GEOLOGICAL SUMMARY OF THE CAYUGA REGION

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INTRODUCTION

No general summary of the geology in the region around Ithaca and Cornell University has appeared since that in the N.Y. Geol. Assoc. Guidebook of 1959. Not only has much information been gathered since that time but also the geological emphasis has shifted. Earlier studies stress the geomorphic and paleontologic aspects of the area, whereas more recent attention has been toward the physical stratigraphy, environments of deposition and tectonic evolution of the region. In addition, geophysical studies and deep drill holes have greatly expanded our knowledge of the subsurface geology and deep crustal conditions.

This chapter, therefore, is designed to synthesize the geologic information pertaining to the Cayuga region, emphasizing that material collected since 1959, and is oriented toward physical stratigraphy, tectonics and geophysics. The summary aspect of this paper precludes much detail, but extensive referencing in this and the following papers will enable the reader to pursue topics in greater depth.

GEOLOGIC AND TECTONIC SETTING

The Cayuga region (Fig. 1) is physiographically part of the Appalachian Plateau Province, which forms the cratonic flank of the foreland to the Alleghenian collision zone (Engelder, 1979b). In north central Pennsylvania the foreland fold and thrust belt trends nearly east west, as do the related structures on the foreland in central New York (Wedel, 1932; Engelder and Geiser, 1980). This obliquity with the general northeasterly trend of the Alleghenian collision zone marks the northern flank of a large salient in the structural front, which is in part related to the distribution of the Silurian salt (Davis and Engelder, 1985). There is, however, a similar salient in the internal part of the collision belt, which suggests that initial passive margin configuration (e.g., Rankin, 1976) and/or collision complexities were in large part responsible.

The Cayuga region has lain well within a continental interior during all of Phanerozoic time, yet close enough to the continental margin to show subtle effects of more pronounced tectonic events that shaped that margin from the late Precambrian into the Mesozoic (Colton, 1970; Engelder and Geiser, 1980). Thus the stratigraphy of this area bears witness to the formation of a passive continental margin during the late Precambrian and Cambrian, the Taconic collision in the Ordovician, and the more enigmatic Acadian event of the mid to late Devonian age (Ettensohn, 1985; Bradley, 1983). Although younger sediments have since been eroded from the region, its structural framework is basically a result of the Alleghenian collision. The sum of these processes has produced gently southward tilted and thickening pile of strata (Rickard, 1973), but within that pile are sharply varying trends reflecting earlier events. These trends, primarily in the subsurface, have been delineated by regional stratigraphic and geophysical studies.

GEOPHYSICAL STUDIES

Regional gravity and magnetic data provide a primary source of information concerning the depth and character of Precambrian basement in south central New York. Sparse heat flow, seismologic, and electromagnetic studies give further insights into the deep crust and its behavior. A moderate number of seismic reflection profiles have been run in the Cayuga region, which should clarify structural and stratigraphic relations within the sedimentary column, but none of these have been released for public use.

Gravity

The Bouguer gravity field in New York State (Revetta and Diment, 1971) west of the Taconic zone basically reflects the depth to and density variations of the Precambrian basement. In central New York a very general southward decrease in the gravity field is associated with the 15 m/km southward dip of the basement surface (Hodge et al., 1982; Rickard, 1973). Superimposed on this gradient are sub-circular to more linear NNE trending anomalies. The character of the anomaly field changes markedly across a zone of steep, easterly decreasing gradients that trends NNEerly just west of Rochester (here referred to as the Clarendon-Linden gradient). To the east and including the Cayuga region, anomalies have lower amplitudes (10-15 mgal) and longer wavelengths than to the west. The eastward decrease in density, smoother field, and more circular anomalies have been interpreted as reflecting less mafic Precambrian rocks to the east, which have been intruded by both mafic and silicic plutons (Hodge et al., 1982).

Magnetics

The total field aeromagnetic maps of western New York (e.g., Zietz and Gilbert, 1981) show a good correspondence to the gravity field (Hodge et al., 1982). Thus the magnetic field east of the Clarendon-Linden gradient is more subdued than that to the west. In both areas most magnetic highs correlate with gravity highs and are attributed to mafic intrusions or amphibolites (Hodge et al., 1982).

Lows in both fields reflect granitic or anorthositic bodies. A larger ENE-trending gravity and magnetic low south of Ithaca may imply a syenitic to anorthositic mass in the Precambrian (Sneddon, 1983).

Heat Flow

Heat flow measurements in New York show approximately normal values for stable continental crust (50-60 mw/m^2) but the few measurements in the Cayuga region are significantly higher (65-94 mw/m^2) (Hodge et al., 1982). In general higher heat flow is attributed to the higher radiogenic content of underlying granitic masses.

Variations in temperature gradients differ from those of heat flow because thermal conductivities are a function of lithology. A compilation of temperature gradients in the upper 1 km (Hodge et al., 1982) show east-west trends reflecting surface lithology, but also define a N-S trending band of high gradients near 76° 40'W longitude. Near Auburn, values rise to near 40°C/km, which provided the basis for the drilling of 2 geothermal wells (Hickman et al., 1985).

Seismicity

Although several regions in New York show significant seismic activity (Sykes, 1978; Nottis, 1983), central New York, and in particular that region east of the Clarendon-Linden gradient has been almost aseismic during historic time. This lack of seismicity correlates well with the other geophysical fields in outlining major subdivisions of the Precambrian basement in New York (Zoback and Zoback, 1980).

PHYSICAL STRATIGRAPHY AND DEPOSITIONAL SETTINGS

Emphasis in previous guidebooks on the Cayuga region has been placed on the description of the exposed Middle and Upper Devonian section. Beneath these strata, however, are over 2 km of older, Cambrian to Devonian strata that overlie a much older Precambrian basement. Several drill holes have now penetrated these rocks (Kreidler, 1963, 1972; Flagler, 1966), with which it is now possible to describe these rocks and to explore their regional variations (Figs. 2, 3 and 4). These data in turn permit interpretation of depositional and tectonic environments during early Paleozoic time.

Precambrian

The Precambrian basement has been sampled by four wells in the Cayuga region (Fig. 1). Additional inferences about the depth to basement and its lithology are obtained from geophysical data and from crustal inclusions in the Mesozoic dikes exposed in the region. Basement lithologies from wells have been only cursorily described. By well (located on Fig. 1) these are: Shepard #1; pink biotitic gneissic granite (Flagler, 1966, and Isachsen, 1971); Shaeffer #2, amphibolite (Flagler, 1966); Auburn Geothermal wells; grey and pink marble in one and marble and mica schist in the second (Brayton Foster, 1986, per. comm.). Crustal inclusions in the kimberlite dikes around Ithaca suggest mafic syenite and calcsilicate metamorphic rocks (Kay et al., 1983). These lithologies, in addition to the geophysical data, suggest that the Precambrian basement is comprised of a suite of medium-grade metasediments intruded by silicic to feldspathic (syenitic to anorthositic) plutons. This suite has been correlated with the Grenville province exposed to the north and east, and thus should have a metamorphic age of about 1.1 by.

Cambrian

The oldest Phanerozoic strata in the Cayuga region are the upper Cambrian sandstones and dolostones of the lower Beekmantown Group (Potsdam, Theresa [Galway] and Little Falls formations). These mature shallow water clastics thicken to the east and south, toward the paleoshelf edge (Rickard, 1973).

In addition to the oceanward thickening of upper Cambrian strata, the section adds sequentially older strata in that direction. These Cambrian strata as well as those of the lower Ordovician represent a transgressive wedge of continentally derived material associated with the construction of a late Precambrian passive continental margin that roughly coincided with the present coastline (Fig. 5b).

Ordovician

The lower Ordovician series is represented in the Cayuga region by about 150 m of strata comprising the Tribes Hill Formation of the Beekmantown Group, (Committee on Stratigraphic Correlations, 1966). The Tribes Hill Formation represents a continuation of the pattern established during the Cambrian, with the south and eastward thickening of quartzose sands and dolostones (Rickard, 1973).

Conditions changed markedly at the end of early Ordovician time, when the Knox unconformity was nearly isochronously developed throughout the continental interior of the northeastern U.S. This widespread hiatus in deposition is more easily interpreted as a eustatic event (Vail et al., 1977) than as a result of a regional tectonic event, such as the Taconic collision. This interpretation is reinforced by the subsequent reestablishment of quiet marine shelfal conditions during the early middle Ordovician (Walker, 1973). The deposition of carbonates of the Black River Group testify to the lack of tectonic effect on the continental shelf in the Cayuga region during that period (Rickard, 1973).

Differential relief increased during deposition of the Trenton Group (Cameron, 1972). In the Cayuga region a shallow NE trending trough developed, behind a larger irregular arch to the east (e.g., Jacobi, 1981; Zen, 1973). The arch, which represented the outer swell to the encroaching Taconic Trough and island arc caused the development of westward and migrating unconformities and of the normal faults seen in the Mohawk Valley (e.g., Rodgers, 1971; Cisne et al., 1981).

Except for possible subtle downflexure of the crust on the cratonic flank of the outer swell and a few ash beds in the Trenton limestones, the Taconic orogeny left little imprint on the Cayuga region. Cessation of convergence by the end of the Middle Ordovician led to the filling of the Taconic Trough with clastics, which further depressed the surrounding region, and led to the expansion of basinal conditions. This elastic loading may explain the extension of the easterly derived clastics of the Utica Formation westward across the entire state.

Siliciclastics of the upper Ordovician Queenston Complex mark the continued westward transport of detritus from the Taconic collision zone (Martini, 1971), which appears to have ceased convergence but was still undergoing vertical adjustments. Facies bands within the Queenston, comprising a range from shelfal shales to fluvial or coastal plain sands, trend roughly north-south and mark repeated transgression and regression of the marine conditions that lay to the west (Hughes, 1976; Stone and Webster, 1978). The migrating shorelines during this period produced diachronous lithostratigraphic units that are relatively poorly dated and correlated in the region (Hughes, 1976).

Vertical displacements related to the crustal rebound or relaxation following the Taconic collision might be responsible for the upper Silurian cycles, but late Ordovician glaciation is at least as plausible a cause for the relative changes in sea level (Hughes, 1976).

Silurian

The Early Silurian was a period of continued tectonic quiescence and reduced eustatic variation. A reduced supply of sediment from the east was accompanied by shallow marine to supratidal conditions across the region (e.g., Fisher, 1954). Sediments consist of reworked older strata (e.g., Medina sands, Martini, 1971; Muskatt, 1972), carbonate units, and a striking abundance of iron rich units (e.g., the Clinton oolitic ironstones (Gillette, 1947; Zenger, 1971)). The lateral variations in these environments produced marked facies changes in many of the units of this age.

The Late Silurian saw the remarkable development of evaporates over much of the northeastern interior of the U.S. (Fisher, 1957; Kreidler, 1957; Alling and Briggs, 1961; Rickard, 1969; Treesh, 1972). Central New York lay under part of the Salina Basin, represented by the Vernon, Syracuse, Camillus and Bertie formations. The relative roles of oceanographic and tectonic effects in the creation of this basin are still unclear, but the northeast elongation (Fig. 5c), suggests that some tectonism was involved. Before the end of Silurian time, evaporite deposition had ceased and sedimentation was again dominated by very shallow marine to supratidal carbonates of the lower Rondout formations (Rickard, 1969; Laporte, 1967).

Devonian

Except for the thin Oriskany sandstone, the lower Devonian is represented by widespread, and laterally more uniform carbonates. The Helderberg group represents multiple westward transgressions of neuritic carbonates (Rickard, 1962; Laporte, 1967, 1969). Not only does this group thin westward but the upper units have pinched out westward by the longitude of Cayuga Lake (Rickard, 1969). The Onondaga Formation represents the last major limestone deposit before the westward flood of clastics from the massive uplift associated with the Acadian event. Even during the Onondaga deposition the Acadian event was heralded in the Cayuga region by the Tioga ash beds (Roen and Hosterman, 1982; Rickard, 1984). The extremely widespread distribution of these beds and their silicic and potassic composition suggests that they are the result of caldera eruptions with continental crustal sources rather than of typical island arc eruptions.

With the deposition of the Hamilton group (Baird and Brett, 1981), clastic deposition in the "Catskill Delta" became dominant over carbonate deposition (Faill, 1985; Rickard, 1984), although the shales generally remain calcareous, and a few thin limestones punctuate the section (Dugolinsky, 1981; McCave, 1973). In eastern New York, the upper Hamilton group records the westward migration of the shoreline and the westward progradation of coarser facies, whereas in western New York the group consists of shelfal strata (Brett and Baird, 1982). The overlying thin Tully limestone marks a singular change in depositional regime, developing along a shelf edge between deeper basinal environment to the east and broad shelf conditions to the west (Heckel, 1973). Basinal conditions, and westward migration of coarser clastics developed in the Cayuga region during deposition of the Genesee formation (de Witt and Colton, 1978; Kirchgasser, 1985). The Genesee and succeeding mid and late Devonian section thicken and coarsen markedly southeastward (Fig. 5d) and are represented by more than 1500 m of sandstones and shales in the Cayuga region (Rickard, 1981; Tetratech, Inc., 1981; Van Tyne, 1982).

No younger strata remain in the Cayuga region, but estimates of overburden above the Devonian strata (see Engelder and Oertel, 1985) suggest that a maximum of 1 km of younger, probably Mississippian to Pennsylvanian sediments were deposited before the Alleghenian collision raised the region above sea level.

Igneous Rocks

The only igneous rocks of Phanerozoic age in the Cayuga region are kimberlite dikes of late Jurassic to early Cretaceous (140 m.y.) age (Basu et al., 1984). These dikes are sub-vertical, trend nearly north-south (Fig. 6), are a few centimeters to a meter wide and can be traced from a few meters to a kilometer along strike. Their mineralogy implies a relatively shallow mantle source and either a higher fossil geothermal gradient or a relatively undepleted mantle (Kay et al., 1983). The largest of these bodies probably extended to the surface and were associated with maar eruptions (Williams and McBirney, 1977). The occurrence of diatreme facies in the Poyer Orchard body (see Foster and Kay, this volume) implies that the level presently exposed is relatively close to the Cretaceous surface. The origin of these dikes, which occur sparsely but over a very widespread area of the eastern U.S., is still conjectural.

STRUCTURES

The Cayuga region lies in the very mildly deformed belt in front of the foreland fold and thrust belt that was developed during the Alleghenian orogeny. This anomalously wide zone of mild deformation is related to the distribution of Silurian salt, which is extremely weak and acted as a low-strength decollement, above which strata were displaced northward (Davis and Engelder, 1985). On the gently south dipping strata, which reflect the flexure of the foreland beneath the load of the Alleghenian fold-thrust belt, are impressed a suite of subtle but significant deformational structures. There are large very gentle folds and a few small thrust faults, but most shortening is absorbed by intragranular strain and pressure solution effects (Engelder, 1979a, 1979b). In addition, the study of well-developed joint sets in the region has led to a number of very fruitful studies of the past and present stress field.

Folds

A series of gentle regional folds forms an arcuate pattern in south central New York. The northernmost of these traverse the Cayuga region with a general east-west trend. Surface mapping of these folds (Wedel, 1932) defined anticlines that rise above the regional dip with amplitudes of tens to near 100 m and wave lengths on the order of 10 km. Although very persistent along trend, the folds often show locally irregular axial traces. The south limbs of anticlines are generally steeper, defining folds that are either symmetric when corrected to the regional dip or even slightly asymmetric toward the south (e.g., Sherrill, 1934). All the folding appears to be restricted to the section above the Silurian salt (Prucha, 1968) but there appears to be some uncertainty as to the nature of the structure between the exposures in the middle Devonian and the decollement. Engelder and Geiser (1980) suggested that folding is replaced downward by thrusting in the brittle carbonates of the lower Devonian, but the data to support this suggestion are sparse and ambiguous. Structural contours on the Oriskany sand have been interpreted by Brayton Foster (pers. comm., 1986) as delineating sets of reverse faults, often with opposing dips, beneath the crests of the regional anticlines. Such opposing faults would define tepee structures and pop-ups, which are common in salt-base thrust systems, and would explain the general symmetry of the overlying anticlines.

The Firtree Point (Portland Point) anticline, which is well expressed in exposures along the shores of Lake Cayuga, is the best studied of these folds, largely because of the salt mine in its core. The anticline trends N80E in surface exposures and is grossly symmetric, with flank dips of less than 2° (Prucha, 1968). However, dips on the south limb (in the Cayuga Crushed Stone Quarry) reach 6 to 8°S, and are probably associated with local thrusting (Scott, 1986). Structural relief on the Tully limestone is about 75 m (Prucha, 1968). The mine workings and borings show that the fold in the Syracuse formation is similar in trend, and more importantly, in amplitude as expressed by the fold in surface exposures. There is, however, evidence of a fault in the Oriskany sand beneath the anticlinal crest (Brayton Foster, pers. comm. 1986), which appears to account for some of the shortening within the Early Devonian strata. No relief exists on units beneath the salt. These observations together indicate that the Firtree anticline is not simply an upward continuation of a blind thrust, but a faulted, salt-cored fold. Minor folds within the salt are much tighter and more irregular than the major anticline, and curiously trend about N50W (Fig. 2 of Prucha, 1968).

Faults

Only a very few faults with displacements greater than a meter have been recognized in the Cayuga region, most of which are south dipping thrusts. The recognition of most of these faults in artificial outcrops suggest that there are probably other similar faults in the middle Devonian strata that have not been recognized.

The largest and best documented exposed fault in the region is a thrust high on the south flank of the Firtree anticline, exposed in South Lansing in the Cayuga Crushed Stone Quarry and on adjacent valley walls. This thrust locally trends N84°E, subparallel to the axis of the anticline, and has a southerly dip of 20° to 30° (Scott, 1986). The dip steepens where the fault crosses the Tully limestones, generating a small ramp-flat geometry and related hanging wall structures (small folds). The total displacement on this purely dip-slip feature is 65-70 feet. The extension of this fault westward across Lake Cayuga, noted in New York State Geological Association Guide Book, 31 (1959), has not been subsequently substantiated.

Other thrusts in the region occur in the band of carbonates between the north end of the Finger Lakes and Syracuse (Chute, 1964; Wm. Brice, 1986 pers. comm.). These are all north vergent faults with moderate to steep dips and displacements of up to 50 feet. Faulting may either be more common in these strata (Engelder and Geiser, 1980) or may be concentrated where the deforming sheet of strata overlies the original margin of the salt and resistance along the decollement increases. Thrusting within the Salina group is documented by wells in the Watkins Glen Brine Field by Jacoby and Dellwig (1974, p. 231), who feel these thrusts do not penetrate the overlying section.

Other Deformational Features

Folding and faulting account for less than 1% horizontal strain in the strata above the decollement in the Cayuga region (Engelder, 1979a). Far more strain (up to 15%) is recorded by distributed layer parallel shortening, expressed as ductile intergranular flow, intragranular flow, and pressure solution (Engelder, 1979b). Intergranular flow and rotation of clay platelets is suspected to have accompanied an early soft sediment deformation (Engelder, 1985), and intragranular flow is documented by calcite twinning in calcareous fossils and in limestone units (Scott, 1986; Engelder, 1979a). Pressure solution occurred both as stylolitic seams in limestone and by a faint pressure solution cleavage in siliciclastics (Geiser and Engelder, 1983). All this deformation appears to be Alleghenian in age, but Engelder and Geiser (1983) provided evidence to suggest that an early phase, responsible for fabric orientation and for one joint set had a maximum shortening direction that was oriented slightly west of north in the Cayuga region, whereas a later phase shortening was more northerly directed. Shortening, but of a much reduced magnitude was also noted in the strata beneath the decollement (Engelder, 1979b, Engelder and Geiser, 1979).

Jointing and Stress Studies

The very regular joint sets in the Cayuga region have been noted for years, but new understanding has been provided by the studies of Engelder and colleagues. Four regional joint sets are recognized; two cross-strike sets related to separate phases of the Alleghenian orogeny (Sets lA and lB), a strike set that is a post-Alleghenian "release" set (Set II), and an oblique set that reflects the contemporary stress field (Set III) (Engelder, 1985). The contemporary maximum principle stress, which trends ENE in New York State has been established by seismic focal mechanisms (e.g., Yong and Aggarwal, 1981), by hydraulic fracturing in wells (Zoback and Zoback, 1980), and by analysis of well "break-out" geometries (Hickman et al., 1985). Measurements of residual stress in shallow or exposed strata by such techniques as overcoring show that the elastic stresses impressed during the Alleghenian orogeny remain in the rocks (Engelder, 1982).

CONCLUSIONS

The geology of central New York has been studied for over a century and has been the setting for several seminal geological concepts. It was here that Hall (1959) developed the idea of a geosyncline and here also that Williams (1894) worked out the modern concept of sedimentary facies. With the more recent bias of studies toward the geology of plate boundaries, however, many of us have considered the Cayuga region to be so simple as to warrant little further attention.

The short sightedness of such an attitude has been illustrated by the studies of jointing by Terry Engelder, who has pointed out that the mild deformation of the region affords a unique opportunity to understand deformation mechanisms and the state of stress. With the availability of new tools and techniques, several other regional problems might usefully be addressed. The origin of the kimberlite dikes, which are relatively abundant here, still begs an acceptable explanation. The Silurian salt basin remains enigmatic, and even the contentious nature of the Acadian orogeny might be constrained by regional sedimentary petrographic studies.

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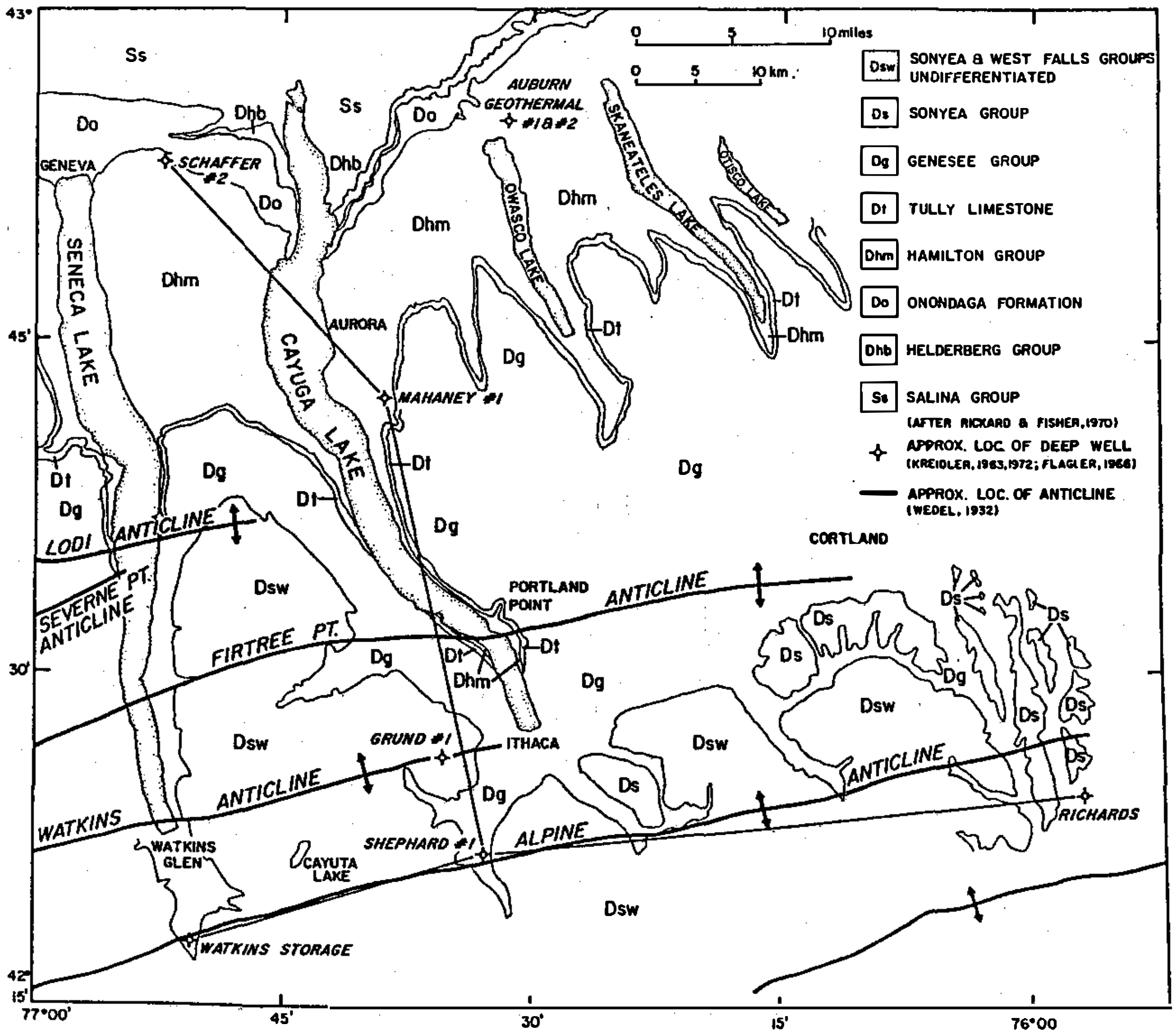

Figure 1: Generalized geologic map of the Cayuga region after Rickard and Fisher, 1970, showing locations of deep wells and anticlines. Sections presented in Figures 3 and 4.

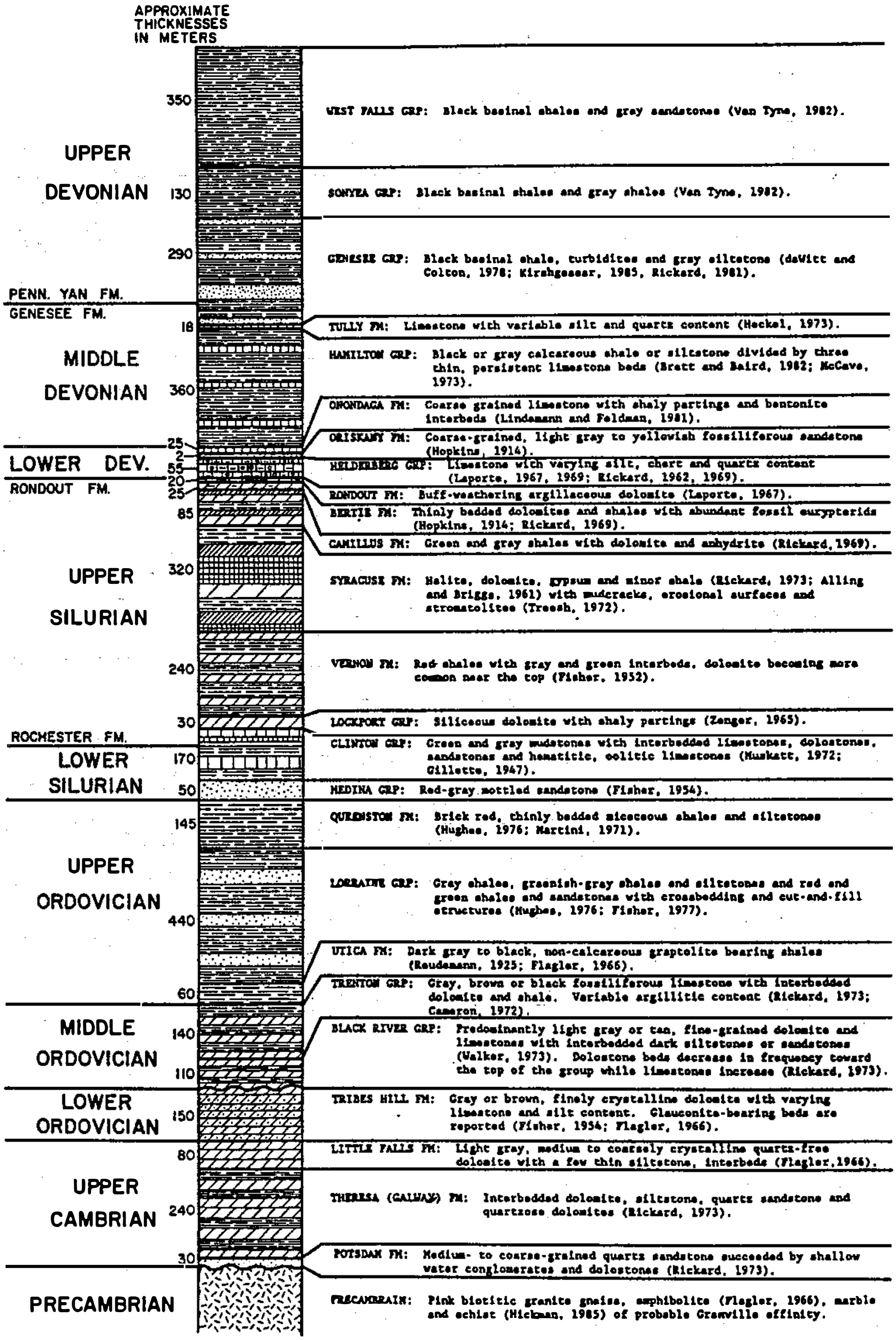

Figure 2: Stratigraphic column near Ithaca, New York. After Committee on Stratigraphic Correlations, 1966, and Rickard, 1969, 1973, 1981.

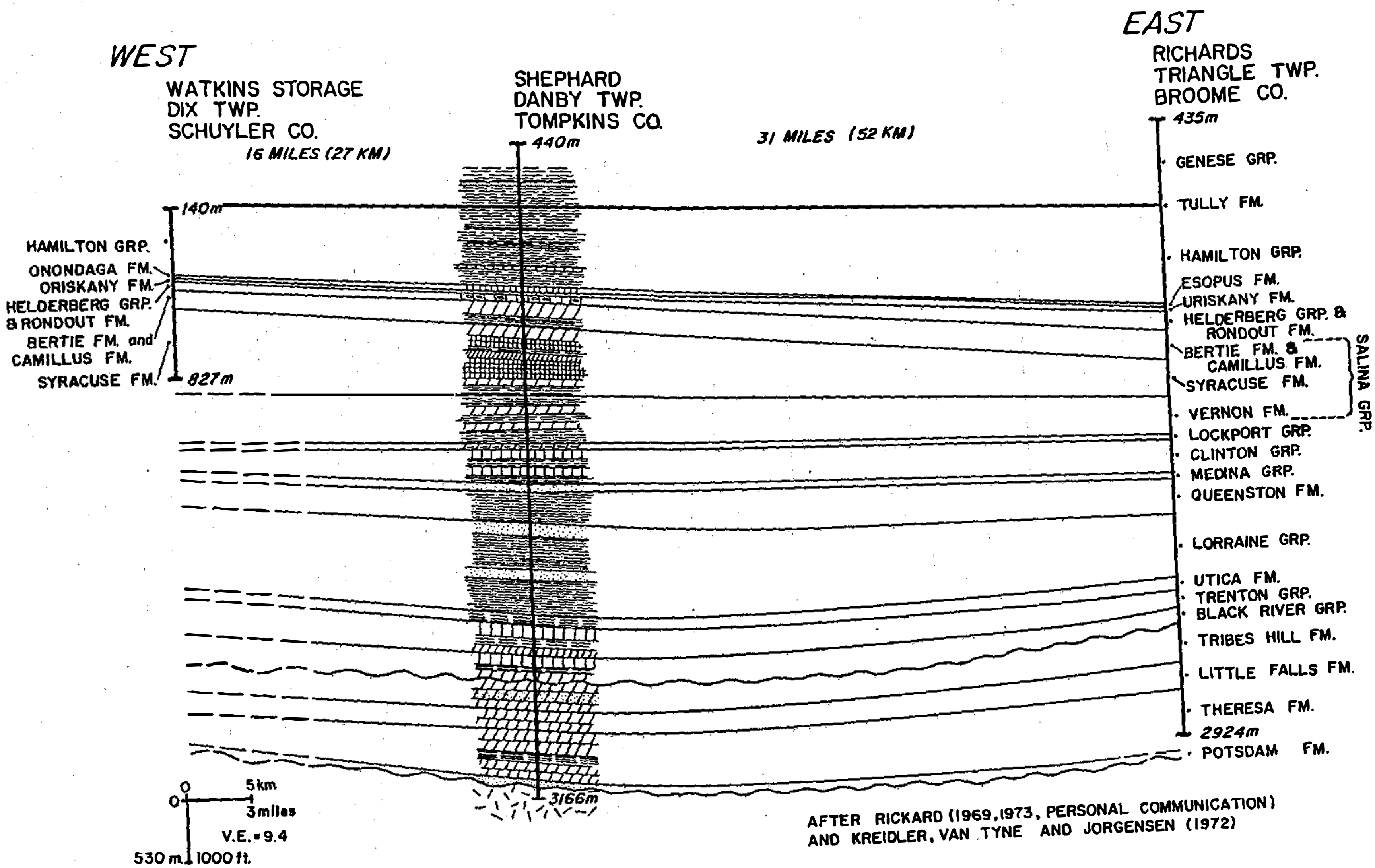

Figure 3: East-west stratigraphic cross-section just south of Ithaca, New York. After Rickard, 1969, 1973, personal communication, and Kreidler et al., 1972.

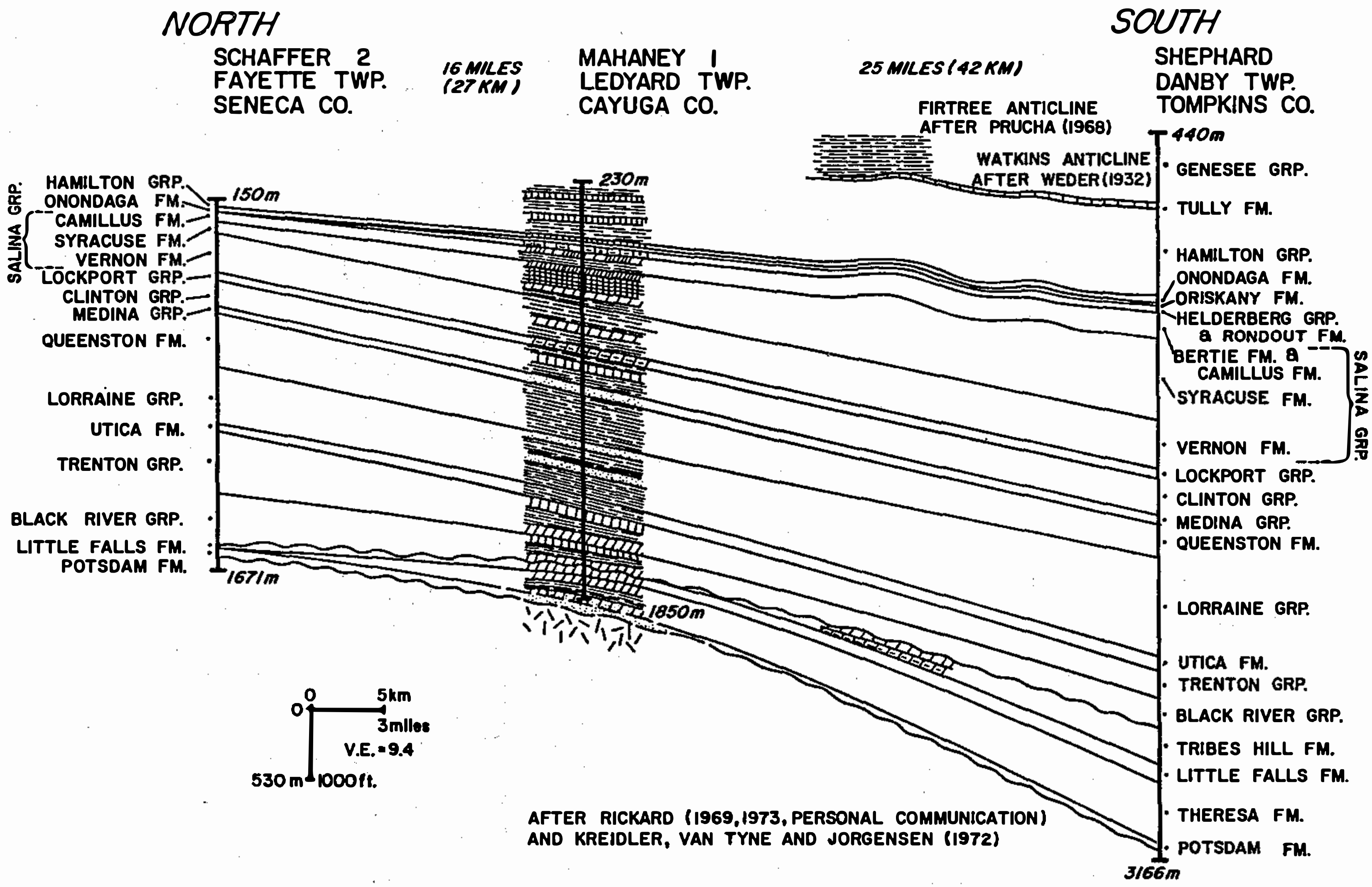

Figure 4: North-south stratigraphic cross section along Cayuga Lake. After Rickard, 1969, 1973, personal communication, and Kreidler et al., 1972.

FIG. 5a

Approximate structure contours on top of Precambrian basement after Rickard (1973) in feet below sea level

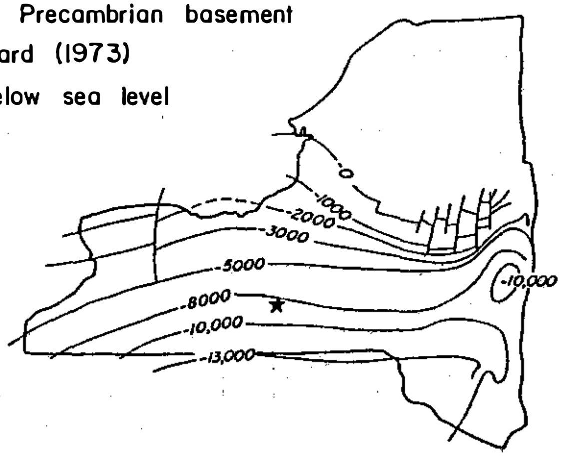

FIG. 5b

Approximate isopach map of Cambrian and Lower Ordovician (all units below the Knox unconformity) in feet, restored over the Adirondack massif after Rickard (1973)

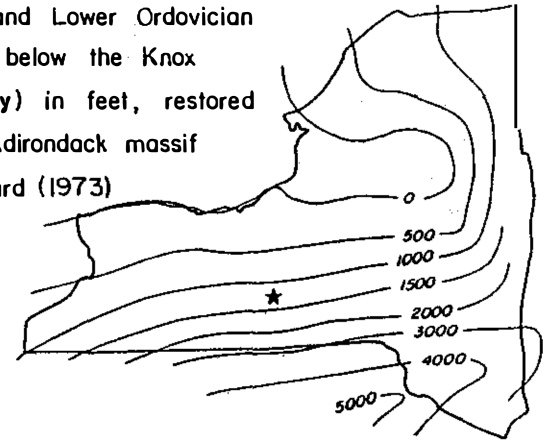

FIG. 5c

Approximate isopach map of the Salina group in feet after Rickard (1969)

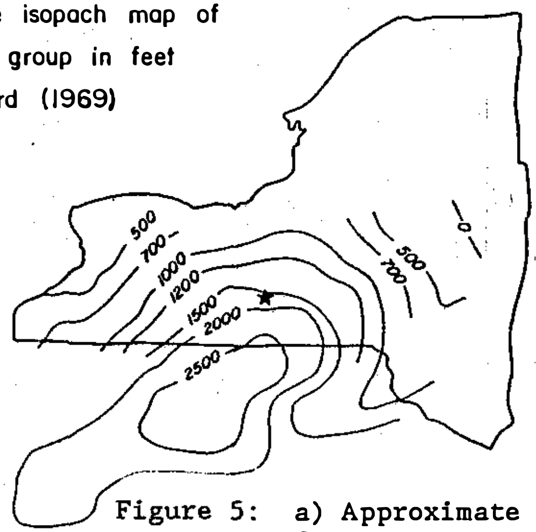

FIG. 5d

Thickness of Genesee in feet after de Witt and Colton (1978)

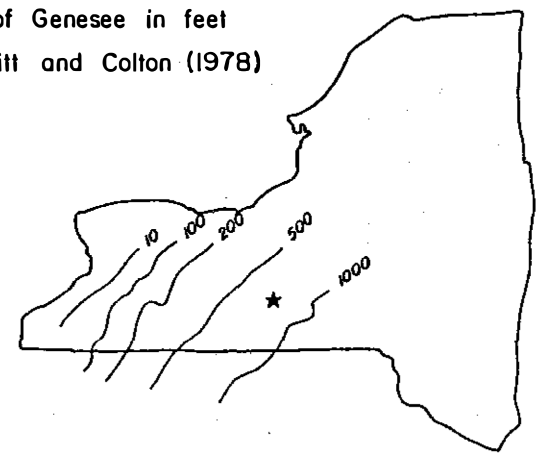

Figure 5: a) Approximate structure contours on top of Precambrian basement in feet below sea level. After Rickard, 1973.

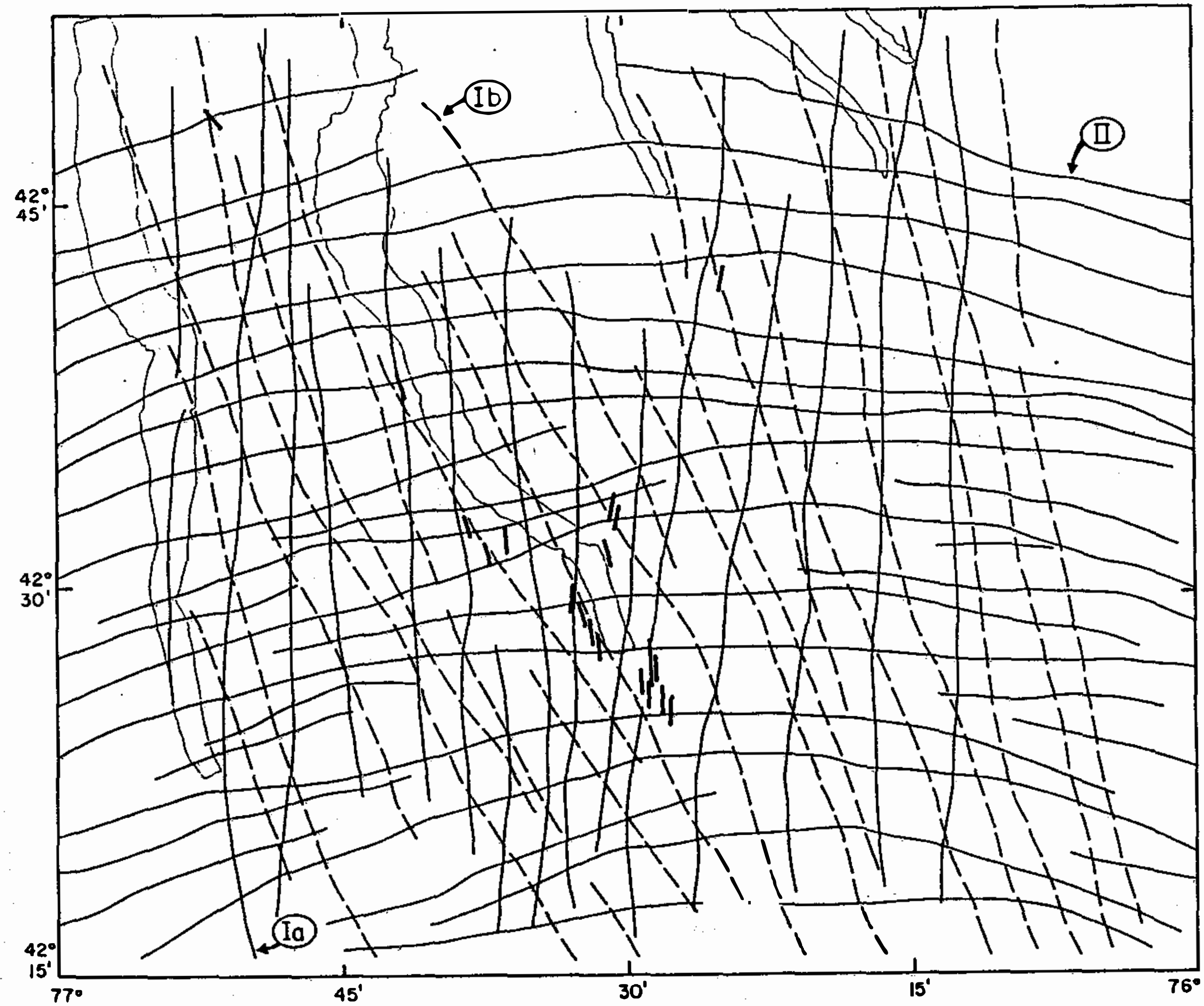

Figure 6: Trajectories of the joint sets I and II (After Engelder and Gieser, 1980) and locations of kimberlite dikes (Foster, 1970) in the Cayuga region.