with normal faulting at the edge of the Newark Basin affected only rocks in the vicinity of the Ramapo Fault. In contrast, stress associated with later stage strike-slip faulting was transmitted throughout the Brunswick Formation. The high negative expected values for samples 6 and 7 may be indicative of overprinted tectonic events.

Reactivation of graben faults by strike-slip motion is common. The classic example is the Rhinegraben where reactivation in middle Pliocene time was by left-lateral strike-slip motion along a series of faults that still control crustal movements and seismicity (Illies and Greiner, 1978). In many places within the Rhinegraben horizontal slickensides of a left-lateral sense overprint dip-slip fault planes (Mullerried, 1921).

Strike-slip faulting following the deposition of the Newark Super-group was common along eastern North America. Sanders (1962) inferred 15-20 km of right-lateral slilp along the NE-SW striking Hopewell and Flemington faults in New Jersey. Although Faill (1973) argues that the fault-fold geometry of the Furlong and Chalfont Faults in the Newark Basin of Pennsylvania precludes a significant strike-slip component on the Hopewell and Flemington faults of New Jersey, abundant strike-slip slickensides are found in the Newark Basin of Pennsylvania. These occurrences of strike-slip motion plus Wise and Students' (1979) observations witness the wide-spread nature of the strike-slip event in the development of the Mezozoic basins of North America. The evidence presented here from the northern end of the Newark Basin further suggests that the event was a response to a north-south compression during the Jurassic.

Swanson (1982) proposed a model that incorporates early dextral, normal and later sinistral faulting for the transform history of central Atlantic rifting from Late Permian to Early Jurassic. In the northern Newark Basin the late sinistral shear phase may be age bracketed between 190 m.y., the age of the Palisades intrusion and 142 m.y., the age of the oldest fault zone mineralization (Dames & Moore, 1977). Therefore, the time range of sinistral shearing may be extended to include the latest Jurassic.

CONCLUSIONS

1) This study demonstrates the effectiveness of twinned calcite as a tectonic strain marker in a terrain developed by extensional tectonics.

2) Using the calcite strain gauge technique the strain distribution across the northern part of the Newark Basin shows a regular decrease away from the Ramapo Fault zone except for high strain anomalies associated with shear zones within the basin.

3) The plunge of the maximum compressive strain decreases across the basin and is compatible with oblique slip faulting adjacent to the Ramapo Fault.

4) Ages of fault zone mineralization indicates that the late stage sinistral shear phase reflected in strained calcite may extend the period of central Atlantic rifting into late Jurassic time.

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