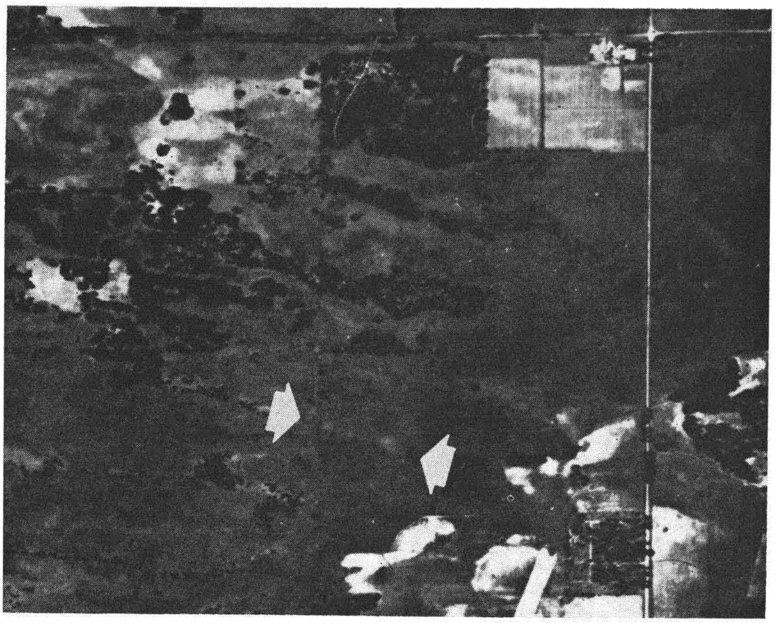

FRONTISPIECE. Area of sandy to clayey ground moraine and crevasse fillings, South-central Dupage County, Illinois. Solid arrows indicate fracture trace which is approximately aligned with light-colored, sandy crevasse deposits to the left. (See text page 502.)

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Fracture Traces in Illinois

Surface identification of bedrock jointing 150 feet beneath helps locate water well sites.

(Abstract on next page)

INTRODUCTION

APPLICATIONS OF AERIAL photographic interpretation to the analysis of shallow bedrock fracture patterns have been well documented in geological literature, but little attention has been given the identification of bedrock fractures buried by thick unconsolidated sediments. Lattman and Nickelson[1] successfully analyzed fracture traces through a thin soil cover, and Kupsch and Wild[2] demonstrated that a study of aerial photographs contributes to understanding subsurface geological structures.

A study of fracture traces in Dupage County, Illinois (Figure 1) complements previous analyses of fracture traces in areas covered by thin soils. The relationships between fracture-trace density, glacial-sediment thickness, sediment character, and field measurements of joints are considered.

An historical review of fracture trace studies and a broad bibliography are included in Lattman and Nickelson[1] and Lattman and Blanchet.[2] According to Lattman,[4] photogeological fractures traces are linear trends

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of topographic features unrelated to outcrop patterns (but including straight stream segments), soil tonal alignments, or vegetative color differences, as imaged on aerial photographs for a ground distance of less than one mile.

Photogeological fracture traces in northeastern Illinois (Table 1) are indicators of jointing in the dolomite bedrock. This is reflected by a close correlation between field measurements of bedrock fractures and photogrammetric data as presented in Figure 2.

ABSTRACT: *Photogeological analysis of Dupage County, Illinois, suggests a close correlation between* deeply-buried *bedrock joints and photogrammetric fracture traces as measured from black and white aerial photographs. Fracture traces indicative of bedrock jointing buried by up to 150 feet of glacially derived sediment have been successfully mapped. Fracture-trace mapping provides a valuable hydrological tool for successfully siting high-yield wells in deeply buried, highly fractured bedrock aquifers.*

GEOLOGICAL SETTING

Gently folded Cambrian, Ordovician and Silurian sedimentary rocks, which rest uncomfortably upon Precambrian basement rocks in Dupage County, dip gradually eastwards and southeastwards at the rate of approximately 10 feet per mile. The gently rolling bedrock surface is composed principally of dolomite which has been subdivided into the Racine, Waukesha, and Joliet Formations. A complete geological description is included in Zeitzel *et al.*[5]

According to Zeitzel *et al.*, interconnected bedrock fractures (joints) developed after deposition and consolidation of the dolomite. Solutionally enlarged joints decrease in width at depth and clay-filled joints are relatively rare. Zeitzel *et al.* also note that ". . . on the basis of geological evidence, this zone with solution enlarged openings is believed to be the zone of relatively high permeability within the aquifer that influences well yields considerably." The permeability of bedrock dolomite in Dupage County is therefore influenced by the size, number and interconnection of joints, fractures, and solution cavities. Such fractured zones would undoubtedly be of greater interest during groundwater exploration for high capacity water wells were they not so deeply buried and difficult to locate.

Overlying the dolomite bedrock is up to 150 feet of unconsolidated, compact to friable glacial sediment (till), including the Minooka, Valparaiso and Tinley moraines. Glacial sediment thickness may exceed 200 feet where infilling has buried bedrock valleys. Glaciofluvial gravels and glaciolacustrine deposits occur throughout the area; the latter occur in depressions in the Minooka ground moraine.

Northeastern Illinois (and specifically Dupage County) was selected for photogeological analysis because of active geological and groundwater study interest, and because of the availability of quantitative field data. Despite efforts to locate areas in which photogrammetrically identified lineaments might be traced into quarries or outcrops and identified as joints, results were inconclusive.

FIG. 1. Index map of Illinois, with Dupage County indicated by arrow.

TABLE 1. Fracture trace directional data as recorded during photogrammetric study of aerial photography of Dupage County, Illinois. Number of joints are indicated in ten degree directional groupings as measured from aerial photographs, and subsequently summarized in Figure 2

Aerial Photograph Number BWS	*West*														*East*					
	Due E–W	*80–89*	*70–79*	*60–69*	*50–59*	*40–49*	*30–39*	*20–29*	*10–19*	*1–9*	*Due N*	*0–9*	*10–19*	*20–29*	*30–39*	*40–49*	*50–59*	*60–69*	*70–79*	*80–89*
1N-5	1			2	1	3	5			1	1	1	2	4	8	4	3			
1N-7	1			1		7	3			1	1	1		1		4	2	1		
1N-9	4	6	3	2	4	4	1	2		1	2	1		1	1	3	4	7		
1N-11	2	2		1	5	8	2	1			4			2	3	5	6		3	3
3N-144								1	1		1	1	1		5	1		1		
4N-58			1				1									1				
4N-64				2		2		1	2						3	2		1	1	
4N-66	1			1								1			1	2	1	1		
4N-68	3						2	1		2	3	1	1		8				3	
4N-70	2	2	4		2	3	1			1		2	3	3	3		2	2		4
5N-13				1		3										2	1			
6N-66		3	2				4	1	2		4			1	4	5	3	2	2	
6N-108	1						2													
6N-124	2	1	1		1		1	1		1	4	1			1		2	3	1	
8N-12	2	3				6		1		2	2		1	2	2	2	1			5
8N-14					1	3		1						1		1	1			
9N-11	3			1	1						1	1	3	2	1	3		2	1	
9N-23	3	1		2	3		5				1	1			3	3	2	2	2	
Total 391	25	18	11	13	18	39	27	10	5	9	24	11	11	17	43	38	28	22	13	12

Similar studies in surrounding counties were equally unsuccessful and it is suggested that cultural activity in the vicinity of most quarries accounts for correlation difficulties. Lattman and Nickelson,[1] however, proved that a parallelism exists between fracture traces and bedrock joints in the Appalachian Plateau. Lattman and Matzke[3] came to a similar conclusion and commented that fracture traces parallel trends of major joints in areas of flat or gently dipping rocks. Such research conclusions are sufficiently valid for application in northeastern Illinois.

Fracture-trace analysis and field studies by the author suggest that two major bedrock-joint sets lie at approximately right angles to one another in Dupage County. These field studies have been summarized in Figure 2, and a comparison has been drawn to photogrammetric fracture-trace measurements.

STUDY METHODS

Aerial photographs of areas lacking extensive urban development were selected to analyze the distribution and variety of glacial sediments; the latter included ground moraine, valley train deposits, end moraine, and glacial-lake clays. Fracture traces were delineated on each photograph. To avoid the introduction of unintentional bias, all photographs were studied out-of-order, directional measurements were completed, and field photogrammetric data were finally compared.

In fracture-trace studies, visual observations of photographs should be made both perpendicular and oblique to the photograph surface and repeated for a number of days. This time-consuming practice becomes increasingly significant in highly cultivated areas or as terrain surfaces vary from flat to rolling.

Comparative test studies following the completion of this research suggest that continuous photographic study exceeding 30 minutes for the untrained observer and 45 minutes for the trained observer reduced accuracy. Artificial light (provided significant glare is avoided) is more satisfactory than daylight, for identifying fracture traces.

INDICATORS

Soil-tonal differences have proven to be the primary indicator of photogeological fracture traces in northeastern Illinois (Figures 3 and 4). Complementary field studies reveal that darkly imaged lineaments identified photographically are either extremely gentle topographic sags, or lack apparent surface expression. Study in areas of fracture traces indicates that surface moisture apparently moves both *towards* areas of fracture traces and *downwards towards* the jointed bedrock surface.

Silty or sandy (permeable), moderately well-drained soils are imaged as light shades of grey, whereas moisture-holding clays or organic rich soils image in dark greys. Movement of moisture towards bedrock joints in permeable soils seems to concentrate clay or silt-sized sediment in fracture-trace zones and

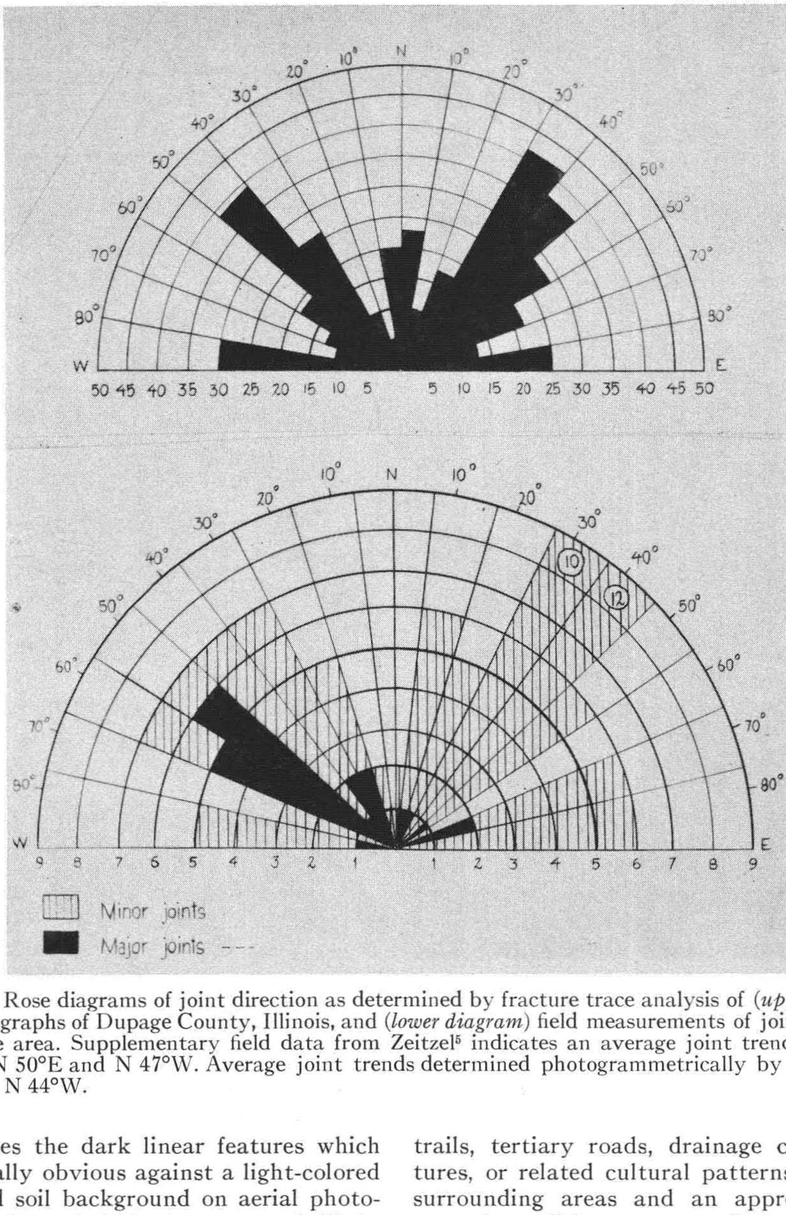

FIG. 2. Rose diagrams of joint direction as determined by fracture trace analysis of (*upper diagram*) aerial photographs of Dupage County, Illinois, and (*lower diagram*) field measurements of joint directions in the same area. Supplementary field data from Zeitzel[5] indicates an average joint trend in Dupage County of N 50°E and N 47°W. Average joint trends determined photogrammetrically by author were N 50°E and N 44°W.

thus creates the dark linear features which are especially obvious against a light-colored to mottled soil background on aerial photographs. Moisture held in clayey zones is likely to produce lush vegetative cover whose dark green color will further accentuate dark colored fracture traces. It is likely that vegetation growing along fracture traces in areas of mixed vegetation may be imaged in dark green on aerial color photography, and produce as distinctive a trace as on panchromatic aerial films.

Besides alignments reflecting geological (bedrock) structures (which include joints, faults, and shatter zones associated with faulting) *apparent* fracture-trace features are produced by cultivation, paths and cattle trails, tertiary roads, drainage control features, or related cultural patterns. Study of surrounding areas and an appreciation of ground conditions are usually sufficient to avoid misidentification of these linear features as fracture traces.

Glaciated midwestern areas as exemplified by Dupage County, offer a unique set of problems in photogeological fracture mapping. Receding glaciers have in places deposited radial to subradial crevasse fillings (Frontispiece) which remain as subtle tonal patterns despite cultural activities. In areas of low relief, or in the absence of careful stereoscopic study, such landforms often suggest fracture traces. The cross-deposition of crevasse fillings (the so-called *waffle pattern*)

FIG. 3. Area of Tinley ground moraine, northeastern Dupage County. Mottled appearance is generally characteristic of tills in the midwestern United States. Arrows indicate one (and possibly two) fracture traces trending N 5°E.

is more obvious than isolated features of similar origin. Light-colored crevasse fillings in Illinois contain a mixture of relatively permeable sand and gravel which image in generally light tones; these deposits usually do *not* contrast with sandy ground moraine, but can be readily identified against a dark-toned background of clayey ground moraine.

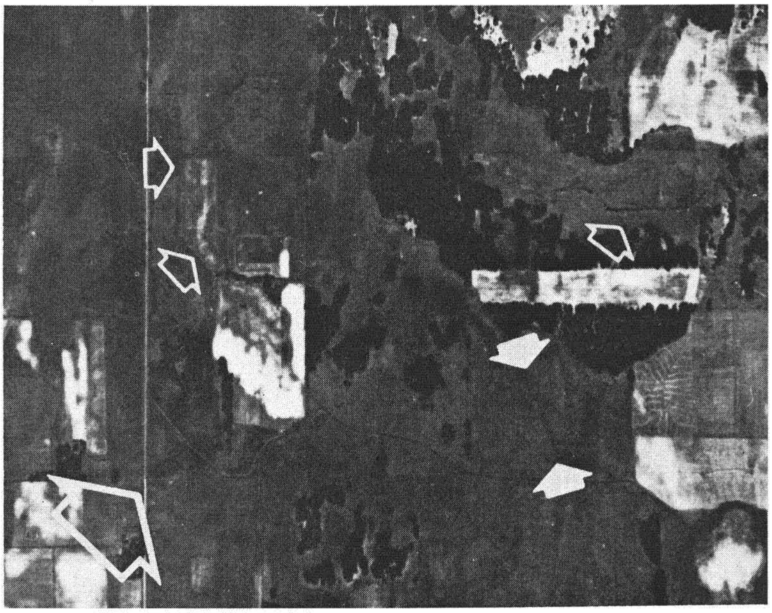

FIG. 4. Area of clayey ground moraine, northeastern Illinois, depth not exceeding 30 feet in this photograph. Solid arrows indicate fracture trace defined by soil tonal differences; other arrows indicate straight stream segments. Quarrying operations in bedrock dolomite are underway to the east. True North indicated by large arrow.

Fracture-Trace Identification versus Glacial Sediment

In order to compare ease of identifying fracture traces (lineaments) with sediment variations, areas of ground moraine, end moraine, valley train, and outwash were identified from surficial glacial sediment maps. Sediment boundaries were transferred to the aerial photographs *after* identification and mensuration of fracture traces. Lineaments identified in each sediment-type area were counted, and total area (in square miles) covered by glacial-sediment type calculated. The data from this analysis are summarized (Table 2), and expressed as number of lineaments per square mile of sediment-type.

Fracture traces are least easily identified in outwash sediments, equally well delineated in ground and end moraine, and most easily identified in valley-train sediment. Identifying fracture traces in areas of permeable glacial sediment (*e.g.*, outwash) is made increasingly difficult by predominant internal drainage. Water falling on such permeable surfaces is quickly absorbed over wide areas, and drainage towards the bedrock surface is controlled mostly by subsurface sediment character. Norris[6] indicated that clayey tills in the midwestern United States have high coefficients of permeability, and that broad similarities in permeability exist between them. His analysis suggests that tills of approximately equal permeability (*e.g.*, ground and end moraine) reflect lineaments equally well despite genetic differences.

Fracture Trace Identification versus Glacial Sediment Thickness

By reference to the original copy of a glacial sediment (drift) thickness map of Dupage County (as published in Zeitzel et al.[5]), the distribution of lineaments relative to drift thickness was determined (Table 3).

Analysis suggests that lineaments are seldom observed where drift thickness exceeds 150 feet, but that fracture traces *can be identified* where thick glacially derived sediments overlie a jointed bedrock to a depth of from 50 to 150 feet. The paucity of suitable photographic coverage in areas of deeper drift prevents statistically rigorous analysis where drift exceeds 200 feet. That bedrock patterns are well defined in areas with a thin soil cover, however, has already been determined.[1] It is most significant that a sediment cover up to 150 feet does not preclude photogeological

Table 2. An analysis of glacial sediment versus fracture trace identification. Number of lineaments (NoL) and area in square miles (AS) are indicated. (1) West Chicago Outwash, northwest corner of Dupage County; (2) Valley train deposits, central to southwestern part of Dupage County; (3) Tinley Ground Moraine, northeastern Dupage County; (4) West Chicago End Moraine, northwestern Dupage County

Selected Aerial Photographs Numbers	*Glacial Sediments*								*Remarks*
	Outwash (1)		*Valley Train (2)*		*Ground Moraine (3)*		*End Moraine (4)*		
	NoL	AS	NoL	AS	NoL	AS	NoL	AS	
BWS-5N-144	16	4.5					11	2.6	Moderately built-up area; photo underexposed
BWS-5N-103	18	5.1					12	2.0	
BWS-1N-11			13	1.4					
BWS-9N-15			12	1.1					
BWS-5N-117					30	9.0			Extensive building in NE quadrant
BWS-5N-6					46	4.2			Fair Photograph
BWS-5N-142							65	9.0	
BWS-6N-68							50	9.0	Scattered building
BWS-5N-105							42	8.0	
Totals	34	9.6	25	2.5	76	13.2	180	30.6	
Average Lineaments per square mile (To nearest whole number)	4		10		6		6		

TABLE 3. Drift thickness versus fracture trace definition (identification) in Dupage County, Illinois. To maintain sediment character as an insignificant variable while testing drift thickness alone, only areas of similar (moderate to moderately slow) permeability (ground and end moraine) have been studied. Some photographs lacked areas of sufficient thickness within the arbitrary 50 foot limits (X) while fracture trace analysis of other photographs was partly limited by urban development (*). Areas studied were: (a) Northeastern Dupage County; Tinley ground moraine; (b) Southeastern Dupage County; Valparaiso moraine (undifferentiated); (c) Southwestern Dupage County; Minooka ground moraine; (d) Northwestern and western Dupage County; Minooka ground moraine

Selected Aerial Photograph Number		*Number of Lineaments per Photograph as drift thickness indicated (feet)*					*Remarks*
		0–50	50–100	100–150	150–200	200	
BWS							
5N-6	(a)	X	10	37	0*	X	Predominatly open ground; good quality photograph.
5N-117	(a)	2	20	7*	0*	X	Partly built-up area; average photograph.
5N-130	(a)	2*	20*	6*	X	X	Western half of photograph built-up area.
6N-80	(a)	0*	2*	0*	X	X	Built-up area; limited contrast
3N-140	(b)	0*	8	6*	1	X	Good quality photograph; urban development.
3N-156	(b)	5	13	10	X	X	Poor contrast; urban development near river.
9N-21	(b)	X	7*	25*	4*	0	Good quality photograph; limited to east urban development.
9N-9	(c)	30	7	3	1	X	Excellent photograph; open ground.
1N-17	(c)	19	7	X	X	X	Good photograph, open ground and little urban development.
4N-72	(c)	14	3*	9	X	X	Good photograph; limited urban development in southeast.
8N-18	(d)	3	25	5	0	X	Urban development in southwest; good photograph.
8N-20	(d)	11	15	X	X	X	Good photograph.
Total Lineaments		86	137	108	6	0	
No. of Photos Analyzed		10	12	10	6	1	
Average per photo per selected thickness (to nearest whole number).		9	11	11	1	0	

analysis of bedrock fractures, and presumably thin sedimentary overburden will only speed fracture-trace identification.

WATER RESOURCES APPLICATIONS

It has been well established that study of photographs made at conventional and (as recently demonstrated by NASA astronauts) orbital altitudes can contribute greatly to solving geological problems. The methods suggested in this brief study may be employed by the ground-water hydrologist or water-well driller who is familiar with local terrain conditions and general geological principles, and who knows how to use a stereoscope.

The techniques described herein offer a potentially valuable tool for locating high-capacity water wells at joint intersections or in bedrock joint "swarms." Problems involved in locating these highly permeable zones in otherwise impermeable bedrock, or in bedrock buried by thick sediments, are consequently reduced. The techniques may be less applicable in urban areas than in outlying, less-culturally disturbed regions. Nevertheless, the opportunity to site water wells in deeply buried bedrock joints by aerial photographic analysis of sediment overburden permits exploratory drilling on more than a "hit-and-miss" basis.

Conclusions

Fracture traces, which were photographically identified by tonal differences, closely correspond to geological field measurements of bedrock joints in Northeastern Illinois. Bedrock fractures have been successfully identified where the thickness of glacial overburden approaches 150 feet, and thinner sediment cover only adds ease to identifying such structural features.

Lineaments are best displayed where a maximum contrast exists between dark-toned fine-grained sediment (accumulated by surface drainage towards bedrock joints) and surrounding permeable (light-colored) glacial sediments. In Northeastern Illinois, a glacial overburden of permeable valley train deposits best reflects bedrock fracture traces.

The method described herein is potentially useful in ground-water exploration, especially where the value of high-yield, jointed-bedrock aquifers has not been realized because of thick sedimentary cover or difficulties in selecting well sites.

Acknowledgments

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