Geothermal Energy Potential in the Appalachian Basin of New York State

New York State Energy
Research and Development
Authority

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GEOLOGY, DRILL HOLES, AND GEOTHERMAL ENERGY POTENTIAL OF THE BASAL CAMBRIAN ROCK UNITS OF THE APPALACHIAN BASIN OF NEW YORK STATE

Final Report

Prepared for

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ENERGY RESEARCH AND DEVELOPMENT AUTHORITY

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306/ET-AES/81

ERDA Report 81-14 June 1981

NOTICE

First Printing: August 1982

ABSTRACT

The published geologic and geophysical records plus data gathered from deep wells during hydrocarbon exploration were inventoried, discussed and summarized to evaluate hydro-geothermal energy potential in the western counties of New York, south of the 42^{o} latitude. An assessment is provided of local geothermal energy potential based on these data. The assessed potential is a function of the geothermal gradient, the depth of porous Cambrian age sedimentary units and a variety of features thought to be related to deep fracturing and hence enhanced porosity and permeability.

The completion history of a selected set of plugged and abandoned deep wells was examined to determine the feasibility and advisability of re-entering these holes for geothermal development. All wells showed extensive cement plugging and 'uncertain' materials introduced for bridging. It was recommended that no attempt be made to re-enter these wells.

The hydro-geothermal energy potential in Western New York State is largely comparable to that of other regions possessing pourous/permeable units of sedimentary rock at sufficient depth to contain formation waters of useful temperatures ($>140^{o}F$). A comparison of geothermal reservoirs in New York to similar sites now under development in Canada and France has revealed that potential resources in New York State are slightly hotter, though somewhat thicker and less permeable with significantly higher proportions of dissolved constituents. Thus, cautious optimism with regard to the future development of low-temperature geothermal resources in New York State is warranted.

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SUMMARY

Water present in sedimentary rock formations occurring below 3000 feet from the surface is commonly heated to useful temperatures by normal geothermal gradients. If the water occurs in sufficient quantities and can be extracted easily, the geothermally heated 'formation water' may be economically used to heat buildings or provide low-grade process heat for industrial or agricultural applications.

In this study the Appalachian Basin of New York State below the 42° parallel was evaluated for its hydro-geothermal resource potential. The data examined was gathered from published geologic, geophysical, hydrologic and tectonic studies of the region. In addition, information was obtained from oil and gas exploration records and deep-well waste disposal studies.

A hydro-geothermal resource has two primary characteristics: 1) Pore fluids in the target formation are heated to a useful temperature, and 2) The permeability of the target formation permits a pumping rate of pore fluids that yields economic quantities of heat energy at the surface. Other characteristics that bear on the ultimate viability of the resource are water chemistry and the hydraulic head of the formation fluids.

The target formations in the study area are the Cambrian-aged Galway and Potsdam formations. The lower (older) Potsdam formation is believed to be a blanket basal sand that lies unconformably on the eroded surface of Precambrian metamorphic and intrusive rocks. These sands are replaced upward by fine- to course-grained quartzose dolostones and dolostones of the Galway formation. In the southern region of the study area the Galway is capped in the west with a 50-100 feet thick sandy member called the Rose Run Sand and a dolomitic formation called the Little Falls. The top of this sequence of rocks is marked by the wide spread Knox unconformity. Water 'shows' have been encountered in wells throughout the study area in all these formations and at the Knox unconformity.

Water encountered in wells drilled for oil and gas exploration flowed from 2 to 1300 gal/hr without stimulation or pumping. At one deep-well disposal study project near Buffalo, N.Y., the Potsdam was tested for injection capability and achieved an inflow rate of 24,000 gal/hr. A viable geothermal

well must produce, through pumping, at least 6000 gal/hr. These data indicate that at least some wells in the deep formations could sustain adequate pumped flows.

The temperature of the target formations and their pore fluids was simply extrapolated downward using surface temperatures and measured geothermal gradients. The formations lie $>$ 3000 feet below the surface, increasing southward and eastward throughout the study area. Calculated formation temperatures range from 90°F to $>$ 220°F in the deeper parts of the Basin.

The chemistry of the formation waters has been measured from 100,000 to 300,000 ppm dissolved solids in some wells. Dissolved NaCl is the dominant constituent and waters range from neutral to moderately acidic. The water chemistry poses a significant challenge to the design of surface heat exchange equipment that resists corrosion and precipation and remains economic.

Whereas temperature of the target formations can be confidently predicted and is adequate for a range of low-temperature applications, the prediction of porosity and permeability is very difficult and is critical to the viability of a hydro-geothermal resource. Subsurface samples, although sparse, suggest a general 'tightening' of the matrix porosity of target formations to the east. Some evidence exists that fracture porosity is developed at tectonic structures composed of steeply dipping deep fracture zones throughout the study area. These zones may provide significant enhancement of the flow characteristics of the target formations. The geologic and geophysical factors that may assist in locating the deep fracture zones have been identified here and a synthesis of the tectonic indicators of potential enhanced porosity and permeability are presented for the study area.

The feasibility of reentering abandoned oil and gas wells to reduce the high cost of drilling was studied. It was found that due to the uncertainties of redrilling operations and the stringent casing requirements of geothermal wells, reentry was not a viable solution to reduce initial capital costs. It is suggested that some of the 400 wells plugged and abandoned annually in New York be intercepted from destruction and evaluated in the context of hydro-geothermal energy resource potential.

Other sites throughout the world have developed hydro-geothermal energy resources. Sites with published information available and similar geologic contexts have been developed near Paris, France and at Regina, Saskatchewan, Canada. The conditions anticipated in New York have been compared here. Reservoir temperatures are potentially higher in New York, as are reservoir thicknesses. However, formation porosity and permeability are somewhat lower in New York and the proportion of dissolved constituents is significantly higher. A cautious optimism is warranted with regard to New York's potential for viable low temperature geothermal energy resources.

ILLUSTRATIONS (Continued)

I. INTRODUCTION

The following report is divided into 6 major sections:

1. Introduction to the nature of geothermal energy derived from sedimentary basins, also known as hydrothermal energy.

2. An inventory of available data from oil and gas exploration in the western part of New York State.

3. Discussion and advice on the feasibility and adviseability of reentering old oil or gas wells to establish hydrothermal energy systems.

4. Summary and analysis of geologic and hydrologic data of the study region that bears on its geothermal energy potential.

5. Summary and analysis of physical and chemical property data from the Cambrian-age target formations.

6. Presentation of tectonic data that aids in locating sites of deep-fracturing and associated enhancement of porosity characteristics of the target formations.

1. Scope and Objectives of Investigation

The geology and hydrocarbon exploration records from the western counties of New York State lying along the northern flank of the Appalachian Basin south of the 42 north latitude were considered in this study (FIGURE 1). The rock formations in this region of interest for their geothermal energy potential are the Cambrian-age Little Falls, Galway and Potsdam. In order to evaluate resource potential a geologic model must be formulated that reflects the hypotheses that are thought to govern the location and concentration of the resource (FIGURE 2). The geothermal hot water resource has two fundamental characteristics; 1) pore fluids with adequate temperatures and 2) aquifer rocks that have adequate permeability and porosity to sustain pumping roles sufficient to transfer significant heat energy to the surface. Other characteristics such as the chemistry of formation water and the hydraulic head of the aquifers also bear on the practical potential of the resource. This study has gathered, summarized and evaluated existing information concerning, subsurface temperature, porosity and permeability of the Cambrian rock units and the chemistry and hydrology of their pore waters. In addition, other geological and geophysical data have been examined to obtain the best estimate of the locus and potential of geothermal energy resources in western New York State.

2. Introduction to Geothermal Energy from Sedimentary Basins

Geothermal energy, traditionally associated with volcanoes and roaring geysers, may come in much less spectacular form. When the geology and economics are right, simple geothermally heated hot water may be used successfully and economically to heat public and private buildings, or to provide low-grade heat for industrial processes or agricultural applications. If properly designed, these systems can be dependable and have minimum environmental impact.

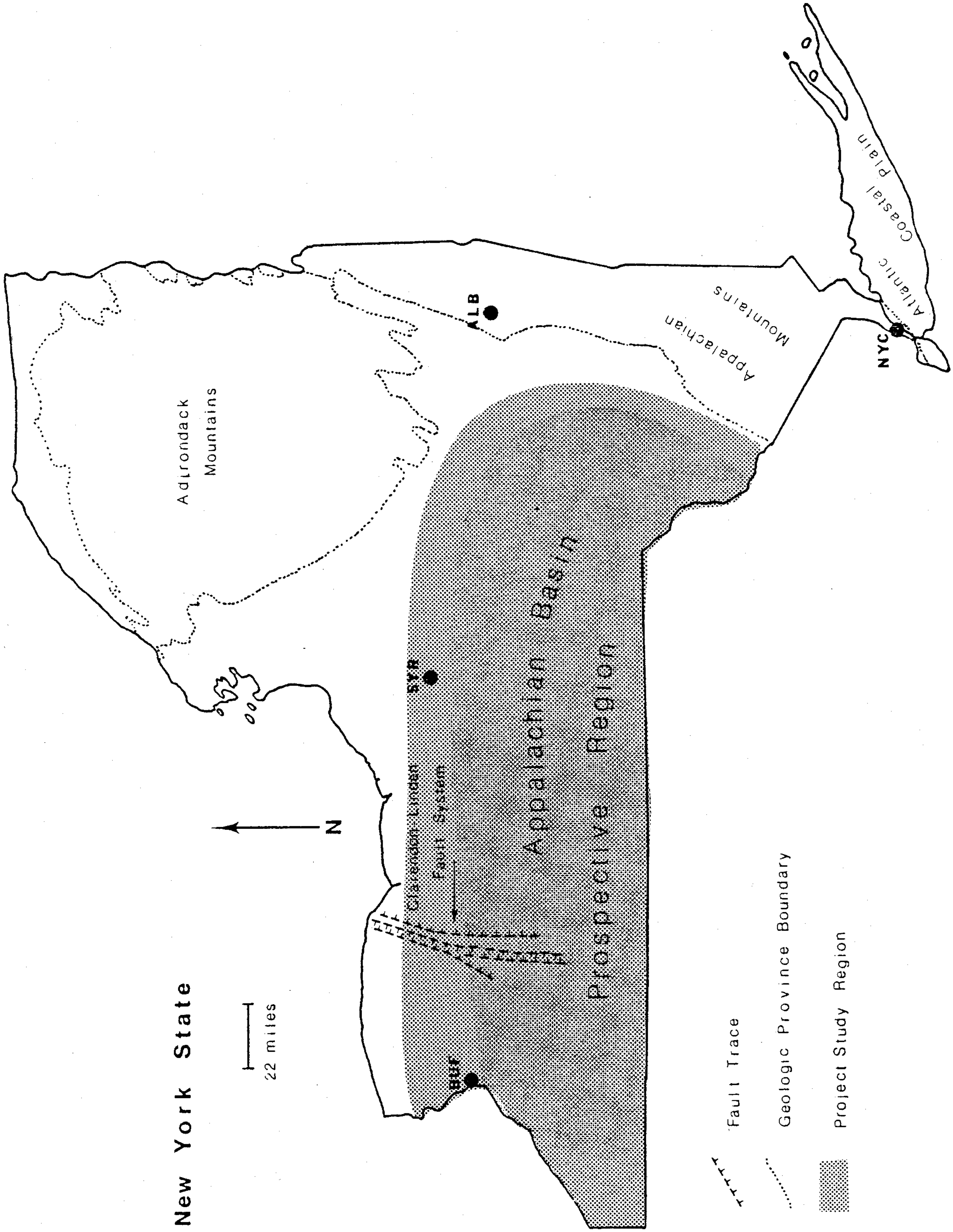


FIGURE 1. Region of investigation.

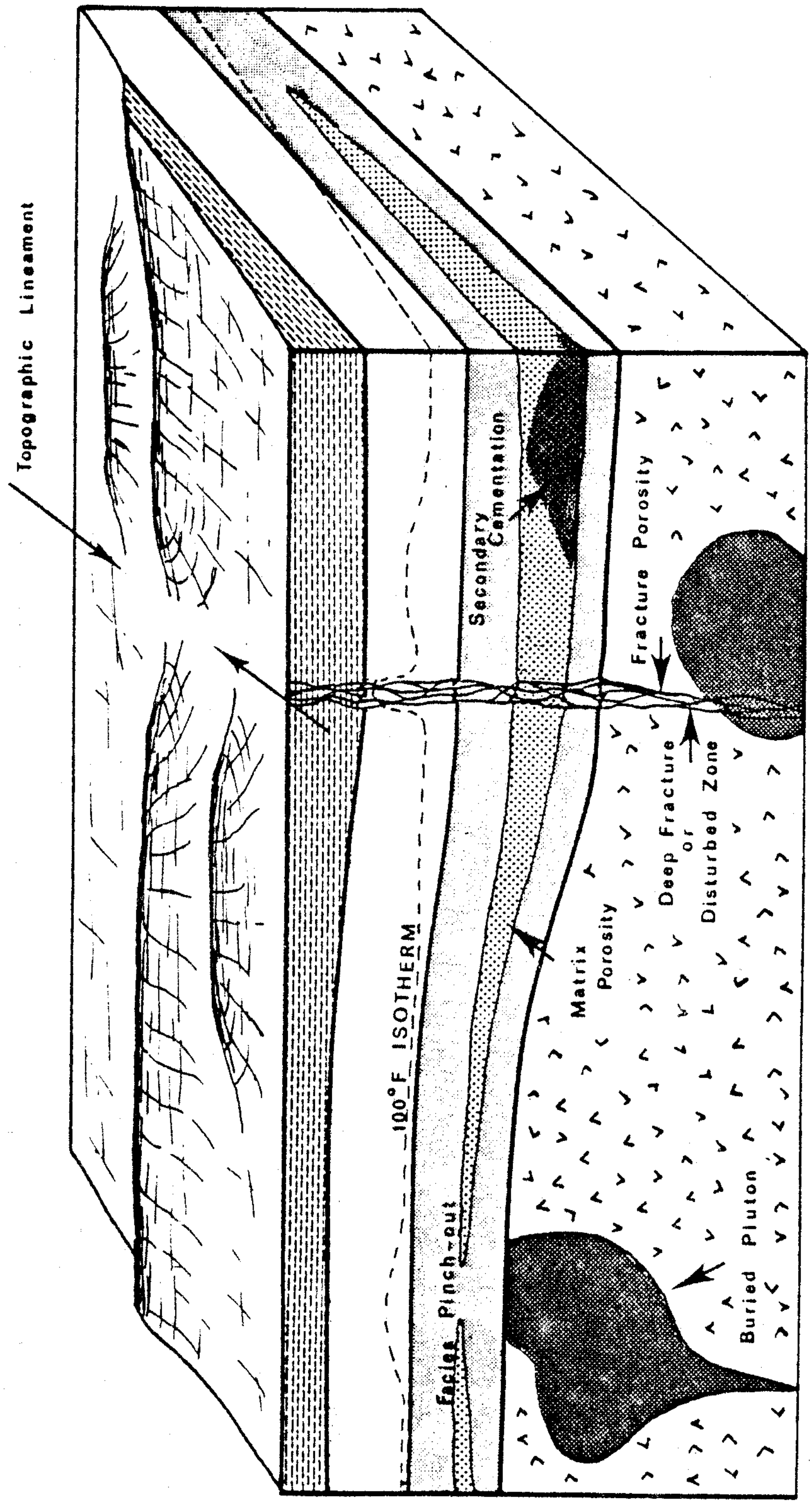
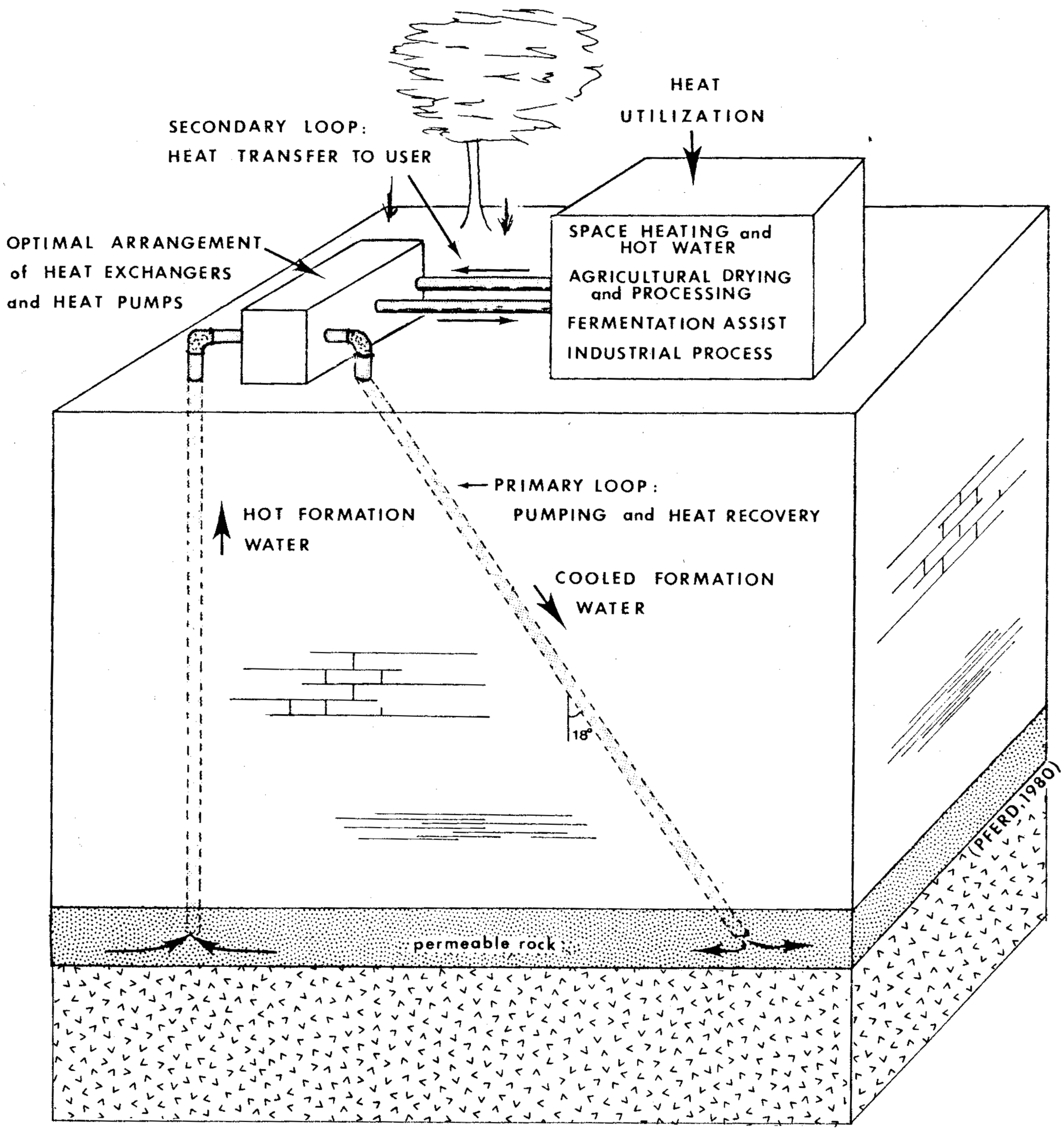


FIGURE 2. Geologic model of a potential geothermal energy resource in sedimentary basins.



Typical System for Obtaining Energy from Geothermally Heated Sedimentary Basin Water

FIGURE 3. Hydrothermal energy resource recovery.

The familiar occurrences of geothermal energy are found in volcanic zones, but there is potentially useful heat in saturated porous rock wherever sedimentary sequences occur at a depth of about 2.0 km (6000 ft) and coincide with geothermal gradients that are equal to or greater than the world average of 20^{o}C/km (14 F/kft). The heat is held in the hot interstitial water of the sedimentary formations. These fluids provide the primary medium for heat transfer between the subsurface and the users application.

A typical system for obtaining this energy is shown in FIGURE 3. It consists of three parts: 1) A pair of wells forming the primary circulation loop that brings the hot formation water to the surface and returns the same water, after heat extraction, to the rock formation, 2) An engineered facility that recovers the geothermal heat from the primary loop and circulates clean hot water at an appropriate temperature to the user through a secondary pumping loop, and 3), an engineered facility that applies the heat stream to the tasks of the user.

A few examples of this type of geothermal energy utilization exist today. For example, in an operation that is analogous to the conditions of the Appalachian Basin of New York State, the French have been cycling 70^{o}C (140^{o}F) formation water of the Paris Basin. The system pumps from a depth of approximately 3000 m (9000 ft) and provides 75 percent of the heating load of a 10,000 unit apartment complex. In the Western Canada Sedimentary Basin, near Regina, Saskatchewan, a feasibility study has been performed to evaluate its subsurface geothermal resource (Jessup, 1976, Vigrass, et al, 1978) and a demonstration project is presently underway to cycle 74^{o}C basinal waters from 2220 meters (7000 feet) to provide space conditioning to a university building complex. In Szeged, Hungary and in the USSR, geothermally heated sedimentary formation water is being used for space heating, green houses and agricultural processing (Tikhanov and Dvorov, 1970).

TABLE 1 presents topics of study that deserve investigation before deep drilling to fully evaluate a hydrothermal energy resource. This study draws on available data to address a number of these topics and provides insight into the potential problems and promise of geothermal energy exploration in western New York.

TABLE 1

DATA CATEGORIZED RELATED TO THE CONFIRMATION OF POTENTIAL SUBSURFACE GEOTHERMAL RESOURCE OF WESTERN, NEW YORK

A. Geologic Data

Stratigraphic position, thickness and depth to target formation.

Lithologic Composition.

Sedimentological model of formation origin.

Water content of target formation.

B. Temperature Data

Heat Flow Values.

Geothermal gradient.

Conductivity model from target formation.

Formation temperature estimation.

C. Porosity Data

Typical values of porosity for similar geologic materials.

Estimates of porosity from closest available well-logs.

Determination of the origin and size of void spaces in the target rock formation.

D. Permeability Data

Typical values of permeability for similar geologic materials.

Pump tests and laboratory determination of permeability from closest available studies.

E. Chemical Data

Composition and concentrations.

II. INVENTORY OF DEEP WELLS AND AVAILABLE DATA

Deep drilling for oil and gas provides a valuable record of the subsurface geology and hydrology. Much of the data gathered during the course of oil and gas exploration can be useful in assessing a region's potential for geothermal energy resources. All wells that have been drilled into the Cambrian age rocks of the study area before 1980 are listed in TABLE 2. They are ordered from earliest to most recent. Their locations are shown on FIGURE 4; a map of well locations.

Deep drilling into Cambrian-aged units has occurred throughout the history of oil and gas exploration in western New York with generally poor results. The first deep well of the study area (Elma) was drilled in 1903 in Erie County. Such deep drilling was rare during the discoveries of the 1930's, but picked up to an average of more than one per year after 1950. The study area has experienced two periods of increased activity since 1950; one in the late 50's and early 60's and another in the early 70's (see TABLE 3). The first boom was related to the formulation of an exploration hypothesis of large gas potential in the good reservoir rocks of the Cambrian units. Some success was had with this theory outside the study area, notably in the shallower parts of the Appalachian basin in New York and in a very few wells in Pennsylvania (Personal communication, unspecified oil and gas operators, and Oil and Gas Geologist, Pa. State Survey, 1980). As a result a number of deep wells were sunk in New York. A large proportion of these wells encountered adequate porosity, but only brine saturation. None tapped the gas fields that were thought to lie outside the region of salt water saturation.

The second boom was driven more by economics than exploration hypothesis, although a few companies drilled with greater interest in refining their knowledge of Cambrian rock types, hoping to apply recently learned lessons about stratigraphic trapping of hydrocarbons. Unfortunately, no markedly successful finds were recorded. However, this activity has not yet died out and the possibility of deep gas may still lead some to further explore the floor of the Appalachain Basin in New York. In any event, these wells provide an important reservoir of information to those interested in the hydrothermal energy potential in western New York. TABLE 2 reveals some of the participants in the area, the depth to the formations of interest, total well depth and of particular interest to the geothermal energy prospector, whether water was encountered in the Cambrian section and bottom hole temperature.

Each of these wells was examined with some geophysical down-hole logging tool and many were logged by geologists during drilling or from "chips". TABLE 4 summarizes the available geophysical and geological data that has been noted on the drilling reports to the N.Y. State Department of Environmental Conservation and the Geological Survey. No verification of these records has been made, although copies of most of the gamma ray logs are held by these agencies. Much of the other data is available by request or special arrangement from operators. TABLE 4 lists the type of logs run for each well and the present well status. The record of water in the Cambrian section is also presented.

TABLE 2 - Deep Well Inventory in New York

Well Name	NY State Permit #	Latitude	Longitude	County Code	Contractor Code	Operator Code	Completion Date	Water in Cambrian	Depth to Galway for from surface	T.D. from surface	Bottom Hole Temp
Union Garage	A0001	42.88482	78.75601	9	12	29	9/54	M	NA	3660	
Pierce	A0002	42.57373	79.09685	9	12	26	?/24	M	NA	4560	
Batten	A0003	42.54628	78.99587	9	12	26	?/25	NR	NA	4602	
Elma	A0004	42.84952	78.63889	9	12	30	?/03	NR	NA	3986	
Depew	A0005	42.93533	78.68806	9	12	20	??	NR	NA	3685	
Kesselring	443	42.19602	76.53694	6	12	5	5/53	M	10068	11445	246°
Mahaney	478	42.68478	76.64414	4	12	27	6/31	D	NA	6166	
Arcade/Wilson	615	42.53058	78.42361	21	12	16	8/46	30	4842	7144	
Miller	1173	42.83139	75.40241	14	13	20	11/59	H	2503	2918	
Ellis	3868	42.45569	79.04071	3	12	15	10/57	M	4652	6528	
Maurice Gans	3904	42.33361	74.23075	11	13	32	3/59	L	4572	7185	
Olin	3924	42.06302	77.43093	19	4	5	12/58	9	10106	13497	215°
Keith	3928	42.86797	75.42656	15	13	5	12/58	D	2568	4366	101°
Conger	3934	42.46008	79.04016	3	12	15	7/58	M	NA	5807	
Cook	3956	42.45308	78.17427	1	10	24	6/60	M	5551	7337	
Branagan	3970	42.80480	75.65048	14	13	5	1/60	M	3666	5703	85°
Shepard	3973	42.37020	76.50630	20	4	5	8/59	510	8123	10438	
Skramko	3993	42.88073	74.91648	12	13	5	4/60	260	3300	3581	
Danisevich	4032	42.79630	75.40465	14	13	5	9/60	100	4550	4889	
Puskarenko	4034	42.90926	74.83521	12	13	6	6/60	M	912	2717	
Lum	4055	42.63100	74.70814	17	13	5	2/61	20	3001	5504	101°
Veith	4092	42.61732	78.08016	21	4	5	11/61	336	6330	7180	127°
Strathern Bros.	4133	42.83059	78.11692	21	7	31	9/63	NR	3704	5507	
Shadle	4154	42.34208	79.13185	5	5	14	1/62	L	4644	6281	
Schaffer	4203	42.87620	76.85854	18	8	32	11/62	H	4339	5538	
Campbell	4213	42.18265	74.92180	8	4	11	11/62	D	7596	10992	
Wolfer	4248	42.47051	78.16014	1	4	5	1/63	12	5455	7560	140°
Grund	4310	42.44215	76.59279	20	13	5	11/61	D	8590	8900	150°
Lanzilotta	4379	42.27360	74.62771	8	4	11	8/63	D	5975	9070	
Werner	4392	42.74767	78.19779	21	13	5	2/64	1300	4013	5714	125°
Harrington	4437	42.15031	79.33785	5	5	33	2/64	H	5788	7692	
La Scala	4440	42.55590	78.50632	9	6	15	1/64	40	4474	5911	
Leslie	4455	42.39045	75.04458	8	11	11	12/63	D	NA	7950	
Summers Tuttle	4460	42.52116	79.26225	5	10	1	5/64	1	3796	4460	
Cox	4464	42.83032	78.09675	21	6	31	11/63	NR	NA	5620	
Fee Richardson	4467	42.38437	76.54075	20	4	5	3/64	M	7936	9390	162°
Page	4536	42.82673	78.13843	21	7	31	9/64	M	3696	6237	
McClung	4552	42.83529	77.93701	13	4	5	8/64	127	3894	5644	
Gage	4561	42.23450	79.37288	5	11	19	9/64	M	4750	6292	
Johnson	4567	42.93234	77.88406	13	4	5	11/64	L	4241	4840	

TABLE 2 (Continued)

Well Name	NY State Permit #	Latitude	Longitude	County Code	Contractor Code	Operator Code	Completion Date	Water in Cambrian	Depth to Galway for from surface	T.D. from surface	Bottom Hole Temp
Kennedy	4630	42.65027	77.75595	13	4	3	12/64	NR	5039	6380	
Clough	4714	42.51886	76.00093	7	4	11	12/65	D	6471	8270	
Alnutt	4715	42.92171	76.67162	4	13	18	12/65	5	3989	4835	
Wyman	4760	42.98943	77.77993	16	3	12	4/66	NR	3514	4305	
Richards	5087	42.32346	75.94787	2	4	8	8/67	D	8135	9640	
Fisher	6073	42.75524	78.09764	21	7	9	6/69	L	4023	5718	
Frankish	6395	42.81262	77.20285	16	9	13	11/68	2	4430	6012	
Fee Bethlehem	6668	42.80332	78.84441	9	2	2	5/68	H	3808	4310	
Thomasett	8581	42.45627	79.03301	3	6	15	7/71	L	4267	5701	
Manning	8610	42.37140	78.84115	3	1	15	8/71	L	4038	6756	
Enterprise Transit	9235	42.03333	78.56925	3	4	25	11/72	M	NA	11657	
Newman	9355	42.43709	79.40148	5	5	7	10/72	D	NA	4769	
Shepard	9578	42.95120	75.80455	14	4	5	12/73	L	NA	4927	
Lesch	9939	42.41578	79.37796	5	15	10	6/73	L	4172	5013	
Matejka	10355	42.16875	76.62514	6	12	28	4/74	D	NA	10614	
Belt Danby	10776	42.92054	78.16733	10	15	10	6/74	D	3075	4340	
Kinney	10893	42.94104	76.87658	18	4	13	8/74	L	3908	4740	
Metz	10939	42.76683	78.41787	21	15	10	7/74	D	3700	5420	
Brown	11002	42.55754	78.53566	9	4	10	9/74	D	4515	6293	
Leitz	11114	42.59783	78.98487	9	12	17	3/75	D	3782	4800	
Emling	11387	42.21886	79.65575	5	14	23	5/75	D	4528	6189	
Darling	12910	42.46623	78.80111	9	4	5	11/77	M	4519	5826	
NYS Reforestation	13699	42.46595	77.26224	19	4	4	5/79	H	6938	9806	154°
Hilts	13700	42.69712	77.88842	13	4	4	7/79	H	4592	6387	118°

Code Key for Table 2

County Codes

1	Allegany
2	Broome
3	Cattaraugus
4	Cayuga
5	Chautauqua
6	Chemung
7	Cortland
8	Delaware
9	Erie
10	Genesee
11	Greene
12	Herkimer
13	Livingston
14	Madison
15	Oneida
16	Ontario
17	Ostego
18	Seneca
19	Steuben
20	Tomkins
21	Wyoming

Water Codes

Y	Yes, no specifics
D	Dry
NR	No Record
L	Low, < 2 gal/hr
M	Med, 2-25 gal/hr
H	High > 25 gal/hr
#	Units in gal/hr

Contractor Codes

1	Akron Nat Gas
2	Amer Disposal
3	Dee Drlg.
4	Delta Drlg.
5	Fairman Drlg.
6	Flanigan Bros.
7	Flanigan, J.
8	Graytex Drlg.
9	Jack Drlg. Co.
10	Kabel
11	Lohman-Johns
12	NA
13	Otis Eastern
14	Paramount
15	Underwater

Operator Codes

1	Appalachina Basin Gas
2	Bethlehem Steel
3	Blair Assoc.
4	Columbia Gas
5	Cons. Gas Supply
6	Devonoan Oil
7	E. H. Linn
8	Fenix and Scisson
9	Flanagan, J. F.
10	Flint Oil and Gas
11	Gulf Oil
12	Hammerstone
13	Hoover, M.
14	Humble Oil
15	Iroquis Gas
16	K. R. Wilson
17	Marmik Oil Co.
18	Midwest Oil
19	Minard Run Oil
20	N.A.
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23	Paragon Res.
24	Parsons Bros.
25	Penzoil Amoco
26	Reservation Gas
27	Reserve Oil Co.
28	Shell Oil
29	Souzzi, D.
30	Stearns, J.
31	Trans. Am. Pet.
32	United Production
33	Wolfshead Oil

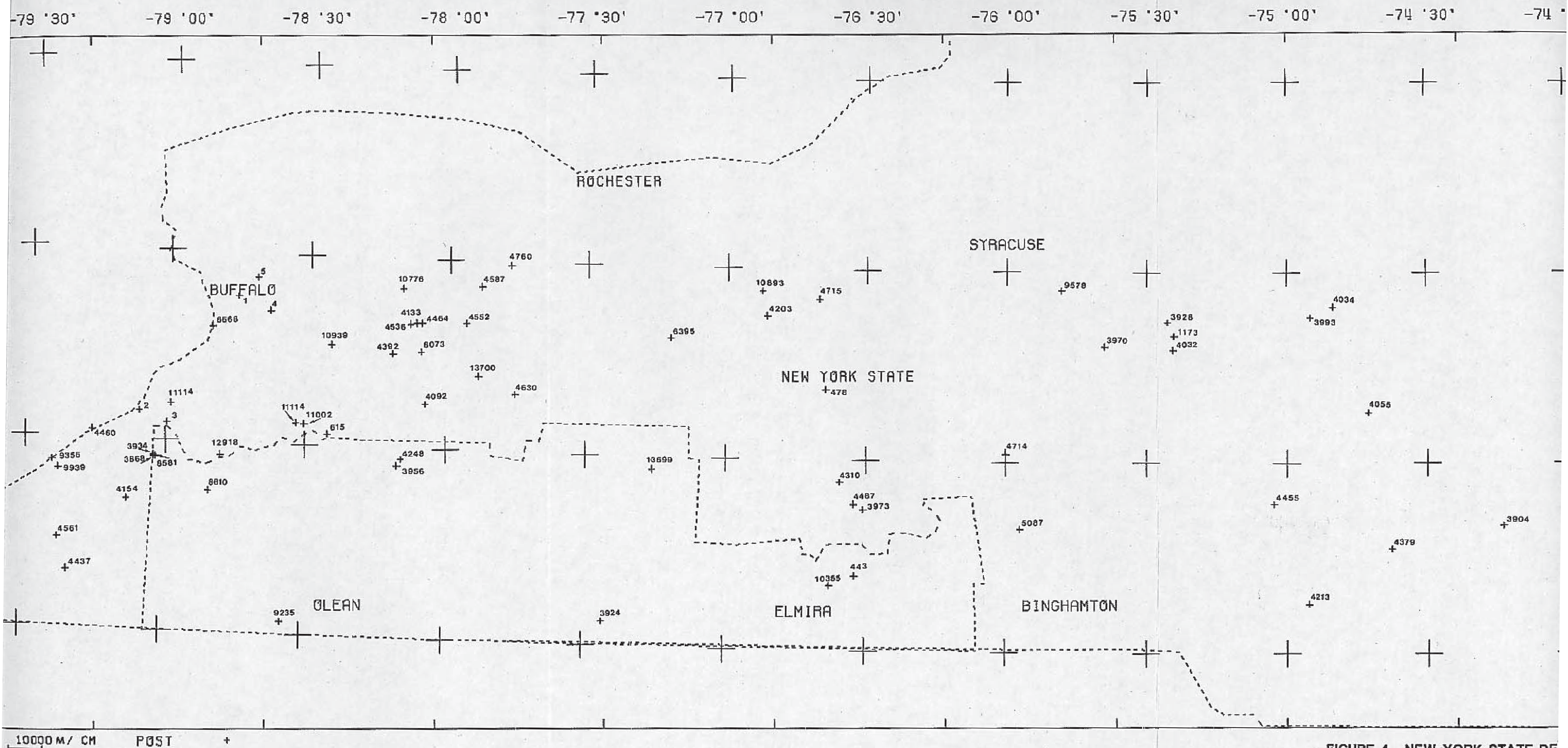


FIGURE 4. NEW YORK STATE DE

TABLE 3

Deep Drilling History in Study Area

Period	Number of Wells
pre 1950	6
1950-1955	3
1956-1960	11
1961-1965	23
1966-1970	7
1971-1975	13
1976 to present	3+

TABLE 4--Available Geophysical and Geologic Data

Well Name	NY State Permit #	Water Shows	Caliper	Temp.	GR	GRN	GG	NEUT	IL	LL	DENL	Well STATUS	GEOLOGIC OR LITHIC SAMPLES	Driller Log
Union Garage	A0001	X										1G	0	0
Pierce	A0002	X										1G	0	X
Batten	A0003											PA	0	X
Elma	A0004											PA	0	X
Depew	A0005											D		X
Kesselring	443	X			X							PA		X
Mahaney	478											DA	X	
Arcade/Wilson	615	X										DA	X	X
Miller	1173	X	X		X							PA	X	
Ellis	3868	X										STG	X	
Maurice Gans	3904	X			X					X		PA	X	
Olin	3924	X		X		X				X		STG	X	X
Keith	3928											SIG	X	
Conger	3934	X										STG	0	0
Cook	3956	X	X	X	X							PA	X	
Branagan	3970	X		X	X							PA	X	0
Shepard	3973	X				X		X		X		PA	X	0
Skramko	3993	X			X							PA	X	X
Danisevich	4032	X			X			X				PA	X	
Puskarenko	4034	X			X			X				DA	X	X
Lum	4055	X	X	X		X						DA	X	X
Veith	4092	X		X	X			X				PA	X	X
Strathern Bros.	4133					X	X		X		X	1G	X	0
Shadle	4154	X				X						PA	X	X
Schaffer	4203	X	X		X			X				DA	X	0
Campbell	4213				X			X				PA	X	
Wolfer	4248	X		X	X			X				PA	X	
Grund	4310				X							PA	0	X
Lanzilotta	4379					X						DA	X	
Werner	4392	X			X							PA	X	
Harrington	4437	X			X			X				PA	X	
La Scala	4440	X	X		X			X				PA	X	X
Leslie	4455					X						PA	X	X
Sommers Tuttle	4460	X	X	X	X			X			X	1G	X	X
Cox	4464		X			X				X	X	DA	0	0
Fee Richardson	4467	X	X		X		X			X		PA	X	0
Page	4536	X										PA	X	X
McClung	4552	X			X						X	PA	X	X
Gage	4561	X										1G	X	X
Johnson	4567	X			X						X	PA	X	X

Table 4 (Continued)

Well Name	NY State Permit #	Water Shows	Caliper	Temp.	GR	GRN	GG	NEUT	IL	LL	DENL	WELL STATUS	GEOLOGIC OR LITHIC SAMPLES	Driller Log
Kennedy	4630					X	X					PA	X	
Clough	4714	X	X			X						PA	X	0
Alnutt	4715	X									X	PA	0	X
Wyman	4760				X			X			X	PA	X	
Richards	5087					X	X			X		PA	X	X
Fisher	6073	X	X		X				X		X	PA	X	X
Frankish	6395	X	X		X			X			X	PA	X	X
Fee Bethlehem	6668	X	X			X					X	DSPL	X	X
Thomasette	8581	X			X						X	PA	X	X
Manning	8610	X			X			X	X		X	D	X	X
Enterprise Transit	9235	X	X		X						X	1G	X	
Newman	9355				X				X		X	1G	X	
Shepard	9578	X										PA	X	X
Lesch	9939	X	X		X				X		X	1G	X	
Matejka	10355									X		PA	X	X
Belt Danby	10776								X			PA	X	X
Kinney	10893	X	X		X			X			X	PA	X	
Metz	10939				X					X	X	1G	X	
Brown	11002		X	X	X				X		X	1G	X	
Leitz	11114			X	X			X	X		X	1G	X	0
Emling	11387		X		X			X	X	X	X	1G		X
Darling	12910		X	X	X			X	X		X	PA	X	X
NYS Reforest.	13699	X	X			X		X				PA	X	X
Hilts	13700	X	X		X			X				PA	X	X

X = present

0 = not present

blank = no record

TABLE 5

Log Functions

Code	Log Type	Function
GR	Gamma ray	lithology, shale content
GRN	Gamma ray-neutron	porosity index
GG	Gamma-gamma	bulk density determinations
NEUT	Neutron	porosity index, gas-liquid contacts
IL	Induction log	lithology, pore contents
LL	Laterolog log	lithology, indirect porosity
GRDL	Guard log	lithology, pore contents
DENL	Density log	porosity, shale content

Logging devices test a variety of characteristics of the rock formation or the hole itself. The functions of these logs are presented in TABLE 5. Some provide information on the lithology, others yield estimates of porosity and others specifically determine the amount and kind of hydrocarbons and fluids present in the formation. Other logs evaluate the temperature profile, the geometry of the hole and a variety of other characteristics. Much of this information is useful for evaluating the holes and/or the regions potential for geothermal energy. The following portions of this report draw on some of the findings from well logs and other data that bear on the potential for geothermal energy in the study area.

III. WELLS FOR POSSIBLE REENTRY

An important objective of this study is to evaluate the feasibility of reentering wells that have been drilled during the course of oil and gas exploration. Particular consideration was given to those wells that have been plugged and abandoned after encountering uneconomic quantities of hydrocarbons. A set of criteria was established to focus on those wells that might afford the best opportunity for reentry to recover geothermal resources. Selection criteria included a total well depth of greater than 5500 feet to assure adequate temperatures, a "show" of water from the drilling records and a completion date after 1960 to assure a minimum level of technology in plugging techniques and preservation of well casing. TABLE 6 presents the 10 wells that were selected as possible candidates for reentry. All have been plugged and abandoned.

The feasibility of reentry was evaluated by examining the plugging history of wells for which it was available and personal contact of contractors and operators. FIGURES 5 and 6 present diagrams of the configuration of 5 typical wells of the selected set. Many have had most of their deep casing pulled and cement filling of the remaining hole in its entirety or bridged across intervals of rock strata with gas or water shows. These diagrams look neat and orderly, however, they do not represent the reality of the plugged holes. Operators reported that bridging was accomplished with brush, logs, scrap metal or any other available material. Holes commonly served as a disposal site for waste materials after drilling. In addition, all operators and contractors advised that even though well reentry was technically possible and potentially could save substantial costs of drilling, the risk of complications from known or extraneous plugging material was substantial. Costs in remedying such complications could easily exceed costs of new well drilling. Another drawback of well reutilization occurs from the generally poor condition of well casing that has been left in the well. No preexisting casing would possess the adequate quality nor would the contractor have sufficient knowledge of the condition of casing to survive the 20 to 30 year design-life required by most hydrothermal energy systems.

In summary, well conditions and hydrothermal well design considerations strongly suggest that well reentry is not a viable solution to reducing initial capital costs of such energy systems.

The negative aspects of attempting to use existing oil or gas exploration wells for geothermal energy applications arise from considering aged and plugged wells. To avoid these uncertainties, consideration for geothermal energy should be given to wells before plugging. In New York State, 350 to 450 wells are plugged and abandoned annually. Perhaps a few of these wells that are rather expensive investments of capital, materials and energy could be intercepted from destruction and applied towards exploring and unknown potential of hydrothermal energy in the State.

TABLE 6

Selected Wells for Possible Reentry

New York State Well Number	Completion Date	Well Name	County	Operator	Depth to Galway	Total Depth
4092	61	Veith	Wyo.	Con. Gas	4785	7182
4154	62	Shadle	Chaut.	Exxon	4644	6281
4248	63	Wolfer	All.	Con. Gas	5455	7560
4310	61	Grund	Tomp.	Con. Gas	7331	8903
4467	64	Fee Richardson	Tomp.	Con. Gas	7936	9390
6073	69	Fisher	Wyo	Flannigan	4023	5718
6395	68	Frankish	Ont.	Hoover	4430	6012
9235	72	Enterprise Transit	Catt.	Penzoil	NA	11657
13699	79	N.Y. State Reforestation	Stuben	Columbia	6938	9794
13700	79	Hilts	Living	Columbia	4592	6403

FIGURE 5. Plugging history for some selected deep wells.

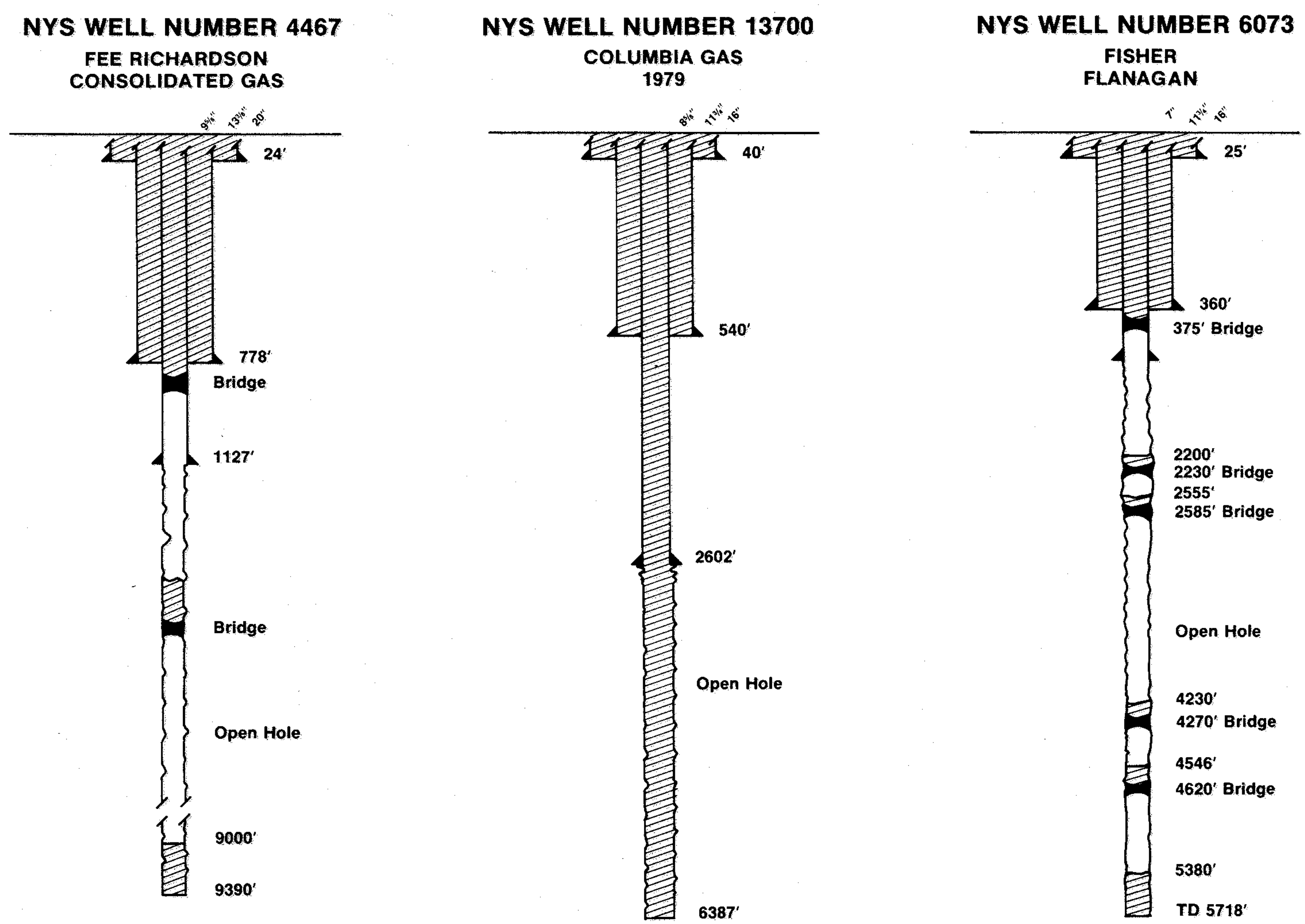
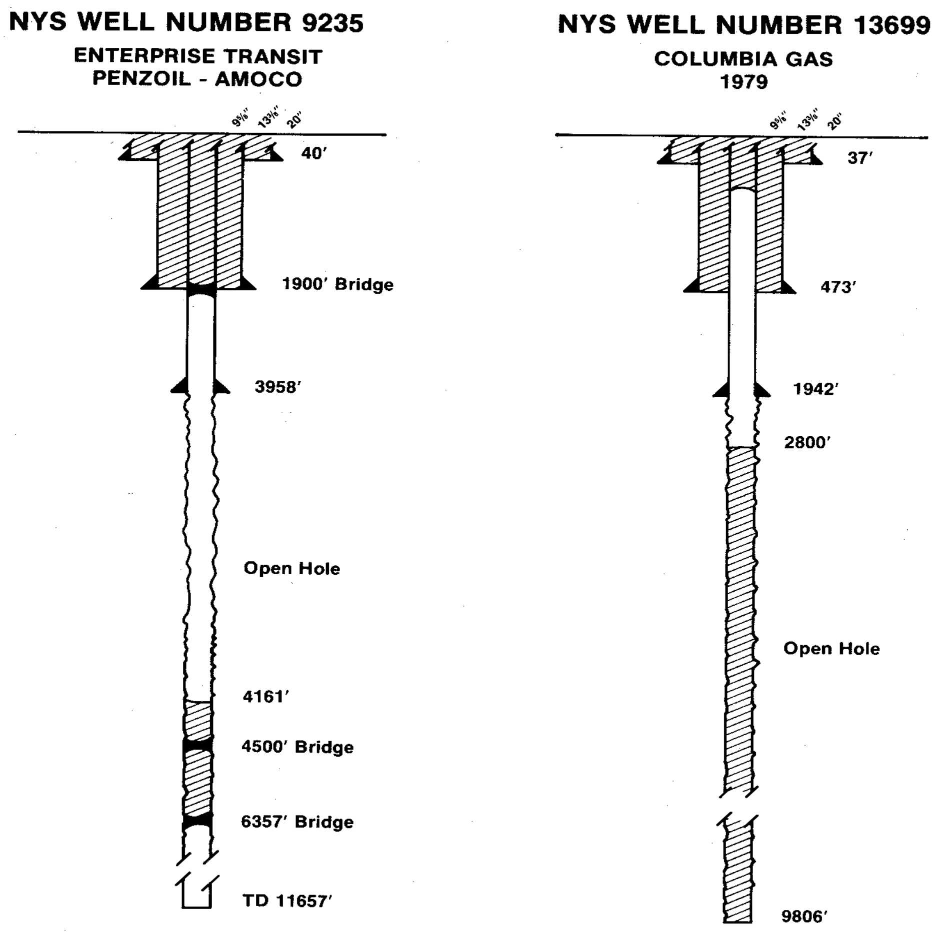


FIGURE 6. Plugging history for some selected deep wells.



IV. GEOLOGIC DATA

1. Stratigraphy

The basal Cambrian-age Galway (also called Theresa) and Potsdam formations of the Appalachian Basin are believed to possess the greatest potential for geothermal energy recovery in western New York State. These units are covered by a sufficient thickness of insulating overlying rocks to permit formation temperatures of potential usefulness (i.e.140°F). In addition, and of crucial importance to hydrothermal energy resources, they commonly possess rock porosity and permeability sufficient to permit thermal energy recovered by withdrawal and reinjection of their pore fluids.

The Potsdam formation is believed to be a blanket basal sand that lies unconformably on the eroded surface of Precambrian metamorphic and intrusive rocks (Rickard, 1973). This blanket sand is replaced upward by fine to coarse-grained quartzose dolostones and dolostones of the Galway formation. A generalized stratigraphic section showing just the lower Paleozoic rock formations is shown in FIGURE 7. These rocks reveal that sedimentation began during the late Precambrian in the deeper sections of the Appalachian Basin (southeastward in PA) and slow subsidence caused a westward and northward transgression of sedimentation across the Precambrian erosional surface. No obvious coastal accumulations of these sands into barrier islands or deltaic complexes have been recognized. However, this may be due, in part, to the sparsity of data available on these deeply buried units. Nonetheless, the westward transgression of sedimentation culminated in the accumulation of a depositional sequence that covered the whole of the study area and is continuous through the Early Ordovician (Harris, L. D. 1975). The top of this sequence is clearly marked by the Knox unconformity. This unconformity is exceeding widespread and of relatively short duration, thus providing an excellent regional time marker. FIGURE 8 shows a cross-section approximately north-south across the study area. The Knox unconformity has been used as the datum to better display the stratigraphic relationships of the Cambrian units.

Thickness estimates of the Galway-Potsdam sequence have been estimated from Rickard, 1973, Kreidler, 1975 and Harris, 1975. The top of the Galway ranges from 2500 feet below sea level in the northwestern portion of the study area to greater than 10,000 feet below sea level near the southern border of Chemung county (FIGURE 9). The general land surface rises gently from about 300 feet above sea level in the north to approximately 1500 feet in the south. This yields a range of sedimentary cover over the Cambrian formations from 2800 in the north to greater than 11,000 feet at the Pennsylvania border. The total Cambrian and Ordovician section thickens below the Knox unconformity from north to south toward the axis of the basin (FIGURE 10). It ranges from less than 200 feet thick south of the shore of Lake Ontario and is approximately 1500 feet thick at the NY-PA border.

The available evidence suggests that only portions of the entire Cambrian-Ordovician sequence may have suitable porosity and permeability for hydrothermal energy development. At least four types of porosity have been recognized in this rock sequence; 1) intergranular matrix porosity developed in sandstones, 2) solution porosity developed in carbonates, 3) brecciation produced by volume reduction from dolomitization, and 4) fracture porosity developed by tectonic mechanisms. The first three types of porosity are a function of the rocks present and their pore history. Kreidler, 1975 examined the potential of all

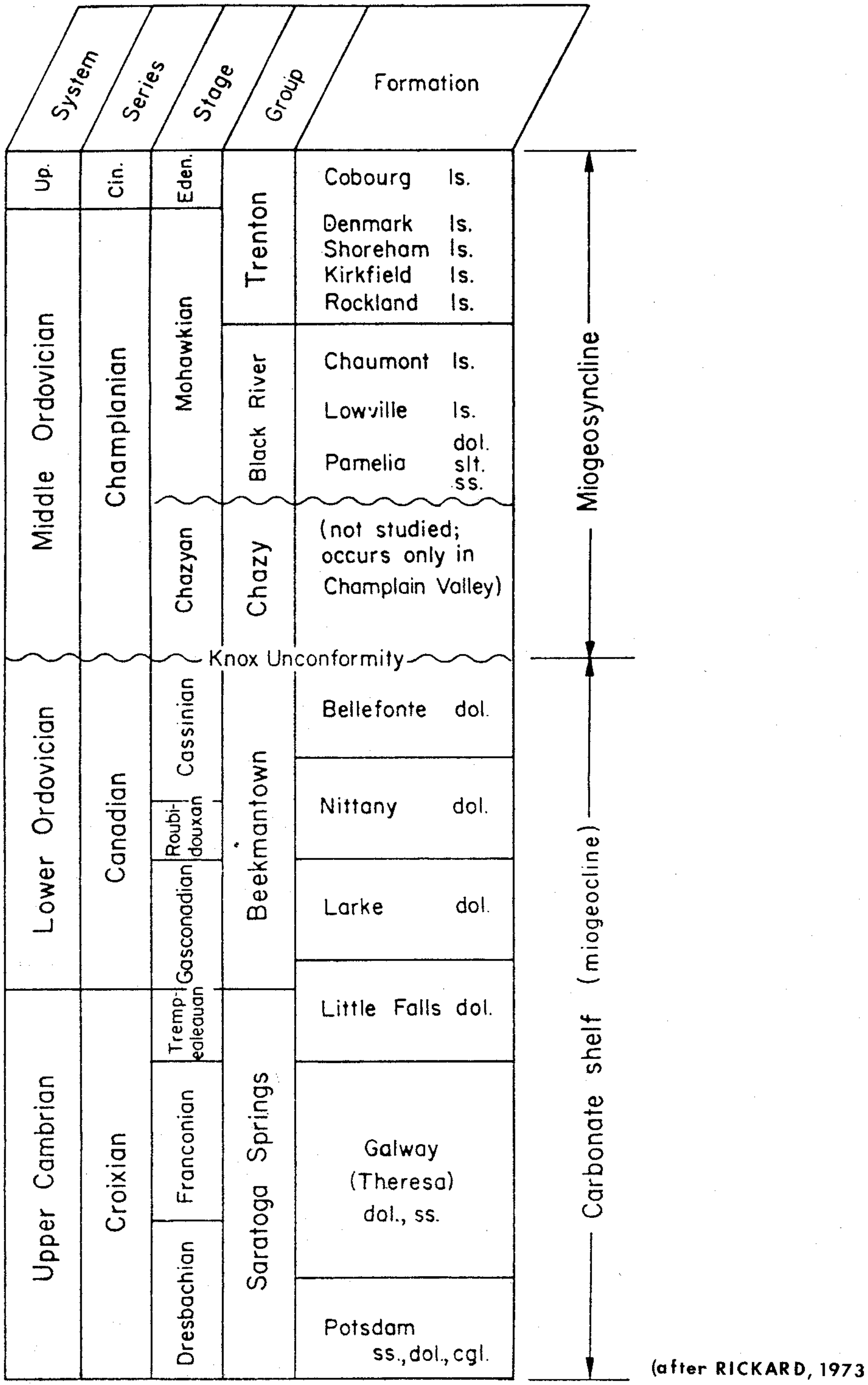
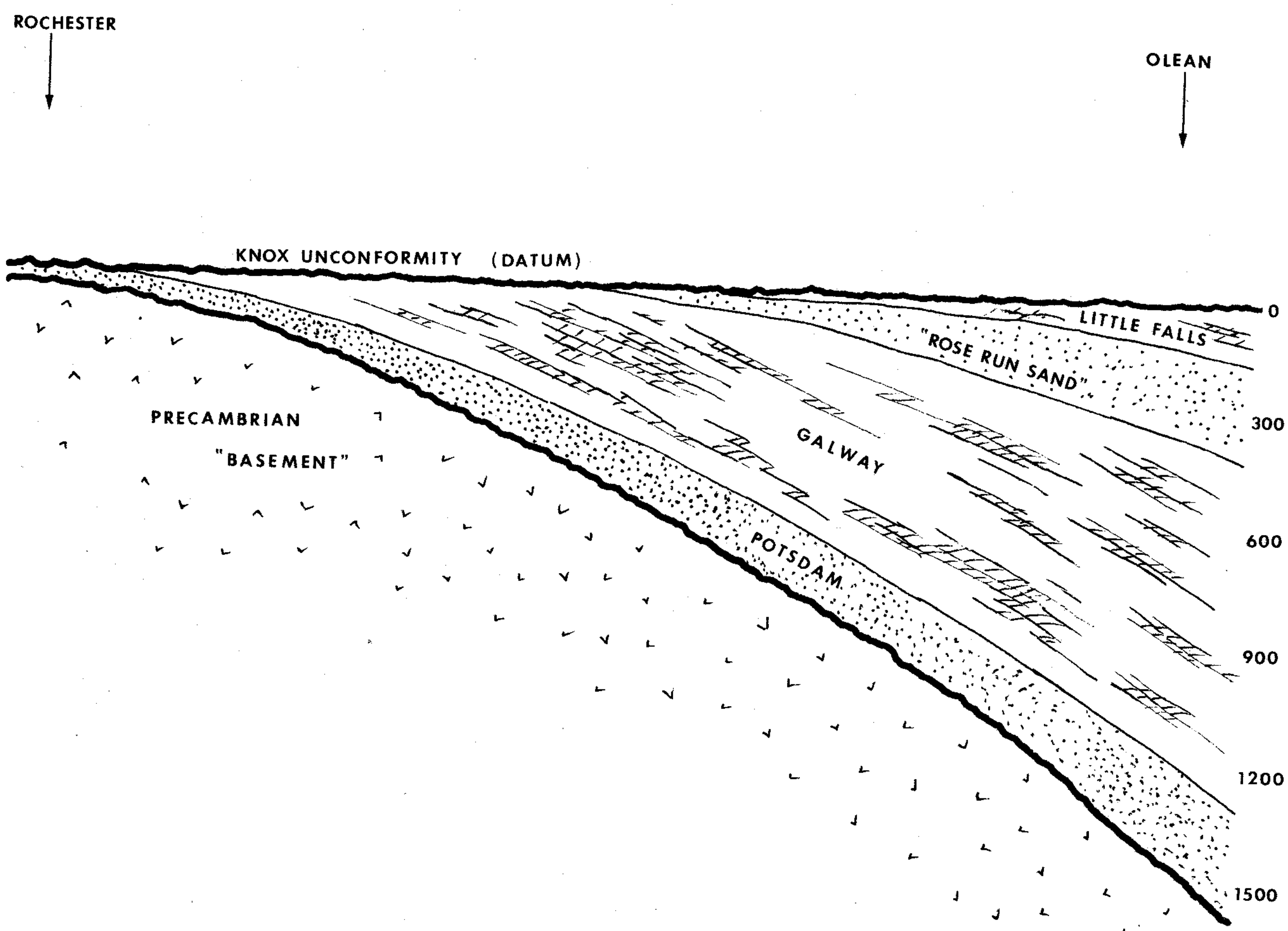
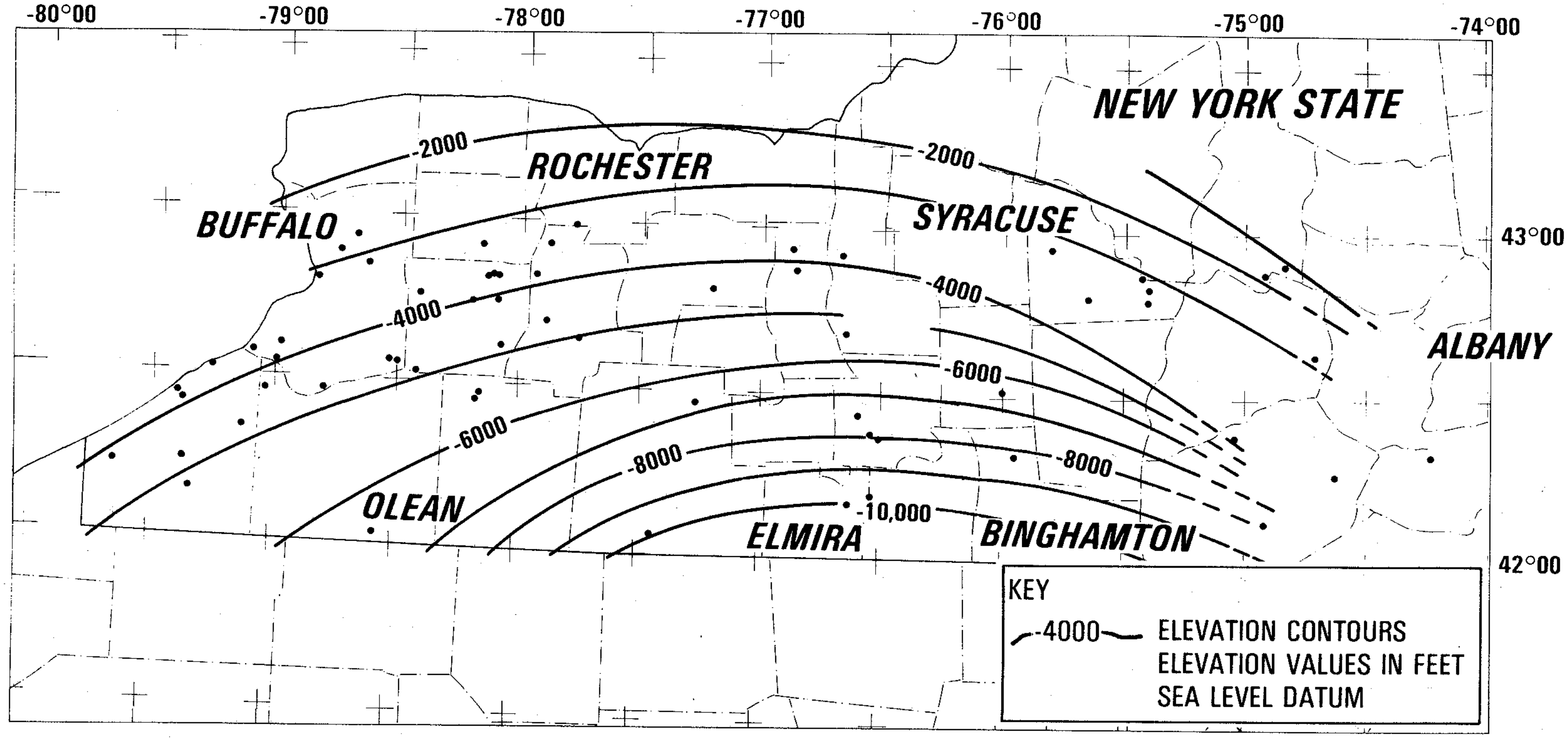


FIGURE 7. General stratigraphic section.

FIGURE 8. Cross-section oriented north-south across study area.



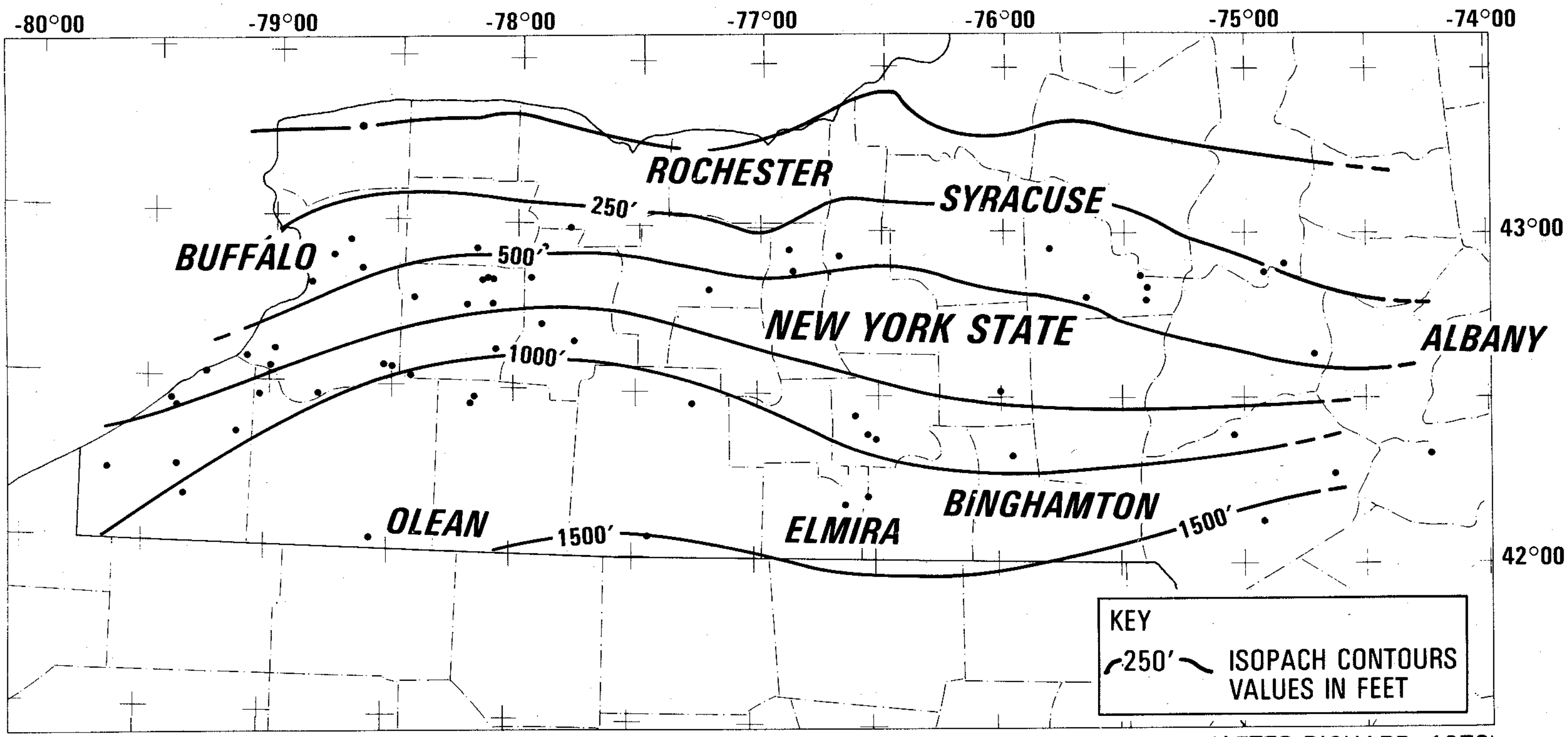
DEEP WELLS IN WESTERN NEW YORK STATE



(AFTER KREIDLER, 1975)

FIGURE 9. STRUCTURE CONTOURS ON TOP OF GALWAY

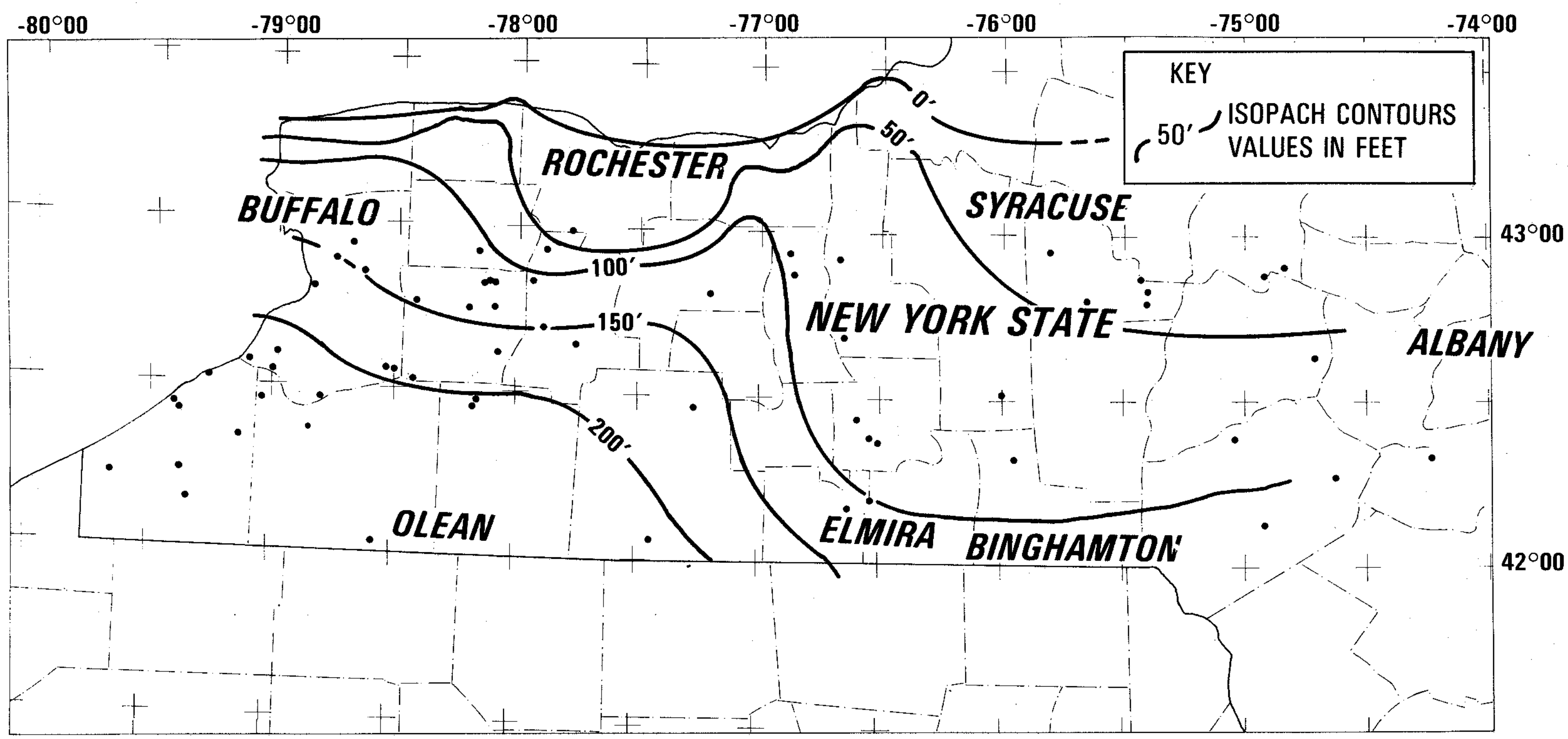
DEEP WELLS IN WESTERN NEW YORK STATE



(AFTER RICHARD, 1973)

FIGURE 10. ISOPACH OF CAMBRIAN SECTION

DEEP WELLS IN WESTERN NEW YORK STATE



(AFTER KREIDLER, 1975)

FIGURE 11. ISOPACH OF POTSDAM FM

DEEP WELLS IN WESTERN NEW YORK STATE

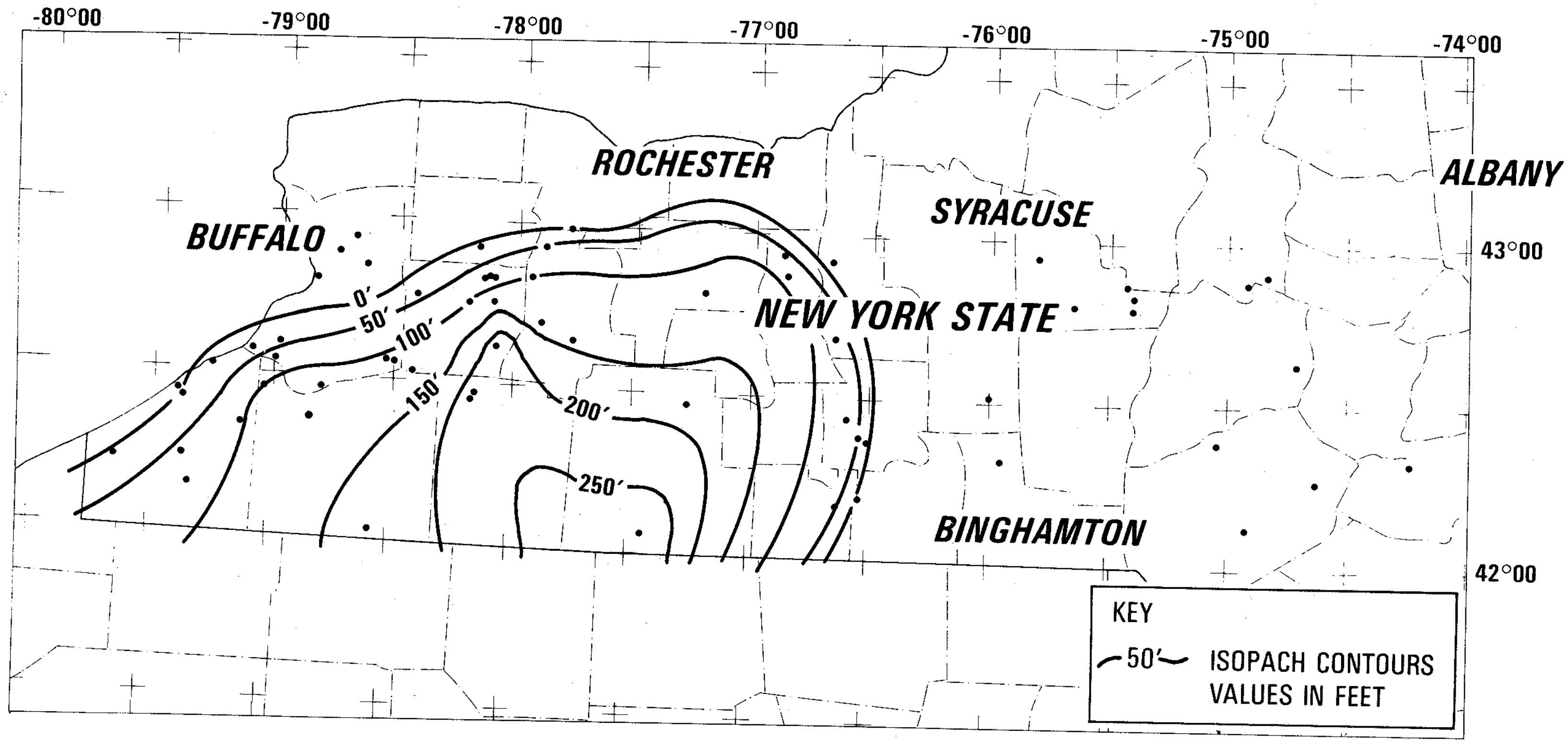


FIGURE 12. ROSE RUN ISOPACH (AFTER KREIDLER)

Paleozoic rocks in western N.Y. State for fluid waste disposal. He noted that in many areas a portion of the Cambrian stratigraphy possesses considerable porosity and significant volumes of connate waters. These characteristics are of great interest to the geothermal explorationists. He showed well data that indicated the basal Potsdam sandstone, the Galway sandstones and dolostones, the Rose Run sands and the rocks just below the Knox unconformity all possessed connate water and good porosity and permeability. Limited data is available on these units in the deeper portion of the basin. However, isopach maps have been prepared for the Potsdam sandstone and the Rose Run Sands (FIGURES 11 and 12). The Rose Run is not continuous and thins to the north and east. The zones of porosity in the Galway formation are of variable thickness and stratigraphic position. The thickness and lithic constituents of the Cambrian section vary with considerable predictability across the study area. The Rose Run Sand, the carbonate Galway Formation and the basal sands of the Potsdam are readily apparent. The Knox unconformity has commonly displayed abundant connate water, however it is generally a thin zone and in much of the northern portion of the study area is too shallow to possess attractive temperatures.

2. Water Shows in Deep Drilling

Connate water has been encountered commonly in the Cambrian stratigraphic section occasionally in considerable volumes. These 'water shows' provide the only direct evidence that heated formation fluids occur in sufficient quantities to serve as the medium of heat transfer from the deep formations to hydrothermal energy users at the surface. The location and volumes of these shows are posted on a map of the study area (FIGURE 14). Two significant patterns are apparent from data that bear on the potential for viable hydrothermal energy resources in the study area. The deeper portion of the Appalachian Basin to the east in the region of Otsego, Delaware and Greene counties, although possessing higher formation temperatures (see Temperature Patterns) has less free formation water. A number of deep wells in this region were drilled to basement and only seepage or weeping of formation water was reported coming into the hole (personal communication, Roger Roland, Gulf Oil, 1980). An attempt was made in one hole of this area (Lanzilotta, NYS No. 4379) to complete with hydrofacturing. However, even after such stimulation the formation water could only be swabbed out and flowed into the hole at less than 5 bbl/hr. Tight Cambrian formations have been encountered commonly enough in this area to suggest that low permeability/porosity is typical of the deeper axial area of the Appalachian Basin in New York. The only shows of significant formation water in this eastern portion of the study area were encountered in wells in Southern Madison and Herkimer counties. Two wells exhibited flows of greater than 100 gal/hr. Skramko, NYS No. 3993, 260 gal/hr. and Danisevich, NYS No. 4032, 100 gal/hr. (Kreidler, 1975).

A more optimistic regional pattern is evident west of and including Cayuga, Tompkins and Tioga counties. A distinct enhancement of water flow and porosity appears in the vicinity of certain tectonic features of the study area (FIGURE 14). These features are fault systems in the subsurface whose only surface manifestations are gentle warping of the shallow dipping overlying Devonian age sediments. The most notable of these structures is the Clarendon-Linden structure (Van Tyne, 1975). The highest recorded flow of formation waters into a well occurred nearby one of these structures. Another unnamed subsurface fault structure is located eastward of the Clarendon-Linden fault in the vicinity of Canandaigua Lake (Rickard, 1973) and nearby wells record higher than average flows. These structures have been active over a considerable period of time. Evidence exists for Ordovician to post-Devonian age movement (Van Tyne, 1975). In fact scarse minor seismicity has been monitored along the present day trace of the Clarendon-Linden (Fakundiny, et al 1979). Other minor seismic events have been noted during historic time at scattered sites throughout the western part of the State. These events imply brittle deformation at depth and the associated development of rock porosity and permeability. The Clarendon-Linden fault system and others in this region are steeply dipping fracture zones in the Paleozoic sediments. The fracture zone loci are controlled by various tectonic and lithologic boundaries of the underlying Precambrian basement. Fracture tectonics of the study are and their implications for geothermal energy are discussed in greater detail in the last section of this report.

3. Cementation and Pore History of the Cambrian Rocks

The pore space in the Cambrian rocks that is filled with geothermally heated connate water constitute the basic geothermal resource of the area. Additional thermal reserves reside as the stored heat of the rock material itself, but this energy, too, must pass through the rock pores to reach the user at the surface. Preliminary studies have shown that the pore volumes and their interconnection have undergone a complex history during the geologic period of the buried rock units. Some original, primary pore space has been destroyed and other secondary pore space has been created and modified. These events constitute the pore history of the rock units. When some understanding of this history is available, predictions as to the amount of pore space and its distribution in the basin may be made. Unfortunately, little detailed information is available on the pore history of the Cambrian rocks of western New York primarily due to sparse samples. A pilot examination of a few samples of the Potsdam formation was carried out by William Rogers of the New York Geological Survey and some consideration of this problem has been made by Gulf Oil scientists. Rogers' study was performed as a part of a feasibility study for the deep well disposal of liquid wastes. His samples came from NYS well number 6668 southwest of Buffalo N.Y.. He recognized three types of porosity in the Cambrian section, 1) a matrix porosity in terrigenous clastic rocks composed of well-rounded grains of quartz feldspar and rock fragments, 2) solution passage-ways in stromatolitic sections in the dolomite and 3) open uncemented fractures. Cementation in terrigenous clastic rocks shows a sequence of quartz and calcite filling of primary pore space. Little or no grain penetration was observed suggesting that this phase of cementation occurred shortly after deposition and before deep burial of the rock units. He noted evidence of preferential dissolution of feldspathic rock fragments occurring after the early cementation and the addition of authigenic feldspar to incomplete fillings of the primary pore space. Secondary pore space seems to be developed parallel to layering in stromatolite layers in the carbonates and along uncemented fracture planes in all rock sections. Styolites were noted in the cores and suggest significant volume changes may have occurred at some time, although no preferential orientation of these features were noted to link them to Paleozoic or later phases of deformation. Rogers and O. Snow, a drilling contractor active in the study area, have noted that abundant porosity and flowing connate water has commonly been found at the top of the Galway formation due to the dissolution of cements in sand layers.

The preceeding observations have been made on a limited number of samples. All are from the western most portion of the study area. The eastern area yields less optimistic reports. Roger Roland of Gulf Oil noted that their studies have found apparently good primary solution porosity, however, these passageways have been sealed and filled by later secondary chert with only minor development of secondary porosity. They believe that porosity developed by fracturing is the only hope for significant reservoir formation for most of the deeper parts of the Appalachian Basin. This is one factor in their present exploration hypothesis and has been modeled after some analogous Cambrian-Orodivician fields in West Texas. All their wells drilled in the eastern portion of the study area are reported to have very low porosities and little free connate water.

Even though the data are limited, it appears that the eastern and deeper portions of the Appalachian Basin in the study area have experienced a history of pore reduction that makes this area less capable of supporting a hydrothermal energy system based on the transfer of circulating geothermally heated formation waters. The western area and shallower portions of the basin do not appear to be as sealed and matrix-type porosity and permeability may contribute significantly to fluid systems in the rocks. All workers have noted fracturing and suggested its potentially important contribution to reservoir volumes and permeability. A rough spatial association between tectonic features in the study area and above average water flows in nearby wells further suggests that fractures are important in defining the hydrothermal systems of the area.

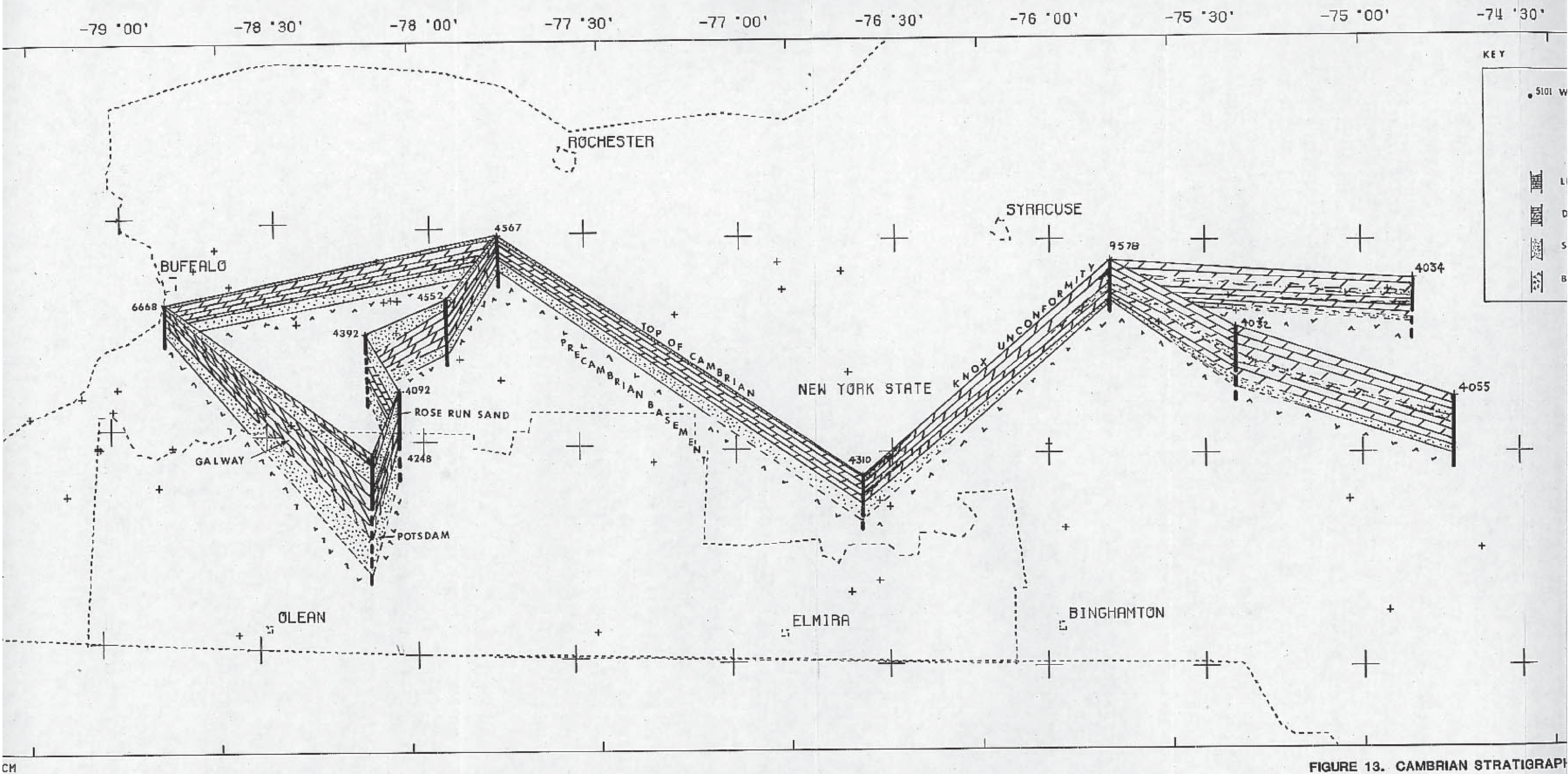
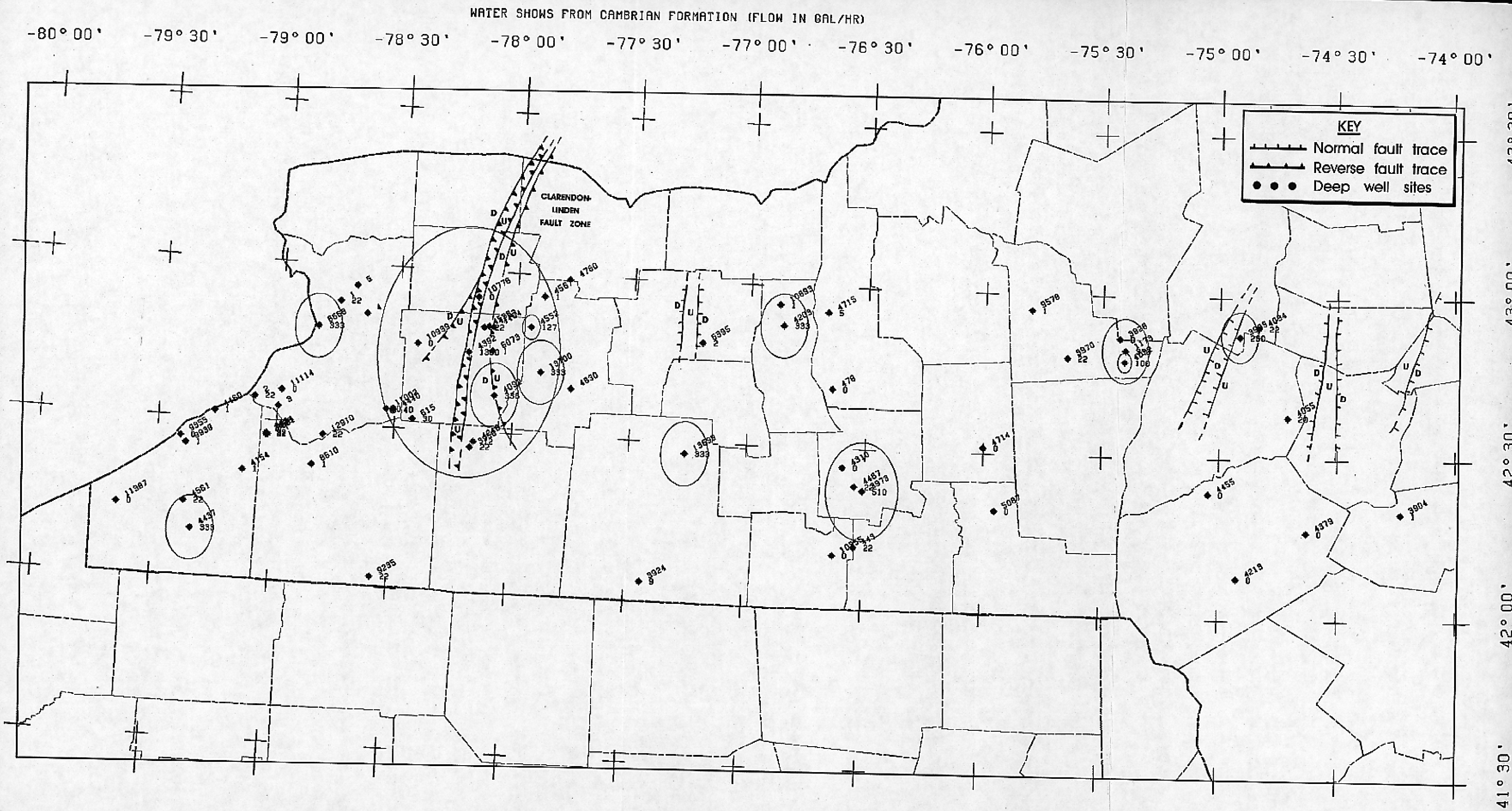


FIGURE 13. CAMBRIAN STRATIGRAPH



SIZE OF ELLIPSE PROPORTIONAL TO WATER FLOW

FIGURE 14. **DEEP WELLS OF WESTERN NEW YORK STATE**

V. PHYSICAL AND CHEMICAL PROPERTIES OF THE CAMBRIAN SECTION

The physical properties of rock porosity, permeability and formation temperature constitute the determinants of the available hydrothermal energy for any fluid-based geothermal system. Some available data is presented here to provide an estimate of these properties and chemistry of pore fluids of the formations of interest in the study area. The properties are compared with those of the reservoirs of the Paris Basin and the Williston Basin at Regina, Saskatchewan Canada.

1. Porosity

Porosity is expressed as the percentage of rock that is gas- or fluid-filled void. These values may be reasonably estimated from a variety of geophysical logs or from core samples. Core sample determinations are usually more accurate. However, these are usually of limited size and geophysical logs, although less precise, may give a better estimate of the larger-scale porosity of a rock sequence. Core samples commonly miss larger-scale porosity such as that of fractures or dissolution zones.

Porosity data for the rocks of the Cambrian section are available from oil and gas operators and the New York Geological Survey. The sandstones range from 2% to 12% and dolomites range from 2% to 14%. TABLE 7 presents data from various studies and sources. (AIDS, 1968, personal communication, R. Stollar, Columbia Gas Trans, K. Wilshaw, Consol. Gas Supply, R. Roland, Gulf Oil, W. Rogers, NYS Geol Survey).

FIGURE 15 shows a typical plot of porosity versus depth in the Potsdam formation. The lithologic and density logs are also presented. The Potsdam is commonly clean quartzite with some dolomite and shale stringers. Low porosity is due to extensive dolomitic and quartzitic cementing. Higher porosity may be from primary intergranular porosity or from fractures and joints. The Galway consists primarily of dolomite and interbedded sandstones and shale. Porosity and permeability vary substantially throughout the formation. These properties are well developed in sandy portions and less so in the dolmitic portions. However, some zones in the dolomite show pockets of exsolution porosity that considerably enhances fluid flow.

2. Permeability

Permeability is the characteristic of the rocks that permits flow through interconnected porosity. It is a dynamic property and must be measured on core samples in the lab or by pumping of wells drawing from the formations of interest. The same problems of scale occur between laboratory and field measurements of permeability as with porosity. Even less data is available on this rock property. However, during the late 60's, feasibility studies for deep well disposal of hazardous wastes were carried out under an interstate commission of technical representatives from New York, Pennsylvania and Ohio. This commission produced a number of documents that discuss the suitability of various porour and permeable rock formations for waste injection. (AIDS, 1968). During this investigation, two test wells for waste injection were evaluated for pumping characteristics of the Cambrian Galway and Potsdam formations in the Buffalo,

TABLE 7

Porosity Data for Cambrian Formations in Western New York

Well Name	Well #	Source	Porosity Range
Bethlehem Steel	6668	log	4.5-30.6%
" "	"	cores	0.5-11.8%
Emling	11387	log	3.0-9.5%
NYS Reforest.	13699	log	~10%
Hilts	13700	log	6.0-10.8%

FIGURE 15. Porosity vs. depth in typical Cambrian stratigraphic section.

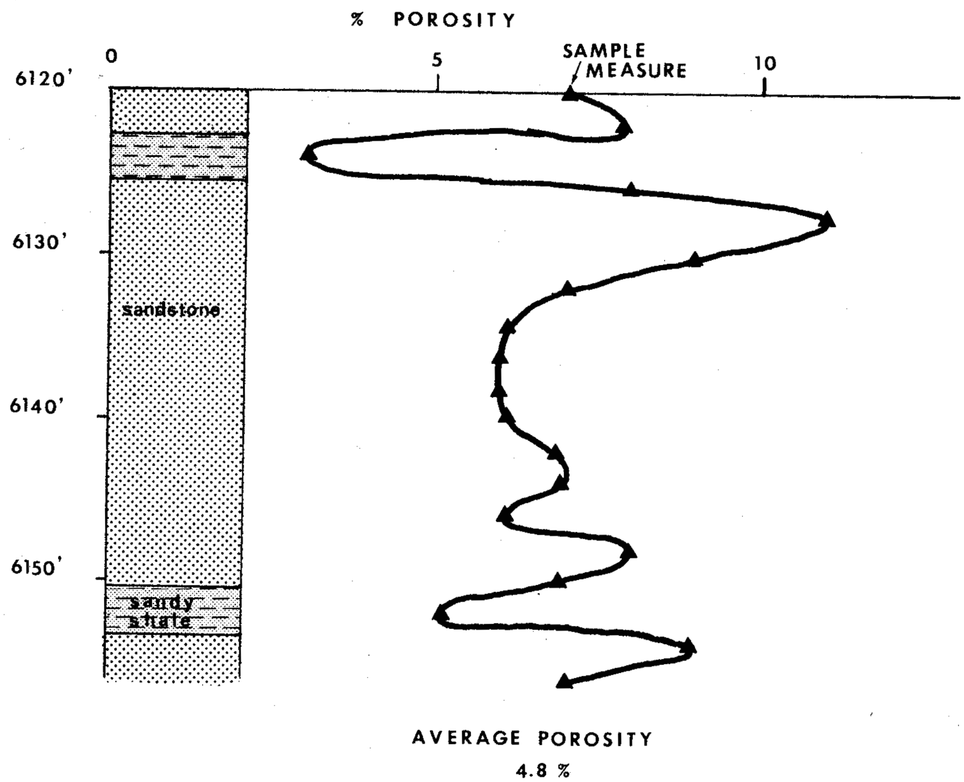
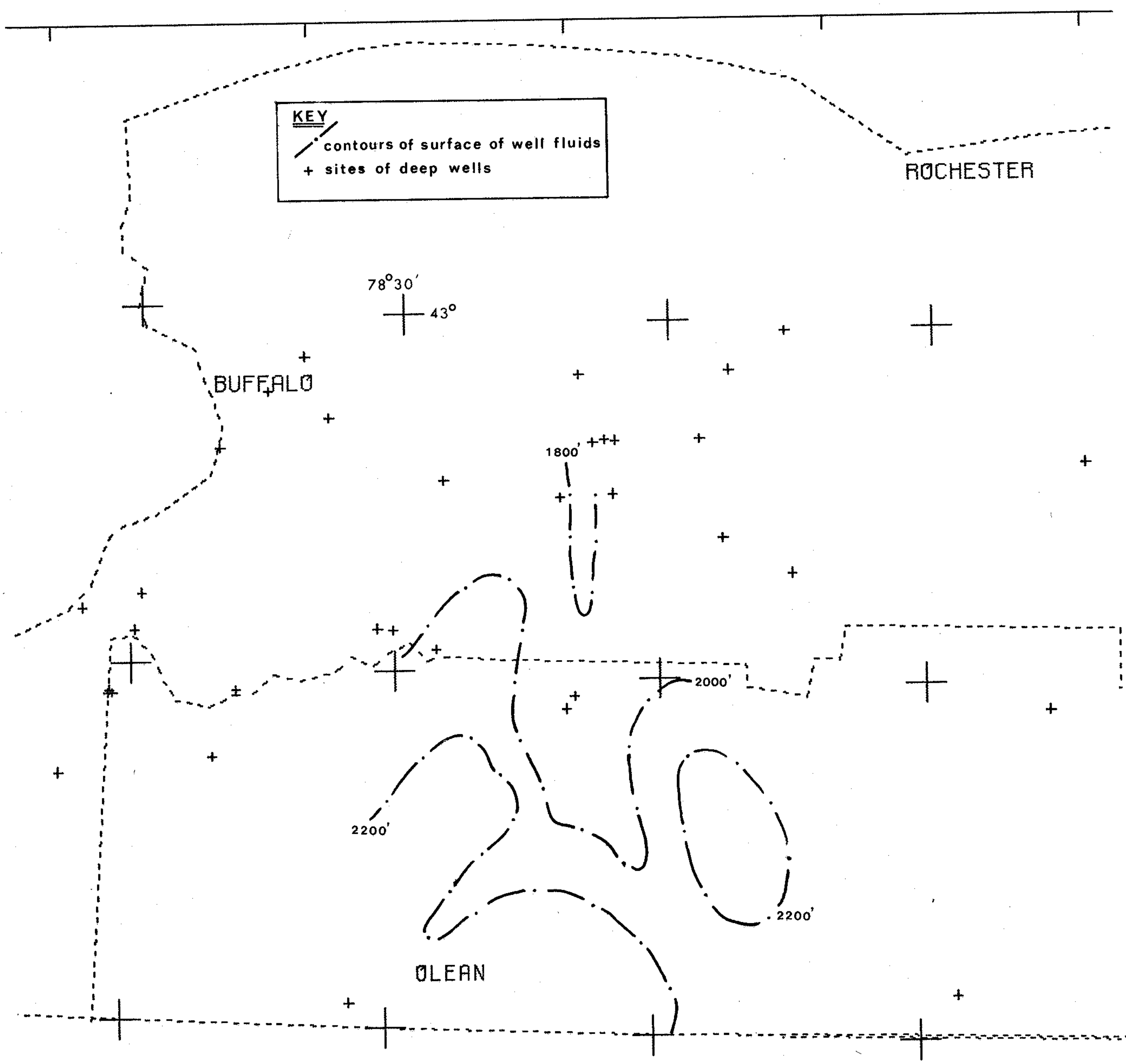


FIGURE 16. Potentiometric surface of deep aquifer in western New York (after Willette).



N.Y. area. These data coupled with laboratory permeability analysis of core samples from the same wells are the only emirical observations in the region (TABLE 8).

Laboratory evaluation of core samples gave values of the rock permeability ranging from less than 1.0 md to no more than 10.0 md. (Waller, et al, 1978). However, pump tests on the wells yielded estimates of bulk rock permeability of 100 to 113 md. These results suggest that much of the connected pore space of the formations is developed on a scale greater than the few centimeter long core samples. Waller, et al, 1968, conclude that fractures and joint planes provide significant permeability in the sandstones and less so in the dolomites. They do note, however, that "some zones of the dolomites have vuggy permeability" which would provide large scale fluid passageways.

The data from these wells may be conservatively applied to characterize the rocks across much of the study area because of the apparent homogeneity of Cambrian formation's lithology and relatively simple geometry. In fact, both greater formation thickness and the effects of tectonic fracturing associated with faulting should enhance the hydrologic characteristics of the formations. Additional strategy to counter low flow conditions may include flow enhancement techniques such as acid treatments, hydrofracturing or multiple completion by whipstocking within the producing interval.

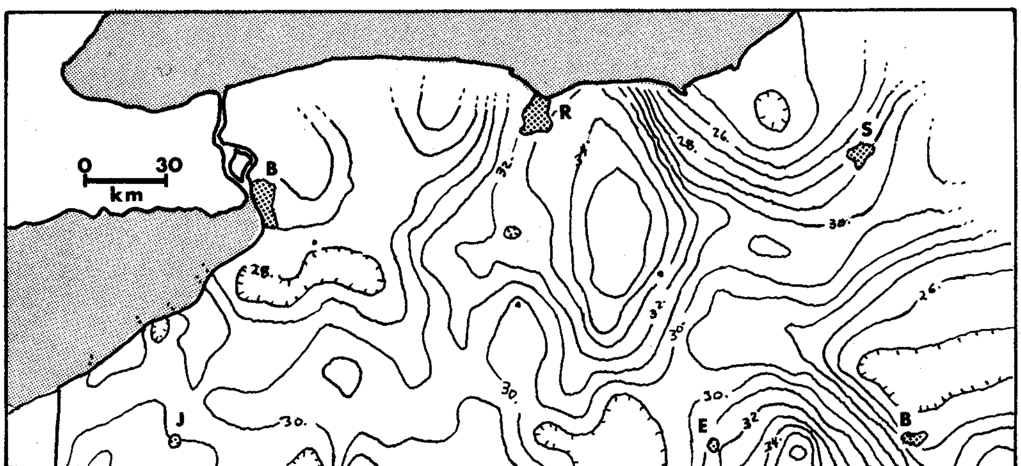
3. Potentiometric Surface of Formation Fluids

Hydrostatic pressure data from the Cambrian rocks of western New York is sparce. Waller, et al (1978) conclude the pressure head at the Bethlehem Steel Corp. well (NYS 6668) may be the only true static level measurement of the brine accomplished to date. They observed that the Cambrian formation fluids rose to within 380 feet of the surface. Other work by Willette (1979), has shown from a study of highly variable drill stem test data that in general the potentiometric surface of deep aquifers in western New York slopes gently northward and lies at about ground level (FIGURE 16). These studies suggest that the hydrothermal fluids from the Cambrian rock interval will rise to within a few hundred feet of the surface.

4. Temperature

Temperature data is available for western New York from regional surveys. The AAPG (1976) and D. Hodge, et al (1979) have produced maps that provide a broad picture of the geothermal gradient throughout the study area. FIGURE 17 shows the estimated geothermal gradient determined from wells deeper than 750 m. The values for the study area range from 24^{o}C/km (16.8^{o}F/k ft) to 36^{o}C/km (25.2 F/k ft). If these values are projected downward to the Cambrian units, a formation temperature of between 60^{o}C (140^{o}F) and 120^{o}C (248^{o}F) is possible. The potential distribution of these formation temperatures for the study area is shown in FIGURE 18. The available recorded bottom hole temperatures were examined to determine the range of actual subsurface temperatures recorded. These values have been reinterpretted by other workers to correct for drilling mud cooling and other sources of potential error. However, they are direct measurements of

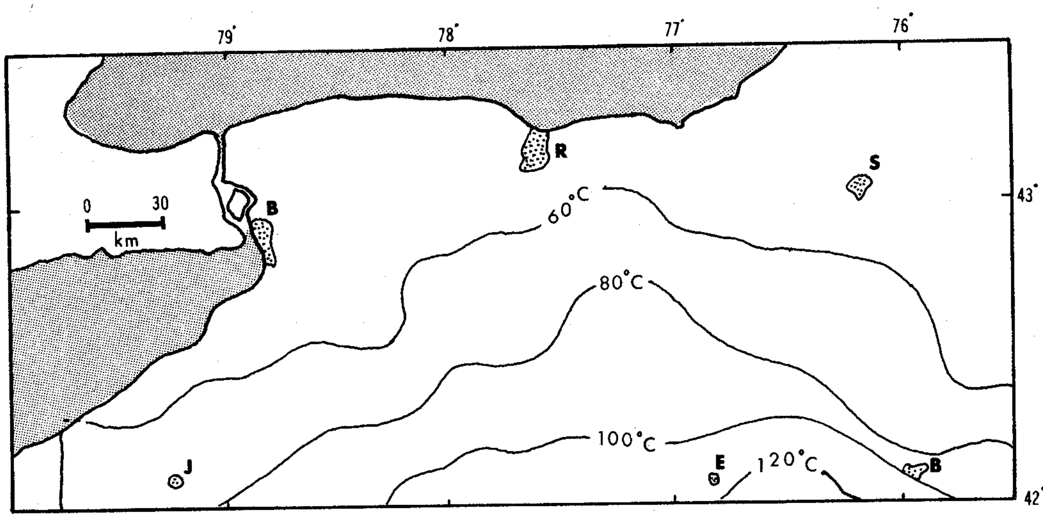
FIGURE 17. Map of estimated geothermal gradient (after Hodge).



after Hodge ,1979

Contoured Geothermal Gradiants for Wells Deeper than 750 m. in Western New York State (°C / km)

FIGURE 18. Map of potential rock temperature in Cambrian formation of study area.



Contoured Values of Expected Water Temperature in Cambrian Rock Units of Western N Y

TABLE 8

Hydrologic Characteristics of the Basal Cambrian Galway and Potsdam Formation near Buffalo, New York

Name of Well	Bethlehem Steel	Hooker Chemical
Location	N 42 48' 11" W 78 50' 40"	N 43 04' 54.4" W 79 00' 22.8"
Formation Depth		
Galway Top	-3808	-2837
Potsdam Top	-4208	-2902
Basement	--	-3044
Range of formation porosity	5.4 - 10.4%	1.0 - 14%
Range of formation permeability	108 - 113 md	about 100 md
Formation flow capacity (Transmissivity)	4000 md ft	285 - 657 md ft
Initial formation fluid pressure	1900 psi	1410 psi

Data Source: Liquid Waste Injection Feasibility Study, 1968
Report to the N.Y. State Geological Survey by AIDS.

the formation temperatures of Cambrian-aged rocks and workers have had mixed results from the downward projection of superficially determined geothermal gradients (personal communication L. Vigrass, 1980). A conservative estimate of formation temperatures may be made with the bottom hole temperature data from the study area. FIGURE 19 shows this data with the mean gradient and 1 and 2 standard deviations of confidence limits. Also plotted are the formation temperatures that would be expected using Hodges' work. Any improved estimation or a site-specific determination of geothermal gradient and formation temperature should be considered along with the estimate of regional thermal values presented here.

5. Chemistry

High salinity of formation water has been noted by drillers, well loggers and researchers. Concentrations of dissolved solids have been measured in excess of 300,000 ppm in some wells penetrating the Cambrian section in western New York. Dissolved NaCl is the dominant constituent and the waters range from neutral to acidic. Sulphate (SO_4) concentrations range from below detectable limits to 457 ppm. Hardness as $CaCO_3$ ranges from 83,500 to 110,907. Measureable concentrations of Lithium, Bromide and Iodide were encountered in some wells. TABLE 9 summarizes chemical data available on connate waters from the Cambrian formations in the study area.

This brief summary of water chemistry data clearly shows that a major challenge exists to the design of surface heat exchange equipment and the configuration of components that can resist the problems of corrosion, precipitation and the handling of environmentally objectionable concentrations of dissolved constituents. The engineering solution must have acceptable economic costs and a design life of in-well components that is compatible with a thermal resource life of approximately 20 years. Undoubtedly, the expertise and experience of the oil and gas well operators will prove valuable in this area. Many wells throughout the U.S. pump up and reinject large volumes of heated, saline brines along with the hydrocarbon resource. Continued operation of these wells suggests that some measure of success treating these problems has been achieved.

6. Comparison of Western New York with other Low Temperature Geothermal Sites

Other sites throughout the world have been developed as hydrothermal energy resources. Full development in space heating and agricultural applications have occurred in the USSR, Hungary and France. A demonstration space heating project has recently been undertaken at the University of Regina, Regina Saskatchewan Canada. The geologic context of this project is very similar to that anticipated in Western New York. At present a single well has been installed and information on the reservoir, its temperature and the formation fluids is available (personal communication, Vigrass, 1980). TABLE 10 provides a comparison of resource characteristics of the French and Canadian with those anticipated for Western New York.

Reservoir temperatures are comparable. This is due to the fact that nominal geothermal gradients or heat flux are utilized at all sites. The depth to adequately porous and permeable formations is also comparable. These depths are in fact the shallowest position of usable formation fluid temperatures calculated from the nominal geothermal gradients noted above.

FIGURE 19. Estimation of geothermal gradient with envelope of probable error from BHT.

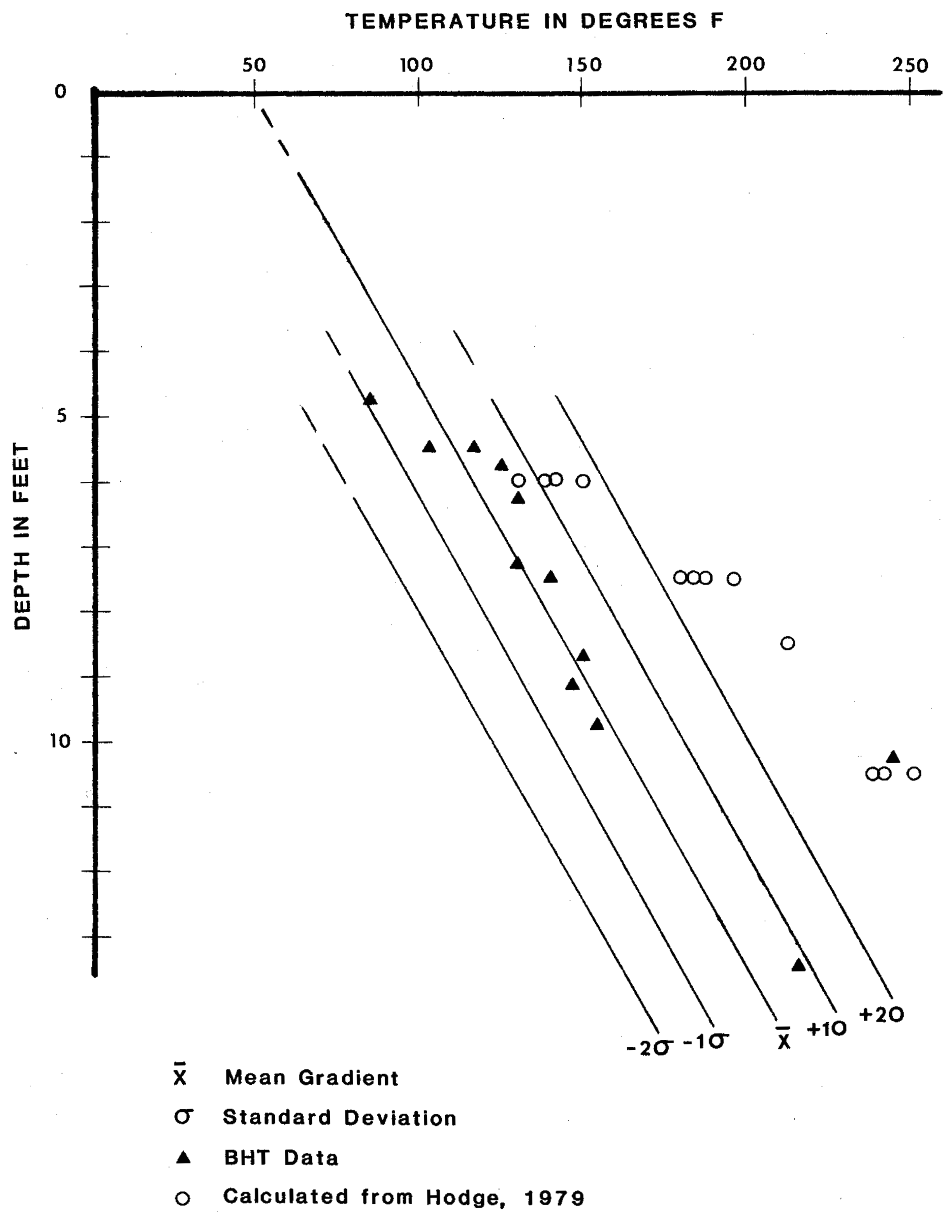


TABLE 9

Chemical Analyses of Cambrian Brines in Western New York

Characteristic/ Constituent	NYS #6073†	NYS #9235†	NYS #6668† @ 3818	NYS #6668† @ 4300
Specific conductance (mho/cm at 25C)	--	229,000	--	--
Resistivity (ohm-meters at 20-21C)	0.054	--	--	--
Silica (SiO_2)	--	28	1.9	2.1
Iron (Fe)	3.5	2.5	--	--
Manganese (Mn)	--	.21	--	--
Calcium (Ca)	29,550	36,000	30,827	31,713
Magnesium (Mg)	3,880	5,100	4,640	3,965
Sodium (Na)	60,150	78,000	84,200	80,400
Potassium (K)	60,150	8,200	3,030	3,148
Bicarbonate (HCO_3)	--	307	14.5	.5
Sulfate (SO_4)	3	--	57 *	43 *
Chloride (Cl)	156,600	200,.000	192,300	185,450
Dissolved-solids concentration	250,550	335,000	321,722	302,080
Hardness, as $CaCO_3$	83,500	110,907	84,676	85,770
pH	5.1	6.0	7.0	4.5
Temperature (C)	--	--	--	40.
Specific gravity (15.6/15.6 C)	1.21	--	--	1.22

† After Waller, et. al. 1978
* Sulfite (SO_3)

TABLE 9 (cont.)

Chemical Analyses of Cambrian Brines

Characteristic/Constituent	NYS #4714	NYS #4561
Specific Conductance	-	-
Resistivity	-	-
Silica	-	-
Iron	-	-
Manganese	-	-
Calcium	28,300	35,700
Magnesium	2,400	3,400
Sodium	93,300	73,100
Potassium	3,700	5,300
Bicarbonate	0	90
Iodide	12	25
Sulfate	T	T
Lithium	-	54
Chloride	204,000	189,000
Bromide	1,800	1,700
Dissolved Solids	-	107,000
Hardness	-	-
Temp. °C	-	-
Specific Gravity	-	-

TABLE 10

Western New York Compared to Other Hydrothermal Sites

	Paris Basin, Fr.	Regina, Sask, Can.	Western New York, USA
Reservoir Temp.	65°C	62°C	60°-100°C
Depth to Reservoir	9,000 ft	7,200 ft	8,000-11,000 ft
Reservoir Thickness	220 ft	333 ft	? < 500 ft
Porosity of Producing Intervals	15%	12-17.5%	10-12%
Permeability	300 md	128-331 md	100 md
Static Fluid Pressure (below K.B.)	Artesian flow	-200 ft	-380 ft
Salinity	25 g/l	108.5 g/l	200-300 g/l

The thickness of producing intervals in all reservoirs is similar within a few hundred feet. New York's producing intervals may be larger, but the conditions of porosity and permeability are not as favorable as the other sites. Measured porosity for the Cambrian formations in western New York are significantly below those values encountered in France and Canada. Permeability values are about 1/3 as high. Here, clearly is the greatest threat to establishing a viable hydrothermal energy recovery system in New York. The exploration and feasibility studies for the region must concentrate on finding those sites that possess the greatest potential for enhanced porosity and permeability in the Cambrian units. The following section provides some useful hypotheses concerning this problem.

The static fluid pressure of formation waters at the New York site is slightly lower than at the Canadian site. These both contrast to the artesian flow experienced at Creil, France. It is important to note that in utilizing well couplets the advantage gained by high static pressures during recovery are lost during the reinjection phase when those pressures must be overcome to inject the cooled, spent fluids.

The concentration of dissolved components is lowest at the French site and substantially higher at the Canadian and New York sites. All sites experience or expect corrosion and scale problems and no site may discharge its brine fluids into surface waters. As a practical matter, the problem of dissolved material in the geothermal fluid is faced by all and only varies in severity.

In summary the characteristics of the operating hydrothermal energy resource in France exceed New York on the basis of flow and porosity. The lower static fluid pressures of New York are not as detrimental as they might seem because all systems utilize a reinjection circulation procedure and the higher fluid pressures must be counteracted during reinjection. Restricted permeability and porosity in New York may be offset by higher water temperatures and optimizing system siting by consideration of potential subsurface porosity enhancement. Therefore, with the available data in hand we may still hold a cautiously optimistic view of the regions potential for viable low temperature geothermal energy resources.

VI. FRACTURE PATTERNS AND PERMEABILITY

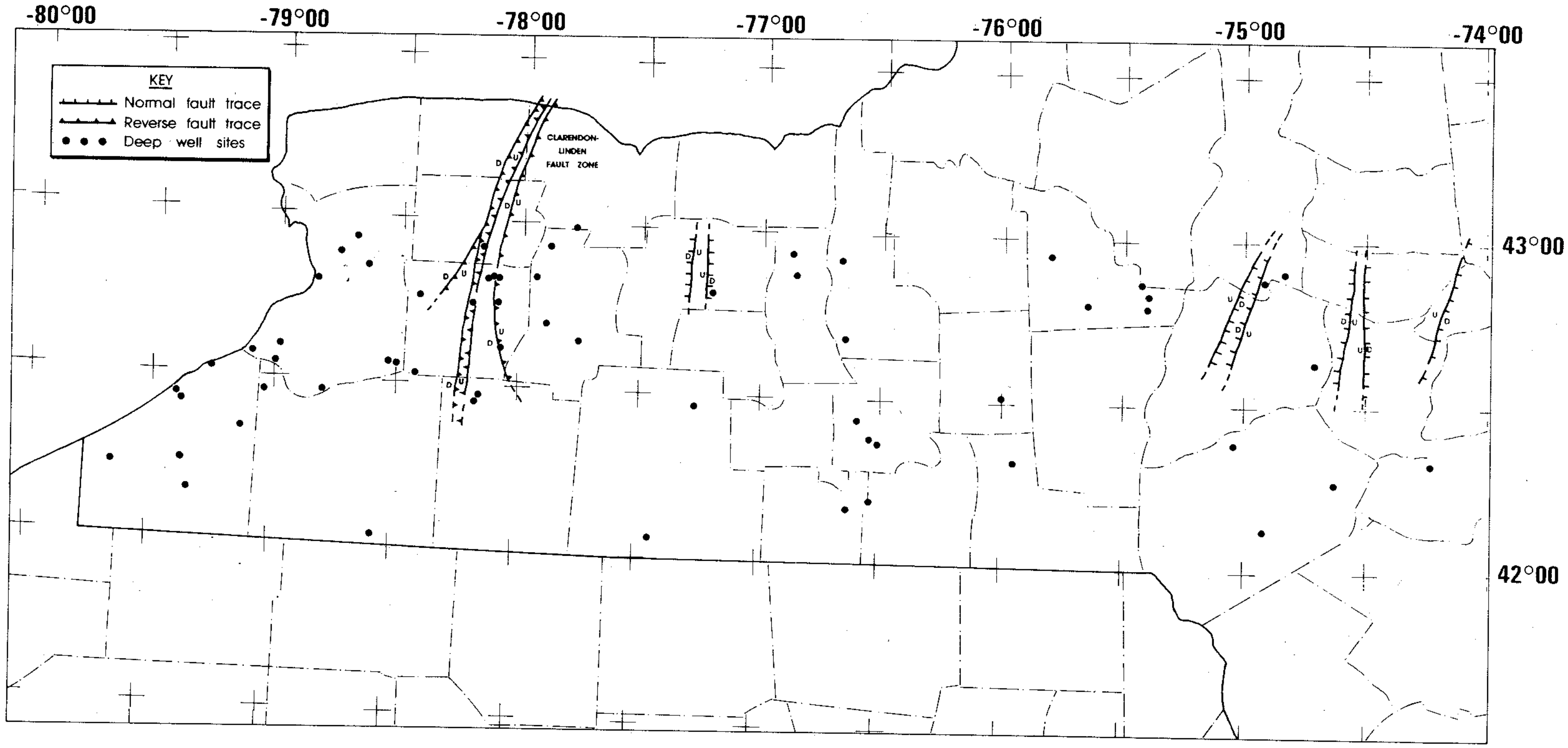
Geothermal energy recovery from hydrothermal resources is a function of the fluid temperature of the formation waters, the volume available of heated waters and the ease with which the water may be pumped to the surface. In the study area, as with many other geothermal prospects, the formation temperatures can be expected to be adequate, however, marginal values of porosity and permeability may be common. This aspect of possible geothermal resources in New York is the least encouraging and the most difficult to assess from the surface.

In order to fully identify the resource potential of western New York, possible natural enhancement of porosity and permeability must be sought and evaluated. We have noted that pore characteristics may be enhanced by chemical solution and by tectonic fracturing. Subsurface samples are too sparse to evaluate the solution effects any further than to note the general "tightening" of the formations to the east. However, some evidence exists that tectonic structures composed of steeply dipping deep fracture zones are present throughout portions of the region and may provide significant enhancement of the flow characteristics of target aquifers.

The most notable of these tectonic features in the study area is the Claredon-Linden Fault Zone. (FIGURE 20). It extends as a recognizable flexual monoclinal structure for over 90 miles. Its great linear extent belies its rather subtle surface manifestation and very minor displacement. However, study has shown (VanTyne, 1975) that the zone has existed as a minor but persistent zone of crustal dislocation for over 300 million years. While little cumulative displacement has occurred during this period, deep fracturing persists to the present day as evidenced by historical low level seismicity. Vibroseis reflection seismic survey work (Fakundiny, et al, 1980) has shown that a subsurface region of multiple, minor, high angle reverse faults are present at depth in the zone. An interpretation of the seismic record across the zone (A-A, FIGURE 21) suggests considerable brecciation and "disturbed" bedding planes. The regions of poor data recovery imply regions of high attenuation and possible fracturing. In addition, direct evidence of favorable porosity and permeability is available from NYS, wells number 4392, 4552, and 13700 which exhibit significantly higher than average natural water flows. Another evidence of enhanced flow characteristics appears in the patterns of potentiometric head as determined from deep aquifers and presented by Willette (1979) (FIGURE 22). The lower potential head shown along the trace of the fault zone suggests that aquifer flow is less restricted in that region. Thus it appears that deep fracture zones such as the Clarendon Linden structure may provide guidance in locating regions with more favorable characteristics of porosity and permeability in the deep aquifers.

Additional zones of deep fracturing may be located by lineament studies. Recent research has shown that some LANDSAT imagery lineaments correlate with enhanced flow capacity in sandstone aquifers in Arizona (Babcock, 1979). A preliminary lineament study has been performed in selected portions of the study area and is presented in FIGURE 23. In an effort to relate these lineaments to geologic features gravity, magnetic, topographic and drainage data for the same area

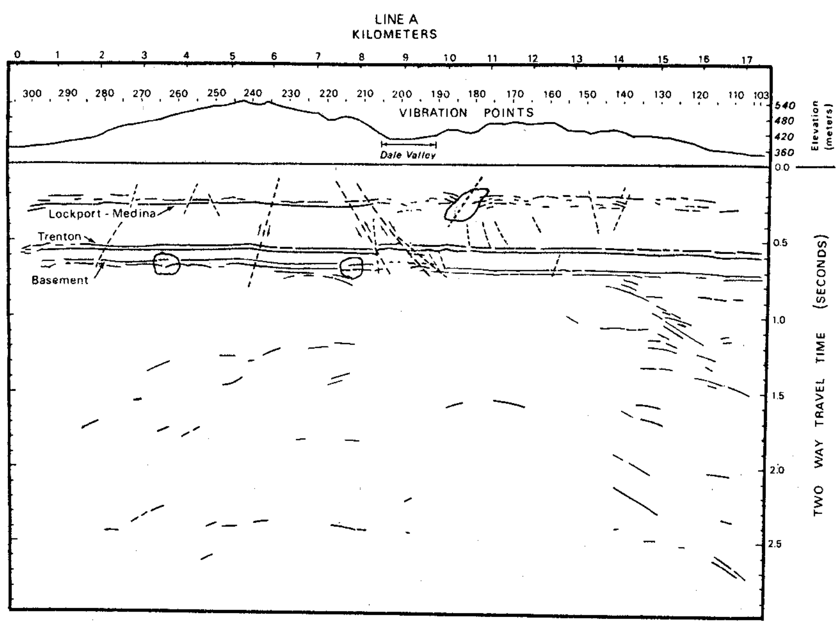
DEEP WELLS IN WESTERN NEW YORK STATE



(from Fakundiny et al, 1979, and Rickard, 1973)

FIGURE 20. MAP OF CLARENDON - LINDEN AND OTHER BASEMENT FAULT STRUCTURES OF THE STUDY AREA

FIGURE 21. Vibroseis interpretation across the Clarendon-Linden fracture zone.



Interpretation of VIBROSEIS line . Vertical scale is two-way travel time of seismic waves in seconds. Circular shaded zones are regions of poor data definition. Topographic surface profiles are in meters above sea level.

FIGURE 22. Potentiometric surface of deep aquifers and deep fracturing.

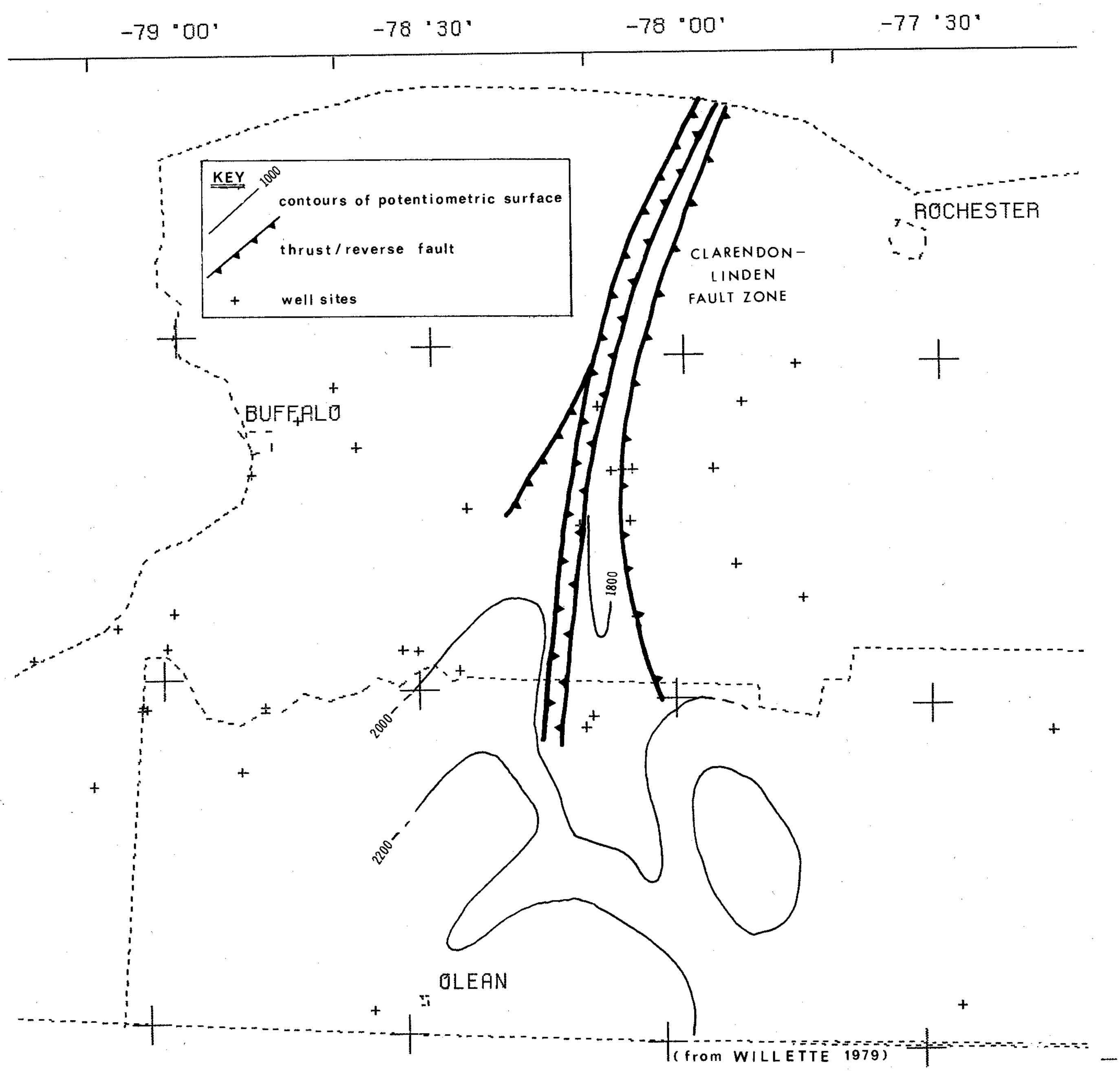
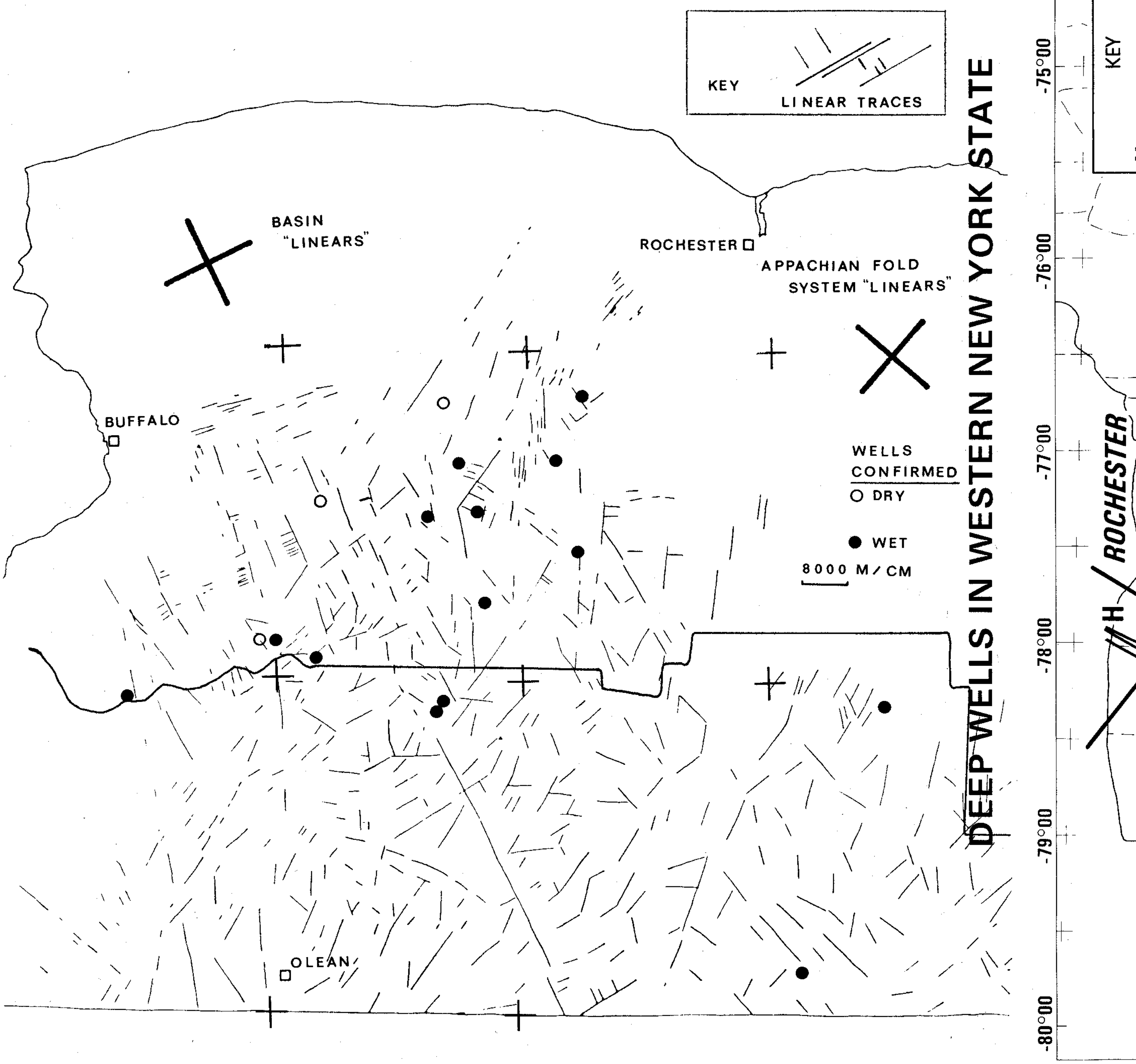


FIGURE 23. Preliminary lineament study for a portion of the study area.



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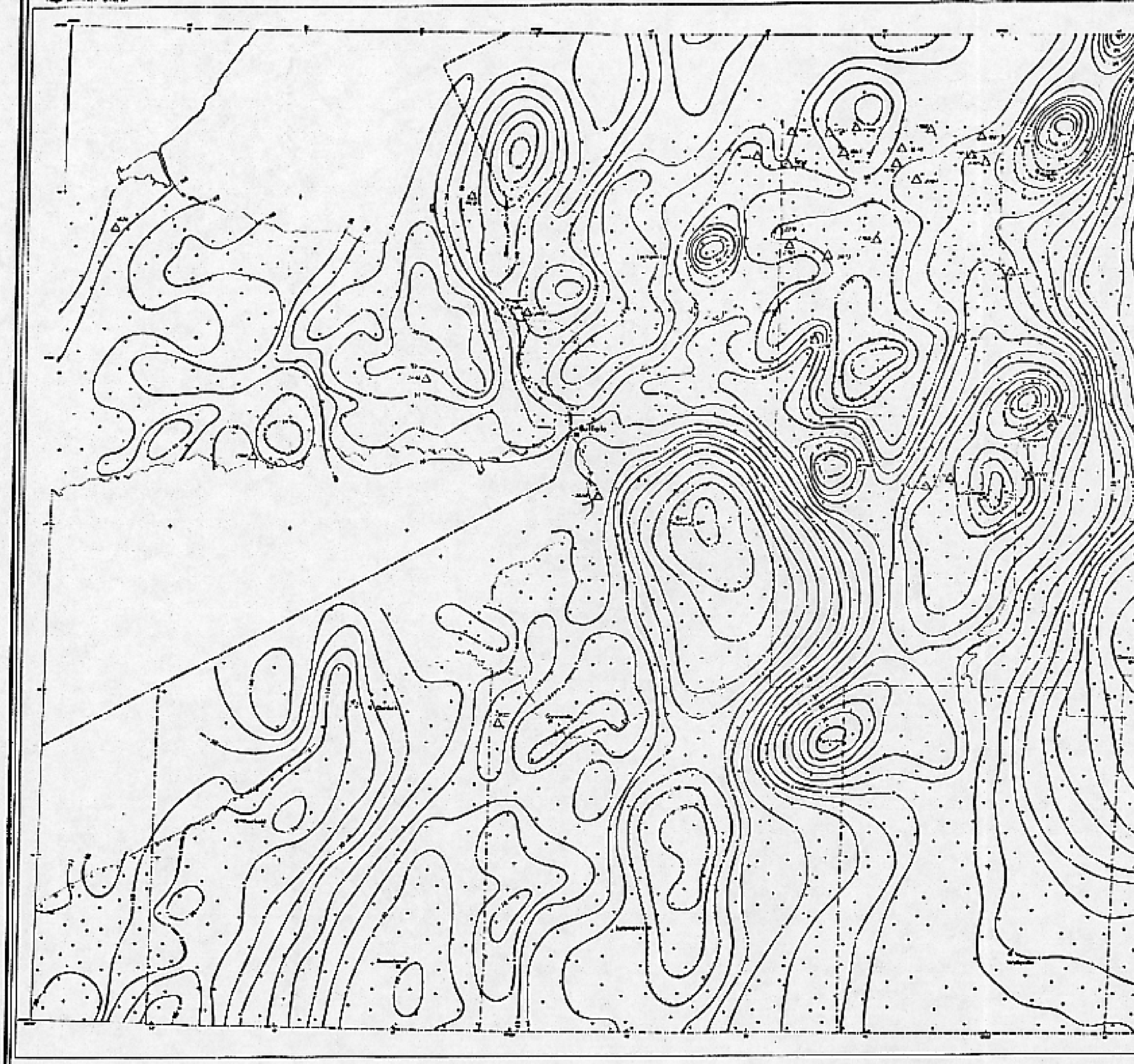

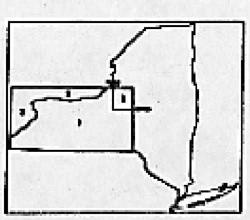

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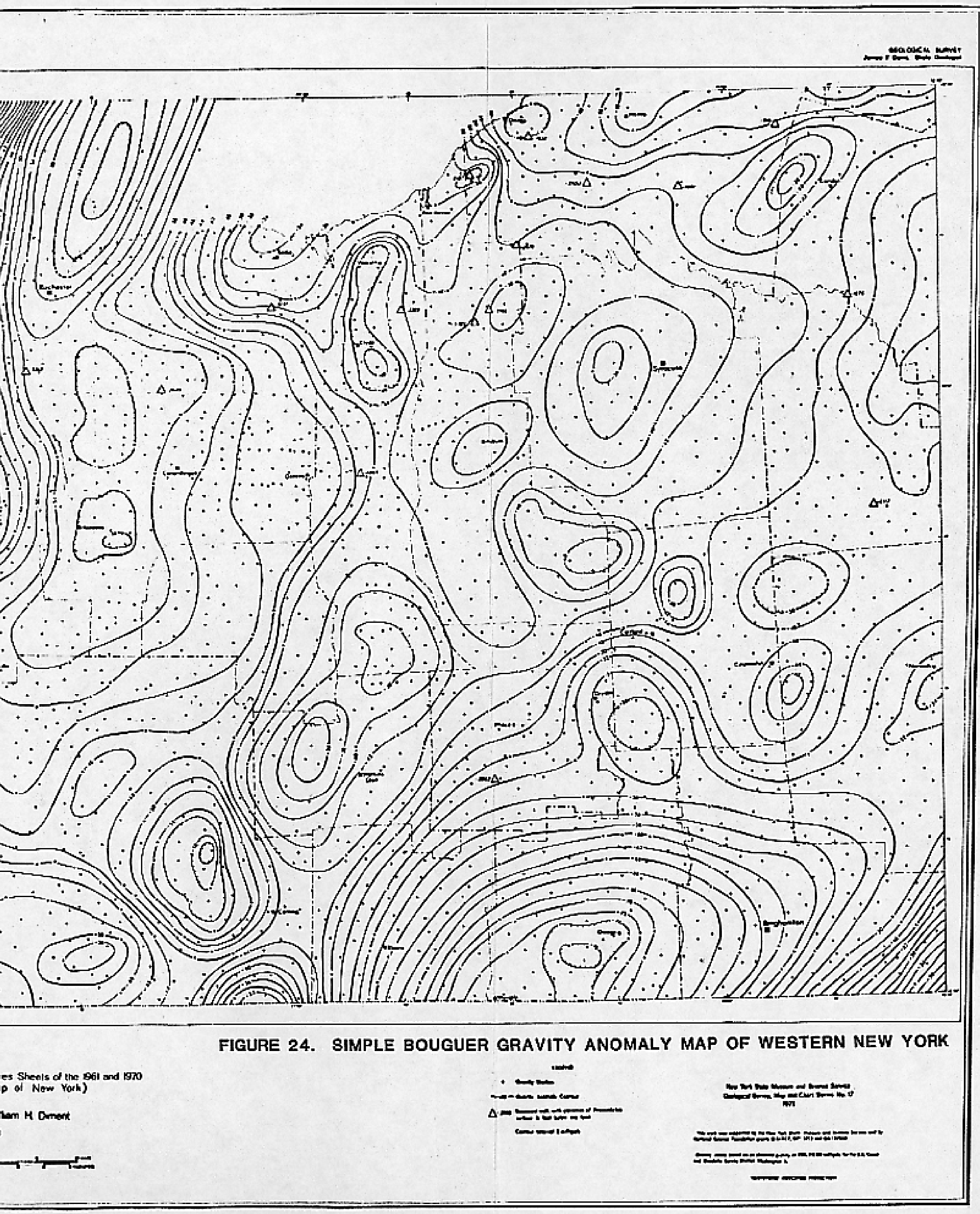

FIGURE 24. SIMPLE BOUGUER GRAVITY ANOMALY MAP OF WESTERN NEW YORK

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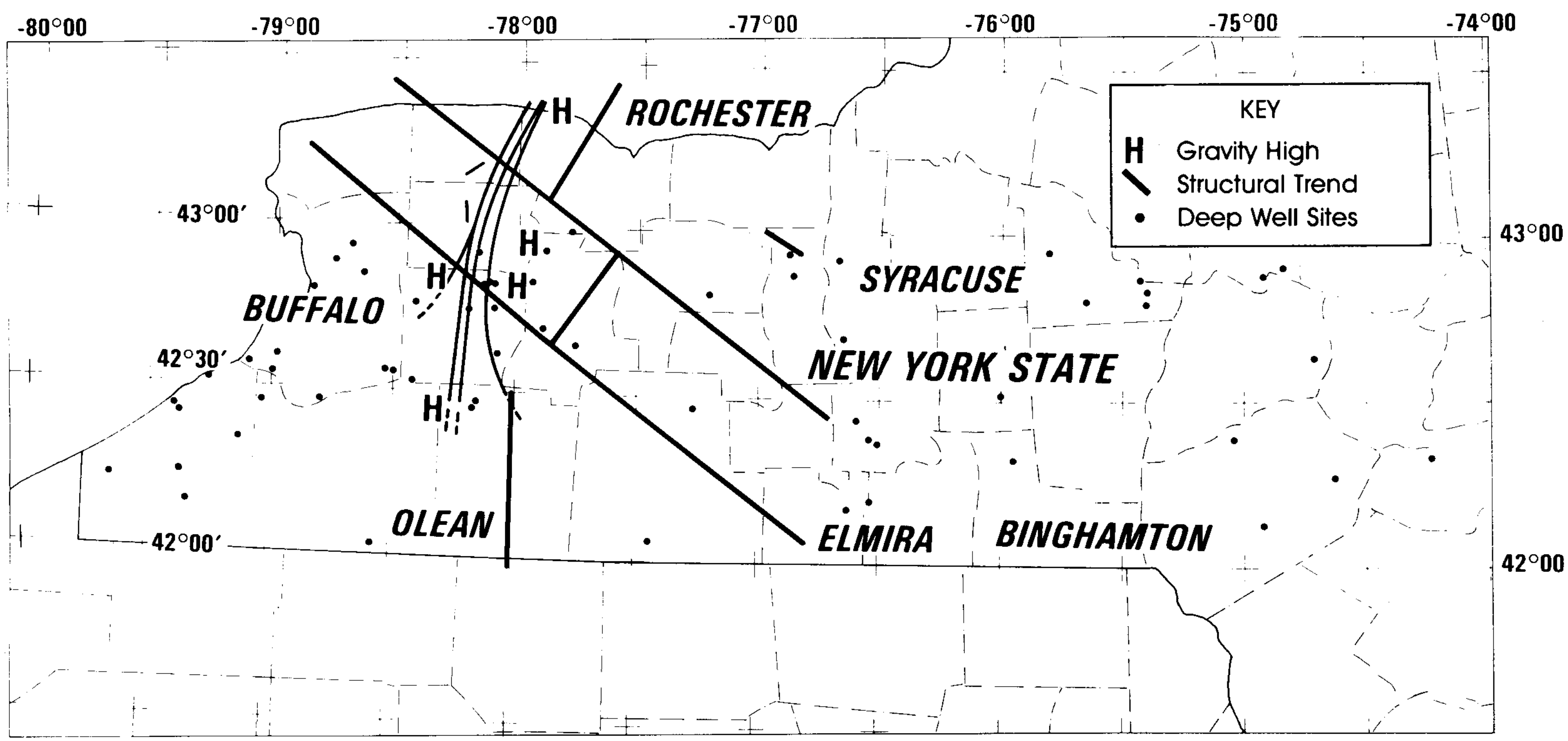
DEEP WELLS IN WESTERN NEW YORK STATE



(from Fakundiny et al, 1979, and Rickard, 1973)

FIGURE 25. LARGE-SCALE CRUSTAL DISCONTINUITIES BASED ON GRAVITY DATA

FIGURE 26. Conceptual model of deep fracturing of sedimentary cover controlled by basement structure.

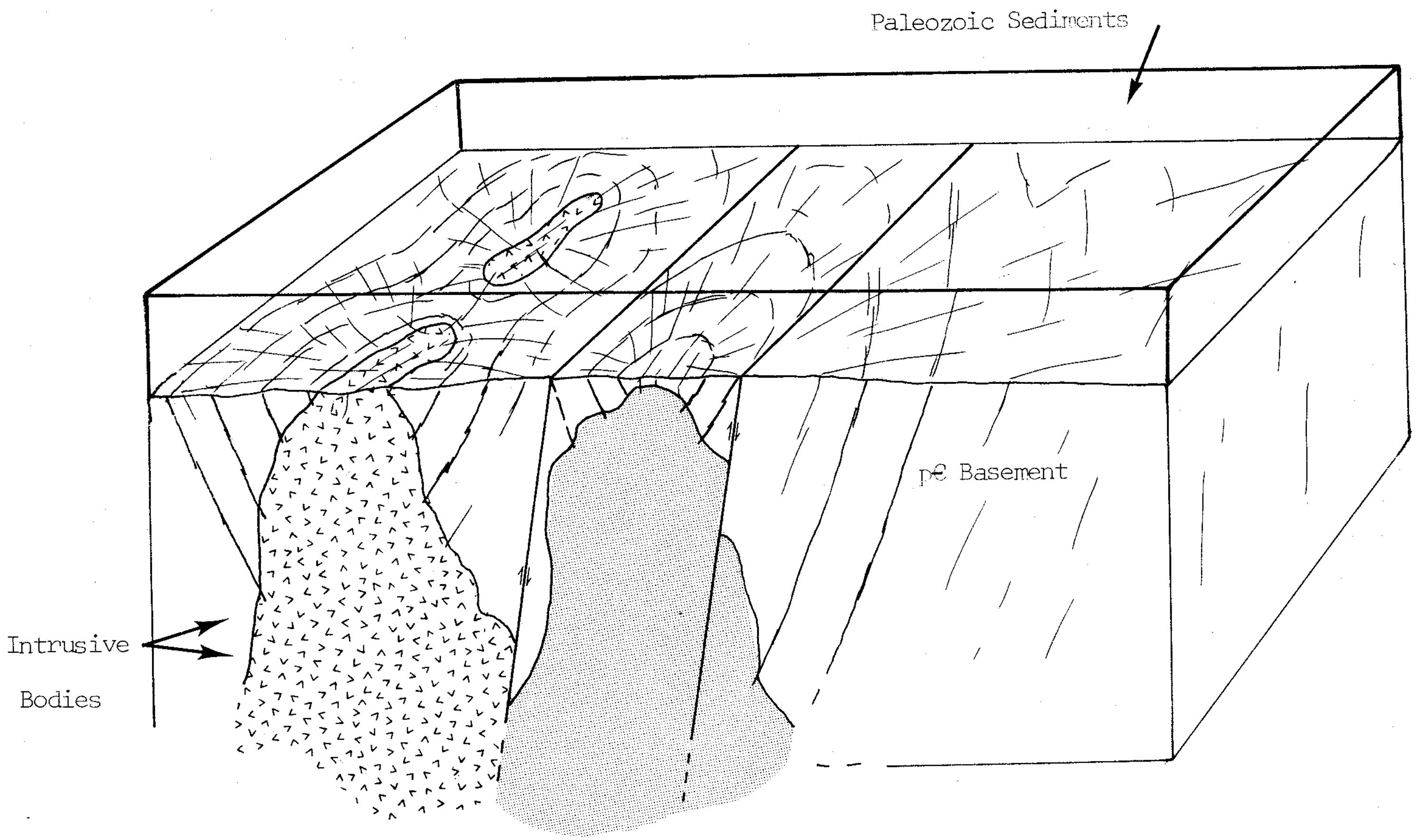


FIGURE 27. Young's moduli of some common rocks.

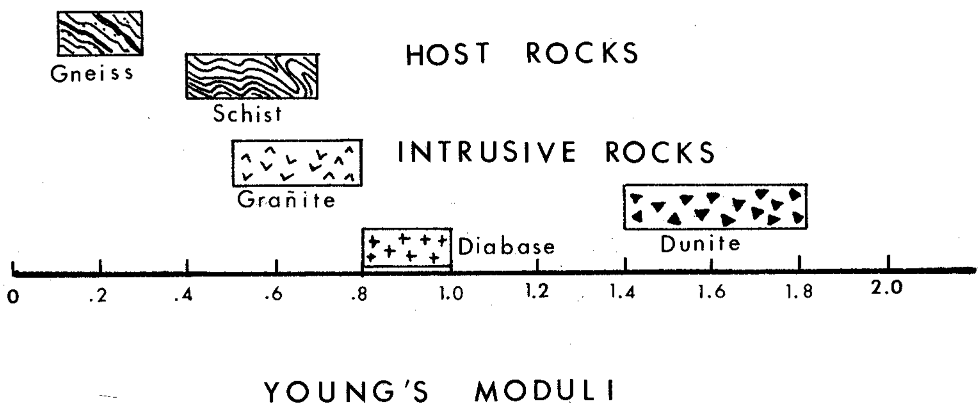


FIGURE 29. Relationship between basement-controlled fracturing and gravity anomalies.

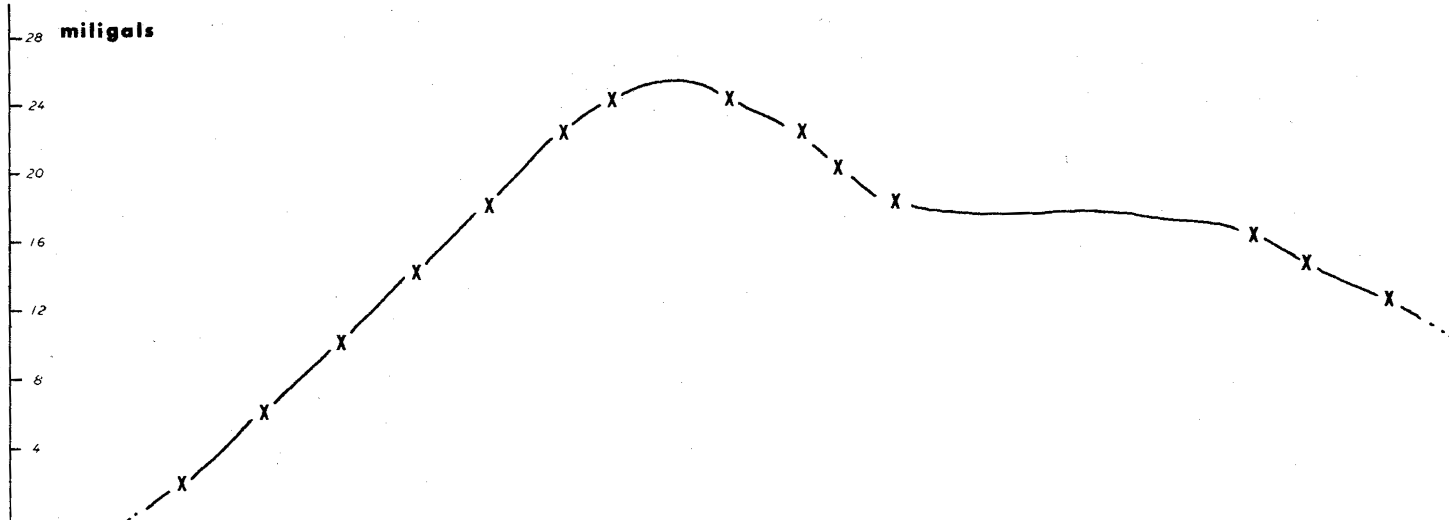


FIGURE 28. Conceptual model of fracturing of sedimentary cover controlled by differential strain between intrusive bodies and the host terrain.

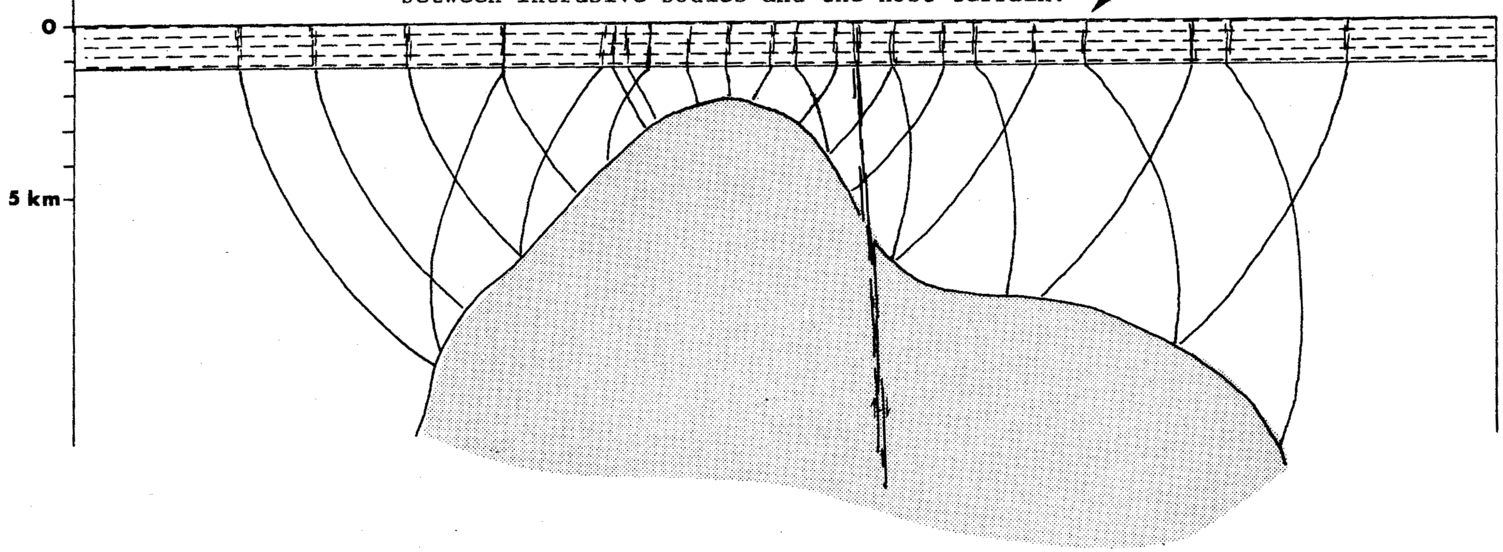


FIGURE 30. Detail of map of gravity anomaly.

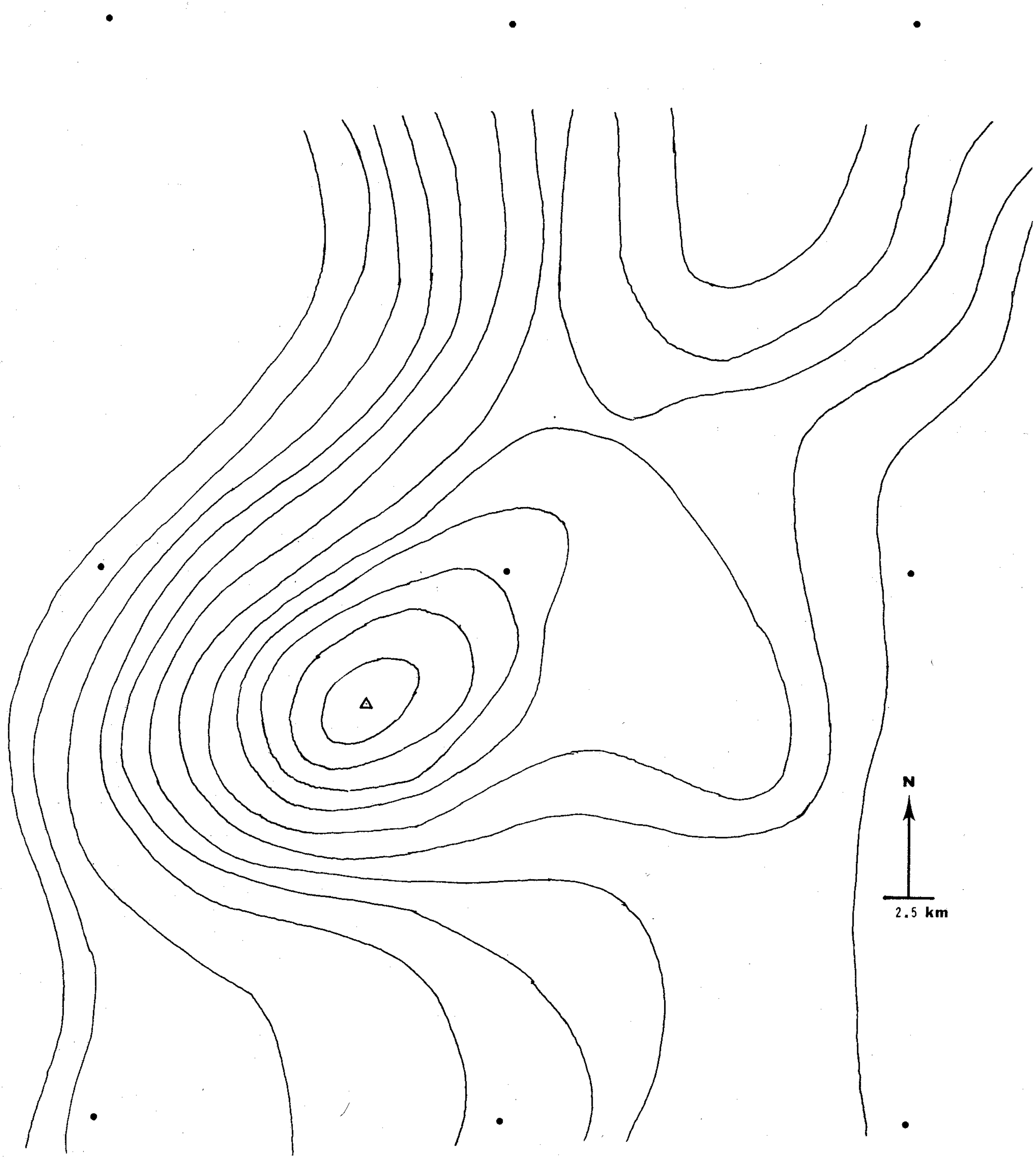
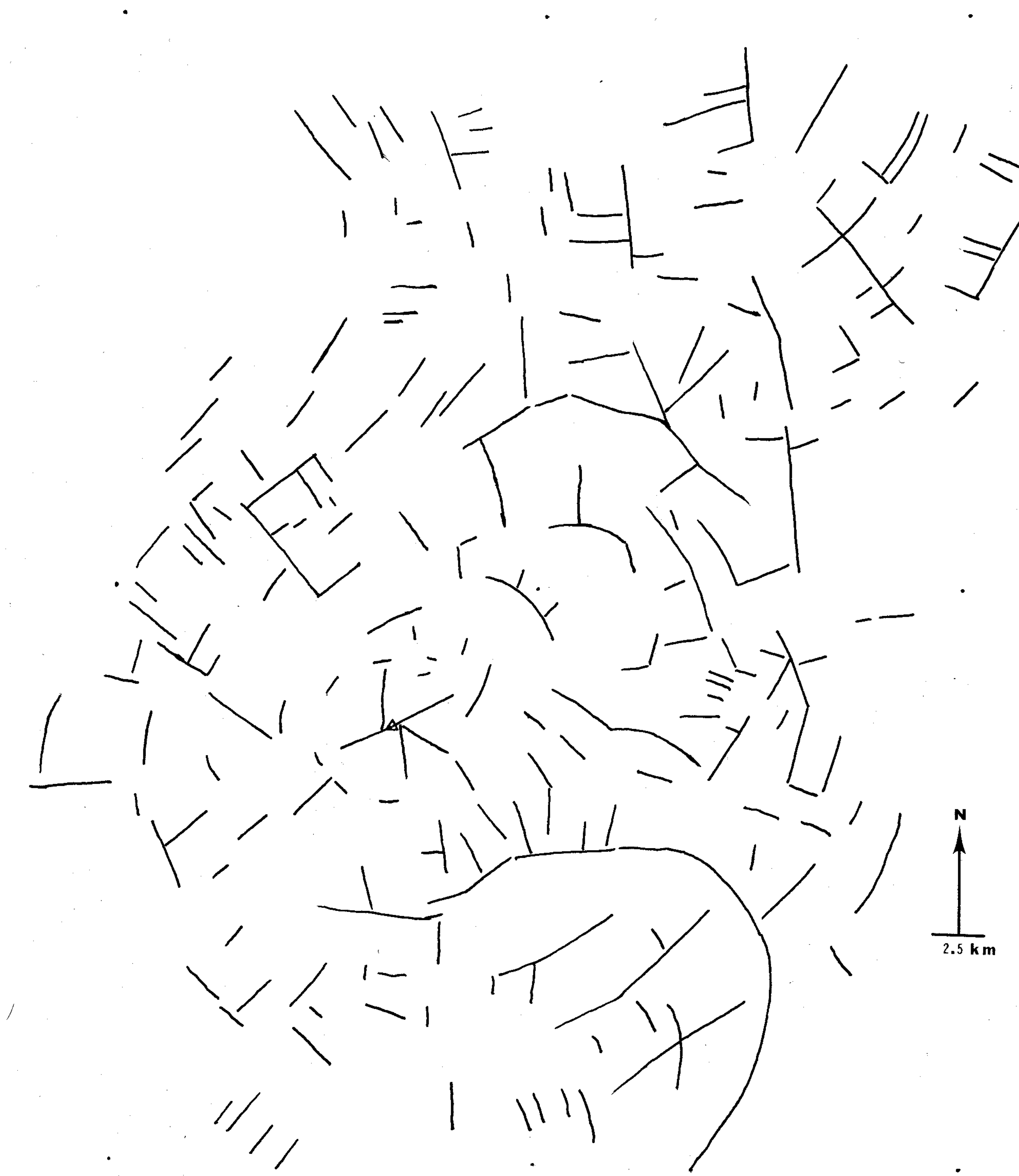


FIGURE 31. Detail of map of lineament segments potentially related to basement intrusive controlled fracturing.



was examined. Successful spatial correlation of lineaments, drainage patterns and gravity anomaly patterns suggest a possible genetic association of these features and deep fracture zones. Traditional interpretation of deep-fracture controls has rested primarily on correlations with regional tectonic events (Parker, 1942) and the geometric distortions due to sedimentary basin formation (Prince,1960). These factors undoubtedly exercise some control on the patterns and extent of deep fracturing in the Paleozoic rocks of Western New York. Other workers have noted structural patterns or "grain" that are believed to exist in the Precambrian basement rocks underlying the study area. These patterns have been identified from earthquake epicenters and the Bouger gravity anomaly map (Revetta and Diment, 1971) of the region (FIGURE 24). These patterns have been interpreted as revealing large-scale crustal discontinuities possibly related to Precambrian continental plate boundaries. The Clarendon-Linden structure appears as a strong N-S boundary between two distinctly different basement terrains. Some transcurrent structural trends have been noted in the gravity patterns (FIGURE 25). These possibly represent sites of transform faulting that may have occurred along the Clarendon-Linden paleoboundary. These structures are believed to have acted as weak crustal junctures that have been the locus of seismicity, fracturing and minor displacement to the present.

In addition to these large-scale zones of localized crustal fracturing, this author has noted substantial correlation between the gravity expression of intrusive bodies in the basement and systematic patterns of surface lineaments, primarily expressed as drainage paths. A conceptual model of the relationship between these intrusive bodies and fracturing in the overlying Paleozoic sediments is shown in FIGURE 26. Little or no displacement along these fractures is expected as they developed in response to minor, but persistent differential strain that is concentrated by the differing moduli of deformation existing between the basement intrusive bodies and their metamorphic host rocks. FIGURE 27 is a graphic representation of the Young's Moduli for some common rocks found in the Precambrian basement complex. FIGURE 28 is a model of the fracturing produced in the Paleozoic sedimentary cover by differential strain between an intrusive body and the host metamorphic rocks. The overlying sedimentary rocks have been subject to more than 400 million years of minor flexure as this portion of the North American plate has moved over the earth's mantle. This persistent localization of stress and strain may have produced deep fracture zones that now enhance the permeability and porosity of the Paleozoic section. FIGURE 29 shows the relationship between the basement-controlled fracturing and gravity anomalies due to the intrusive body in the subsurface. To demonstrate the relationship between gravity anomaly patterns and possible deep fractures, FIGURES 30 and 31 present gravity and fracture data for a local region in western New York. FIGURE 30 shows the gravity contours (milligals) over a distinctive anomaly located about 60 miles southwest of Buffalo (See FIGURE 24). FIGURE 31 shows surface linears for the same area. Notice the high degree of association between directions that are concentric and radial to the gravity anomaly isogals and the pattern of surface linears. It is suggested here that the orientation and position of the surface linears is controlled by deep fracture zones linked to basement junctures and intrusive bodies. FIGURE 32 is an interpretive map of the prominent surface linears of western New York based on a model of control by basement structures. These linears are typically controlled by subtle concentration of joint sets. Areas of concentration and intersection of these linears are proposed to possess enhanced potential for porosity and permeability due to deep fracturing. A synthesis of the indicators of potential enhanced porosity and permeability that includes surface linears, large-scale basement trends, recognized fault structures and earthquake epicenters is presented in FIGURE 33. Areas within the counties studied for LANDSAT linears have been ranked with respect to their likelihood of possessing enhanced porosity and permeability due to tectonic fracturing.

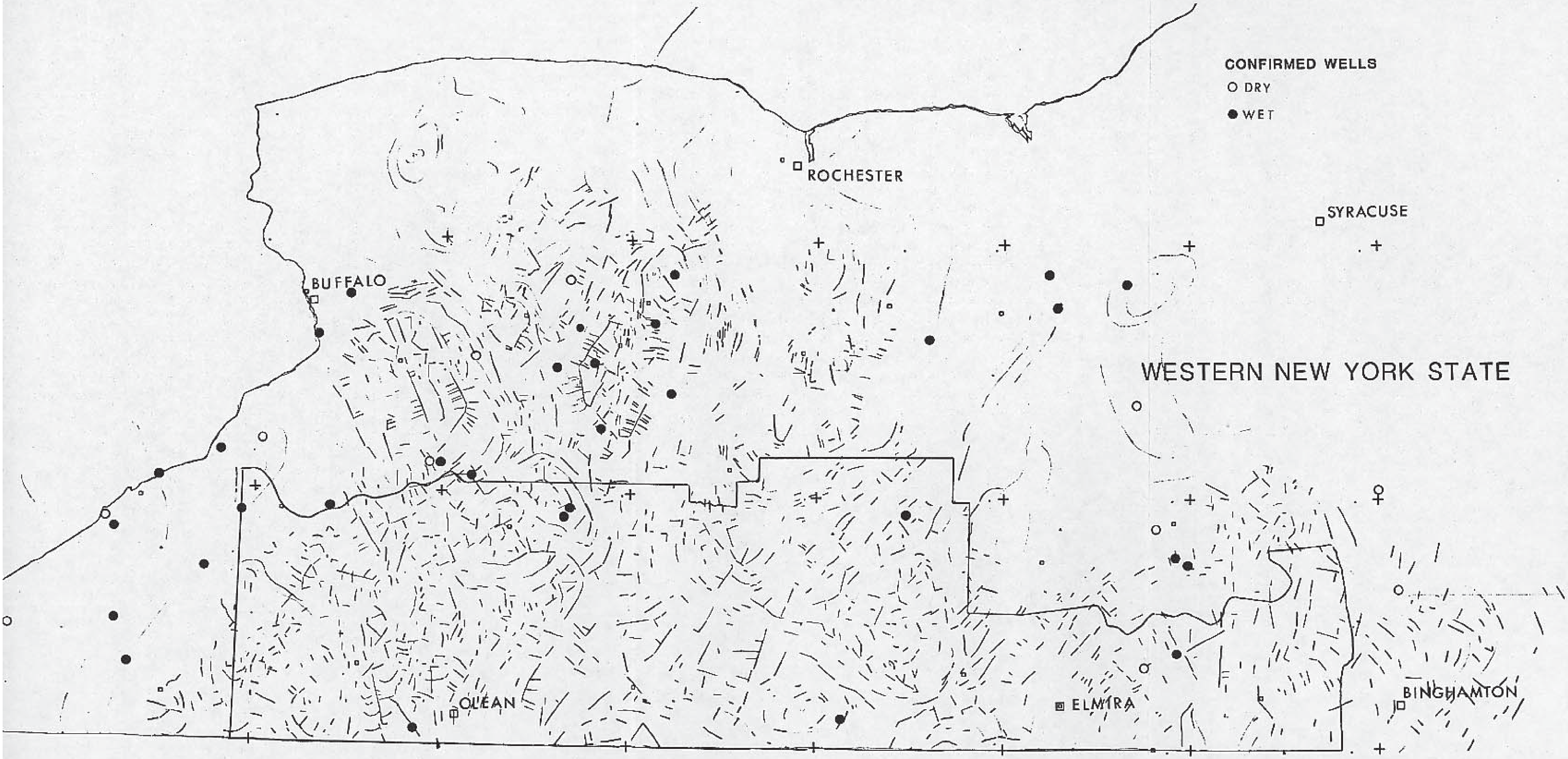


FIGURE 32. MAP OF SURFACE "LINEARS" POTENTIALLY RELATED TO BASEMENT-CONTROLLED FRACTURING

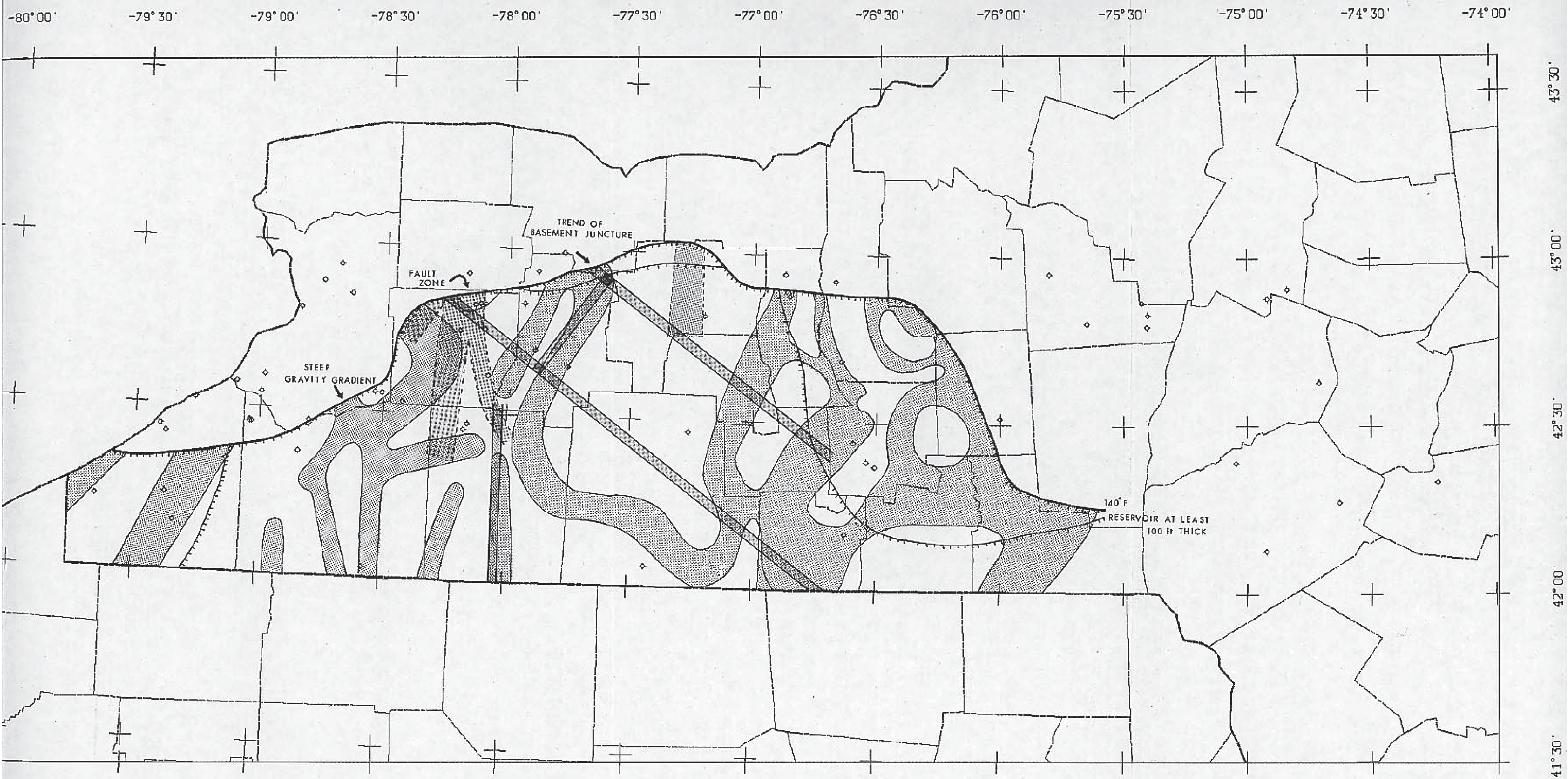


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FIGURE 33. **AREAS RANKED BY GEOTHERMAL POTENTIAL**

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