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Photolineament study for the Phippsburg, Bath, Richmond, Boothbay Harbor, Westport, Wiscasset, Pemaquid Point, Bristol, and Damariscotta 7.5' quadrangles

Robert G. Gerber

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August 13, 1985
File #329

Maine Geological Survey
Maine Department of Conservation
State House Station 22
Augusta, Maine 04333

Attention: Mr. Marc Loiselle

Dear Mr. Loiselle:

In accordance with our contract #923263, Appropriation #4508.1015.4099, we have completed the Photolineament Study for the Phippsburg, Bath, Richmond, Boothbay Harbor, Westport, Wiscasset, Pemaquid Point, Bristol, and Damariscotta 7.5' Quadrangles for the Maine Geological Survey.

Our findings and conclusions are given in the attached report.

Sincerely,

ROBERT G. GERBER, INC.

William R. Holland,
Senior Geologist

STATE OF MAINE
ROBERT GRAHAM GERBER
CERTIFIED GEOLOGIST

Robert G. Gerber,
Certified Geologist #110

Enc: Report, lineament maps, paper copies of basic data maps

PHOTOLINEAMENT STUDY FOR THE PHIPPSBURG, BATH, RICHMOND, BOOTHBAY HARBOR, WESTPORT, WISCASSET, PEMAQUID POINT, BRISTOL, AND DAMARISCOTTA 7.5' QUADRANGLES

for

MAINE GEOLOGICAL SURVEY

by

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I INTRODUCTION

I.1 Background Information

Federal statute currently requires that the State of Maine be responsible for the disposal of all domestically-generated low-level radioactive wastes by January 1, 1986. The Low Level Radioactive Waste Siting Commission is now investigating several courses of action to address this requirement. One of these is the construction of a disposal facility within Maine's borders. In order to facilitate the identification of geologically suitable potential disposal sites in Maine, the Siting Commission has requested the Maine Geological Survey to conduct or oversee the collection of geologic data pertinent to the problem. Two studies have been completed to date. The first study was prepared by the Maine Geological Survey, and assessed the distribution and potential suitability of marine clay terranes in the southern third of the state. The second study was conducted by Robert G. Gerber, Inc., and examined the distribution and suitability of dense glacial till deposits in the Unorganized Townships.

At the request of the Siting Commission, the Maine Geological Survey has undertaken a preliminary investigation of the geologic suitability of the region surrounding the Maine Yankee Nuclear Generating Plant in order to determine the feasibility of pursuing future site-specific investigations. One part of this study, a photogeologic lineament analysis of the region, was contracted to Robert G. Gerber, Inc.

The main purpose of the photogeologic study is to identify and assess photolinear elements within the study area in terms of the likelihood that they are zones of relatively high bedrock transmissivity. This assessment forms the basis for a regional characterization. It is not intended to propose sites for further investigation, nor is it a quantitative study of the hydraulic properties of the bedrock aquifers.

I.2 Working Definition of Terms

I.2.1 Photolinear Element

Several usages of the term 'lineament' exist in the literature. Each is somewhat restrictive in terms of this project. A lineament in the tectonic sense is by convention a "straight or gently curved, lengthy linear feature, frequently expressed topographically as depressions or lines of depressions." (Gary, McAfee, and Wolf, p. 408). A photographic lineament is "any line, on an aerial photograph, that is structurally controlled, including any alignment of separate photographic images such as stream beds, trees, or bushes that are so controlled. The term is widely applied to lines representing beds, lithologic horizons, mineral bandings, veins, faults, joints, unconformities, and rock boundaries." (Gary, McAfee, and Wolf, p. 408).

Both of these definitions imply a cause and effect relationship between landform or land surface appearance and bedrock structure. Because of the absence of field corroboration of many of the features identified during the study, the matter of whether they are in fact structurally controlled or controlled by some external factors which have nothing at all to do with bedrock structure is capable of question.

Wise and others (1985) used as a working definition of lineament the following:"...clear alignment of linear valleys, valley walls, ridges, passes, coastlines, or, preferentially, combinations of these features, such that their total length is greater than 10 km and their combined ratio of length to width (aspect ratio) exceeds 10." Although the length requirement they used is much too restrictive for this study, the rest of the definition lends itself quite well.

We have therefore used a general term which gave us the widest possible latitude during the identification of features: photolinear element, which we will simply define as any remotely expressed fabric element in which the length is greater than 10 times the width. There is no explicit minimum length requirement, although from a cartographic standpoint, 200m proved to be a workable minimum length. There is also no implicit genetic connotation in our definition. If we had restricted ourselves to only those features of known bedrock structural affinities, the accompanying maps would necessarily have a significantly sparser appearance.

The lines shown on the maps accompanying this report therefore simply constitute a data set of observed features, without potentially perjorative interpretation.

I.2.2 High Transmissivity Zone

The data regarding the hydraulic characteristics of the bedrock aquifers in coastal Maine are extremely sparse, certainly insufficiently dense for quantitative assessments to be made of the features identified in this study. Therefore, for the purposes of this study, the term is envisioned as a relative term indicating a hydraulic characteristic of the bedrock media which is a measure of its suitability for a water supply and also a measure of the rate at which contaminants could be transmitted under unit hydraulic head. Concern for the protection of existing and future ground water supplies is, as we understand it, a primary reason for this study. A second reason relates to the need to isolate the water from the environment for a long period of time.

I.3 Project Personnel and Acknowledgements

William R. Holland was the principal investigator on the project, and conducted all examinations of imagery, linear identification, interpretation, data analyses, and wrote the final report. Stephen R. Pinette assisted in the gathering and compilation of existing data, and did much of the graphic transfer of linear data from image overlays onto compilation maps. Robert G. Gerber assisted in data compilation and analyses, and reviewed the final report. Private consultant John R. Rand kindly provided us with unpublished outcrop data, as did Arthur M. Hussey of Bowdoin College, and Donald Newberg of Bates College. Melanie Lanctot and Andrews Tolman of the Maine Geological Survey provided us with 1:24,000 basic well data maps for the study area. Marc Loiselle of the Maine Geological Survey obtained all requested imagery necessary to complete the investigation. James Connors of the Land Use Regulation Commission made a Bausch and Lomb Zoom Transfer Scope available to us.

II STUDY PROCEDURES AND METHODOLOGY

The study consisted of 3 principal tasks: compilation of existing data; interpretation of remote imagery and identification of photolinear elements; and analyses of the features identified.

II.1 Compilation of Existing Data Pertinent to the Study Area.

Pertinent data included well and other subsurface information, bedrock and surficial geologic maps of the quadrangles involved, results of certain site-specific studies conducted within the area. Data were obtained from published Maine Geological reports, unpublished basic data maps compiled by the Maine Geological Survey, reports from Maine Yankee Corporation, unpublished field data collected by J.R. Rand, and from our own files. All data were xerographically scaled to 1:24,000 (the scale of the 9- 7.5' quadrangles of the study area), and plotted on mylar quadrangle in order to assess easily the degree of correlation between identified linear elements with existing "hard data".

II.2 Interpretation of Aerial Photography and Remote Imagery.

All available aerial photography and non-conventional remote imagery covering the study area was used. Nine unique scales of imagery were employed: 1:1,100,000, 1:1,000,000, 1:500,000, 1:250,000, 1:130,000, 1:128,000, 1:80,000, 1:40,000, and 1:20,000. Image data were obtained from 4 discrete remote data procurement technologies- Landsat Multispectral Scanner (MSS), Return Beam Vidicon (RBV), Synthetic Aperture Side-Looking Airborne Radar (SLAR), and conventional aerial photography with stereoscopic coverage. 435 separate scenes were studied, including composites and mosaics. Imagery included black and white, false color infrared, and color composite scenes, in both film positive and paper positive formats. All imagery for the study was provided by the Maine Geological Survey. A detailed listing of the imagery used in the study is included as Appendix 1.

Where stereoscopic coverage of photographs was available, both a standard F-71 mirror stereoscope and a 2.25X pocket stereoscope were used. For non-stereo coverage, such as the radar and Landsat imagery, scenes were studied with the naked eye, and with 5X and 10X hand lenses. Because of fortuitous image overlap of two completely different Landsat MSS scenes, a pseudo-stereo effect was obtained which proved to add somewhat to the apparent resolution of certain features.

II.3 Objectivity and Bias

As Wise, et. al. observed (1985, p.959), "lineament detection differs from most other kinds of geologic observation in the magnitude of its potential for observer bias...(Far) greater attention thus must be paid to testing reproducibility and reliability than is customary in geologic research". While the scope of the project precluded rigorous testing in these regards, we formulated a strategy which attempted to enhance reproducibility and minimize misinterpretation.

II.3.1 Reproducibility

The present study is preliminary in nature. In a more detailed investigation, it is possible to mitigate the effects of observer error by having several observers of high and essentially equal photogeologic skills study the same set of photographs. Linear elements are then digitized, filtered numerically, and statistically analyzed. Although we did not use such extensive procedures, we did attempt to minimize observation errors by using different stereoscopes and magnification lenses on the same image. We also used the standardized observation procedures throughout the project. We found this to be important when dealing with many hundreds of scenes and many scales over the relatively long period of time that was required to complete the examination of all of the imagery.

II.3.2 Reliability

The use of many scales and image types helped to minimize misinterpretation and bias. At different scales and image types, different characteristics of the landscape are visible to the eye such that slope aspect, direction of illumination, may result in somewhat of a bias in the identification of a linear element in a particular image type and scale. There were several occasions where features identified as likely bedrock lineaments from small scale imagery were subsequently determined to be cultural when the large scale scenes were examined.

Because of the lack of field verification and subsurface data, it is likely that some of the features depicted on the maps are spurious in terms of their significance as bedrock structures. This may be especially true with regard to the larger scale photography, where vegetal patterns and tonal variations constitute a large percentage of the identified features.

Every attempt was made to avoid the mapping of roads, stonewalls, fences, property lines and other cultural artifacts. In many cases old land use patterns made this relatively easier in a large area. However in cases where there had been a long history of farming, reforestation and logging, anomalous vegetal linears often appeared. While many of these were parallel or subparallel to nearby linear elements which had a very high likelihood of being true bedrock lineaments, several such features showed no obvious correspondence to bedrock structure. Without field data on each of these features it is impossible to say what our reliability is on that score.

II.4 Data Handling Techniques

II.4.1 Data Transfer From Imagery

As each scale of imagery was studied, identified linear elements were plotted either on acetate overlays in ink (in the case of film positives), or, for paper prints, directly on the prints with easily erasable grease pencils. Linear elements were subsequently transferred to true-scale copies of the 1:24,000 quadrangle maps using the following techniques: Zoom-Transfer Scope (kindly provided to us by James Connors of the Maine Land Use Regulation Commission); overhead projection of acetate overlays, projection of slides taken of prints and overlays using a 35 mm camera with close-up lenses; opaque projection of prints; xerographic reduction of 1:20,000 prints; and direct transfer by inspection. A separate quadrangle map was prepared for each scale studied.

II.4.2 Ranking of Photolinear Elements

Every identified linear element was ranked according to a three-fold rating scheme which took into account the apparent strength of a feature as expressed in imagery. Because of the subjectivity and potential for bias in such a rating scheme, only divisions were defined: strong, moderate, or weak.

II.4.3 Classification of Photolinear Elements

Once all of the scales and image types had been thoroughly studied, all linear elements were combined onto a single mylar quadrangle map, and were classified according to the scales at which the linears appeared. This classification roughly corresponds to a classification of topographic strength. Certain linear elements were of a regional scale, and had an imprint which was visible only from great distances. Others, on the other hand, were of a very local scale, and were visible only from relatively small distances. As an aid to the interpretation of the potential significance of the identified linear elements, a 3-order scheme was developed which attempted to classify each feature according to whether they were regional, intermediate, or local in scale.

For logistical reasons, we chose not to attempt to establish a relationship between linear features and the classical geomorphological drainage-order classification. Instead, we classified solely on the basis of image scale: First order features were those which were generally distinguishable only at small scales (1:250,000 to 1:1,100,000). Second-order features were generally visible at intermediate scales (1:80,000-1:130,000), and third order features were generally visible only at large scales (1:20,000-1:40,000). Where a linear element was observed at more than one 'scale-block', preference was given to the smaller scale, and a lower order ranking was assigned.

First order features generally are the principal features of the landscape. They control the first order drainages and the general morphology of the coastal islands and peninsulas. Second order features are prominently displayed but exert less of a controlling influence on the overall landscape. Third order features exert an influence on microtopography and vegetation. These features are generally seen as image tonal and textural breaks, small changes in slope aspect, or alignments of subordinate or minor drainages.

II.5 Analyses of Data

Once all remote imagery were studied, and photolinear elements were discriminated, ranked and classified, the data were analyzed in conjunction with the geological and hydrologic data collected during the initial phase of the project (see Section II.1). This consisted of a visual comparison of photolinear elements with the features previously plotted on the data overlays.

II.5.1 Comparison with Existing Geologic Data

In addition to the obvious purpose of discovering any spatial coincidence among identified photolinear elements and mapped structural features such as faults, we also compared linear elements to individual outcrop data (where they were available) to determine whether the trends of the features seen in imagery were substantiated by field measurements. We compared all available field data, including strikes of joints, foliation, bedding, mafic dikes, slickensided surfaces, and lithologic contacts.

In an attempt to minimize misidentification of glacial flutes, heavily striated pavements, and moraines as potential bedrock linears, we also examined surficial geologic maps. information relative to glacial geologic linear features proved to be somewhat difficult to obtain. The features of greatest interest were moraines, eskers, striations, flutes and drumlins. The last three items invariably did not appear on the latest versions of the surficial quadrangle maps. Striation data were provided exclusively by Arthur Hussey, who collected them during his bedrock mapping excursions.

II.5.2 Evaluation of Hydrogeologic Characteristics of Photolinear Elements

In the same manner in which photolinear elements were visually compared with compiled geologic information, we also compared photolinear elements with subsurface data, specifically well yield. This is a necessary simplification of the problem of defining zones of high transmissivity, given the level of detail concerning the hydraulic characteristics of bedrock aquifers in Maine.

We used a well yield of 5 gallons per minute (gpm) as the threshold for the indication of a potential zone of high transmissivity. This is quite low, but it is sufficient for domestic applications, and we felt that the intent of the project required a conservative approach. It should be noted that there is not a one-to-one correspondence between well yields and transmissivity. Although a high-yield zone is almost certainly a zone of high transmissivity, many high transmissivity zones are unlikely candidates as high-yield zones. Transmissivity is a primary hydraulic property solely of the bedrock medium, while well yield is a secondary property which is related to transmissivity, but also in large part to overburden thickness and overburden recharge capacity.

All points where data indicated well yields greater than 5 gpm were plotted on the photolinear maps, and where possible, areas of elevated yield were colored. Whenever an elevated-yield well was in close proximity to an identified photolinear element or elements, the boundaries of the elevated yield area were drawn so as to conform to the geometry of the linear feature. In those occasions where this was not the case, the data point was simply plotted as a discrete dot.

II.5.3 Classification of High Transmissivity Zones

As discussed in Section I.2, insufficient quantitative data on the hydraulic characteristics of the coastal fracture-flow aquifers exist to calibrate the remotely discriminated linear elements to ranges of transmissivity. Because of this limitation, we have chosen a classification scheme based not on estimated hydraulic properties but on the degree and type of verification by existing data. We developed a three-fold system of classifying the high transmissivity zones: 1) Zones where well data indicated well yields greater than 5 gpm; 2) Zones where photolinear elements coexist with existing bedrock data suggested the presence of highly fractured rock, or of rock types with associated statistically elevated well yields (such as mafic dikes); 3) Zones where, based on patterns recognized from the inspection of linear elements and well yields, we suspect high transmissivities to occur. In effect, these classes correspond to the degree of confidence which we place on the interpretations.

II.5.4 Field Corroboration

The problem of field verification of photolinear elements is not an easy one. The following quote by Wise and others (1985) is a succinct statement of the efficacy of conventional field methods:

"...Some lineaments are clearly identifiable as faults, but most appear to be zones of more intense joint development and local fracturing. Traditional field methods of seeking their origin by detailed examination of individual lines have proved rather frustrating; in most cases, there seems to be relatively little regional geology which can be interpreted from a poorly exposed, deeply weathered zone of closely-spaced joint, having little or no mineralization."

Such difficulties notwithstanding, bedrock mapping in the study area is currently being completed as part of the larger investigation in progress by the Maine Geological Survey. In addition, we are conducting a geophysical field verification of our own, using electromagnetic techniques. We use a receiver capable of discriminating field strength, dip angle and quadrature component of secondary conductor fields in the very low frequency (VLF) portion of the electromagnetic spectrum. Eight sites have been targetted for VLF transects as a check of what we have interpreted to be high transmissivity zones. Unfortunately, scheduling of the instrument has precluded the completion of the VLF survey (an item not in any event called for in our contract), by the date on which our report is due. We will submit the results of the survey as soon as they are available, which will likely be within the next few weeks.

III. RESULTS OF THE STUDY

III.1 Geologic Setting of the Study Area

III.1.1 Major Lithological Features

The majority of the stratified rocks underlying the study area are of Cambrian to Ordovician age, and are referred to collectively as the Casco Bay Group. The oldest formation within the group is the Cushing Formation, which is composed of a variable sequence of quartz-plagioclase granofels, gneisses of several distinct mineralogical assemblages, and quartz-muscovite-biotite schist (Hussey, 1981). The Cape Elizabeth Formation unconformably overlies the Cushing rocks. It is generally a thinly- bedded alternation of fine-grained feldspathic and micaceous quartzite and phyllite. The youngest stratified rocks in the area belong to the Scarboro Formation, composed chiefly of phyllite. The stratified rocks of the Casco

Bay Group are intruded by elongate bodies of Devonian granite and granodiorite, and by Mesozoic mafic dikes.

The Cape Elizabeth Formation is underlain by the Bucksport Formation, a thinly-bedded to moderately thickly-bedded sequence of granofels or gneiss, with occasional zones of schist. The contact between the Bucksport and Cape Elizabeth Formations has been variously described as conformable or structural (Hussey, 1984). In the case of the former, the Bucksport would tentatively be correlative with the Cushing Formation. In the case of the latter, the contact is interpreted as a premetamorphic thrust.

III.1.2 Major Structural Features

The stratified rocks have been multiply deformed. In all, 6 structural suites are represented (Hussey, 1981). The folding event which appears to be responsible for the majority of the map patterns of the large-scale folds is related to the development of mesoscopic upright to slightly overturned asymmetrical folds. The major lithic units have a regional strike in a roughly northeasterly direction.

Three major fault systems have been mapped in the study area. The Flying Point Fault trends northeasterly across the northwestern part of the Bath 7.5' quadrangle, and diagonally northeasterly across the Richmond 7.5' quadrangle. The net movement along this fault is uncertain, but 50 to 60 km of left- lateral movement is possible if net slip was strictly horizontal.

The Phippsburg Fault follows a major topographic lineament trending north-northeasterly into Phippsburg village. An April, 1979 earthquake epicenter lay near an extension of the lineament in Woolwich. The net movement along this fault is uncertain, but appears to have been minor.

The Blinn Hill Fault extends northeasterly from the north- central part of the Wiscasset 7.5' quadrangle into the North Whitefield quadrangle, where it follows a well-defined topographic lineament (Newburg, pers. comm.). Net movement on this fault is also uncertain.

A feature identified as the Georgetown- Edgecomb Fault trends in a northerly direction from south of Georgetown to just northeast of Sheepscot (Hussey and Pankwiskyj, 1976). Recent mapping by Hussey and field investigations by J.R. Rand (pers. comm.) has failed to document unequivocally the existence of the fault, and although 11 minor faults have been identified in the general area very few are oriented parallel to the trace of the postulated feature.

III.1.3 Principal Bedrock Hydrogeological Features

Bedrock aquifers in the study area consist entirely of fractured crystalline rocks. With the possible exception of certain carbonate rocks in Aroostook County, no known examples of porous rock media exist in the entire state of Maine. Caswell (1979) has noted that the average yield from most of the bedrock wells in Maine is less than 10 gpm. Higher than average- yields from bedrock wells occur where the bedrock aquifer is "...well-fractured, saturated, and has a source of recharge that can sustain the rate of withdrawal" (Caswell, 1979).

Data collected chiefly since the mid- 1970's (Lanctot and Caswell, 1976a,b,c,d,e,f,g; Caswell, 1979, Caswell and Lanctot, 1976) suggest that high-yield bedrock zones are of limited extent, except in the vicinity of fracture zones, such as faults, where such zones may extend for many thousands of feet, or even miles. Published compilations of well yields for Lincoln, Sagadahoc, and Cumberland Counties indicate that the majority of high-yield bedrock zones in fact are parallel to, if not coincident with the mapped locations of major northeast-trending faults. The data do support the interpretation that many high-yield zones trend obliquely or orthogonally to the regional structural trends, although in some instances the contoured data do not reflect this. No systematic collection of hydraulic data of fractured bedrock has been initiated in Maine, so that other than these few preliminary observations, very little is known about the distribution of high-yield zones within bedrock aquifers in the coastal zone.

With the exception of locally thick deposits of glaciomarine clay and silt, surficial materials tend to be thin over much of the field area. Insofar as well yields are concerned, this phenomenon, as much as the limited extent of zones of highly fractured rock, accounts for the relatively low yields of wells in this area. However, with the sparse distribution of sand and gravel aquifers, and the very limited potential for surface water supplies, increasing demands for water supply are being placed upon bedrock aquifers in the study area. As stated in Section I.2, it is out of concern for the future bedrock ground water usage here that the well yield criteria for discrimination of high transmissivity zones was set so low.

III.2 Identification of Photolinear Elements

Over 2000 discrete photolinear elements were identified from the imagery used in this study. By far the largest segment of the population is represented by third order features. The average length of first order features is approximately 5.3 km. On the other hand, the average length of second and third order features is .98 km and .79 km, respectively. With the exception of several strong first order elements, most of the photolinear elements tended not to be long, discrete features. More often features occurred in groups, with one family of generally parallel or subparallel elements intersecting another at relatively consistent angles in a single area. Certain areas contain representative members of the entire population of linear elements, while other areas portray only a single subset. The spacing of linear elements within the study area is much closer than was suspected before the project was started. In fact, no area larger than approximately 2.2 km^2 is without linear elements of some order or strength.

Visual inspection of the data overlays with the photolinear maps confirms that most of the photolinear elements identified are parallel or subparallel to the traces of bedding, foliation, joints, faults, or contacts as depicted on the geologic maps. However, as has been discovered in many other photogeologic studies, the trends of a few linears, and the location of many do not correlate well with known geology. There may be several reasons that could account for this. One reason might be that some unexplained linear elements represent the traces of zones of intersection among 2, or perhaps even more planar features which have been identified in the field. Because the intersection of 2 planes forms a line, it is logical to infer that such intersections, were they to occur near the bedrock surface, would be zones of relative susceptibility to weathering and erosion, and would lend themselves to remote discrimination.

A simpler explanation for the lack of correspondence between certain photolinear elements and mapped bedrock features is that one of the data sets is in error. However, it is well recorded in literature that topographic lineaments and photolinear elements often occur in areas where existing geologic data would not indicate the presence of structure or lithologic contacts. A structural sketch map of the Monterey Bay area in California produced in 1972 from the first available Landsat-1 color composite showed many lineaments not shown on current geologic maps, their larger scale notwithstanding. Subsequent detailed investigations of the curious features has demonstrated their existence. (Lowman, p. 109-111). This example has been repeated many times since remote mapping began and points out the value of photogeologic exercises.

After analyses of the lineaments and the existing data concerning the structure of the field area, it would appear that many of the photolinear elements, particularly the first order elements, are features related to regional tectonics. While not well-documented within the study area, a similar conclusion has been reached in other areas where mapping was done specifically to calibrate a photogeologic study. Such a case is given for portions of Alaska in Rowan and Lathram (p. 553-557). They concluded that linears indicating crustal tectonic elements are generally very long, and they occur "...as alignments that are combinations of surface geologic structures, linear valleys or ridges, and linear changes in tonal contrast marking differences in soil type, moisture, or vegetation. Most are broad and diffuse, some being poorly identifiable for short stretches along their length. Parts of the trace of many of these linear features coincide with the trace of major known faults" (Rowan and Lathram, p. 553-557).

Several second and third order features lay along the extensions of first order features in places where the latter became indistinct in high altitude imagery. In such cases, the significance of the lower order elements is established, at least insofar as their relationship with regional features are concerned. Most of the lower order elements, however, correspond not to mapped faults, but to joint sets, traces of mafic dikes, traces of bedding or foliation, or did not correspond to mapped data.

III.3 Identification of Potential Zones of High Transmissivity

Due to the non-random distribution of the data, the subsurface data do not represent a numerically valid sample of the total population of well yields. Many photolinear elements and intersections were not located in areas were well data exist, and several wells with yields greater than or equal to 5 gpm were located in areas where no photolinear elements were identified. Because of this, statistical inferences of any cause and effect relationship between plotted linears and well yields were quite difficult to make. From the sparse and uneven distribution of data, we attempted to recognize patterns in the degree of correlation among threshold well yields and photolinear elements.

It was apparent that several high-yield zones were located at or near the intersections of photolinear elements, particularly those identified as first and second order features. This is not surprising, since the porosity of a single fracture is increased locally in the vicinity of the line of intersection with another fracture. The data support the interpretation that high yield zones in the vicinity of linear element intersections are of quite limited areal extent. Although the subsurface data are not sufficiently strong to compel this conclusion unequivocally, it is one which has been drawn by others from essentially the same data (Caswell, 1979; see Section III.1.3).

Several high yield zones were also apparently concentrated along narrow linear bands associated with first order linear elements, even in areas where they were not intersected. Correlation among high-yield zones and unintersected third order elements was nearly impossible to establish, although many examples of coincidence were found. In general, there appears to be a rough correspondence between the order and strength of a linear in imagery and the bedrock well yield.

Many linear elements identified in the larger scale imagery are visible simply because of a lack of soil cover. In many such cases, their presence likely does not indicate significant fracturing. However, in certain cases, such as in the southwestern part of the Phippsburg quadrangle, the density of exposed linear features in an area of very shallow to non-existent surficial cover almost certainly indicates that the linears represent bedrock troughs which were more susceptible to weathering and erosion due to a high fracture density.

Once these patterns were identified, we established a set of criteria for the discrimination of potential high transmissivity zones. In order of what we suspect would be descending transmissivity, they are:

1) High density intersections of photolinear elements of any order or strength.

2) Intersections of two or more strongly-expressed, first order photolinear elements.

3) Intersections of first-order photolinear elements with lower order elements.

4) Unintersected first-order photolinear elements.

5) Intersections of two or more strongly-expressed, second order photolinear elements.

6) Unintersected second and third order photolinear elements.

III.4 Limitations and Degree of Reliability of the Maps

There are 2 basic questions concerning the utility of the photolinear element maps and their use as indicators of high transmissivity in the bedrock:

1) What is the likelihood that the photolinear elements are truly representative of real bedrock fractures or fracture zones?

2) If indeed the identified features are indicative of real fracture phenomena, what is the likelihood that the 6 areas outlined in Section III.3 are truly zones of high transmissivity?

Without substantially more field data, from both the surface and subsurface, these questions are quantitatively unanswerable. There is no doubt that the significance of lineaments of various scales has been debated ever since they were first recognized simply because of the inability to come up with a rationally based explanation for the existence of many of them. It may be that some linear elements, even some of the larger ones, may be purely accidental (Wise et.al., 1985)

Even if all of the identified features are indicative of bedrock structure, there are still areas of uncertainty regarding their actual locations and lengths which are introduced by virtue of the massive scale changes involved in the compilation of the final maps. The lack of stereoscopic imaging at the smallest scales is also somewhat of a cause for concern, since several very strong linear features in imagery turned out to be positive relief features, and likely represent zones of relatively resistant rock, rather than the opposite.

It is possible, given the length to width ratio criteria established in Section I.2, that certain very broad, diffuse topographic troughs may in fact represent zones of profound structural discontinuity, but may not be shown as linear elements on the maps. Two such examples are the valley of the Kennebec River from Popham Beach up to Phippsburg, and the reach of the Damariscotta River from Clark Cove to Port island.

As uncertain as the nature of the linears themselves is, the assessment of high transmissivity zones is even more uncertain, in that the interpretation assumes that the linear elements are truly indicative of bedrock fracturing. Although we have been guided by the subsurface data that are available, we relied most heavily on our linear mapping. These uncertainties are inherent in the project, given the limited scope. Our classification schemes and observational procedures were selected so as to enhance the utility of the final product, but there remains a high degree of uncertainty, and the user should keep in mind a healthy attitude of skepticism when using the maps.

IV. CONCLUSIONS

Based on the results of the investigation, we are able to draw the following conclusions:

1) Photolinear element mapping, in conjunction with field verification and data compilation, is probably the most efficient manner of forming a preliminary impression about the spatial distribution of certain hydraulic properties of crystalline bedrock aquifers. In the study area, this is chiefly a result of a generally shallow surficial mantle. It will be many years before sufficient well data are available to take a purely empirical approach to the same problem.

2) First order photolinear elements are the principal artifacts of the landscape. Second and third order elements impart less of an imprint. Although statistical analyses have not yet been completed on the data, it appears that the first order elements are generally parallel to the regional structure, while second and third order elements tend to parallel joints, mafic dikes, and minor faults. One working hypothesis that is suggested by this observation is that the ordering of photolinear elements may roughly indicate their relative ages, with the strength and scale of the feature as a function of the time exposed to weathering, erosion, and topographic adjustment. At this time, alternative hypotheses are legion.

3) High transmissivity zones in the vicinity of linear element intersections appear to be of limited areal extent, i.e., yield appears to decrease with distance away from the linears. Several such zones were also apparently concentrated along narrow linear bands associated with first order linear elements, even in areas where they were not intersected.

4) In general, there is a correspondence between the order and strength of a linear in imagery and the inferred presence of a high transmissivity zone. Six categories of potentially high transmissivity indicators are: 1) High density intersections of photolinear elements of any order or strength; 2) Intersections of two or more strongly-expressed, first order photolinear elements; 3) Intersections of first-order photolinear elements with lower order elements; 4) Unintersected

first-order photolinear elements; 5) Intersections of two or more strongly-expressed, second order photolinear elements; 6) Unintersected second and third order photolinear elements.

5) Features of glacial erosion are difficult to discriminate from bedrock features, because they are often parallel. In places where field data indicate that they are not, glacial overprinting is almost non-existent. Features of glacial deposition (mostly DeGeer moraines) are visible at scales of 1:40,000 and 1:20,000, and have a unique "fingerprint". One is left with the overwhelming impression that, at least in the area
of study, glaciation had an extremely minor impact on the pre-existing landscape.

6) No single set of remote images contained representatives of the entire population of identified features. This indicates the superiority of using very small scale imagery as well as large scale imagery for a photolinear study. The most abundant linear elements came, however, from the largest scale, as might be expected. In terms of the efficiency of interpretation, the side-looking airborne radar imagery yielded the greatest number of linear elements for the least amount of observation time. Not coincidentally, this imagery was the easiest to use.
The Landsat imagery at 1:1,000,000 scale and 1:500,000 scale was useful, but in terms of the effort required to interpret it and the apparent potential for bias, was far less useful than the radar imagery.

7) From the standpoint of bedrock transmissivity, there appear to be a number of potentially suitable sites for a low-level radioactive waste disposal site within the study area. It is not the intent of this study to propose such sites, other than to suggest that areas identified as high transmissivity zones on the maps be avoided. Given the uncertainties of the results, however, site-specific investigations may prove to eliminate many such areas, or discover others in areas where they have not been identified.

V. RECOMMENDATIONS FOR FURTHER STUDY

Other than the need for site-specific investigations, more basic data of the surface bedrock geology, and more subsurface data, the photolinear data needs to be statistically analyzed. We believe that the features plotted on the maps constitute a sufficiently valid sample of the total population of lineaments for spatial analyses to be conducted. Conventional image analyses, such as domain, cluster, and/or factor analyses would prove extremely helpful in relating the broad spectrum of features to those measured at the outcrop. The results would enable some quantitative generalities to be made about phenomena that have only been crudely approximated in this study. Since the ultimate use of this information is to assist in rational decision-making about the siting of a disposal facility, there would be immediate and invaluable benefit, not only with regard to ground water hydrogeology, but also to rock slope stability and other geotechnical considerations.

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APPENDIX 1

IMAGERY USED FOR THE STUDY

FLIGHT LINE OR IMAGE ID NUMBER: EOJ-2FF
DATE FLOWN: 11/2/64 SUPPLIER: MGS
SCALE: 1:20,000 IMAGE TYPE: Black and white print
FRAME NUMBERS:
48-196

FLIGHT LINE OR IMAGE ID NUMBER: EPY-5GG
DATE FLOWN: 5/14/66 SUPPLIER: MGS
SCALE: 1:20,000 IMAGE TYPE: Black and white print
FRAME NUMBERS:
163-175, 237-252

FLIGHT LINE OR IMAGE ID NUMBER: EPY-6GG
DATE FLOWN: 5/15/66 SUPPLIER: MGS
SCALE: 1:20,000 IMAGE TYPE: Black and white print
FRAME NUMBERS:
37-56, 208-233, 235-250

FLIGHT LINE OR IMAGE ID NUMBER: EPY-7GG
DATE FLOWN: 10/26/66 SUPPLIER: MGS
SCALE: 1:20,000 IMAGE TYPE: Black and white print
FRAME NUMBERS:
3-112

FLIGHT LINE OR IMAGE ID NUMBER: 5720006894106
DATE FLOWN: 9/20/72 SUPPLIER: NASA Aircraft; EROS
SCALE: 1:128,000 IMAGE TYPE: Color Infrared
FRAME NUMBERS:
4106-4113

FLIGHT LINE OR IMAGE ID NUMBER: 5730014433645
DATE FLOWN: 9/13/73 SUPPLIER: NASA Aircraft; EROS
SCALE: 1:130,000 IMAGE TYPE: Color Infrared
FRAME NUMBERS:
3645-3654

FLIGHT LINE OR IMAGE ID NUMBER: 1VECJ00000001
DATE FLOWN: 4/14/76 SUPPLIER: NASA Aircraft; EROS
SCALE: 1:80,000 IMAGE TYPE: Black and white
FRAME NUMBERS:
12-18

FLIGHT LINE OR IMAGE ID NUMBER: 1VECJ00000003
DATE FLOWN: 4/17/77 SUPPLIER: NASA Aircraft; EROS
SCALE: 1:80,000 IMAGE TYPE: Black and white
FRAME NUMBERS:
35-39, 60-66

FLIGHT LINE OR IMAGE ID NUMBER: 83034714441X0

DATE FLOWN: 1/10/79 SUPPLIER: LANDSAT; EROS
SCALE: 1:1,000,000 IMAGE TYPE: Color comp., MSS
FRAME NUMBERS:
Composite

FLIGHT LINE OR IMAGE ID NUMBER: 82172814385XO
DATE FLOWN: 10/16/79 SUPPLIER: LANDSAT; EROS
SCALE: 1:1,100,000 IMAGE TYPE: MSS, band 7
FRAME NUMBERS:
79

FLIGHT LINE OR IMAGE ID NUMBER: 23011 879
DATE FLOWN: 9/9/80 SUPPLIER: USDA
SCALE: 1:40,235 IMAGE TYPE: Black and white
FRAME NUMBERS:
279-293

FLIGHT LINE OR IMAGE ID NUMBER: 23015 879
DATE FLOWN: 9/9/80 SUPPLIER: USDA
SCALE: 1:40,235 IMAGE TYPE: Black and white
FRAME NUMBERS:
219-243

FLIGHT LINE OR IMAGE ID NUMBER: 23023 879
DATE FLOWN: 9/9/80 SUPPLIER: USDA
SCALE: 1:40,235 IMAGE TYPE: Black and white
FRAME NUMBERS:
294-310

FLIGHT LINE OR IMAGE ID NUMBER: 83101314314XC
DATE FLOWN: 12/12/80 SUPPLIER: LANDSAT; EROS
SCALE: 1:500,000 IMAGE TYPE: RBV
FRAME NUMBERS:
23

FLIGHT LINE OR IMAGE ID NUMBER: 83130114412XC
DATE FLOWN: 9/26/81 SUPPLIER: LANDSAT; EROS
SCALE: 1:500,000 IMAGE TYPE: RBV
FRAME NUMBERS:
15

FLIGHT LINE OR IMAGE ID NUMBER: Radar Mosaic
DATE FLOWN: 5/1/84 SUPPLIER: Sioux Falls
SCALE: 1:250,000 IMAGE TYPE: SA-SLAR
FRAMES:
Bath, Bangor