CHANGE IN STRATIGRAPHIC DIP ACROSS THE CATTARAUGUS CREEK BASIN: STRUCTURAL IMPLICATIONS

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Introduction

This paper is an expansion of some of the material that we presented at a recent public lecture in Springville (McGoldrick et al. 1993).

In previous papers (Vaughan et al. 1993a, Vaughan et al. 1993b), we have shown how planes of stratigraphic dip can be derived from our own measurements, using a least-squares fit. Our measurements have been taken in two locations along Cattaraugus Creek: 1) Directly south of Springville, between Mill Street and Scoby Bridge, and 2) a few miles west of Springville, between the mouth of Connoisarauley Creek and Zoar Bridge.

Three separate series of measurements were conducted in the first of our two study areas. Measurements were made on various strata within the Canadaway Formation. In the three different series of measurements we found the dip to be 38 ft/mile at 257.5°, 35 ft/mile at 251°, and 48 ft/mile at 247°. The average is roughly 40 ft/mile at 252°. See Vaughan et al. (1993a) and Vaughan et al. (1993b).

Further downstream on Cattaraugus Creek, in the study area located between the mouth of Connoisarauley Creek and Zoar Bridge, we took a single series of 22 measurements on various strata within the Canadaway Formation. Results in this study area were substantially different from those in the first area. The stratigraphic dip in this second study area was found to be 78 feet/mile at 164.5°. See Vaughan et al. (1993a).

In this paper we employ published data for the top and bottom of the Canadaway Formation instead of our own measurements. Otherwise the analysis is carried out in a similar fashion. Any group of data points that we judge to be essentially coplanar is fitted to a plane. Such a plane represents the least-squares fit for the top or bottom of the Canadaway, but only within the particular area in which data points appear coplanar. Results derived in this manner are compared to our previous results. Of particular interest are the changes that occur across the Cattaraugus Creek watershed, from one area of essentially constant stratigraphic dip to another. The relationship of known faults to these areas is briefly explored, and these faults are put forward as explanations for the discontinuities between the areas of essentially constant dip.

Study Method

The Canadaway Formation occurs at or near the surface in southern Erie County and in the northern and eastern parts of Cattaraugus County. Although largely covered by glacial deposits, it is visible in outcrops in both counties.

The bottom of the Canadaway Formation (i.e., its contact with the underlying Java Formation) has been identified in various places in southern Erie County, as depicted on the geologic map of the county that was published by Buehler and Tesmer (1963). Likewise, the top of the Canadaway (its contact with the overlying Chadakoin Formation) has been identified at a number of locations in northern and eastern Cattaraugus County, as indicated on the geologic map of that county which was published as Plate 14 of Tesmer (1975).

Data points from both of the above maps were employed for the study described here. Points of known contact between the Canadaway and Java Formations were read from Buehler and Tesmer's map of Erie County. An 8x loupe was used to read the approximate elevation of the contact from the map. A ruler was used to measure distances east and north from a selected reference point. A series of (x,y,z) data points for the bottom of the Canadaway Formation was obtained in this manner. Elevation of the contact above sea level is represented by z, while x and y represent distance east and distance north, respectively. See Vaughan et al. (1993b) for the coordinate system used here, which employs the top of the upper A4 waterfall as the xy coordinate origin.

Table I shows some of the data points obtained in this manner for the bottom of the Canadaway Formation.

A similar procedure was used for the top of the Canadaway Formation in Cattaraugus County. Points of known contact between the Canadaway and Chadakoin Formations were read with an 8x loupe from Tesmer's map of the county. Two inferred contacts were also taken from this map. (In both cases, the inferred contacts were bracketed between closely spaced outcrops, one in the Canadaway and one in the Chadakoin.) Data points (x,y,z) were generated accordingly for the top of the Canadaway Formation. Such points are listed in Tables II and III.

A physical model was then constructed to allow visual comparison of the various data points. Points for both the bottom and the top of the Canadaway were included in the model. The model was made of a piece of plywood to which a section of the 1:250,000 Buffalo topographic map was glued. A finishing nail was driven partway into the plywood at the correct map location for each data point. The height of each nail head above the plywood represents the elevation z of the data point.

In this particular model, the plywood surface to which the map was glued was arbitrarily assigned an elevation of 700' above sea level. Each 25' increment above 700' was represented by a vertical distance of 1 mm on the model, so that an elevation of 1500', for example, was represented by a nail protruding 32 mm above the surface of the plywood. A model built on this scale has sufficient vertical exaggeration (about 33x) for visual judgment of whether groups of data points are essentially coplanar, and also for general visualization of trends within the data sets.

This model was on display during our recent geology lecture in Springville (McGoldrick et al. 1993) and is available for inspection upon request. The primary use of the model was in separating the data into groups of essentially coplanar points. Points that were judged to be essentially coplanar were fitted to a plane by least squares, using a BASIC program written for this purpose (copy available upon request).

Results

Seven points in southeastern Erie County were judged to be essentially coplanar. These seven points and the plane which best fits them are listed in Table I. The best-fit plane for this portion of the bottom of the Canadaway dips 31 ft/mile at 222°. Additional data points from valley locations near Colden and Holland could probably be taken from Buehler and Tesmer's map to reinforce this conclusion. It has not yet been determined whether additional data points from Wyoming County or northern Allegany County would fit, or fail to fit, this same plane.

No best-fit plane has been calculated for a few additional data points in southwestern Erie County. These points, representing the bottom of the Canadaway, deviate somewhat from the plane of the seven points listed in Table I. It has not yet been determined whether these points are sufficiently coplanar with one another, or with possible additional data points in northwestern Cattaraugus or northern Chautauqua County, to justify the calculation of a least-squares fit.

Nine points in eastern Cattaraugus County were judged to be essentially coplanar with one another. These nine points and the plane which best fits them are listed in Table II. The best-fit plane for this portion of the top of the Canadaway dips 19 ft/mile at 186°. Tesmer's geologic map of Cattaraugus County implies that few if any additional outcrops can be found in the county to reinforce this conclusion; however, the current result is well-supported by these nine points, especially given their goodness-of-fit and the large area they cover. It remains to be seen whether additional points that are coplanar might be found in Allegany County.

Six points in northern Cattaraugus County were judged to be essentially coplanar with one another (but not with the nine points listed in Table II). These six points and the plane which best fits them are listed in Table III. The best-fit plane for this portion of the top of the Canadaway dips 23 ft/mile at 206°. It has not yet been determined whether additional points that are coplanar might exist in Chautauqua County.

Discussion

Figure 1 shows the magnitude and orientation of dip, and the approximate geographic bounds within which data points lie, for each of the three best-fit planes described above. The calculated plane that dips 31 ft/mile corresponds to the bottom of the Canadaway Formation. Both of the other two planes (dipping 19 and 23 ft/mile) correspond to the top of the Canadaway.

Figure 1 also shows the magnitude and orientation of dip of strata within the Canadaway Formation, as measured at our two previous study locations along Cattaraugus Creek.

Figure 1 also shows the approximate locations of three relatively well-known structural features: the Clarendon-Linden Fault, Attica Splay, and Bass Island Trend.

We find the interrelationship of the various features in Figure 1 to be significant. More precisely, Figure 1 shows several things that we consider sufficiently well-established and of sufficient import to require immediate further study. These things include 1) at least five distinct "blocks" of different stratigraphic dip, within each of which the stratigraphic dip is relatively constant; 2) intervening areas whose exact boundaries are not yet well defined, but within which the stratigraphic dip must change; and 3) known structural features such as faults, or extensions thereof, that pass through some of these intervening areas.

We refer to "faults, or extensions thereof," because geologists have not yet determined how far the known faults shown in Figure 1 extend. Our purpose, in this and previous reports, is to help identify the extent of these faults and/or help convince others of the need for a full geologic study of the extent of these faults. In this series of reports we are building an increasingly strong case that some sort of connection exists between the known faults and the anomalous dip seen along Cattaraugus Creek between Springville and West Valley.

When we say that five distinct "blocks" of different stratigraphic dip are shown in Figure 1, we are assuming that the top, bottom, and all intermediate strata of the Canadaway Formation lie in more or less parallel layers. Such an assumption is needed if we are to compare stratigraphic dip in different locations, using different layers of the Canadaway Formation as evidence. We consider this assumption—that the layers are more or less parallel—to be a reasonable assumption in light of current knowledge of the Canadaway Formation.

Proceeding on this assumption, we can use a single layer or "stratigraphic surface" to represent the shape and orientation of any and all layers in the Canadaway Formation. While the layers are not likely to be perfectly parallel, the idea of a single stratigraphic surface serves as a good approximation. Such a surface must maintain a constant (i.e., flat) tilt of 31 ft/mile in the indicated area in Figure 1, and likewise constant tilts of 19 and 23 ft/mile in the areas so indicated. Furthermore, the surface must conform to the local tilts of 40 and 78 ft/mile that have been identified along Cattaraugus Creek. In the intervening areas the surface is not known in detail but must be either continuous or discontinuous. If continuous, it must be folded and/or twisted to accommodate the transition from one area of constant dip or tilt to another. A discontinuous surface probably indicates a fault.

What we currently lack is information on <u>vertical offset</u>. In most cases we still cannot say how much, if any, vertical offset exists between different parts of our stratigraphic surface. There does appear to be some offset (a fault or fold, on the order of 80 feet, down-on-the-southwest) between the area of 19 ft/mile dip and the area of 23 ft/mile dip. This can be identified because both dip values refer to the top of the Canadaway Formation. But this case is an exception. In terms of vertical offset, we cannot yet correlate measurements from the top of the Canadaway with those from the bottom, nor can we correlate measurements from either top or bottom with measurements from intermediate strata.

Identifiable marker strata that overlap each other, if such can be found, will be the key to accurate vertical offset measurements and to a fuller understanding of the stratigraphic surface in general. We have done this in a small way in one of our Cattaraugus Creek study areas, where we have found several locations in which both the "hard stratum" and the "big stratum" can be measured. The vertical separation between the two strata is about 70 feet. The challenge that we are now working on is to go beyond this, particularly to trace one or both of these strata over a sufficient distance that we can establish their positions in the stratigraphic column relative to the top and/or bottom of the Canadaway Formation.

We have already tentatively identified our "big stratum" as a siltstone bed that lies at or near the bottom of the Laona Member (see Vaughan et al. 1993b). More recently, as we reported in McGoldrick et al. (1993), we have found what we believe to be our "big stratum" in the town of Holland, N.Y. (on the E side of Phillips Rd., 1 mile N of Holland-Glenwood Road, at an elevation of about 1545 feet). These two tentative identifications, and others we are working on, tend to corroborate one another. If borne out, they will represent a major step in our ability to make vertical correlations.

Two other points deserve further discussion. These points are the strength or soundness of the evidence for the various dip values shown in Figure 1, and the reasons for urgency in further study.

Strength of evidence for different dip values. We believe that all five dip values in Figure 1 (actually ten values, counting both magnitude and direction) are based on strong evidence.

These ten values, while approximate, should be considered accurate to within several feet per mile (dip) and within several degrees (strike).

The dip of about 40 ft/mile at about 252° is based on three sets of our own measurements, involving two entirely different measuring strategies. The similarity of our three sets of results leaves little room for doubt about their general validity. The differences among these three sets of results are small and not unexpected, given the fact that the three sets of measurements were taken in overlapping but not identical study areas, and given the probable occurrence of small faults (with several feet of vertical offset) within the study areas.

The dips of 31 ft/mile at 222°, of 19 ft/mile at 186°, and of 23 ft/mile at 206° are based on very strong evidence, given the fact that we used groups of published data points, with each group of points extending over a large area. Some may question the way in which we have separated the published data points into groups, but we believe that our criterion of essentially coplanar points is sound. It should be noted that we apply this criterion only at the edges of an area that contains essentially coplanar points. We do not reject points that lie within such an area.

The dip of 78 ft/mile at 164.5° is seemingly based on the weakest evidence—our series of 22 measurements—yet we see no room for substantial error. Our confidence in this result is based on several factors, including our familiarity with the measurement technique, general consistency of the data (as judged by the fact that positive and negative dip values tend to lie in mutually exclusive semicircles around the compass circle, as seen in Figure 5, Vaughan et al. 1993a), and also the way in which we have seen this type of measurement confirmed by later measurement in our other study area on Cattaraugus Creek. While we remain confident in the general validity of our calculated dip of 78 ft/mile at 164.5°, we would certainly welcome either a repetition of the measurements or an independent series of measurements in the same study area.

Reasons for urgency. We have been issuing these papers on geology as a series of progress reports rather than a fully developed treatment of the structural geology of the Springville-West Valley area. We have done so for two reasons: Our sense of urgency and our limited resources. In view of our limited resources we have considered it unlikely that we could, through our own efforts, develop an adequate picture of the structural geology of this region in time for the EIS now being prepared for the Western New York Nuclear Service Center.

One of our major purposes in these reports has been to point out the urgent need for competent geologic field work. Such field work is needed to resolve the growing discrepancy between the conclusions we are reaching as a result of our own work, and the old information of questionable validity that agencies responsible for the nuclear site are using for the EIS.

We remain concerned, as we have made very clear over the past few years, that the agencies preparing this EIS have an inadequate understanding of the structural geology of the region. We cannot understand the low level of interest that these agencies exhibit toward the structural geology questions we have raised. We are very concerned by their lack of any sense of urgency in answering these questions. In our view, the agencies are wasting valuable time in refusing to review and investigate the facts that we are inexorably bringing to light. The EIS cannot be properly completed until these issues are addressed and resolved.

Conclusions and Directions for Further Study

Analysis of published data for the top and bottom of the Canadaway Formation shows three distinct "blocks" of essentially constant dip in northern Cattaraugus and southern Erie Counties. Two additional "blocks" are known from our previous studies along Cattaraugus Creek. Discovery of these "blocks" seems to contradict the usual depiction of the Canadaway Formation as a slightly dipping, gently undulating geologic unit. The available evidence indicates that the stratigraphic dip does not change in a gradual or continuous manner but, instead, in a series of discrete changes across the Cattaraugus Creek basin. The dip remains essentially constant across certain areas (the "blocks") and changes through folds or faults in the intervening areas.

The intervening areas between the "blocks" appear to be geologically interesting, for two reasons. One reason is the inescapable inference that folds and/or faults must occur in these intervening areas to accommodate changes in dip between the known "blocks." A second reason is our observation that known structural features, or extensions thereof, pass through some of the intervening areas between the "blocks."

Thus, there are two reasons for believing that folds, faults, and/or other structural features occur in the intervening areas between the "blocks." We think these two reasons are probably related. In other words, the folds and/or faults whose existence can be inferred in the intervening areas are probably identical with, or extensions of, or caused by known structural features such as the Attica Splay and Bass Island Trend. This hypothesis is not yet proven but, based on the evidence presented here, clearly warrants investigation.

Much investigation remains to be done, particularly in proving or disproving the existence of faults in the intervening areas between the "blocks." If faults are found, their exact location, state of evolution, and connection to known structural features must be determined. We will continue to pursue these issues, but the responsibility is not ours alone. Agencies currently working on the EIS for the Western New York Nuclear Service Center must take an active role in addressing and resolving these important questions of structural geology.

References

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Table I: Approximate coordinates (x,y,z) expressed in feet for **bottom of Canadaway** (contact with Java Formation) **in southeastern Erie County**:

x = distance east from top of upper waterfall in A4
y = distance north from top of upper waterfall in A4
z = elevation above sea level

(-11088', 57024', 930')	At Boston
(3168', 68112', 1020')	7/8 mile N of Colden
(4224', 74052', 1050')	2 miles N of Colden
(36960', 65472', 1150')	1 mile NW of Holland
(24816', 87120', 1200')	1-3/8 mile W of South Wales
(51744', 72336', 1240')	2-3/4 miles NE of Holland
(54384', 89760', 1320')	4 miles E of South Wales

Best fit by least squares:

Dip: 31 ft/mile at 222° true
z-intercept: 718'

Table II: Approximate coordinates (x,y,z) expressed in feet for **top of Canadaway** (contact with Chadakoin Formation) **in eastern Cattaraugus County**:

(79728', -109824', 1500')	3/4 mile W of Hinsdale
(87120', -92400', 1540')	Between Ischua and Hinsdale
(100320', -93984', 1540')	4-1/2 miles NE of Hinsdale
(73392', -75504', 1610')	At Fitch
(105600', -58080', 1620')	7/8 mile SSW of Rawson
(23232', -46464', 1680')	NY 240 and Fancy Tract Rd.
(7920', -23760', 1760')	Rock Springs Rd., Ashford Hollow
(-5808', -17424', 1760')	Monk Hill Rd., East Otto*
(95040', -3168', 1900')	W of Crystal Lake, Freedom

*Inferred from closely spaced outcrops above and below contact.

Best fit by least squares:

Dip: 19 ft/mile at 186° true
z-intercept: 1840'

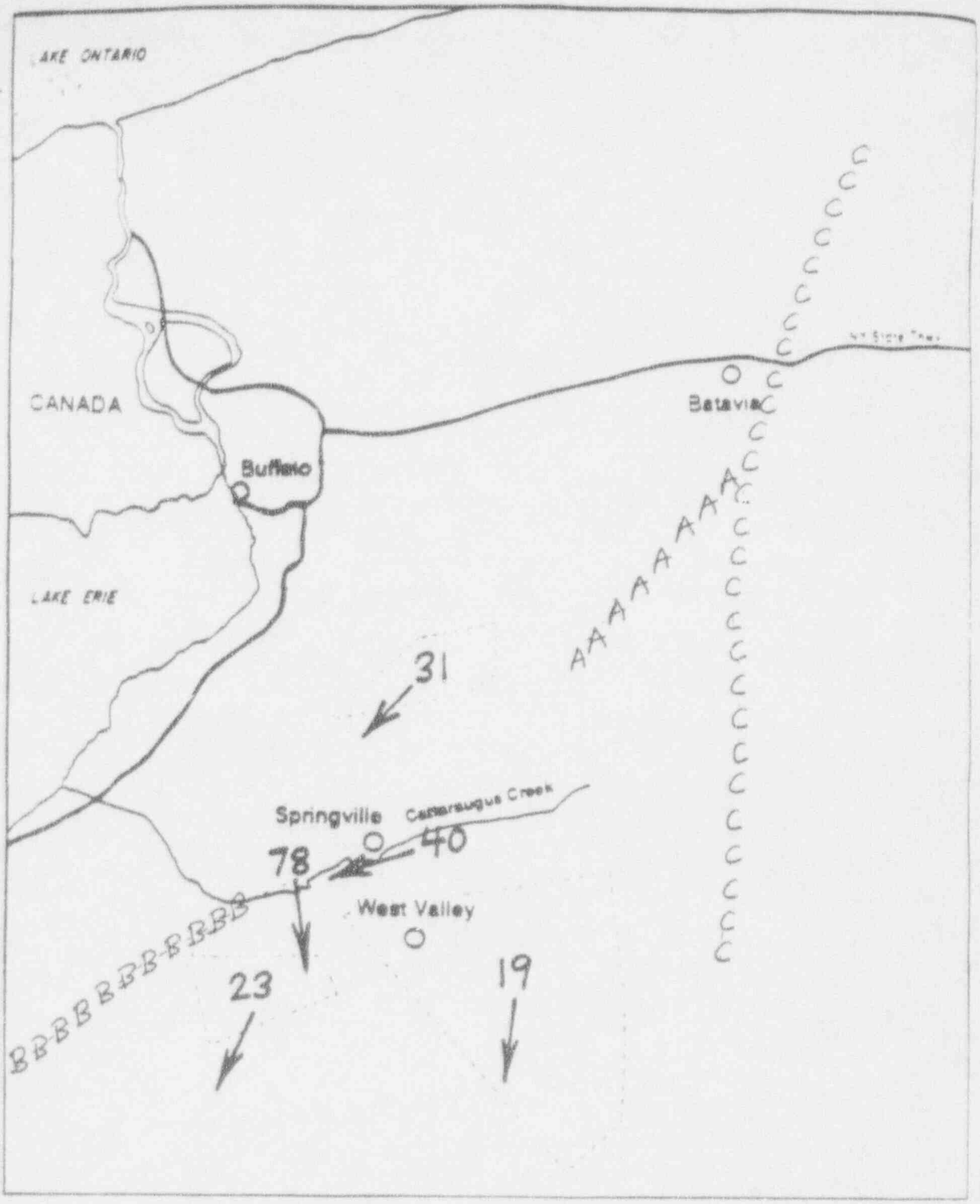
Table III: Approximate coordinates (x,y,z) expressed in feet for **top of Canadaway** (contact with Chadakoin Formation) **in northern Cattaraugus County**:

(-52800', -66000', 1400')	Immediately NW of New Albion
(-56496', -64944', 1450')	1 mile W of New Albion
(-64944', -33792', 1500')	1/2 mile S of Persia*
(-54912', -35376', 1550')	2 miles E of Persia
(-7392', -47784', 1560')	Stony Pitcher Falls, Mansfield
(-16632', -34320', 1630')	8/10 mile S of East Otto

*Inferred from closely spaced outcrops above and below contact.

Best fit by least squares:

Dip: 23 ft/mile at 206° true
z-intercept: 1780'



CCC **Clarendon-Linden Fault**
AAA **Attica Splay**

BBB **Bass Island Trend**

Arrows and numbers show direction and magnitude (in ft/mile) of stratigraphic dip, as determined in this and previous studies.

FIGURE 1