Appalachian Foreland Thrusting in Salina Salt, Watkins Glen, New York

C. H. Jacoby
L. F. Dellwig
International Salt Company
Clarks Summit, Pennsylvania and
University of Kansas
Lawrence, Kansas

ABSTRACT

The Watkins Glen area lies along the western edge, and at the northern termination of mapped Allegheny Plateau folding. Surface mapping of the Devonian strata identified a series of northeast-southwest trending open folds. Studies to the northeast of the brine field in the mine of the Cayuga Rock Salt Company at Myers, New York resulted in the identification of a decollement beneath the mine-salt section, the faulting and folding being easily correlated with the major surface structure. In the Watkins Glen brine field a major north-south strike-slip fault extends down at least to a bedding (step) thrust along which the block to the west of the tear fault has moved north a minimum of 1200' in the southern portion of the brine field. As the thrust breaks up into the upper portion of the section to the north, the fault divides into several faults each of which compensates for a portion of the total displacement along the single thrust to the south. Additional faulting on a small scale as well as minor folding are recorded in nearly all wells, but correlation of these is not possible.

INTRODUCTION

The Watkins Glen area lies along the northwestern edge, and near the northeastern termination of mapped Allegheny Plateau folding (Figure 1). Surface mapping of the Devonian strata in 1909 (Williams, Tarr, and Kindle) defined a series of east-northeast trending open folds, prominent among which is the Firtree Point anticline. Until 1955 most geologists considered such broad open folds of the Appalachian Plateau (Allegheny Plateau of the Watkins Glen area) as deep structures which persisted into the underlying Paleozoic sequence of rocks. Although this view prevailed for the plateau in general, the Cumberland Block marginal to the thrust faulted Valley and Ridge Province in the Southern Appalachians was documented as early as 1934 (Rich, 1934) overlying a bedding thrust (Pine Mountain). Subsequent study (Wilson and Stearns, 1958) resulted in the identification of a similar thrust to the south and west of the Sequatchie anticline.

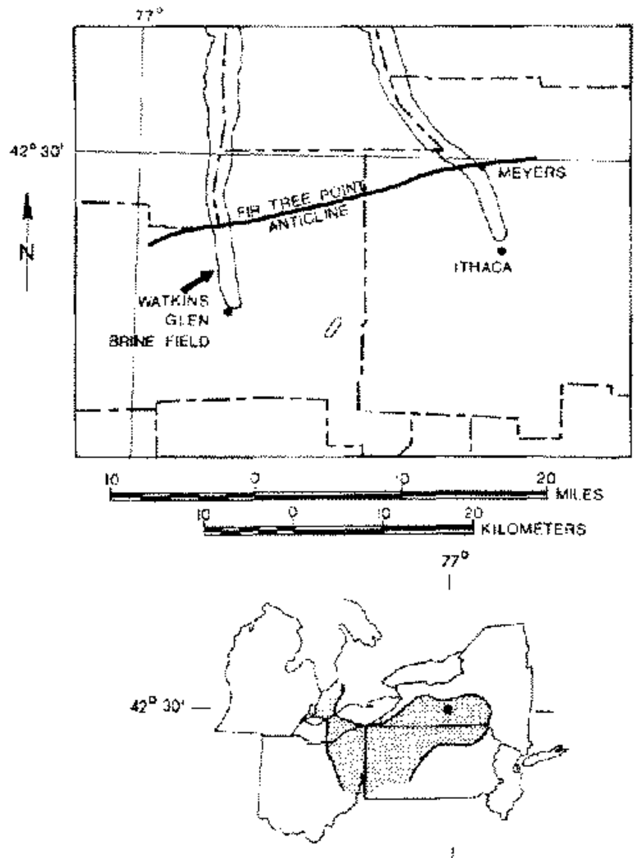

Figure 1. Index map, Watkins Glen, New York area.

Although bedding thrusts were accepted for the Cumberland Plateau of the Southern Appalachians, no such

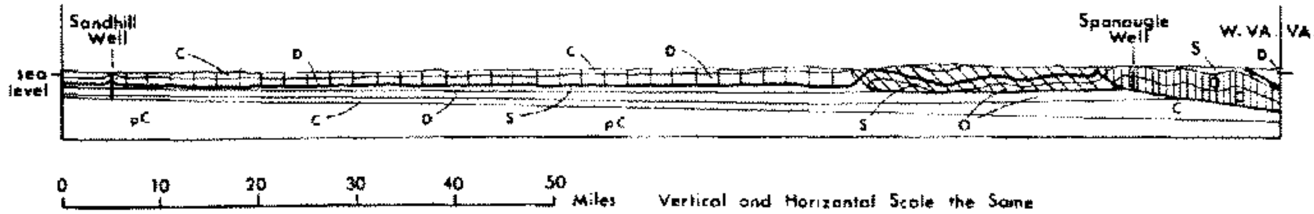

Figure 2. Theoretical cross section of Appalachian Plateau province in West Virginia (along line A-A', Figure 5) to illustrate the decollement hypothesis for folding. Vertical and diagonal lines indicate possible extend of decollements, as in Figure 5. Letter symbols: C—Carboniferous (including Permian); D—Devonian (heavy line = Lower Devonian); S—Silurian; O—Ordovician; C—Cambrian; pC—Precambrian (Rodgers, 1959).

structures were identified or even considered a probability in the Allegheny Plateau adjacent to the Central Appalachians. This in part might be attributed to the domination of the deformation of the adjacent Valley and Ridge Province by folding rather than by faulting. However, with the drilling of the Sandhill Well, in Wood County, West Virginia in 1955, there began the development of the concept of northwestward sliding of the near horizontal strata which overlie the viscoplastic Silurian salt on the Plateau (Figure 2), (Rogers, 1959). This concept has since been documented in several additional areas as a result of renewed subsurface exploration on the Plateau.

Although by 1955, the regional picture of the decollement tectonics in the Allegheny Plateau was well established, little was known about the details of movement in and above the lubricating Salina salt. In 1955 Jacoby obtained the first salt core recovered in the Watkins Glen area and a year later secured a similar Watkins Glen area core from Well 25 (Figure 3) which cut only the F3 and F2 salts. Partially due to the intense deformation and flowage which had been observed in the F1 salt in the Cayuga mine at Meyers, New York, the faulting in the Watkins Glen-Ludlowville area went uninterpreted.

With the drilling of Well 29 at Watkins Glen in 1958, core logs and gamma ray curves gave the first discernible evidence that thrust faulting had occurred. Coring and logging of additional wells led to the establishment of the first cross section of the Salina in this area in 1961 (Jacoby, 1963, 1969).

Prucha (1968) in 1964 conducted a study in the mine of the Cayuga Rock Salt Company at Meyers, New York which resulted in the identification of the decollement beneath the mine salt section, the faulting and folding being easily correlated with the major surface structure. In his analysis of deformation he predicts that southward the surface of detachment would pass into a thrust fault. In 1967, Dellwig undertook a comprehensive study of the structural aspects of the Watkins Glen brine field, utilizing additional cores and gamma logs made available by the drilling of Wells 39, 40, 41 and 42 in 1964. In 1968 this study was further expanded by utilizing logs from the

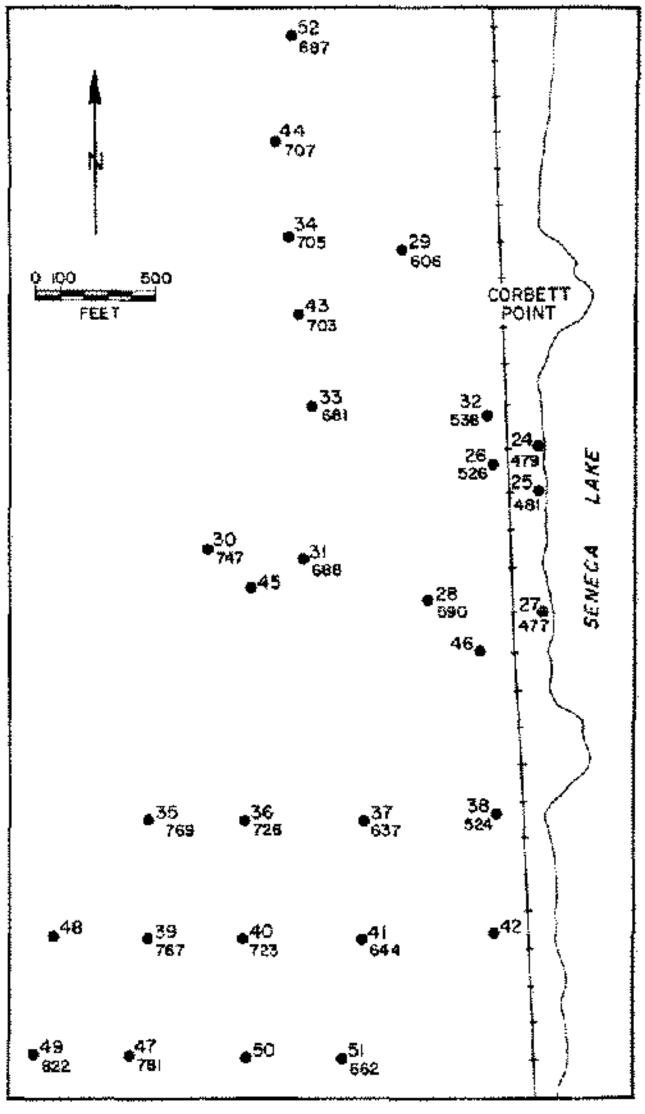

Figure 3. Index map, Watkins Glen, New York, brine field, International Salt Company. Upper number of each pair is well number, lower is surface elevation (where known).

newly drilled Wells 43 and 44 and again in 1972 with data from Wells 47, 48, 49, 50, 51 and 52.

BRINE FIELD

The first salt well was drilled in Watkins Glen at Salt Point in February 1893. This and the subsequent wells were located in and around International Salt Company's evaporator plant in the development of what is now termed the "South Field." These wells used the system known as "Annular Injection" in which water is pumped down the annulus formed by the casing and the tubing of the well and the brine is recovered through the tubing. Due to the folk-lore belief of the cable tool drillers as to the location of bottom of the salt formation, plus the presence of a 4 to 6 ft. layer of anhydrite within the F3 salt sequence which blankets the Watkins Glen area, wells were terminated after penetrating 90 ft. of the F3 salt.

Wells drilled during these early years were drilled as single wells equipped with a string of swaged two diameter wrought iron casing, some type of pumping device and tubing. The wrought iron casing was not cemented in place and occasionally was galvanized or wrapped to prevent its corrosion by the Oriskany or Cherry Valley "black water." The original air lifts which were installed in the wells were made necessary by the lack of the seal behind the casing which would have isolated the brining fluids from the overlying formational fluids. This air lift system gave way to modernization by the installation of submersible pumps and tubing. Gradually, during brining operations, all of these old style wells which had formed a morning glory-shaped cavity, coalesced with adjacent wells at the contact between the top of the F3 salt and the overlying shale. Due to the broad roof spans which were developed, there was apprehension of damage to the surface by rock movement. Brining operations in the vicinity of the plant were discontinued with the closing down of Wells 4 and 7A in 1960.

With the drilling of Well 25 in 1955, not only was the first accurate subsurface geological data obtained in the Watkins Glen area, but a rotary oil field rig was utilized for the first time for the drilling of a salt well in the state of New York. Additionally, this was the first salt well in the state of New York to be hydraulically fractured. This new style of salt well was fractured at the bottom of the salt sequences which was by then (1955) known to have a total aggregate thickness of over 500 feet. Generally, these wells were drilled with a 12-1/4 in. bit equipped with a string of 8-5/8 in. steel casing and cemented back to surface. This cementing not only allowed a pair of fracture connected wells to operate on pressurized U tube system, but it also protected the casing against the corrosional black waters of the formations penetrated by the well. Fracturing of the salt formations was accomplished either by perforating the casing at a pre-selected point in the salt just above the Vernon shale or "landing" the casing just above this point, drilling out and applying the pressure to the formation exposed to the well bore.

All subsequent wells were cored and electrically logged in order to clarify an understanding of the local geology, interpret the results of hydraulic fracturing and extrapolate these findings for the location of other salt wells. As development proceeded with respect to fracturing and brining operations, it became obvious that more care was required in the interpretation of the geological data.

STRATIGRAPHY

The salt sequence of the Syracuse Formation penetrated by the brine wells at Watkins Glen consists of an interbedded sequence of salt, dolomite and shale, ranging in thickness from north to south from 725 ft. (a true thickness with no duplication through thrusting) to 800 ft. The base of the sequence there is found to depths of 2900 ft. (at an elevation of –2100 ft.) as compared with a depth of –1880 ft. at the Cayuga Rock Salt Company mine. Based on subsurface log data, the base of the sequence strikes N. 78° E. and dips 185-190 ft./mi. to the south.

In the definition of stratigraphic units in the wells in the Watkins Glen brine field, both the classification used in early logging and that of Landes (1945) are indicated. The uppermost identifiable salt of the sequence was originally defined as the No. 1 Salt (F3 Salt) and the rock unit immediately below the No. 1 Rock. On this basis six salt and 5 intervening rock units were originally defined, units were easily recognized by the gamma ray log signature (Figures 4,5). Several stratigraphic logs show some digres-

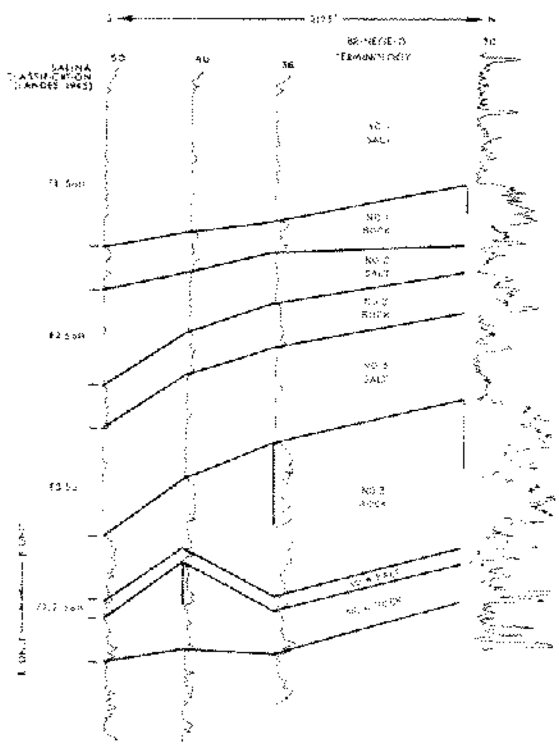

Figure 4. North-south section correlating on gamma ray logs, No. 1 Salt to No. 4 Rock. Thick vertical lines delimit repeated section.

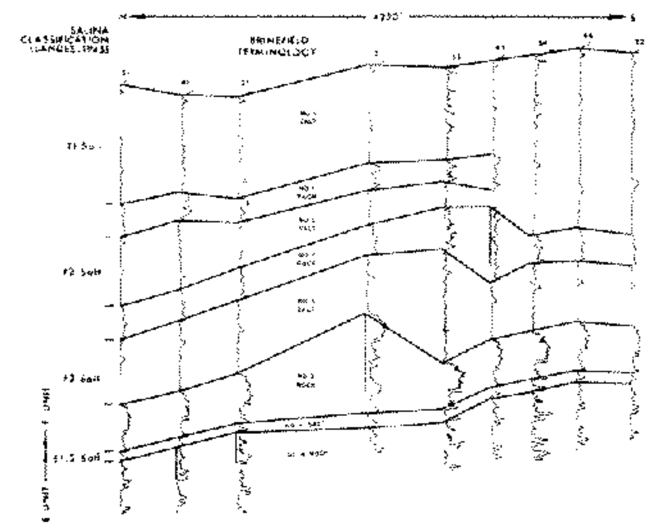

Figure 5. North-south section correlating on gamma ray logs, No. 1 Salt to No. 4 Rock. Thick vertical lines delimit repeated section.

sion from the normal classification and these were revised to fit the normal sequence. At the northern end of the field, correlation of No. 4 Salt, No. 6 Salt and No. 4 Rock can be accomplished with little difficulty, whereas in the south end of the field, repetition of the lower units is common but correlation can be accomplished with relative ease in rock and salt units 1, 2 and 3. Repetition of rock units is generally easily identifiable, for the gamma ray-neutron log "signature" of each individual unit is unique (Figure 6). Repetition within a salt unit is more difficult to recognize because of the lack of a characteristic signature.

STRUCTURE

In gross aspect the local structural picture is relatively simple, provided of course, that one ignores the multiplicity of small faults which play a critical role in the development of the brine field. A major north-south strike-slip fault is located east of Wells 41, 37 and 29; a tear which extends down at least to a bedding (step) thrust along which the block to the west of the tear fault has moved north a minimum of 1,200 ft. in the southern portion of the brine field. This estimate is based on the repetition of the No. 3 Rock in Wells 36 and 30 (Figure 4), the distance between these wells being approximately 1,200 ft. The north-south section through Wells 37 and 31 (Figure 5) shows good correlation of No. 3 Rock, duplication between 30 and 31, but to the south in Well 37 the repeated section is in No. 4 Rock, indicating some tearing between Wells 36 and 37. This condition is not uncommon throughout the brine field. The major tear has been defined by a consistent lack of correlation between wells across this line (Figure 7). As the thrust breaks up into the upper portion of the section to the north, the fault divides

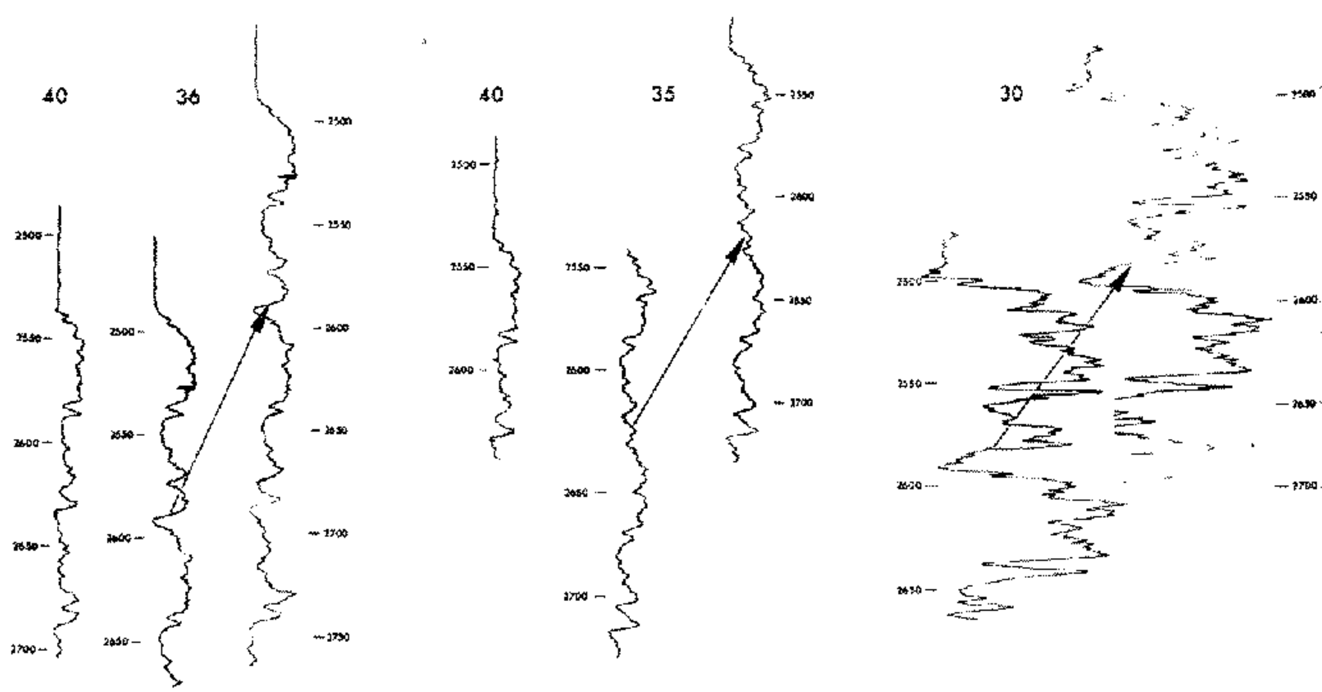

Figure 6. Sample correlations in faulted sections. *Left*—Gamma-ray log for Well 40 is normal, correlation at top of rock unit with Well 36 is shown in center log, correlation at base is effected through movement into position on right. *Center*—Log for Well 40 is normal. Correlation with top of log 35 is shown in center log. Correlation with base of rock unit is effected through movement into position on right. *Right*—Duplication of section is demonstrated through movement of log as shown by arrow, numbers are logging depth, *not* elevations.

into several faults each of which compensates for a portion of the total displacement along the single thrust to the south. These movements, along with flowage in the incompetent salt units, collectively accommodate the movement along the single fault to the south. Additional faulting on a small scale as well as minor folding are recorded in nearly all wells, but correlation of these is not possible. East of the tear fault, thrusting is on a small scale and displacement is negligible. The absence of significant repetition through thrusting east of the tear fault has been used to establish the position of the fault.

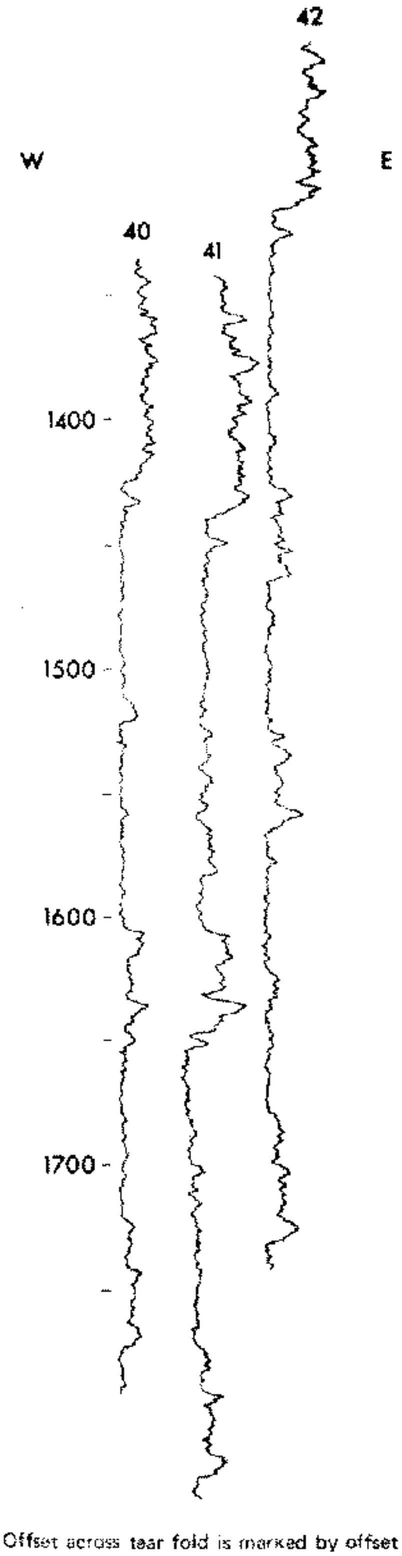

Figure 7. Offset across tear fold is marked by offset between Wells 41 and 42. All logs plotted relative to sea level datum as shown on left.

The major thrust in the western half of the brine field is identifiable through repetition of beds in the lower portion of the section at the south end of the field. Thrusting apparently has occurred in shale beds or along salt-shale contacts. At irregular intervals the thrust breaks into and across the overlying rock and salt to the next higher lubricating shale layer along which movement can continue. As the fault breaks across the No. 3 Rock into the overlying salt, the angle of dip of the fault plane increases and the fault horsetails. Some thickening and locally high dips in the beds indicate that flowage has also compensated for some of the displacement which appears to have been along the single fault surface to the south. The structure contour map on the top of the salt gives no indication of the faults breaking up into the overlying sediments. It would seem reasonable to assume that to the south the fault drops down into the underlying Vernon Shale.

Structure contour and isopach maps reveal that both the upper and lower surfaces of the salt are relatively uniform; the lower surface shows a regional southerly dip and the upper surface shows a pronounced dip to the west as a result of a general southeasterly thickening of the salt unit. However, thickening to the southeast is contrary to expectations, because thickening through faulting has occurred west of a north-south tear fault east of Wells, 41, 37, and 29 and west of Well 28. Repetition of units east of this line has been minor.

In addition to the faulting described, it is noted in lithologic logs that slickenslides at the top of the No. 3 Rock are apparently common to all wells. In general the section downward from the top of the No. 3 Rock is dominated by clastics, whereas the section above the No. 3 Rock is predominantly salt. The movement of the upper more plastic section over the underlying more rigid section would be anticipated and apparently has occurred, but the extent of movement cannot be determined. In the northern portion of the field, to accommodate slippage along this contact, the major strike-slip fault may extend down below the thrust fault to the top of the No. 3 Rock.

In detail the picture is much more complex. Numerous small faults resulting in repetition of section and identifiable in only a single or several wells are found throughout the field. Variations in thickness of salt units though flowage and/or faulting (inseparable because of the lack of a characteristic log signature) is also not uncommon and this, combined with the faulting presents a complex pattern of minor displacements superimposed on a general south dipping decollement broken by a major north-south tear, the terminal expression of the total movement finding surface manifestation in the Firtree Point anticline.

STRUCTURAL CONTROL OF BRINEFIELD DEVELOPMENT

It should thus be expected that difficulties in production arising from the geologic environment should be encountered and explainable to at least some degree in the light of the structural setting. For example,

Well 29. During fracturing, a flow of brine at the surface 0.5 mi. to the north must certainly be interpreted as the result of movement of brine from the well along the tear fault.

Well 33, 34, 43. In fracturing of Well 33 to 34, alternate buildup and recession of pumping pressures indicated that the solution channel was being closed by rock movement from time to time. In the light of subsequent geologic information, the occurrence of intermittent collapse should not have been unexpected, inasmuch as in this area of the brine field the major thrust has broken up, into and through the No. 3 Salt. Faulting above the cavity created by solution between Wells 33 and 34 may have resulted in a weakness which led to the observed periodic collapse and pressure buildup. It is over this area that the major thrust bifurcates at several different points, creating a series of planes of weakness in the section overlying the solution zone.

Wells 41, 42, and 37. The inability to fracture from Well 41 to 42 and the subsequent connection between 41 and 37 may be related to the position of the tear fault. One might postulate that movement of solution from Well 37 may have been blocked to some degree by the tear fault (if it extends below the thrust) but, even if this were not the case, movement of fluid along the tear fault or up dip along the thrust would be with a much greater degree of ease than across the tear fault into Well 42. However, an effort to fracture from Well 40 to Well 39 resulted in connection with Well 42; no connection was made with 41, this demonstrating the complexity of the structural setting in this area.

SENECA LAKE SALT ANTICLINE

The total salt-rock sequence shows a constant increase in thickness in a west to east direction (Figure 8). As mentioned previously, the base of the salt shows a consistent dip to the south, whereas the top of the sequence expresses the increase through a dip to the west.

Seneca Lake stands a 445 ft. above sea level and bottoms at 174 ft. below sea level. Northward projection of data obtained through drilling south of the lake in glacial valley-fill suggests that the lake is bottomed with approximately 600 ft. of gravel, thus, the estimated elevation of

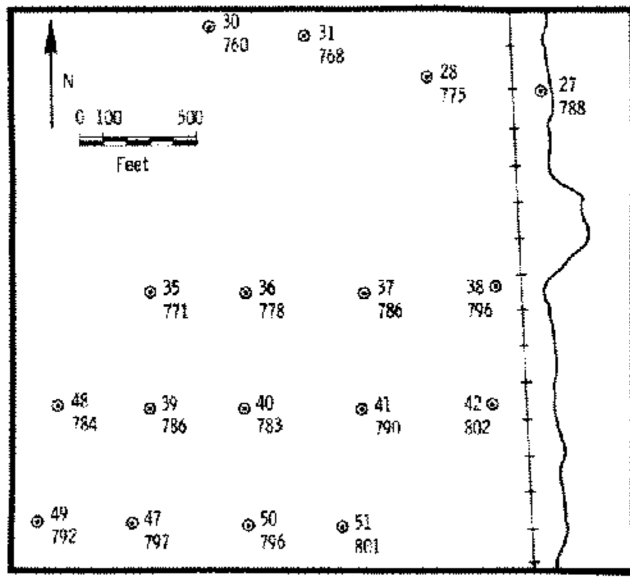

Figure 8. Southern half, Watkins Glen brine field showing well designations (upper figure of each pair) and total salt thickness (lower figure of each pair).

the bedrock surface at the bottom of the lake is approximately −775 ft. The top of the salt section in Wells 24, 25, and 27 next to the lake is at an elevation between 1305 ft. and 1315 ft. Westward from the lake in the brine field area the ground elevation rises to approximately 300 ft. above lake level. Thus the salt in the brine field is loaded with approximately 2,000 ft. of rock compared with the salt beneath the lake which is loaded with the equivalent (assuming a porosity of 30 per cent for gravel and an average rock density of 2.7) of 1300 ft. of rock. In the present atmosphere of geofantasy one cannot help but postulate that the higher elevation of the upper salt surface to the east toward the lake is in large part due to flowage of the salt toward the area of least overburden beneath Seneca Lake and there is the possibility of the existence of a salt structure province in west central New York.

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