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SOME ASPECTS OF MISFIT STREAMS IN SOUTHERN ESSEX AND KENT COUNTIES, ONTARIO

By

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APPROVED

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Finally, that the thesis is complete is more to the credit of the perseverance of my wife Mary Lynne than my own. She pressed for it an paid for it at considerable sacrifice.

ABSTRACT

Eleven separate streams or stream segments in southern Essex and Kent Counties were examined with the view of determing the existence of misfitness and the degree of misfitness, as well as the cause and approximate dates of that misfitness.

Using power spectrum analysis, the streams did show some positive degree of misfitness, however, the nature of the program and the data made further use of the spectral results difficult. The standard technique of measurement and analysis advanced by G.H. Dury also supported the hypothesis of misfitness, in addition to providing results which could be transformed into discharge approximations for further study.

Assessment of the longitudinal profiles and sediment profiles from the valley floors and sides, in view of the late Pleistocene and Recent(Holocene) glacial history and the changing levels of Lake Erie,showed that the cause could not be attributed to glacial derangement. Reconciliation of profiles and lake level evidence with palynological studies by other authors indicated that the initiation of the cutting of the large meanders occurred between 8,000 and 10,000 years B.P. while abandonment took place between 5,000 and 7,000 years B.P. Climatic conditions during these periods seem to be consistent with those conditions postulated by Dury as being most conducive to the cutting and abandonment of these features.

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PROBLEM AND LITERATURE REVIEW

I:1 INTRODUCTION

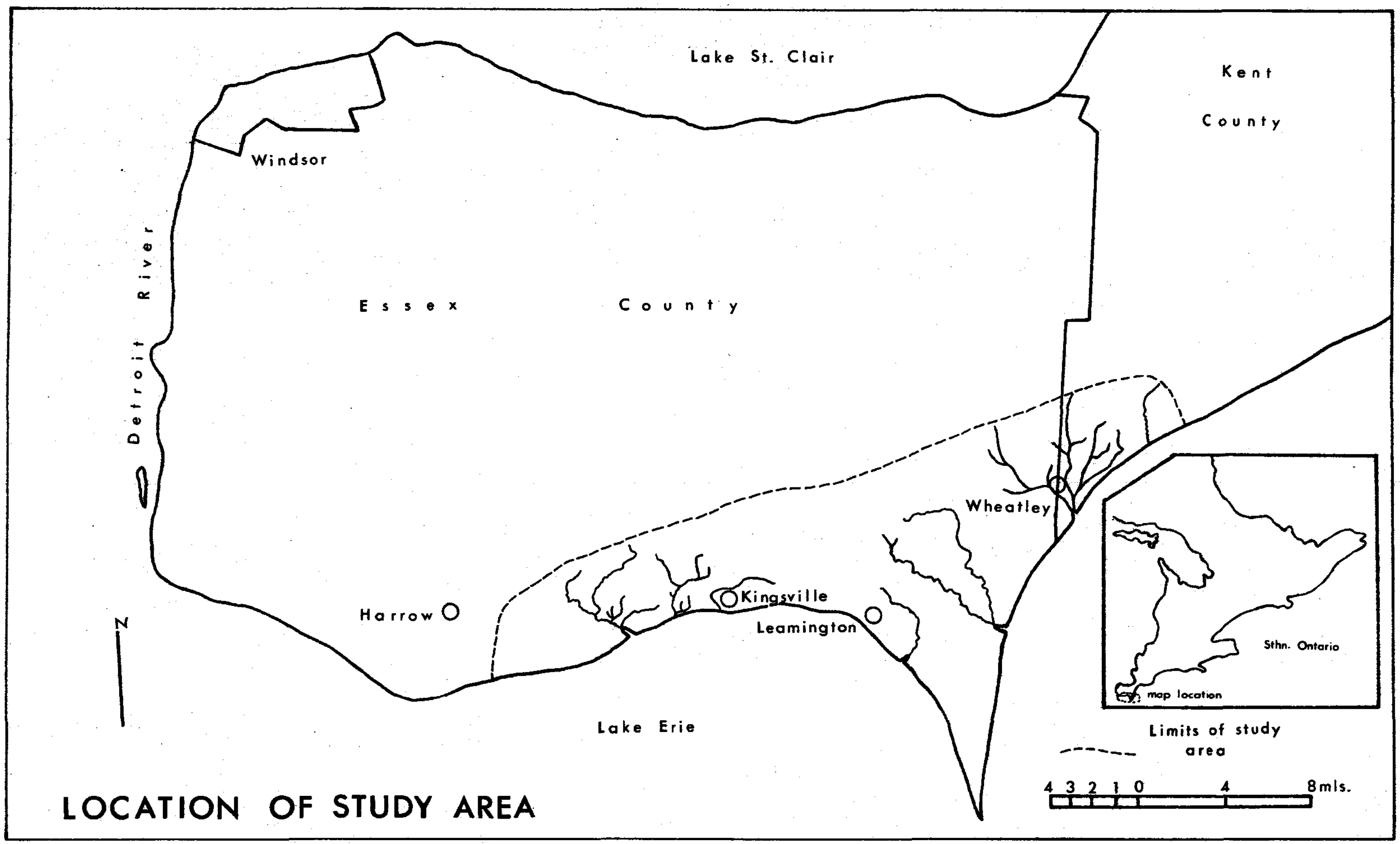
Apart from the statement that suggests that a stream is a volume of water flowing through an established course, streams can be described in a multitude of different manners, each with its own distinctive term of description. Such terms are generally developed to ascribe to a particular stream attribute a state of being relative to other possible states of that sttribute. For example, the attribute under consideration may be the pattern traced by the stream on the landscape. In that case, the terms, "straight", "braided", and "meandering" are used to describe that pattern with a strictly defined connotation to each. The attribute may be the action of the stream on the land over which it flows and in such cases, the possibilities include "aggrading, "transporting", or "eroding". With the hydraulic parameters of the stream, relative description is of an empirical nature where discharge is measured in cubic feet per second, channel width is measured in feet, and so on.

The terminology used in describing the relationship between a stream and the valley in which it flows has not been well developed and, as a result, is not overly effective in its ability to ascribe a state of being to that relationship. There is no term available to describe a valley-stream combination where the valley is evidently a product of the stream flowing through it at present. In the case of valley obviously cut by a discharge which is greater than the current discharge, the terms, "misfit" and "underfit" have been coined (Dury,1964a,b,c). Unfortunately, neither term is able to rigourously describe an exclusive state such that clarity of definition is acheived.

In southern Essex and Kent Counties (Ontario), there are a number of streams which appear to be underfit or misfit on the basis of the general description offered above. The purpose of this study has been to examine those in light of the limited body of theory that exists on the subject. Firstly, attempts were made to clarify the definitions established by previous workers. Secondly, the features were tested empirically in an attempt to establish misfitness and, finally, the possible formative factors were examined with a view to determining the cause of these features and the approximate dates of formation.

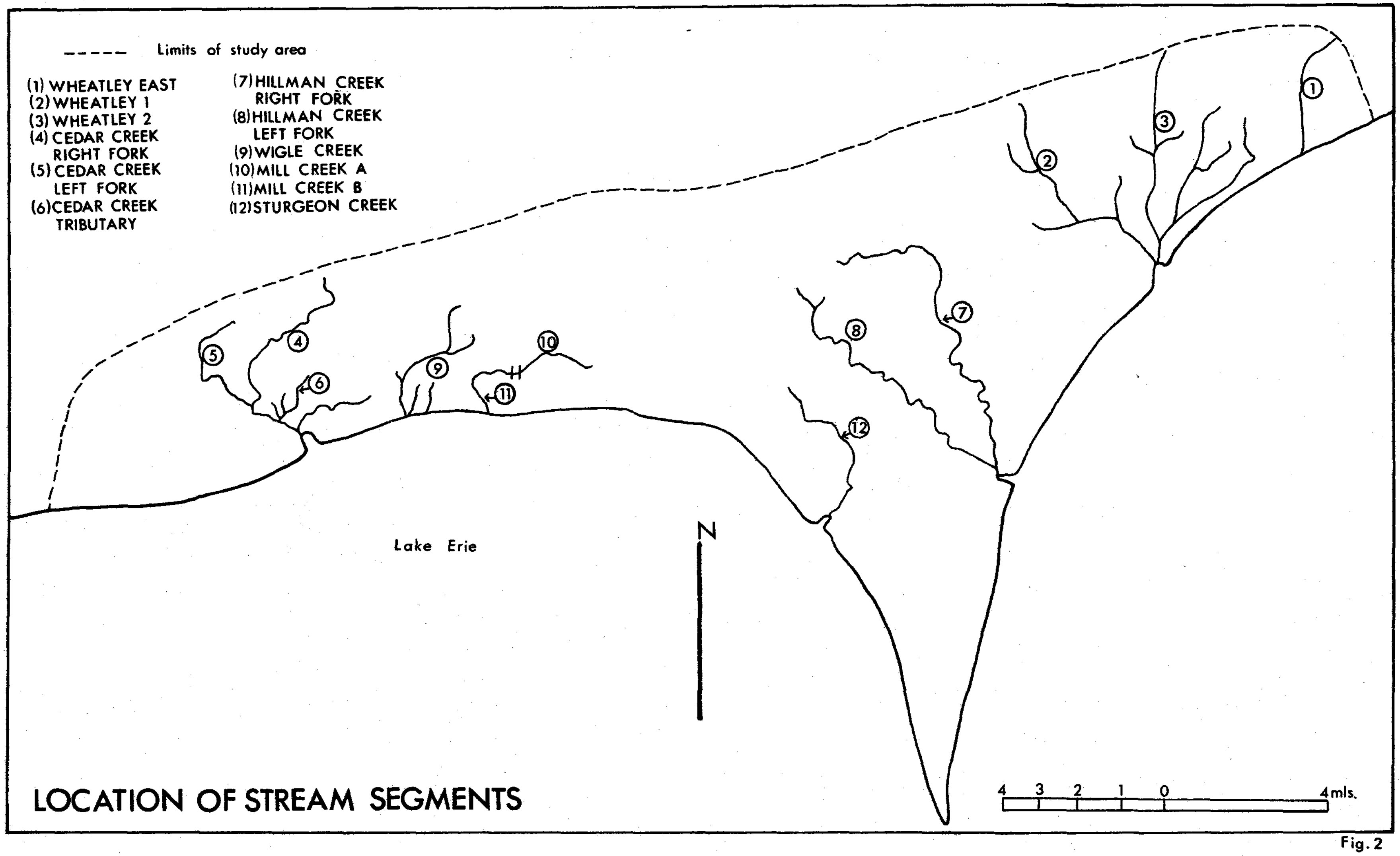
I:2 STUDY AREA

The study area extends along the north shore of Lake Erie from several miles east of Harrow, Ont. to approximately five miles east of Wheatley, Ont. (Figs. 1 & 2). Its farthest penetration inland (north of Lake Erie) is less than five miles. Chapman and Putnam(1966) have classified the area as part of a physiographic subregion, the Essex Clay Plain, noting its fairly uniform characteristics. The dominant soil type throughout the area, according to Chapman and Putnam(1966), is a Brookston Clay loam developed under near bog conditions. The almost total lack of relief in the area, broken only by



LOCATION OF STUDY AREA

Fig. 1



LOCATION OF STREAM SEGMENTS

Fig. 2

a terminal moraine knob near Leamington and abandoned shoreline remnants in the eastern section, is reflected in the drainage patterns and the lack of drainage area definition. Most of the drainage in the sub-region is to the north into Lake St. Clair and the Detroit River. The relatively small amount of drainage to the south has been badly disrupted due to artificial drainage systems in the low-lying areas.

Most of the area has been the subject of detailed geological mapping by the Ontario Dept. of Mines and Northern Affairs (Vagners,1971). Vagners(1971a) found that the bedrock is middle Devonian limestone, dolomite, shale, and upper Silurian dolomite overlain by a thick mantle of Quaternary sediments. The Quaternary sediments may be divided into two categories, Pleistocene and Recent(Holocene). The Pleistocene sediments include till, glaciofluvial sand and gravel and glaciolacustrine gravel, sand silt and clay. According to Vagner's (1971) map, glaciolacustrine sediments appear to dominate the immediate area under study, although such sediments are not especially common throughout the remainder of the sub-region despite its having been lacustrine conditions in its entirety at various times. The Recent(Holocene) sediments described by Vagners include the alluvium found in the floodplains of the larger creeks and rivers and the beach sand along the Lake Erie shoreline.

Hough(1958) and Prest(1968) have provided a reasonably concise history of the area for the Pleistocene and Recent(Holocene) Epochs. Prest(1968) speculates that the last total ice coverage of the area occurred approximately 14,500 to 15,000 years B.P. with the last possible glacial effects occurring circa 14,200 years B.P. This appears to be generally consistant with the findings of Goldwait et al.(1965).

Following the final retreat of the ice, the area was subjected to a series of post, proglacial lakes which inundated or partially inundated the present land mass. Coakley(1972) suggests that the result of these proglacial lakes was the development of a thin layer of lacustrine clay and silt formed under Lakes Whittlesey and Warren and overlying the existing ground moraine.

I:3 NATURE OF STREAMS UNDER STUDY

It may be said that in the area described above there are seven streams or stream systems which give the visual impression of misfitness. In the application of tests directed toward proof of misfitness, these were treated as eleven separate streams or stream segments. In the Cedar Creek system, for example, three tributaries were assessed because the main trunk is in what was suspected to be a drowned state for virtually all of its length. Testing some of the sample streams was also ruled out due to disruption caused by residential development or the excavation of artificial drainage canals by farmers and others. In the Wigle Creek example, natural patterns have been disrupted by the building of a golf course. These factors and the topographic nature of the area inject a note of caution into studies involving stream behavior.

Implicitly, southern Essex and Kent Counties are not ideal areas in which to undertake stream studies. The region is low and flat with drainage divides virtually indefinable. Agriculture has need in certain sections to resort to artificial drainage as do those involved in the extensive residential development taking place in parts of the area. Leopold(1973) found that such disturbance of natural stream patterns can have a profound effect on what otherwise might be predictable stream behavior. This has indeed manifested itself in certain sections of the area where extensive gullying has been produced by the high erodability of the soil combined with the dredging of drainage ditches. Every care has been taken to allow for the inevitable bias caused by such disruption, but it still must nevertheless be borne in mind when the results are being assessed.

Figures 3 - 12 are diagrams showing the patterns established by each of the stream segments under study. The size of the streams as in length, width, depth, and discharge varies considerably as does the complexity of the networks of which each stream is a part. Cedar Creek is the most complex network composed of a main trunk (drowned) and numerous tributaries, each of which may be as large or larger than some of the smaller segments. Some segments of the Cedar Creek valleys which were analyzed were approximately 30 feet below the level of the surrounding land and up to 350 or 400 yards wide. In the smallest and least defined segment, however, that designated Wheatley 2, there was only a difference of 10 feet between the valley floor and the level of the surrounding land while the valley was only 30 to 50 yards in width.

Discharge is a particularly difficult parameter to deal with since the bulk of the discharge is concentrated in the Spring thaw and since there are no permanent stream guaging stations on any of the example segments. Indeed, there are no permanent stream guages in the entire sub-region from which to obtain comparative data. During that part of the year other than late March, April and early May measurable discharge is almost non-existant in most of the stream courses except during periods of storm run-off.

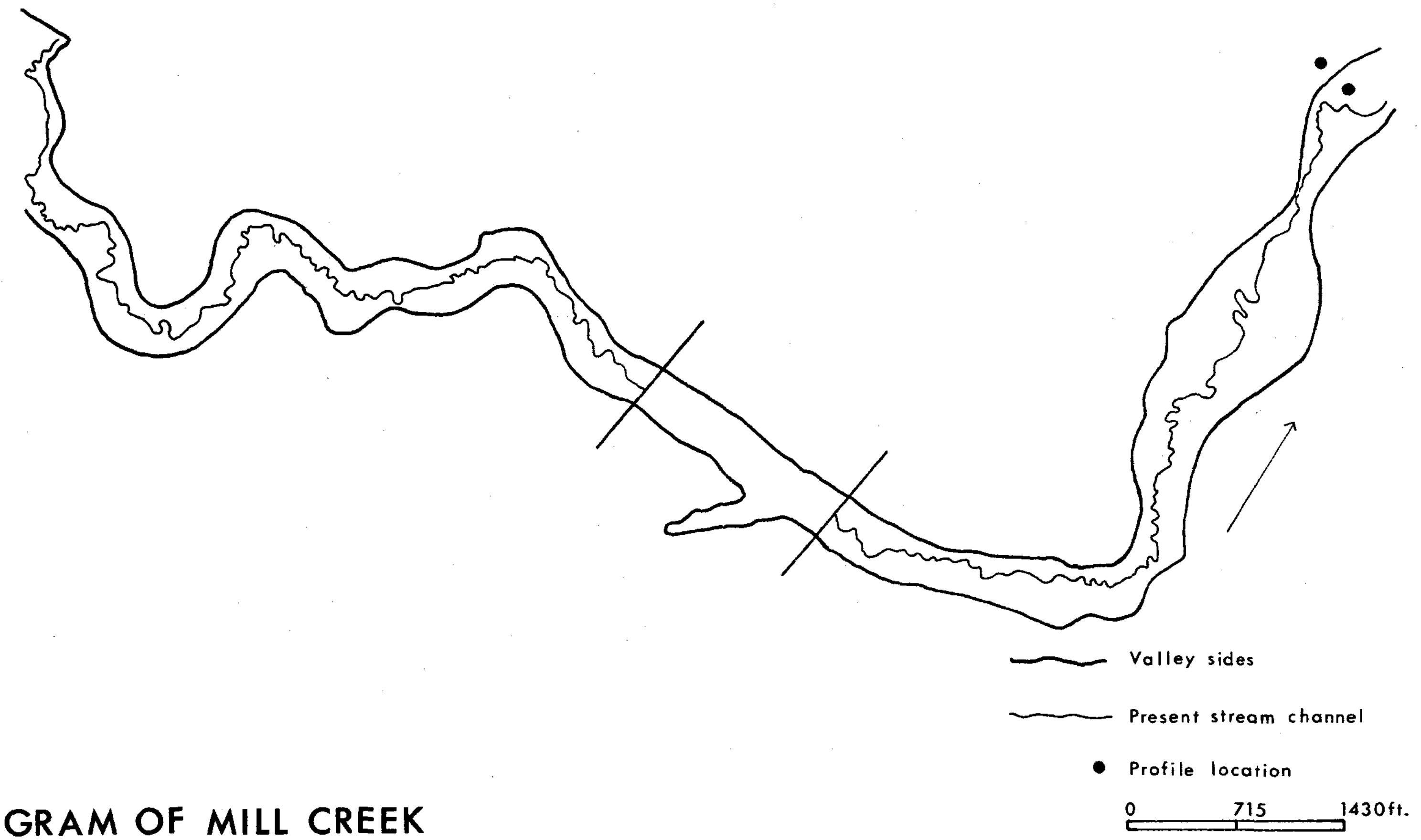


DIAGRAM OF MILL CREEK

Fig. 3

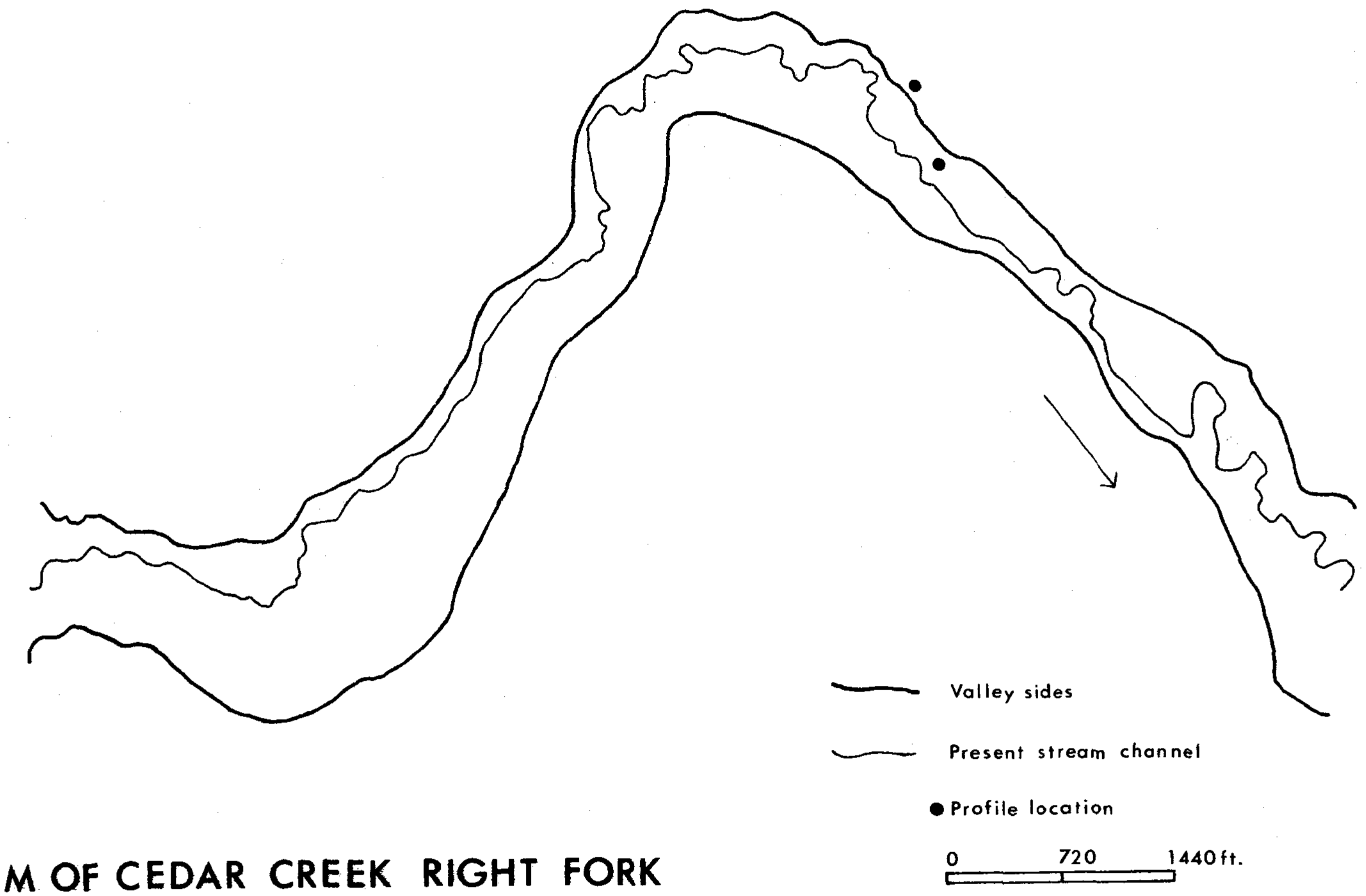


DIAGRAM OF CEDAR CREEK RIGHT FORK

Fig. 4

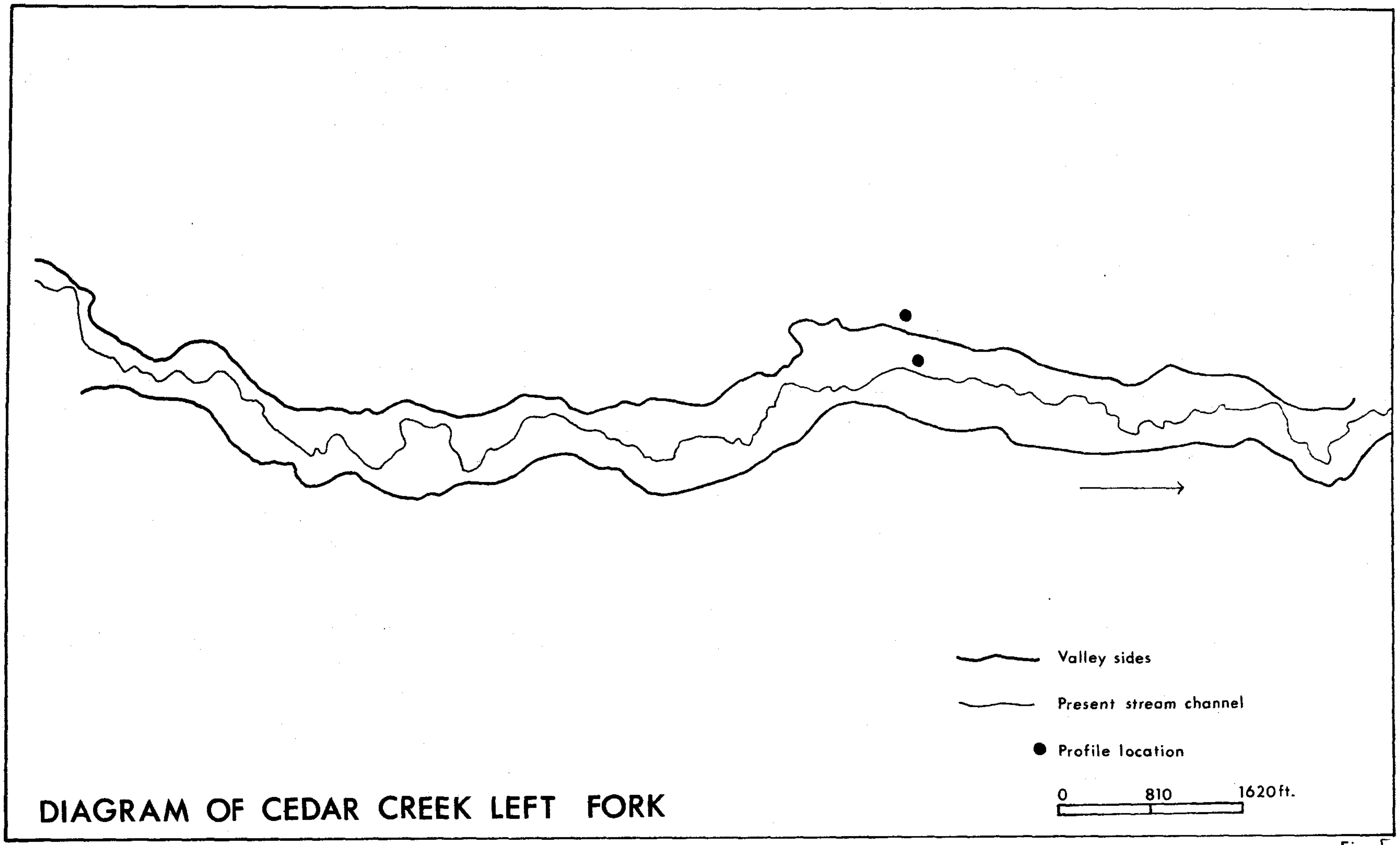


DIAGRAM OF CEDAR CREEK LEFT FORK

Fig. 5

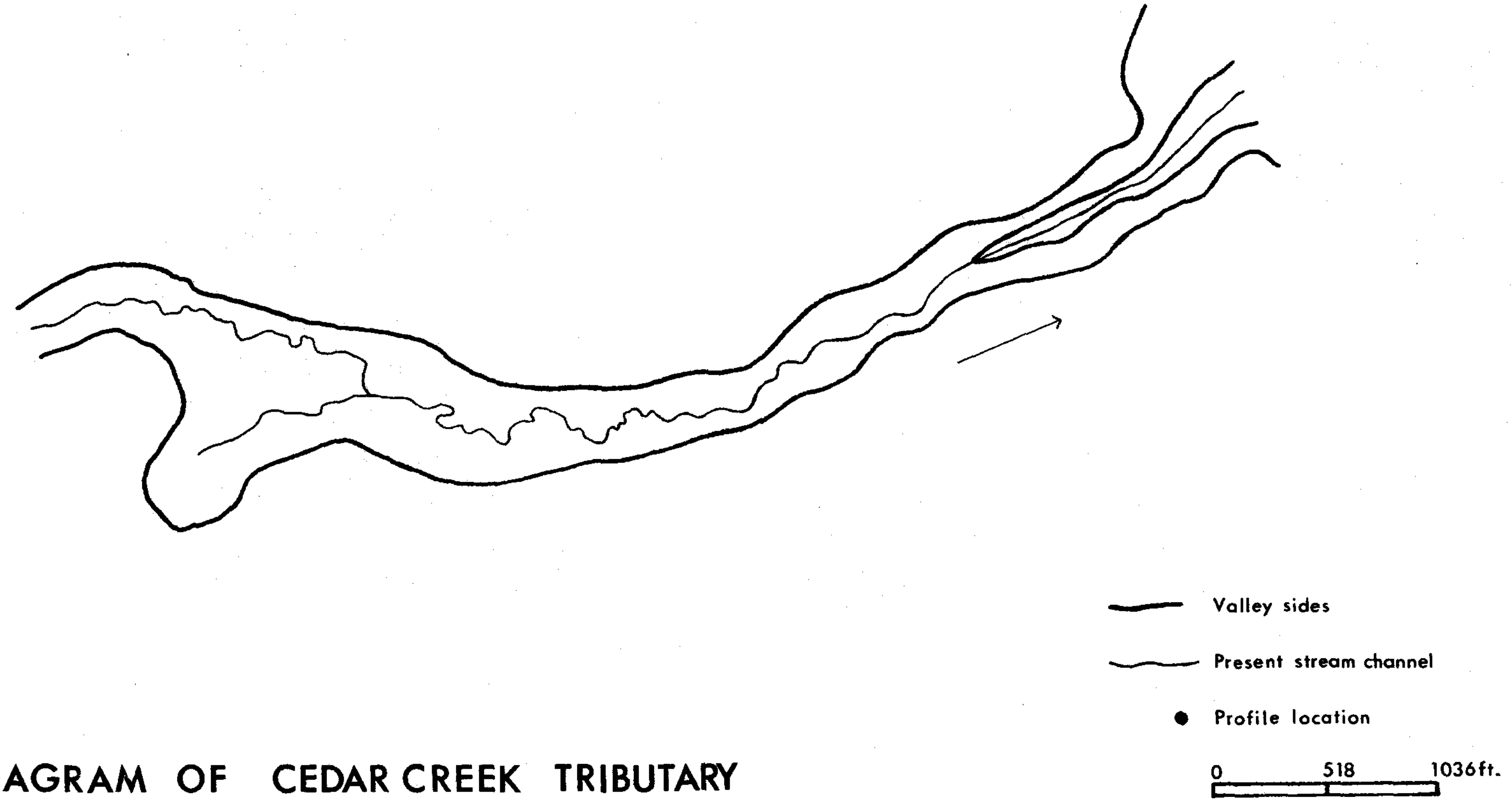


DIAGRAM OF CEDAR CREEK TRIBUTARY

Fig. 6

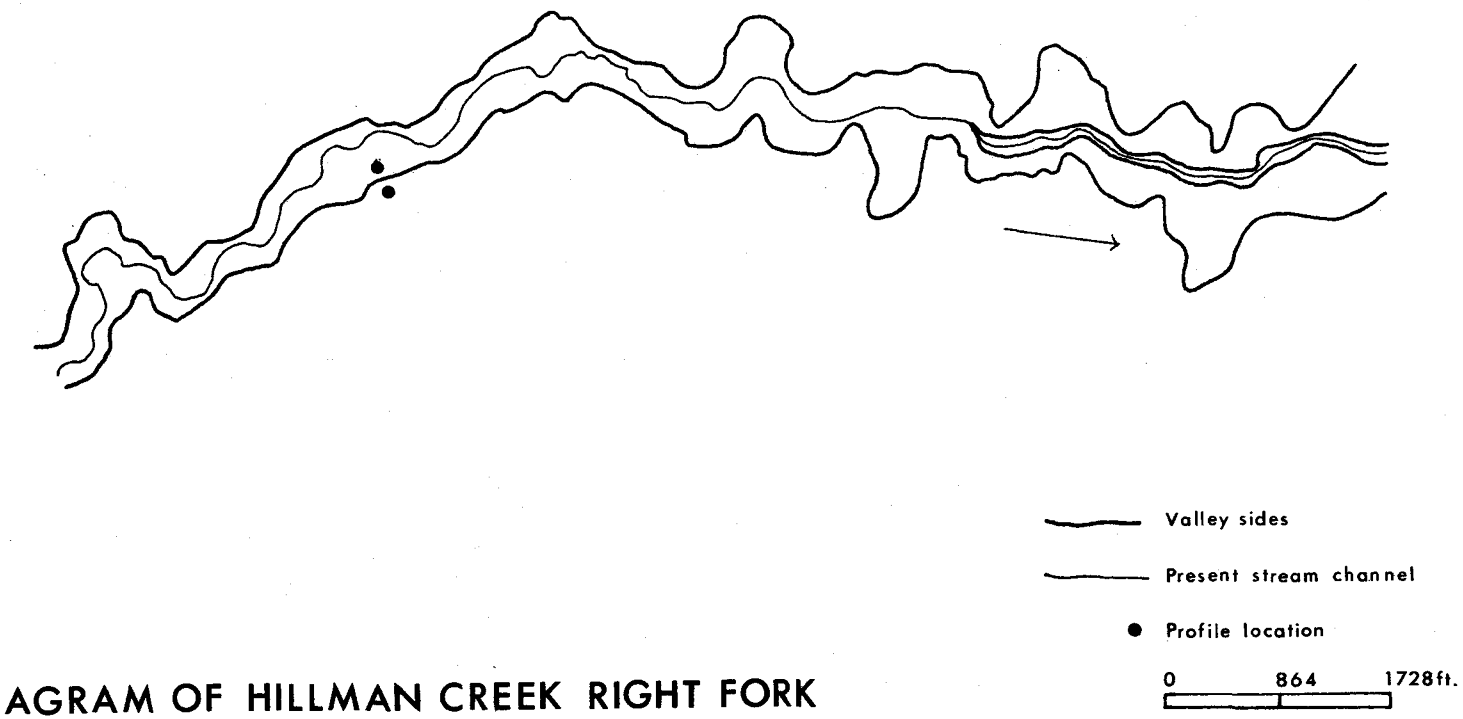


DIAGRAM OF HILLMAN CREEK RIGHT FORK

Fig. 7

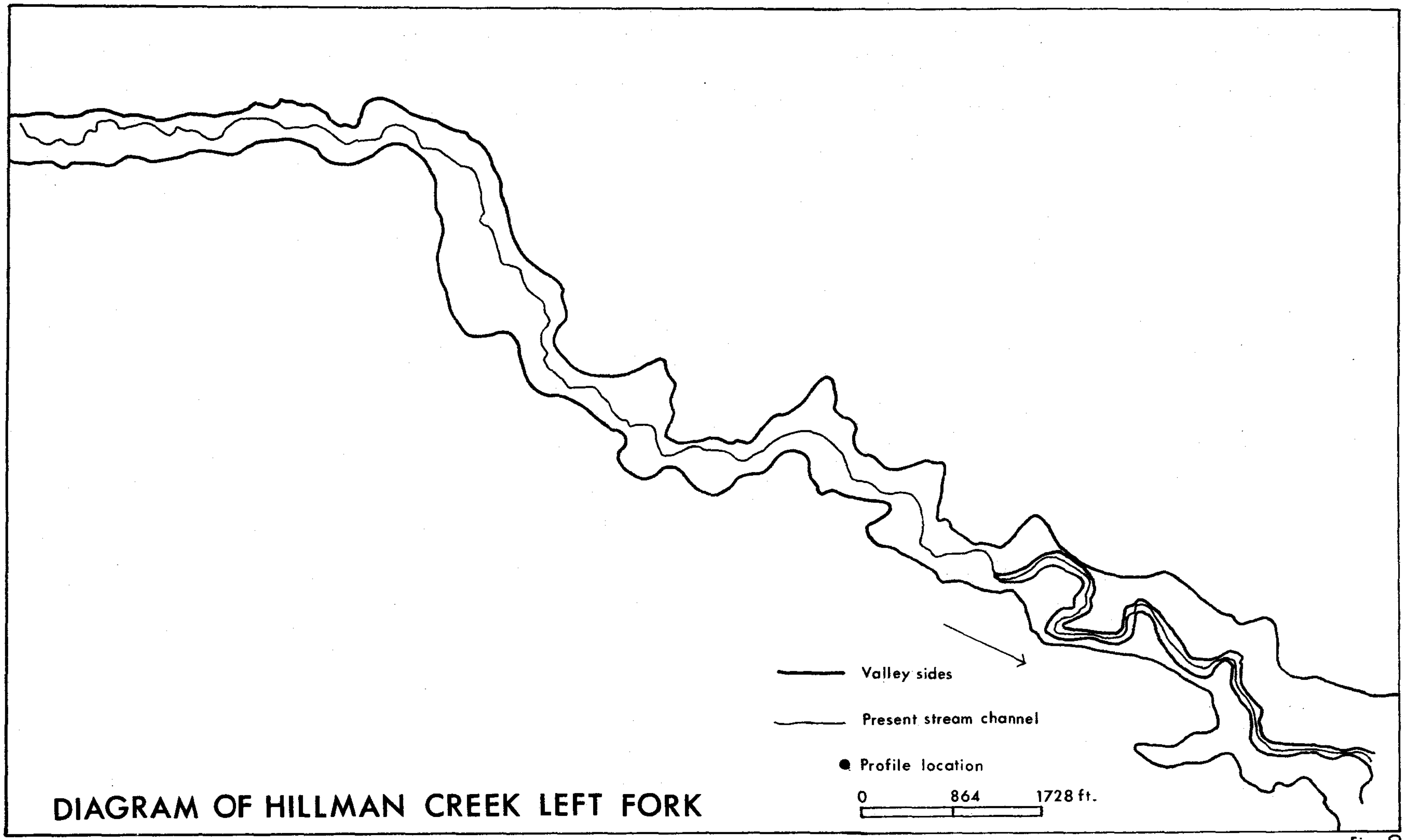


DIAGRAM OF HILLMAN CREEK LEFT FORK

Fig. 8

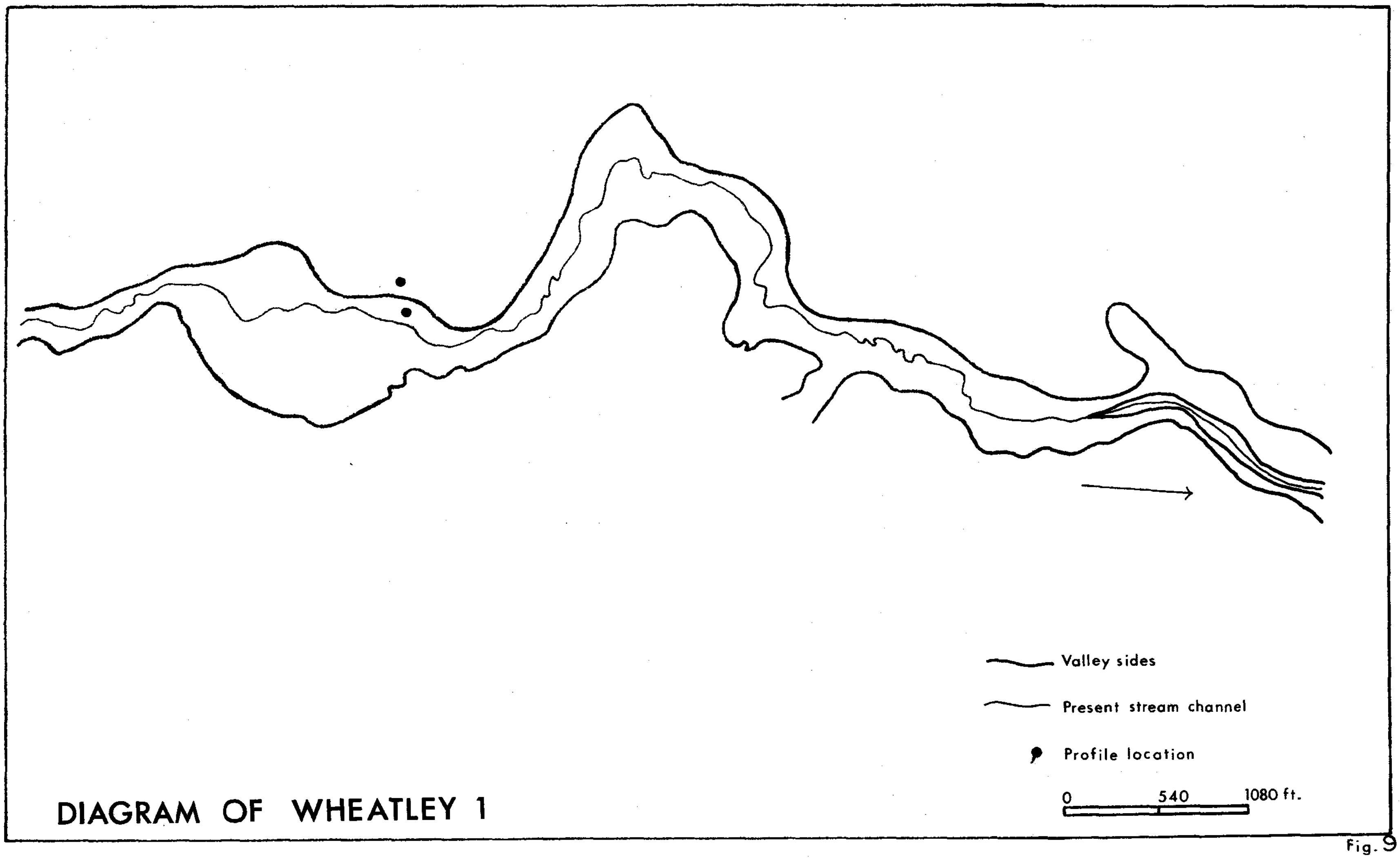


DIAGRAM OF WHEATLEY 1

Fig. 9

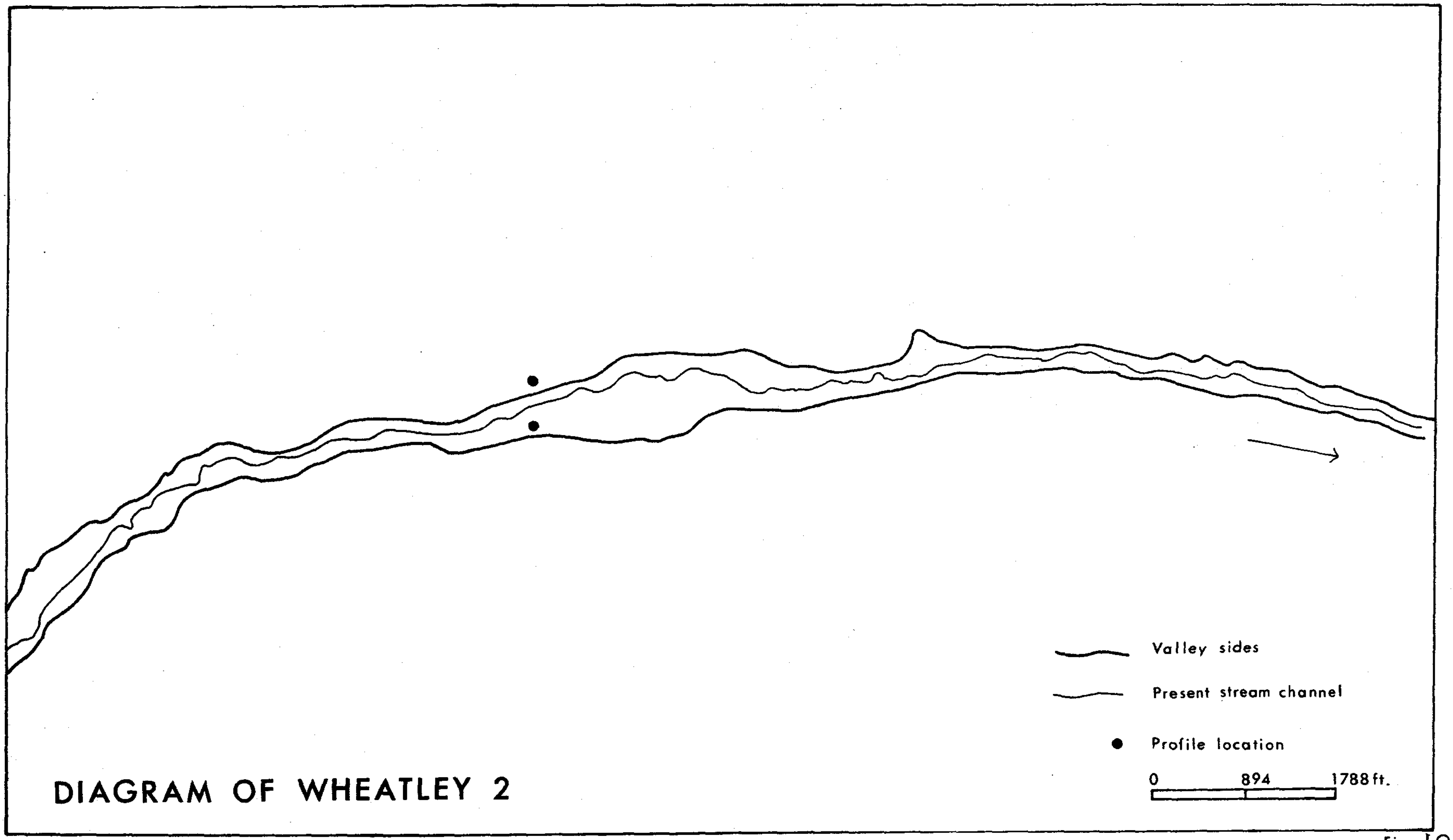


DIAGRAM OF WHEATLEY 2

Fig. 10

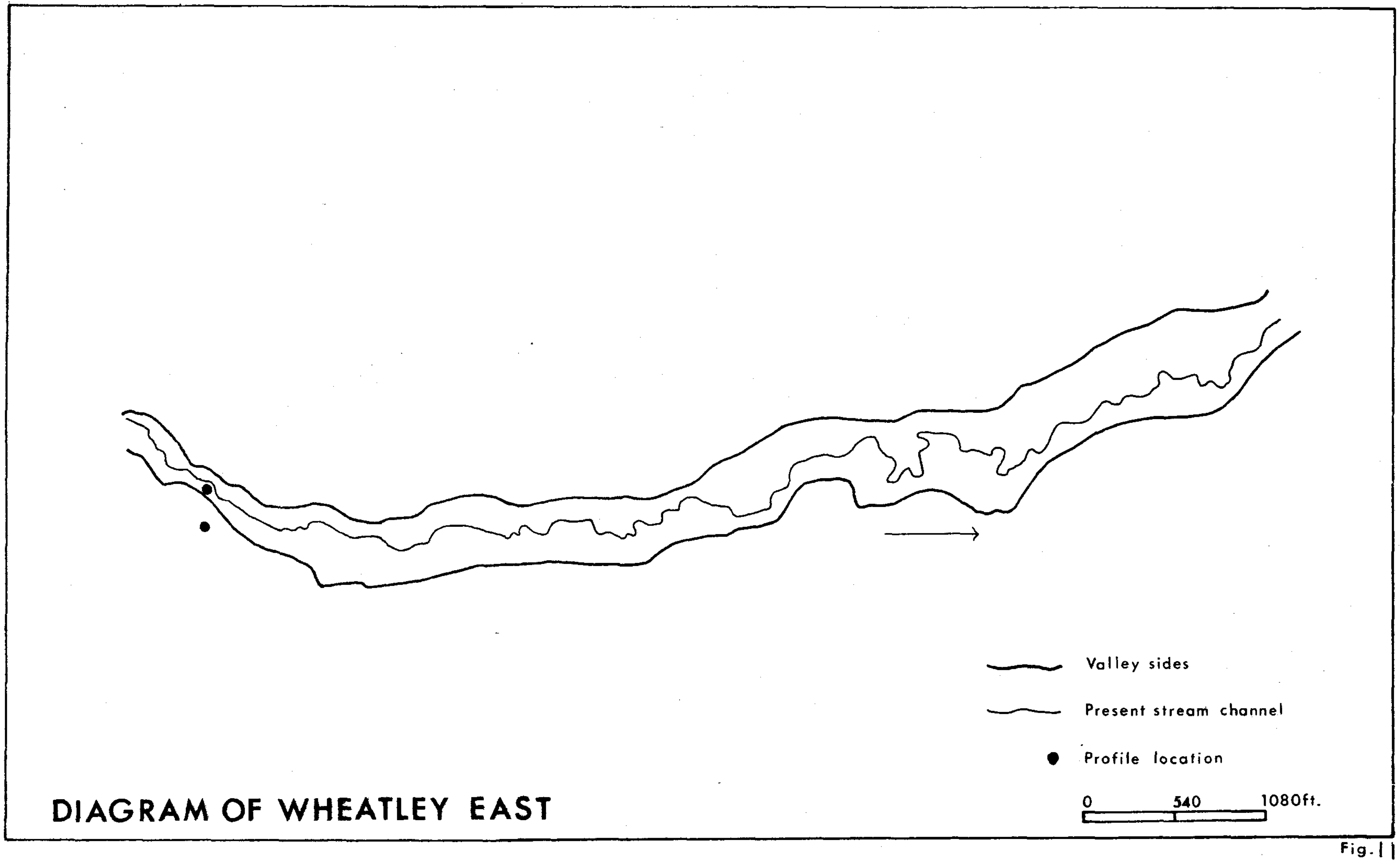


DIAGRAM OF WHEATLEY EAST

Fig. 11

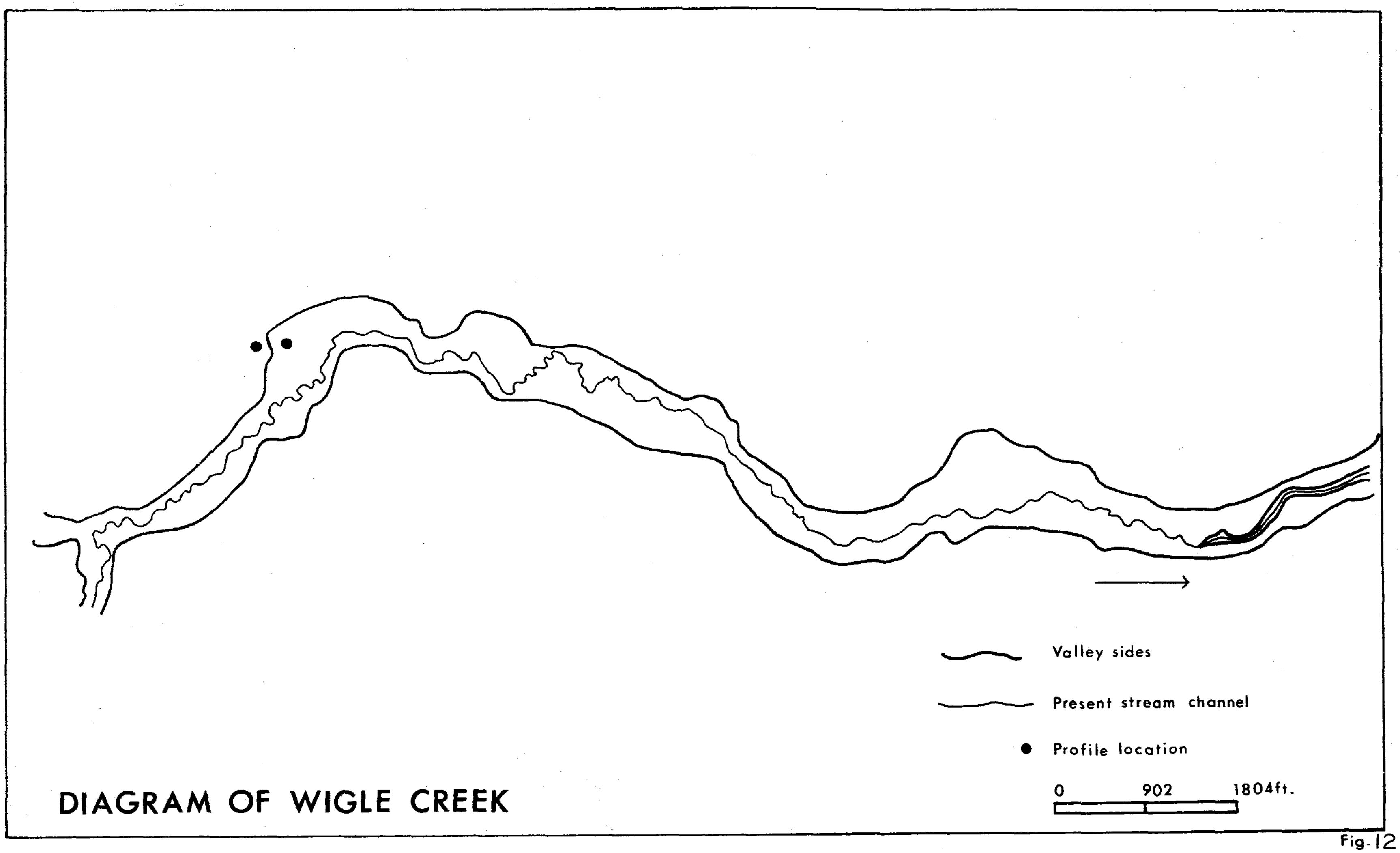


DIAGRAM OF WIGLE CREEK

Fig. 12

During exceptionally wet Springs, some of the lower reaches of the valley floors are flooded in a shallow fashion. This past Spring(1973) flooding occurred in the lower reaches of Mill Creek, Cedar Creek, Hillman Creek and the Wheatley system. In these instances, the smaller stream valleys(within the larger valleys) were drowned and some portions of them remained in the drowned state throughout the summer. Vagners(1971) suggests that the marshes which permanently exist at the mouth of Hillman Creek overlie a drowned river valley. Despite the experience in the area this past Spring and despite the findings of Leopold and Wolman(1957) that suggest overbank flooding might be expected every 1.23 years on the average, there is no evidence to indicate that this has been the case in recent years in any but the lowest reaches of some of the streams under consideration.

It is Mackin's(1948) view that a clue to the direct relationship between a stream and the valley in which it flows is the existance of point bar terraces formed by the stream. Terracing does not appear to exist in any form throughout the area with one exception. In the uppermost reaches of Wigle Creek, point bar terraces have been and are still being formed.

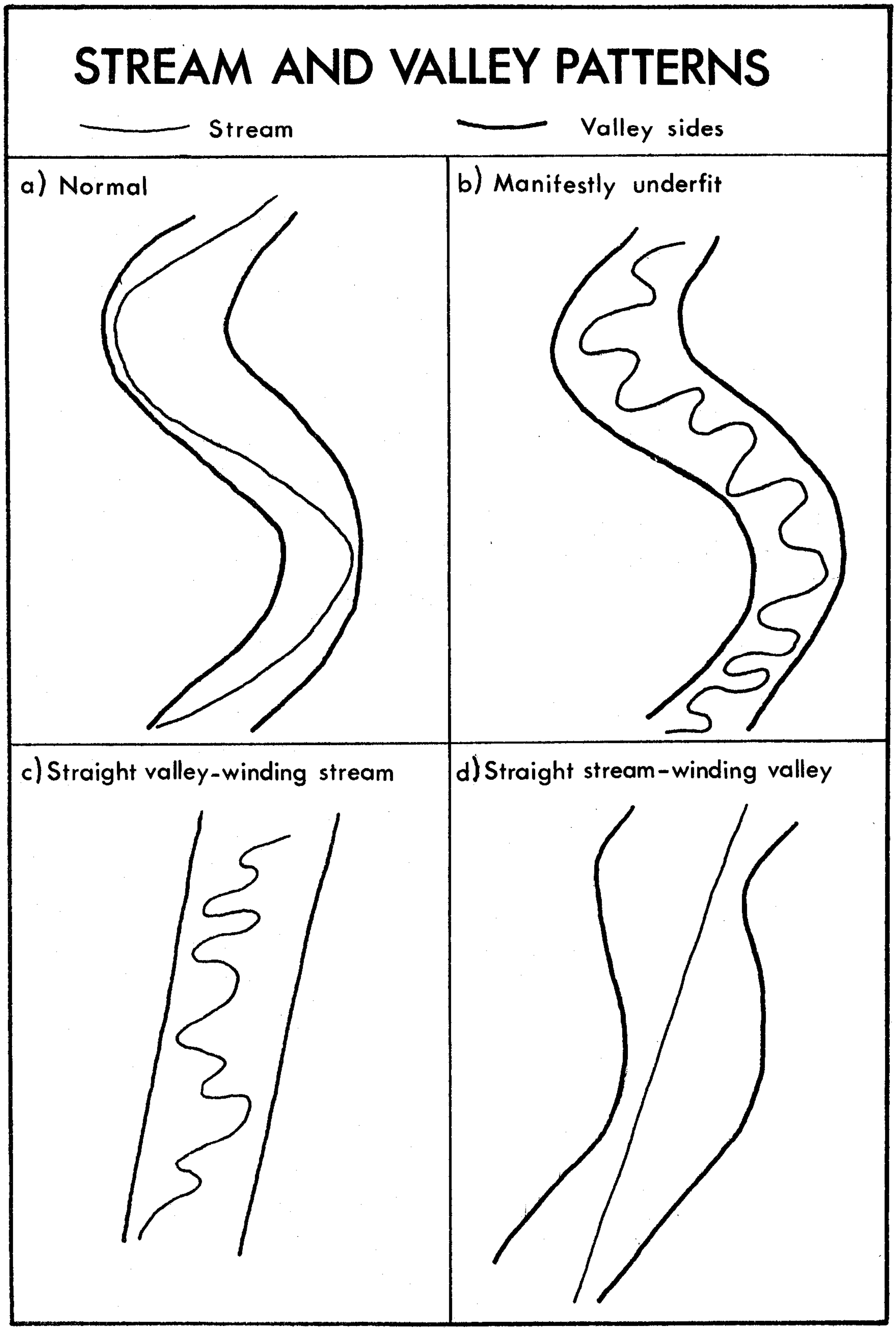
In almost all cases, the approximately equal slopes on either side of the valleys indicate a dominance of intrenching activity, as opposed to ingrowth, in the former stream. This is not to suggest that ingrowth has not been taking place, it has, but to a much lesser degree. The present streams, however, evidence a tendency toward ingrowth as manifested by their well developed slip-off slopes and the low angle opposite slopes. Two distinct transverse profiles appear to exist among the example segments. The difference seems to be largely in that one set is shallower than the other. This may or may not be significant in the present study.

I:4 THEORY OF MISFIT STREAMS - A REVIEW

In the science of geomorphology, which like other sciences, strives toward precision of definition, the theory of misfit or underfit streams emerges as an anomoly. Without suggesting that the feature is undefinable, it is clear that in more than 75 years of studying the phenomena, geomorphologists have been unable to arrive at anything more than a generalized statement of definition. To complicate matters, this generalized statement appears to be the product of an evolution of accepted usage over the years and lacks the universality required of a science ostensibly working toward the formation of laws.

William Morris Davis(1895,1896,1899), for example, in his initial work on the subject, coined the terms "misfit" and "underfit" in application to landforms wherein it appeared that "certain valleys (showed) signs of having been cut by streams far larger than those which now (flowed) in them." (Dury,1954,194). In his discussions, Davis dealt primarily with certain combinations of valley windings and river meanders. As a result, Dury(1954,194) suggests that "his (Davis') interpretation has prevailed to the extent that the underfit stream has passed into the literature as connoting a stream meandering within the limits of the bottom of a winding valley." (see Fig. 13b).

The Davisian combination of meandering streams in winding valleys as well as valleys which could not have been cut by their present streams has, in subsequent work, proved overly restrictive.



STREAM AND VALLEY PATTERNS

a) Normal

b) Manifestly underfit

c) Straight valley-winding stream

d) Straight stream-winding valley

Source: After Dury (1964a)

FIG.13

For example, Leopold and Wolman(1957) have noted that although they are so rare as to be almost non-existant, straight stream channels do exist in nature. Therefore, it would seem possible to have a straight stream flowing in a winding valley such that the stream could not have cut the valley. Indeed, it would also appear possible to have a small meandering stream flowing in a much larger straight valley (Figs. 13c & 13d). The question obviously remains as to under what generic heading would these landforms fall if not under the term "misfit stream"?

G. H. Dury(1960,219), who must be regarded as responsible for the development of the main body of theory on the subject, appears to have recognized the great variety of misfit forms which may exist, defining a misfit stream as "a stream which is either too large or too small for its valley."[1] Apparently, however, other students, and to some extent Dury himself, remained unwilling to divorce the above definition from the Davisian "winding valley/meandering stream" connotation. For example, within the context of a discussion of meandering valleys, Leopold, Wolman and Miller(1964,310) refer to the "classic misfit stream apparently too small for the valley within which it flows." On the basis of material presented by Dury, Morisawa(1968,142-3) has chosen to define a misfit stream as one whose meanders do not fit the size of the valley in which the stream is at present flowing. In other words, she suggests that "the meanders of the present channel are samller in amplitude and less intricate than the bends in the valley walls." Dury(1964a,7), in the opening statements of his U.S. Geological Survey

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[1] Theoretically, it is possible to hypothesize the existance of overfit streams where the stream is too large for its valley, however, presumably all remnants of the former valley would have been obliterated by the action of the present stream.

Professional Paper series(1964a-c) apparently avoids the problem by initiating his discussion with the comment - ". . . in the customary but too restricted sense, an underfit stream is a stream that meanders on a floodplain in a meandering valley." Seemingly, the only further clarity he adds to the subject is to ascribe the term "manifestly underfit" to the above case. He later uses the term "far less ample" to describe the size relationship of the stream meanders to the valley meanders.

Resolution of the problem of definition undoubtedly lies in the question of process; that basically homologous conditions existed for the formation of the valley paths as exist for the continuing formation of the present stream courses but that the magnitude of those conditions has been altered substantially since the valleys were cut. Therefore, perhaps the definition should revolve around process rather than form suggesting a stream-valley relationship where the discharge cutting the valley was considerably greater than the discharge in the present stream.

Viewing the misfit stream in the context of process clearly indicates why the emphasis on meandering streams and valleys has developed; it appears to be simply the path of least resistance. While discharge through the present stream can usually be measured, discharge through the former streams cannot. Leopold and Maddock(1953,8) found that there are direct empirical relationships between stream discharge and other hydraulic factors such that

$$w = aQ^b \qquad d = cQ^f \qquad v = kQ^m \quad \text{(Eq. 1 - 3)}$$

where Q is discharge at the bankfull stage, w is width of channel in feet, d is mean depth in feet, v is velocity in feet/sec. and a,b,c,f,k, m are numerical constants. With Inglis(1949) having already established that meander wavelength is proportional to the square root of the dominant discharge,

$$l = aQ^{0.5} \qquad \text{(Eq. 4)}$$

where l is wavelength in feet, Leopold and Wolman developed the relationship between wavelength and bedwidth.

$$l = 6.5w^{1.1} \qquad \text{(Eq.5)}$$

Similar relationships developed by Leopold and Wolman and others may be found in Table 1.

TABLE 1 - Empirical relations between size parameters for meanders in alluvial valleys (parameters measured in feet)

Meander Length to Channel Width	Amplitude to Channel Width	Meander Length to Radius of Curvature	Source
$l = 6.6w^{0.99}$	$A=18.6w^{0.99}$		Inglis(1949,pt. 1, p.144) Ferguson data
	$A = 10.9w^{1.04}$		Inglis(1949,pt.1, p.149) Bates data
$l = 10.9w^{1.01}$	$A = 2.7w^{1.1}$	$l = 4.7r_m^{0.98}$	Leopold & Wolman (1960)

Source: Leopold, Wolman and Miller (1964,297)

Dury(1960,231-2), based on the work by Inglis, Leopold, Maddock and Wolman, was then able to undertake the designing of a method to (a) demonstrate a difference in discharge between former and present streams and (b) ascertain the actual size of former discharges. Assuming the general relationship $w = aQ^b$, then

$$W/w = aQ^b/aq^b = (Q/q)^b \qquad \text{(Eq. 6)}$$

or

$$Q/q = (W/w)^{1/b} \qquad \text{(Eq. 7)}$$

where W is the width of the former stream channel, w is the width of the present stream channel, Q is the former discharge, q is the present discharge and b is a numerical constant. Previous research appears to have established 0.5 as an average value for b (see Leopold, Wolman and Miller,1964).

Bedwidth is not, however, always easily measureable, particularly in the case of former channels where alluvial infilling has probably obliterated the surficial traces. Determination of bedwidth in that instance is not possible without subsurface exploration which, to achieve a reasonable degree of accuracy, can be expensive and time consuming. Indeed, the measurement of bedwidths on existing stream channels is also often difficult.

Since meanders are probably the most easily measured stream parameter from topographical maps, air photographs or under field conditions, and since it has been established that there is a relationship between meander wavelength and discharge, it is possible to calculate present and former discharges from the analysis of wavelength, such that

$$Q/q = (W/w)^{1/b} \qquad \text{(Eq. 8)}$$

Dury further develops the relationships between discharge and drainage area, but due to the lack of drainage area definition in the area, these relationships are inapplicable.

I:5 HYPOTHESES OF FORMATION

Dury(1954,194-7) has carefully reviewed most historical attempts at explanation of the formation of misfit streams and they will, therefore, be dealt with only in a general sense here. William Morris Davis(1895,1896) must be considered the first investigator to approach the problem of form and process in the underfit stream although others have been known to comment briefly on their existance. Davis, in dealing with certain western European streams where the size disparity between stream and valley meanders was obvious, suggested that river capture was probably the cause. Somewhat later, Davis(1899) was willing to recognize the existance of anaomolies amongst the underfit streams he observed and commented that these could be the result of a general change in volume which had superimposed its effects on the effects of capture. This, he thought, might have resulted from reforestation or some climatic change of external or obscure origin. In addition, Davis put forward a similar hypothesis regarding sequential or double capture causing three or more distinct sets of meander traces. This hypothesis was in reference to the Cotswold Coln in south-western England.

Dury(1964a) recognizes that stream capture cannot be totally ruled out as a cause of the underfit condition, citing the Neuse and Bar Rivers in southern France as examples of this, Dury suggest that perhaps in these instances, diversion would be a more apt term to describe the processes involved. It is Dury's opinion, however, that diversion offers a reasonable explanation for only certain isolated and independent underfit streams, and that such an explanation is unsatisfactory in dealing with a regionally-distributed phenomena. Dury(1964a) points out in reference to the continental United States, and is supported by work in other areas, that underfit streams are indeed widely distributed on a regional basis. This, he suggests, could not possibly be explained by the diversion theory. In a personal communication, Dury(1973) uses the phrase "second-generation underfit" to describe the effects of what Davis referred to as "double capture." Although he is unwilling to ascribe them to double capture, he feels that perhaps they are the result of a two stage process involving the cutting of a meltwater channel, a large stream cutting meanders in the now dry channel and a subsequent reduction in discharge forming a third set of even smaller meanders. Regarding Davis' remarks on the Cotswold Coln, Dury(personal communication, 1973) dismisses them with the comment that "the evidences he adduces does not exist in the field.....it seems likely he saw the stream through the windows of a train."

A second possibility offered by Davis(1909) for the cause of the underfit condition was that the greater discharge of water necessary to cut the larger meanders could have been the result of the overspill of a glacial lake. Arkell(1947) appears to support this view. Davis(1913), however, later abandonned the idea as being implausable, although his reasons for doing so were obscure. In fact, the spillway hypothesis may be effectively offered for isolated cases of underfitness such as waterways leading away from an ablating ice front, or the outlets from proglacial lakes. However, problems in regional distribution tend to refute the general theory that misfit streams are glacial spillways. To prove glacial spillways as only a complicating factor, streams in non-glaciated areas must be proven underfit (a relatively simple task), or underfitness in glaciated areas must be shown to have resulted from activity after the recession of the ice; Dury seems contradictory on this point. He(1964a) suggests that the changes which reduce discharge will be independent of spillway activity and cites the Wabush River which is known to be a spillway and yet cannot be proven underfit because of the lack of meander definition. However, streams flowing into the Wabush from either side have quite clearly been reduced in volume independently of any cessation of overspill. He puts this forward despite his earlier statement suggesting meltwater as a factor in the Cotswold Coln case (Dury,1954). Dury's 1964 rejection of the spillway hypothesis would also seem to reject the idea that the important consideration in the study of underfitness is the reduction in discharge and not the existance of two sizes of meanders.

Other hypotheses that have been suggested include: (a) underflow advanced by Davis(1913, (b) erosion by floodwater (Engelmann,1922 and Flohn,1935), (c) and the influence of structure as suggested by a number of European writers including Vacher(1909), Mussett (1928) and Blache(1939,1940). Miscellaneous hypothesis have been advanced by Lehman(1915), Bates(1939) and Wright(1942) and others and have been reviewed by Dury(1954).

Perhaps the most acceptable hypothesis to explain the formation of regionally-distributed underfit streams is the climatic one; that they are the result of "decreased discharge in a changing climate....(possibly)....during the waning of the Pleistocene glaciers." (Morisawa,1968,142)[2]

Dury(1960) found that the ratios between the former

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[2] Reference to the Pleistocene here is merely an attempt to attach a temporal meaning as opposed to ascribing a causal relationship.

and present discharges were usually in the area of 80:1 to 100:1 which indicated to him that there had, in all probability, been a change in runoff regimen apparently related to changes in climate. Change in temperature in itself does not provide sufficient explanation for the observed effects "....particularly since the cutting of the large meanders and the scouring of large channels persisted into early deglacial times" and perhaps into even more recent times. (Dury,1964c,39). However, reductions in air temperature combined with increases in precipitation rates, to some degree, could account for a significant increase in surface runoff and consequently in stream discharge. He also found that frozen ground with its increased runoff could not provide sufficient explanation. By inference, Dury suggests that the phenomena would depend largely on momentary peak discharge conditions, requiring a high frequency of single rainfalls of long duration.

The climatic theory naturally leads to a discussion of the chronological sequence of climatic events which, in turn, appears to be the key in the study of individual underfit examples. There are three temporal specifications which are important according to Dury (1964b). They include: (a) the initiation of cutting of the large meanders, (b) the onset of underfitness or the abandonment of the large meanders or channels and (c) the duration between initiation and abandonment. Initiation of the large meanders may often by dated to the "gross surface", the erosional platform or depositional spread. The object is to find the latest date possible for that surface which in turn sets limits before which the valley meanders could not have been cut. Dating of the initiation and abandonment is usually accomplished through radiocarbon dating, pollen profile analysis, or less precisely, reconciliation with a feature such as a moraine, shoreline or contour for which an approximate date is known. Dury's(1964) study, limited in this instance to the continental United States, found that the initiation stage could have ranged from the early Pleistocene to perhaps as late as 2,000 years B.P. in some areas of the Great Lakes region, the later date is particularly important to this study as will be shown later.

CHAPTER II

EMPIRICAL TESTS FOR MISFITNESS

2:1 INTRODUCTION

In the study of underfit streams, a central theme must be the empirical evaluation of misfitness. Although misfitness or underfitness is usually identifiable from the combination of field observation and map and air photo study, such cursory assessment provides only the information necessary for statements on form, leaving the question of degree or magnitude of process for more thorough investigation. In this instance, field observation, when combined with map and air photo interpretation proved most effective in a general way for confirming or denying the existance of misfitness and, to some extent, providing evidence of differences in magnitude or degree of misfitness between some of the example segments observed.

On the basis of such study, it is possible to formulate several hypotheses. Firstly, in the area between just east of Harrow and just east of Wheatley, all of the major streams and creeks with the exception of Sturgeon Creek immediately east of Leamington, show some degree of misfitness, with misfitness being assumed to have resulted from a difference in discharge during the periods of valley formation and stream formation. That Sturgeon Creek, or any other creek in the area, should show no indications of misfitness is not surprising considering the significant amount of disruption of natural drainage patterns that has occurred in the area.

A second hypothesis arrived at from field observation is that there appears to be a wide range of degrees of misfitness among the example segments observed. Hillman Creek, for example, does not appear to manifest the same degree of misfitness as do the others. If further testing does establish a wide variation in degrees of misfitness, it could be a major factor in testing any hypothesis of formation which utilizes the aspect of regional distribution. The two different transverse profiles mentioned in Chapter I could also be an indication of differences in degree and have been assessed in that regard.

The evaluation of these questions has been undertaken in two ways; the Dury technique of simple measurement of the cross-country meander wavelengths for both valley and stream, calculation of the mean wavelengths and application of the wavelength and discharge ratio formuli developed in Chapter I and; with the use of power spectrum analysis applied to the stream and valley meanders as though analogous to time series.

2:2 POWER SPECTRUM ANALYSIS

Although the results of Dury's investigations (see Chapter I) seem reasonably clear and are based on sound principle, they have not gone totally without challenge. F. G. Speight(1967) criticizes Dury's method of measuring all straight line distances between successive points of inflection along a meander train, questioning that Dury can predict flow from wavelength because of the unrealiability of his measurements. Such a technique, Speight argues, is unduly subjective in the selection of points of inflection and straight reaches; that it assumes the smallest meander to be the dominant oscillation and that; finally, the straight line distances are incorrect because the water particles move along a winding channel making straight line distances of little relevance.[3]

As a result, Speight proposes the use of Power spectrum analysis as an alternative. Power spectrum analysis is essentially the determination of the respective contributions of different frequencies to the total variance in a system of oscillations. "The calculation of the spectrum involves the fitting by least squares of sinusoidal curves of different frequencies to a set of data which may be in one, two, or n dimensions. Thus the method is equivalent to multiple regression with trigonometric transformation of the independent variable"(Rayner,1971,2). The theory and mathematics of the technique are well established and will not be reviewed here; further information may be gained from Blackmann and Tukey(1959), Panofsky and Brier(1965), Thoman(1967), Jenkins and Watts(1968) and Rayner(1971).

To derive the data for use in the power spectrum analysis, the valley paths and stream courses were first traced from air photographs(1965, scale - 1:15,550), and then enlarged by varying amounts to provide a sufficient number of data points for analysis without distorting the original pattern any more than necessary. Derivation of the data from the enlargements was accomplished in a slightly different manner than that used by Speight(1967). Instead of taking

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[3] This is based on a personal communication to Speight from Luna Leopold relaying Leopold's findings that the wavelength distance along the channel correlates quite well with discharge and doesn't produce anomolously short wavelengths at narrow meander necks.

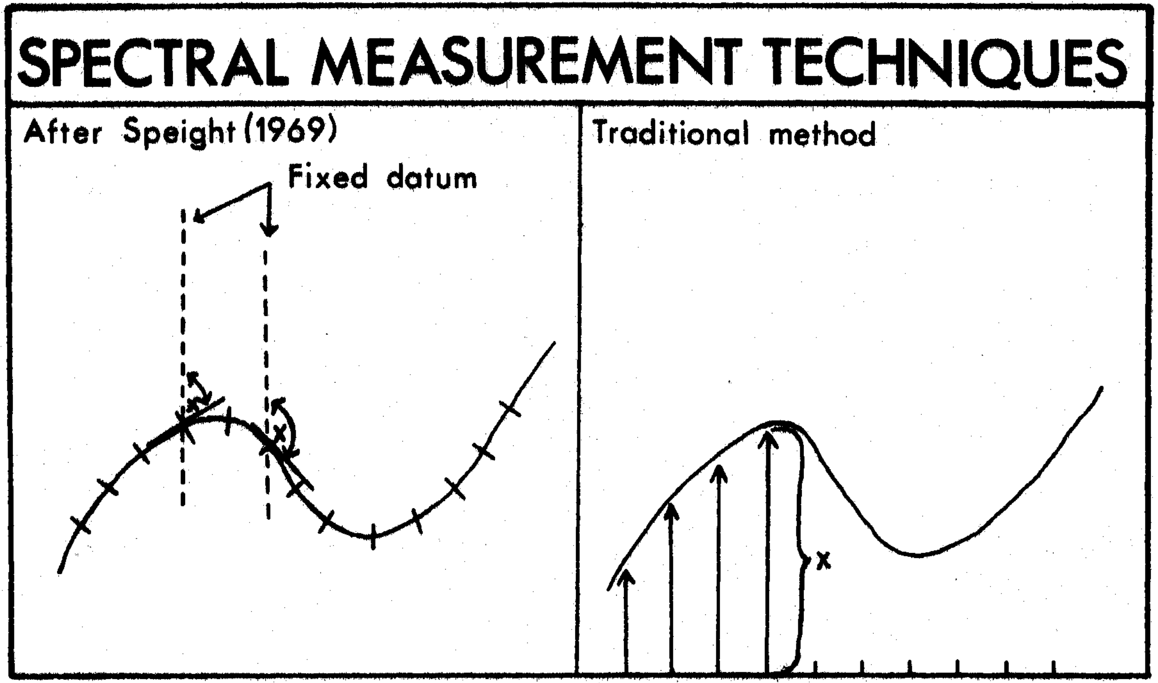

Fig.14

equi-spaced observations along a fixed horizontal datum of values from a vertical axis (Fig. 14b), which is traditional in the analysis of a time series, Speight has taken equi-spaced observations of the angle of flow along the course of the stream such that all values are positive (Fig. 14a). Although this would seem to be similar to the normal procedure, it does appear to have one serious flaw. Measuring angles along the course of flow of a meandering stream places undue emphasis on the radius of curvature of the meander, an hydraulic stream factor which Leopold, Wolman and Miller(1964) have found does not correlate as well as meander wavelength with bedwidth, and subsequently, with discharge. Speight does not appear to have effectively taken the influence of radius of curvature into consideration and thus his analysis is open to challenge. As a result, this study utilises the more traditional form of determining the data for use in the procedure.

Each segment was measured twice at equi-spaced intervals along a fixed horizontal datum, once to ascertain the values for the line of maximum flow for the present stream, and once to find the values for the assumed line of maximum flow in the previous stream valley. Using program BMDO2T from the Bio-Medical Program Series, the data will be then analyzed with a view to two parameters: the spectral estimates and the coherence function[4] (Dixon,1971).

As noted above, the spectral estimates provide estimations of the contributions of wavelengths of various frequencies to the total variance. A fairly uniform distribution of variance with scale indicates randomness of meandering pattern, while, on the other hand, spectra with significant fluctuations may suggest separable generating processes (Rayner,1971). High variance values at 0 frequency show random fluctuations, linear trends, and components of such low frequency that they appear as linear trends. Because the difference in discharge between the present and former streams should manifest itself in different size wavelengths, it might be hypothesized that analysis of the spectral estimates will reveal a consistantly larger contribution to variance at the higher frequencies (smaller meander wavelengths) in the case of the streams. Also, since the stream courses must follow the paths of the valleys and since the larger valley windings will probably contribute most to the total variance for the stream and valley in each example will be quite similar. Finally, since the

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[4] See Appendix A for frequency/wavelength relationship for each segment. Frequency rather than wavelength is used in text as wavelength differs for each segment.

size of the stream segment examples used varies widely, the wavelengths will vary widely, therefore, the total variance for each example will, in turn, indicate a wide range.

The coherence compares the two time series at the various frequencies to find the relationship between the two (Panofsky and Brier,1965). For purposes of analysis, it is usually described as being analogous to the coefficient of determination in in regression analysis (Rayner,1971). Since the present stream must follow the former valley in terms of general course, it is hypothesized that the coherence values will be reasonably high at the lower frequencies (longer wavelengths), but as the stream is not bound by such restrictions at the higher frequencies (shorter wavelengths), the coherence values should decline as frequency increases.

The application of the technique, however, is not without its problems, and these should be recognized before analysis takes place. If the original sample is continuous, the consideration of equi-spaced observations makes it impossible to isolate the highest frequencies. Instead, the high frequencies will be added to the lower resolvable frequencies making them unusable in some instances. Averaging, which is a form of filtering or smoothing, is included in the program without option (Dixon,1971). This will remove high and, in part, medium scale frequencies from the data. Since the spectral estimates are derived from manipulation of the autocovariance function which, in turn, is a function of the mean, the results may be biased toward amplitude, a parameter not related to discharge but to stream bank characteristics and other local factors (Leopold, Wolman and Miller,1964): this problem was also noted by Speight(1967). No provision is allowed in the technique for back meandering more than 90 degrees against the general direction of flow. In the procedure used here, they cannot be measured, while in the Speight approach, they would result in negative values which cannot be handled by the program. This objection is not only relevant to this study but would apply where-ever any amply meandering stream is being assessed. Finally, the fact that the segment examples used are not very long presents somewhat of a problem. The shortness of record may be such that the valley meandering pattern is not sufficiently established for effective analysis. This would undoubtedly contribute to variance at the 0 frequency.

The smoothed spectral estimates are shown in three different forms; Table 2 lists the estimates and total variances; Figure 15:1-11 shows the estimates as well as the coherence graphed in log fashion for the frequencies 0.0 to 5.0 times per period and; Fig. 16:1-11 which graphs the estimates in standard form for the 5 highest frequencies.

As expected, the total variance shows a wide range among the examples tested, 242.04 to 11.94, and, generally speaking, variance seems well correlated with size in that the largest streams show the largest variance. The two exceptions to this, Cedar Creek Left Fork and Hillman Creek Right Fork, are the result of shortness of record and the dominance of the valley meanders (see Figs. 4 & 7). The similarity of variance between valley and stream in each example is also clear and results, as suspected, from the stream having to follow the valley and its dominant meandering pattern which contributes most to total variance.

In most cases, the power spectral estimates seem to confirm the suggestion that wavelengths of higher frequencies contribute more to the total variance in the case of the stream than in the case of

TABLE 2 - Spectral Estimates For Valleys and Streams

	Wheatley 1		Wheatley 2		Wheatley East		Ced.Cr.Lt. Fk.	
Freq.	Valley	Stream	Valley	Stream	Valley	Stream	Valley	Stream
0.0	13.377	15.637	5.809	7.451	5.294	4.463	3.644	4.213
0.5	6.438	7.542	2.897	3.714	2.706	2.410	1.778	2.280
1.0	0.406	0.488	0.330	0.414	0.341	0.486	0.143	0.440
1.5	0.013	0.016	0.085	0.099	0.090	0.175	0.014	0.093
2.0	0.015	0.028	0.047	0.054	0.055	0.078	0.011	0.029
2.5	0.010	0.020	0.031	0.041	0.034	0.043	0.009	0.034
3.0	0.003	0.009	0.022	0.032	0.021	0.026	0.006	0.022
3.5	0.008	0.012	0.019	0.027	0.020	0.027	0.005	0.014
4.0	0.002	0.006	0.016	0.020	0.016	0.027	0.004	0.012
4.5	0.006	0.010	0.016	0.021	0.017	0.025	0.005	0.013
5.0	-----	0.003	0.014	0.018	0.014	0.022	0.004	0.011

TABLE 2 - continued

	Ced. Cr. Rt.Fk.		Ced. Cr. Tib.		Mill Creek A		Mill Creek B	
Freq.	Valley	Stream	Valley	Stream	Valley	Stream	Valley	Stream
0.0	76.896	77.631	13.936	14.358	23.332	24.942	32.983	32.014
0.5	35.525	35.631	6.652	6.681	12.223	13.614	16.179	15.550
1.0	1.702	1.653	0.481	0.364	1.586	1.999	1.663	1.271
1.5	0.216	0.217	0.096	0.065	0.200	0.276	0.422	0.238
2.0	0.149	0.227	0.060	0.045	0.112	0.171	0.244	0.178
2.5	0.111	0.166	0.039	0.029	0.113	0.107	0.170	0.164
3.0	0.064	0.071	0.022	0.021	0.055	0.084	0.117	0.139
3.5	0.074	0.062	0.022	0.020	0.046	0.072	0.110	0.121
4.0	0.045	0.038	0.016	0.011	0.047	0.049	0.083	0.101
4.5	0.060	0.072	0.021	0.013	0.049	0.049	0.089	0.108
5.0	0.038	0.067	0.017	0.010	0.025	0.039	0.077	0.093

TABLE 2 - continued

	Hillman Lt.Fk.		Hillman Rt.Fk.		Wigle Creek	
Freq.	Valley	Stream	Valley	Stream	Valley	Stream
0.0	6.756	6.387	9.744	9.802	13.926	13.561
0.5	3.336	3.247	4.619	4.720	6.727	6.577
1.0	0.283	0.409	0.433	0.537	0.500	0.542
1.5	0.028	0.074	0.145	0.173	0.096	0.153
2.0	0.017	0.033	0.044	0.042	0.071	0.128
2.5	0.012	0.027	0.021	0.024	0.053	0.091
3.0	0.005	0.011	0.017	0.031	0.040	0.057
3.5	0.008	0.010	0.017	0.026	0.041	0.051
4.0	0.004	0.007	0.009	0.011	0.032	0.032
4.5	0.007	0.008	0.014	0.016	0.038	0.022
5.0	0.004	0.006	0.013	0.021	0.032	0.012

Source: Author

FIG. 15

LOG GRAPHS OF SPECTRAL ESTIMATES AND COHERENCE

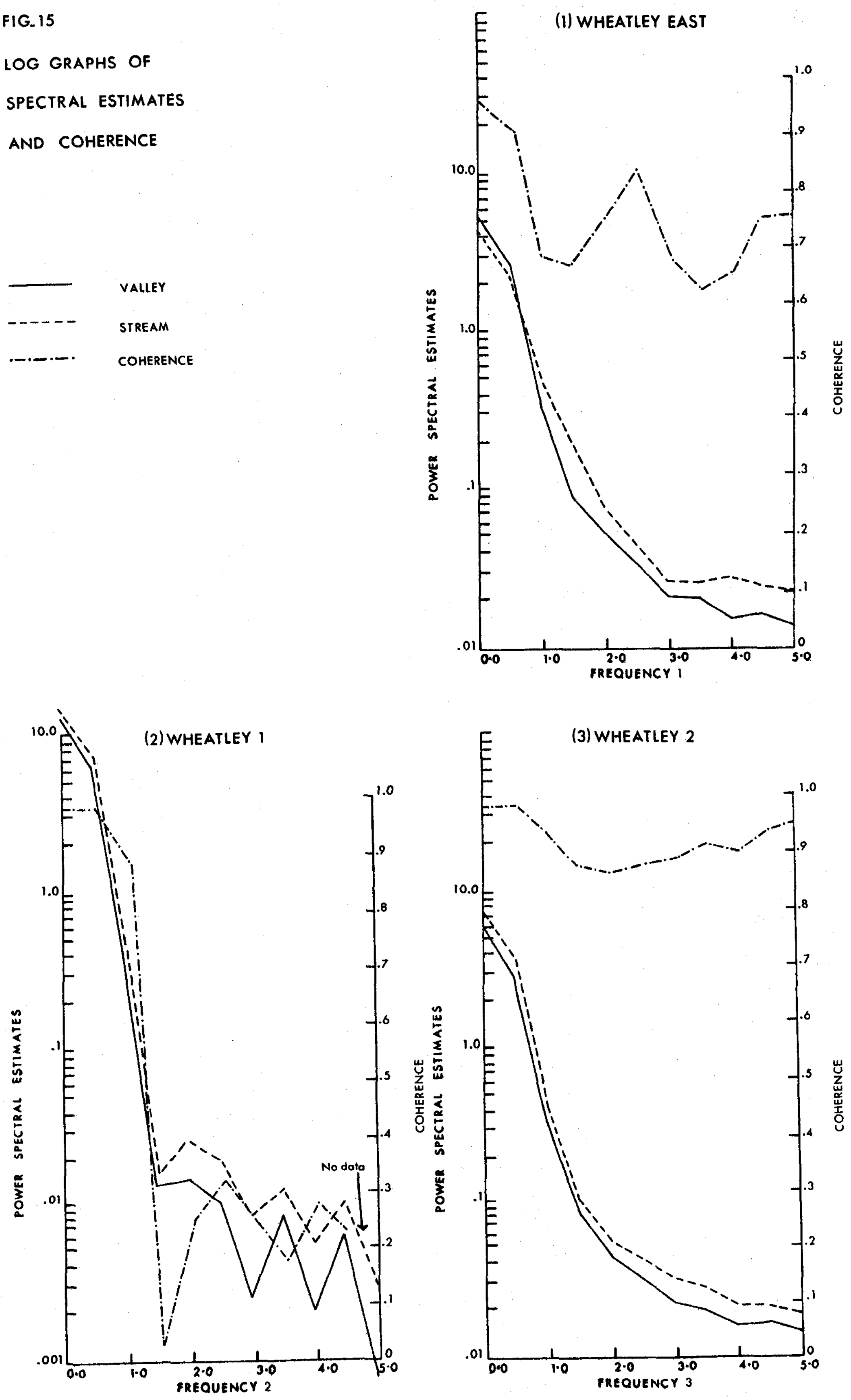


FIG.15 cont'd.

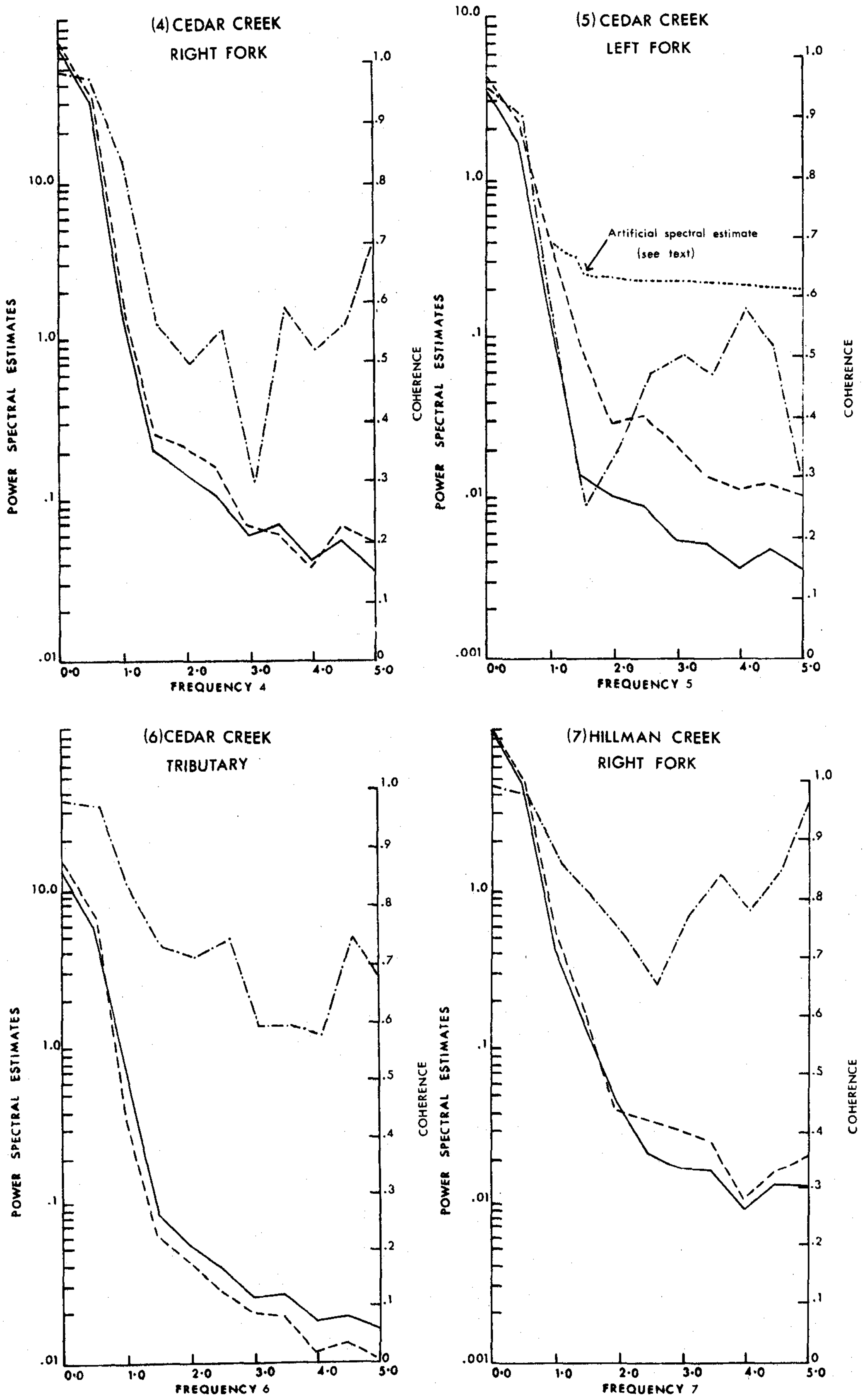

(4) CEDAR CREEK
RIGHT FORK
POWER SPECTRAL ESTIMATES
COHERENCE
10.0
1.0
.1
.01
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0·0
1·0
2·0
3·0
4·0
5·0
FREQUENCY 4
(5) CEDAR CREEK
LEFT FORK
10.0
1.0
.1
.01
.001
Artificial spectral estimate
(see text)
POWER SPECTRAL ESTIMATES
COHERENCE
FREQUENCY 5
(6) CEDAR CREEK
TRIBUTARY
10.0
1.0
.1
.01
POWER SPECTRAL ESTIMATES
COHERENCE
FREQUENCY 6
(7) HILLMAN CREEK
RIGHT FORK
1.0
.1
.01
.001
POWER SPECTRAL ESTIMATES
COHERENCE
FREQUENCY 7

FIG. 15 cont'd.

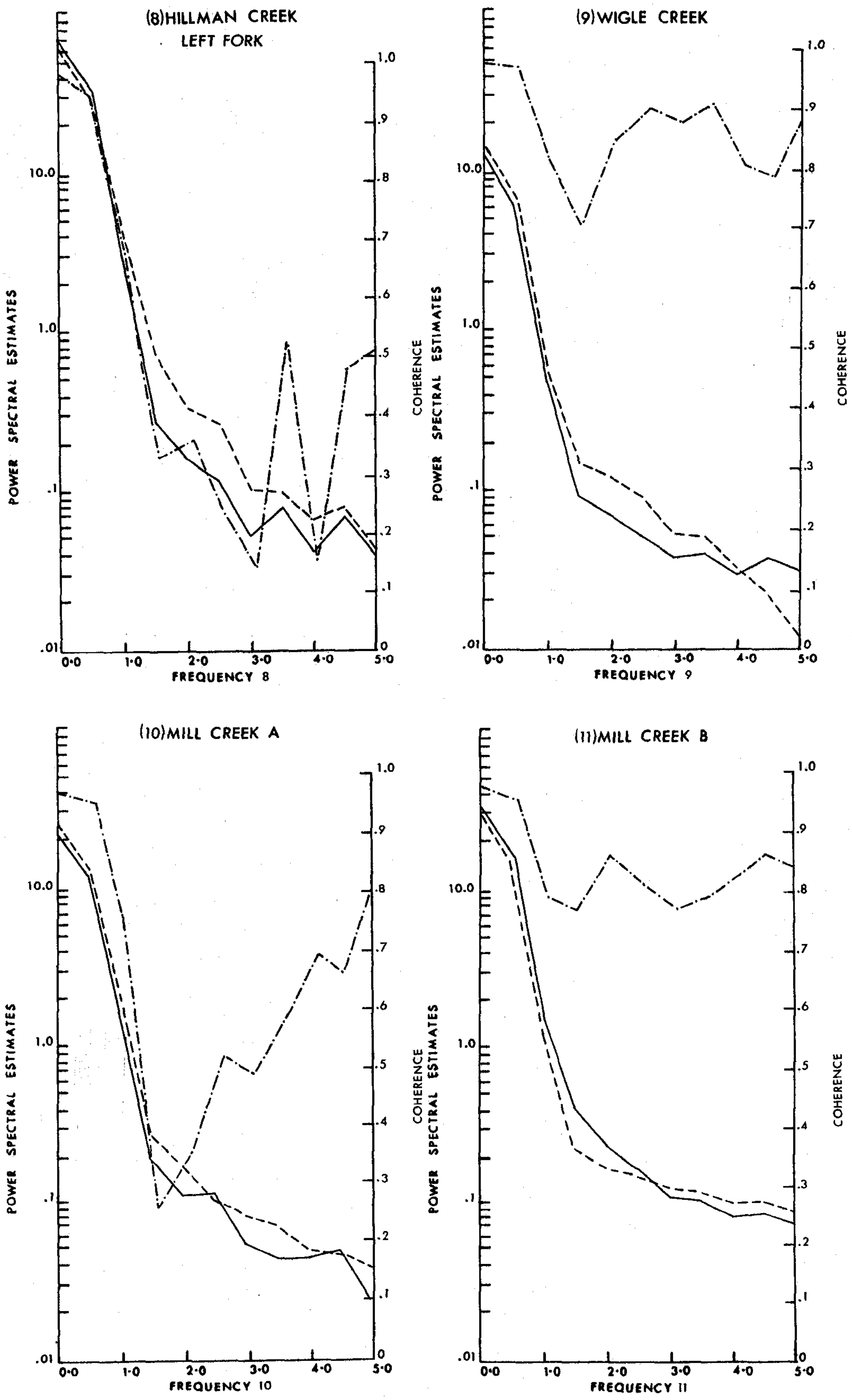

(8) HILLMAN CREEK LEFT FORK
(9) WIGLE CREEK
(10) MILL CREEK A
(11) MILL CREEK B
POWER SPECTRAL ESTIMATES
COHERENCE
10.0
1.0
.1
.01
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0·0
1·0
2·0
3·0
4·0
5·0
FREQUENCY 8
FREQUENCY 9
FREQUENCY 10
FREQUENCY 11

FIG. 16

STANDARD GRAPHS OF SPECTRAL ESTIMATES, FREQUENCY 2·5–5·0

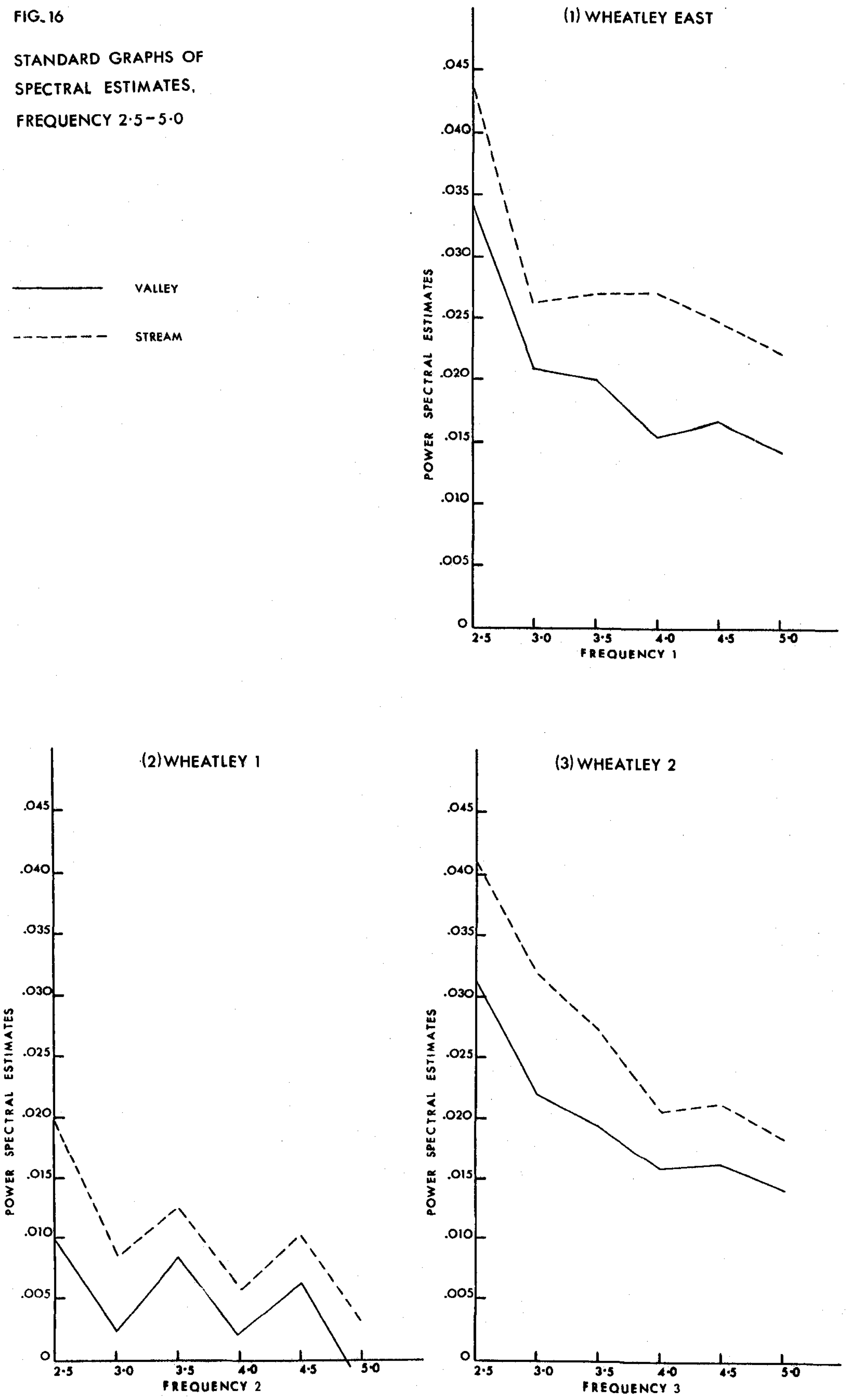


FIG_16 cont'd

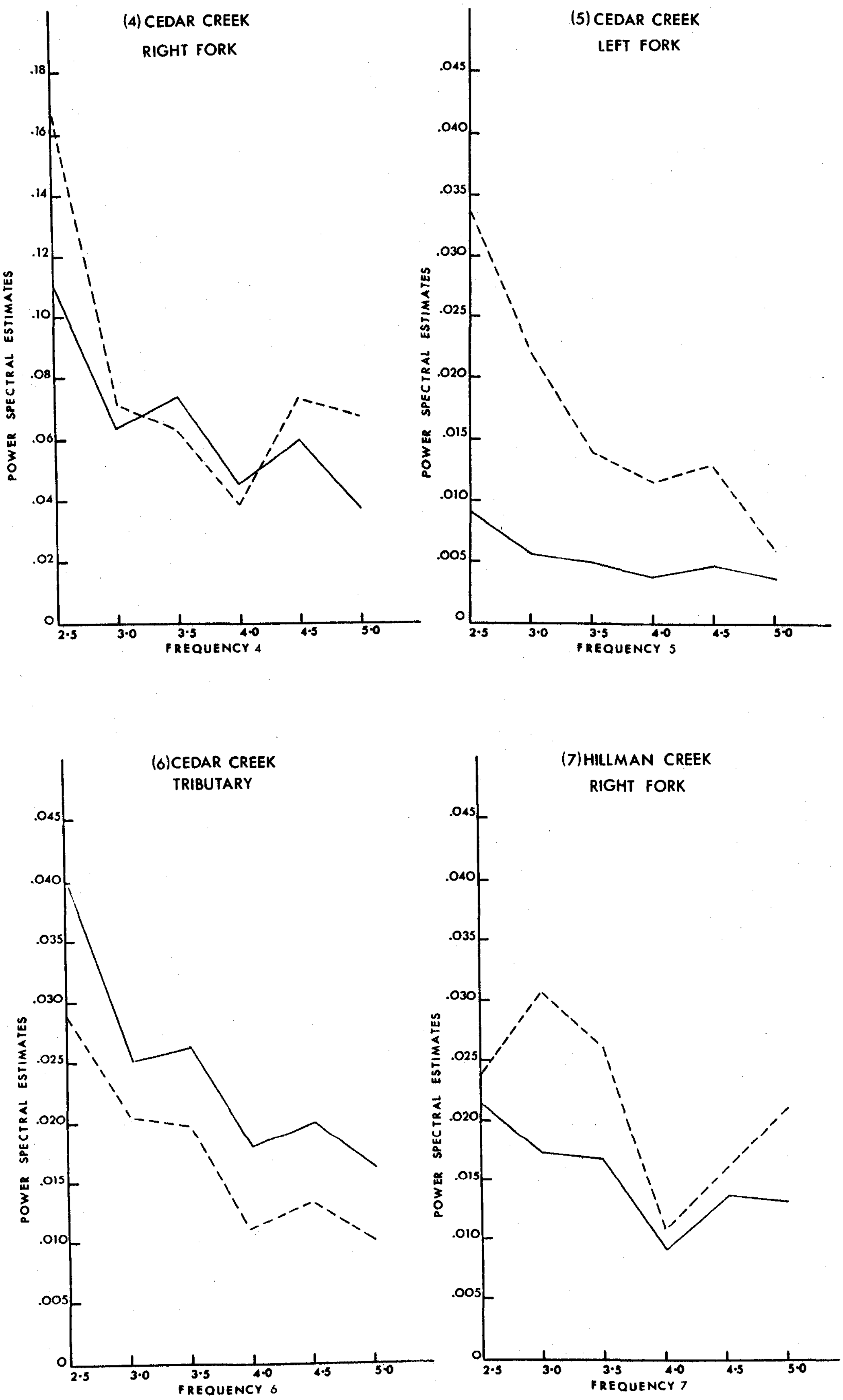
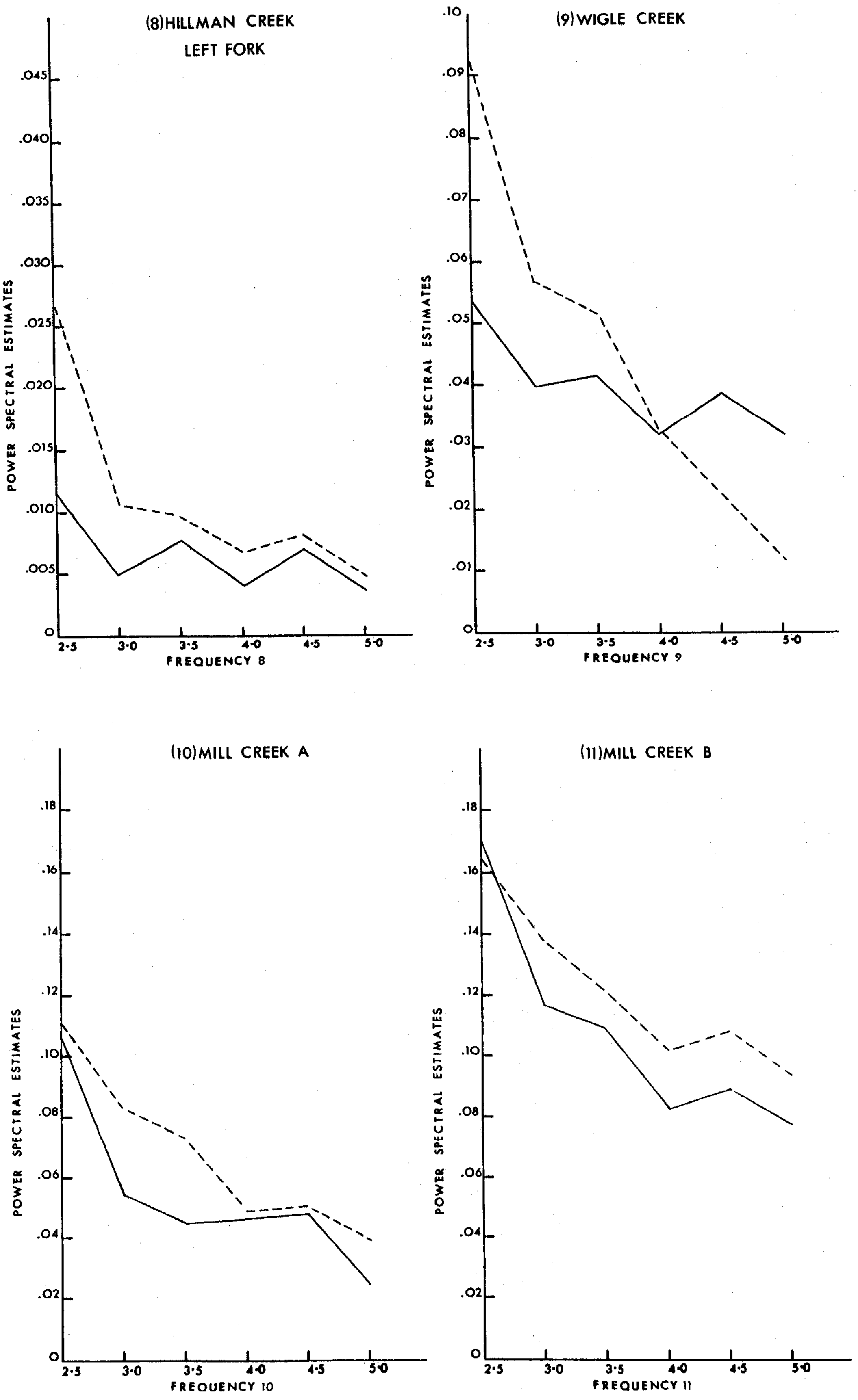

(4) CEDAR CREEK
RIGHT FORK
POWER SPECTRAL ESTIMATES
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
2·5
3·0
3·5
4·0
4·5
5·0
FREQUENCY 4
(5) CEDAR CREEK
LEFT FORK
POWER SPECTRAL ESTIMATES
0
.005
.010
.015
.020
.025
.030
.035
.040
.045
2·5
3·0
3·5
4·0
4·5
5·0
FREQUENCY 5
(6)CEDAR CREEK
TRIBUTARY
POWER SPECTRAL ESTIMATES
0
.005
.010
.015
.020
.025
.030
.035
.040
.045
2·5
3·0
3·5
4·0
4·5
5·0
FREQUENCY 6
(7)HILLMAN CREEK
RIGHT FORK
POWER SPECTRAL ESTIMATES
0
.005
.010
.015
.020
.025
.030
.035
.040
.045
2·5
3·0
3·5
4·0
4·5
5·0
FREQUENCY 7

FIG. 16 cont'd


(8)HILLMAN CREEK
LEFT FORK
POWER SPECTRAL ESTIMATES
.045
.040
.035
.030
.025
.020
.015
.010
.005
0
2·5
3·0
3·5
4·0
4·5
5·0
FREQUENCY 8
(9)WIGLE CREEK
POWER SPECTRAL ESTIMATES
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
2·5
3·0
3·5
4·0
4·5
5·0
FREQUENCY 9
(10)MILL CREEK A
POWER SPECTRAL ESTIMATES
.18
.16
.14
.12
.10
.08
.06
.04
.02
0
2·5
3·0
3·5
4·0
4·5
5·0
FREQUENCY 10
(11)MILL CREEK B
POWER SPECTRAL ESTIMATES
.18
.16
.14
.12
.10
.08
.06
.04
.02
0
2·5
3·0
3·5
4·0
4·5
5·0
FREQUENCY 11

the valley. In turn, this indicates that the wavelengths of the streams are shorter than those of the valleys, figure 16:1 of Wheatley East provides the best example of this. Deviation from this pattern in the cases of Cedar Creek Right Fork, Cedar Creek Tributary and Wigle Creek is difficult to understand, as visually all of these examples show considerable underfitness. Figs. 4, 6 and 13 show that the valleys in the segments chosen for analysis have not had the opportunity to develop an established meandering tendency, although all obviously meander. A more clearly defined meandering pattern would probably solve this problem.

Predictably, the bulk of the variation is concentrated at the 0.0 and 0.5 frequency levels. This reflects the problems of averaging, equi-spaced observations, randomness and shortness of record mentioned above. As an example of the problems associated with the program's use of amplitude for the calculation of variance, an abnormally high value was added to the stream data for Cedar Creek Left Fork and tested. Clearly the combination is misfit (see Fig. 5) and the spectral estimates support this. The resulting increase when the artificial peak is added is shown in Fig. 15:5.

Also of note in the analysis of the spectral estimates is the apparent concurrency of spectral peaks. It appear that when the estimates for the streams and valleys are plotted together they both peak at the same frequencies. Rayner(1971) suggested that spectra with significant fluctuations may suggest separable generating processes. If this is the case, then could two spectra with the same "significant fluctuations" be the result of the same generating process? Speight(1967) also notes this possibility and suggests that it deserves further investigation.

The coherence values from the data do not bear out the original hypothesis that they should be highest at the lowest frequencies (longest wavelengths) and decline as frequencies increase. The values (see Fig. 15:1-11 and Table 3) show relationships between streams and valleys in most cases. Those that do differ may be caused by exceptional peaking in the spectral estimates. For the remaining examples, the problem undoubtedly lies in the stream channel following the valley course, combined with the inevitable aliasing as a result of program mechanisms.

TABLE 3 - Coherence Values

Segment	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
Hillman RT.Fk.	.99	.98	.86	.81	.74	.65	.77	.84	.78	.85	.96
Hillman Lt.Fk.	.98	.95	.68	.33	.36	.24	.14	.52	.15	.48	.51
Mill Creek A	.97	.95	.76	.26	.35	.52	.49	.59	.69	.66	.80
Mill Creek B	.97	.95	.79	.77	.86	.81	.77	.79	.83	.86	.84
Wigle Creek	.98	.97	.82	.71	.85	.90	.88	.91	.81	.79	.88
Ced.Cr. Lt. Fk.	.95	.90	.57	.25	.34	.47	.50	.47	.58	.52	.30
Ced.Cr. Rt. Fk.	.99	.98	.84	.56	.50	.55	.30	.59	.52	.56	.69
Ced. Cr. Trib.	.98	.97	.84	.73	.71	.74	.59	.59	.58	.74	.68
Wheatley East	.96	.91	.69	.68	.75	.84	.68	.62	.65	.75	.75
Wheatley 1	.98	.98	.88	.03	.25	.32	.24	.18	.28	.23	-
Wheatley 2	.98	.98	.94	.88	.87	.88	.89	.91	.90	.94	.95

Source: Author

In summary, several conclusions may be derived from the application of power spectrum techniques to the problem of misfitness. Firstly, there is an extremely close relationship between the valleys and the streams in terms of total variance because of the dominance of the larger winding traces which the stream must follow. Secondly, the analysis of the power spectra, in most cases, clearly shows that the wavelengths for the streams are generally shorter than those for the

PLOT OF AVERAGE STREAM AND VALLEY WAVELENGTHS

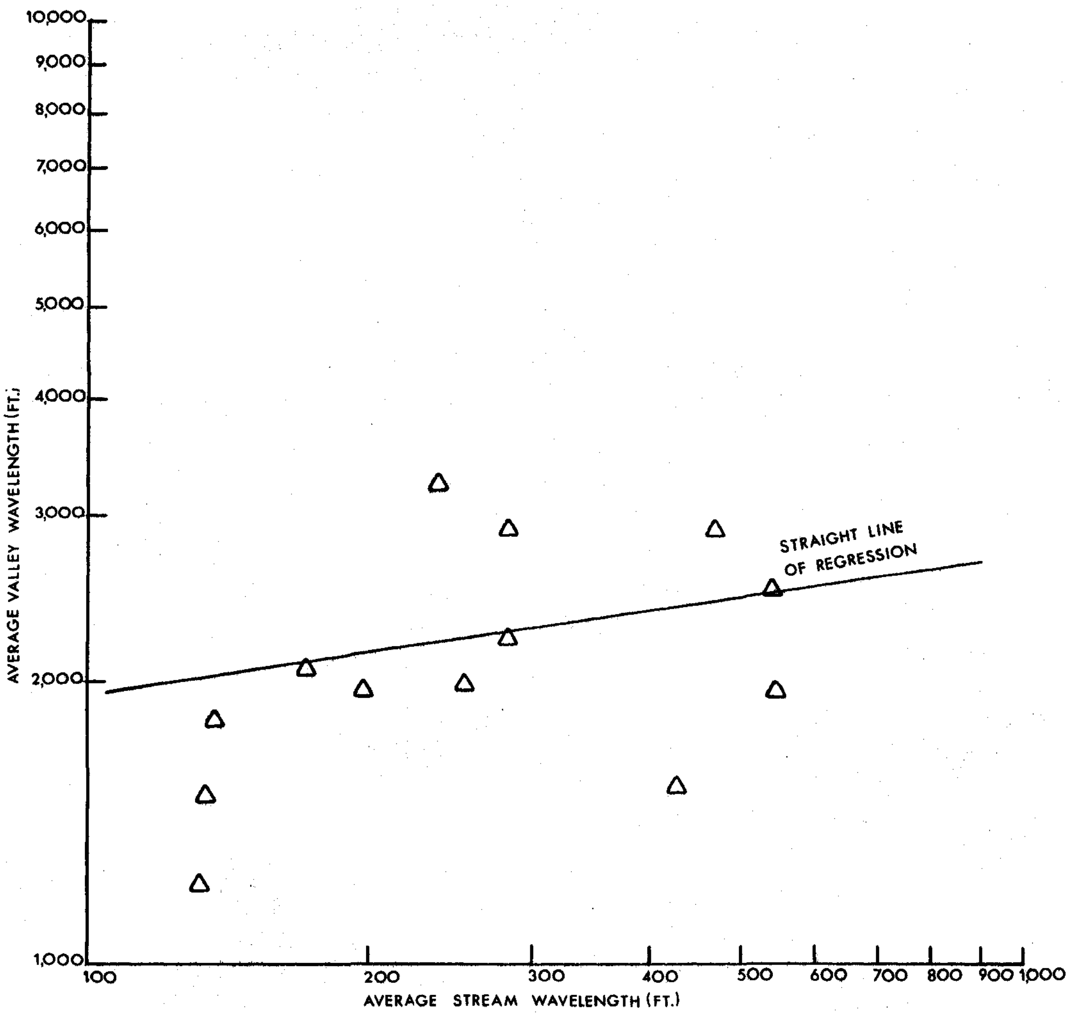


FIG. 17

valleys. Coincident peaking in stream and valley spectra may indicate a similarity of process with difference in magnitude. Such a conjecture is worthy of further study. Finally, it was found that the coherence values did not support the hypothesis of an inverse relationship between frequency and coherence.

2:3 APPLICATION OF DURY TECHNIQUE

Using the Dury(1964b) technique of measurement of cross-country distances between points of inflection on meanders, the results are much more positive. Table 4 lists the mean meander wavelengths for the valleys and streams of each segment, as well as the wavelength ratios and the resultant discharge ratios. The discharge ratios were calculated in the manner outlined in Chapt. I. The mean wavelengths are also shown in Fig. 17.

Dury(1964a-c), from an assessment of numerous examples, generally found the ratio of mean valley wavelength to mean stream wavelenght to range between 3.5:1 and 10:1 when misfitness had been visually suspected.

TABLE 4 - Mean Wavelengths, Wavelength Ratios and Discharge Ratios

Segment	Stream(ft.)	Valley(ft.)	L/l	Q/q
Wigle Creek	236.88	3269.75	13.8:1	190.44:1
Mill Creek A	132.92	1229.04	9.25:1	85.56:1
Mill Creek B	136.59	1809.88	13.25:1	175.56:1
Cedar Cr. RT. Fk.	282.31	2880.00	10.20:1	104.04:1
Cedar Cr. Lt. Fk.	294.84	3013.68	10.22:1	104.44:1
Cedar Cr. Trib.	198.02	1954.36	9.86:1	97.21:1
Hillman Rt. Fk.	542.16	1944.00	3.59:1	12.88:1
Hillman Rt. Fk.	424.57	1555.20	3.66:1	13.40:1
Wheatley 1	253.26	1980.00	7.82:1	61.12:1
Wheatley 2	418.29	2889.60	6.90:1	47.61:1
Wheatley East	171.72	2079.00	12.10:1	146.4:1
Mill Creek mean	134.75	1519.46	11.27:1	127.0:1
Mean - all segs.	281.05	2233.77	7.95:1	63.2:1

Source: Author

More precisely, Dury(1964a) found a ratio of 5.5:1 to 7.5:1 for selected French examples and suggested that this resembles the ratio found in some parts of the United States. This ratio range is confirmed by some of Dury's results which are shown in Table 5.

TABLE 5 - Selected Wavelength Ratios From the United States[1]

Area	Wavelength Ratio	Source
Sheyenne R. N. Dakota	5:1	Dury(1964a,21)
Shenendoah R. Virginia	5:1	Dury(1964a,39)
Ozarks 1	8:1 - 4:1[2]	Dury(1964a,45)
Ozarks 2	3.5:1 - 7.5:1	" "
Wisconsin	5:1	" "

1 Selected randomly as examples of wavelength ratios for comparison
2 Downstream decrease in ratio found to exist in the area

The mean wavelength ratios in Table 4 are consistantly larger than those found by Dury, with the exception of both forks of Hillman Creek which are considerably smaller. When, however, the mean ratio for all eleven segments is determined, the ratio 7.95:1 does not appear unusual. Few of the downstream reaches of the streams considered in this study were subject to analysis because of the drowning mentioned in Chapter I. Since Dury(1964a) discovered that wavelength ratio usually declines downstream, inclusion of these reaches would have lowered the mean ratio to the point where, possibly, it would have approached the ratio of 5:1 found to be most common by Dury (see Table 5). The higher ratio for the Mill Creek B as opposed to Mill Creek A does appear to contradict the downstream ratio decline found by Dury as the B section is downstream from the A section. The reasons for this are not readily apparent, but it is suspected that they may be related to the disruption of natural drainage patterns by subdivision development in the Town of Kingsville, through which the stream flows.

The mean wavelength ratio confirms the hypothesis that the streams under consideration are misfit. Since the wavelength ratio may be used as an index of the degree of misfitness, the second hypothesis regarding range of magnitude is also confirmed. The suspicion that Hillman Creek is the least misfit of all the examples is also confirmed.

The wide range of wavelength ratios and the resulting even wider range of discharge ratios after conversion, suggest a dramatic alteration in area drainage patterns since the former valleys were cut. Given the lack of drainage area definition and flatness of the area described above, the event or events required to alter the pattern need not necessarily be catostrophic or even substantial. The influence of man in clearing the area of forests, digging drainage canals, building dikes and carrying out other activities inherent to human occupance could easily result in the drainage alteration expressed by the wide range of discharge ratios. For example, there may be, through artificial, a higher proportion of flow through Cedar Creek and less through Wigle Creek now than when the valleys were formed. This is not to imply that the formation of these features was recent, although it may be, but rather to suggest that recent activities certainly must have an effect on stream patterns at least to some extent.

In any event, the mean discharge ratio that has been calculated as a result of comparison of wavelengths does indicate a substantial difference in discharge between the formation of the valley meanders and the cutting of the present streams. Some possible causes of this difference as well as some questions of dating will be discussed in Chapter III.

2:4 CONCLUSIONS

Perhaps the most important conclusion arising out of the above analysis is the confirmation, by both techniques, of the existance of two distinct sizes of meanders associated with most of the landforms reviewed. The more traditional of the techniques affirmed misfitness in all cases with the demonstration of variance in degree. The power spectrum analysis, however, was not so universal in its finding, indicating some obviously misfit streams to be otherwise.

It was clear from analysis of the results gained from the use of spectral techniques that, without considerable alteration, it is inadequate for application in the appraisal of stream and valley data. The form in which the results are obtained make it even less useful in deriving the relationships to discharge which must be derived in this type of study. Speight(1967) attempted this but was able to generate only rough approximations and admitted his dissatisfaction with its lack of capability to arrive at more precise responses. This problem, it seems, was forseen by Rayner(1971,7) pointing out that "to be useful, spectral analysis should provide not necessarily concrete results but should suggest new lines of inquiry toward the problem." The application of more involved variations on the technique utilizing some of the concepts of filtering might solve some of the difficulties evidenced in this study, but it would remain questionable as to whether the necessary discharge relationships could be developed, even under those circumstances.

Speight's criticism of the Dury method of obtaining stream and valley data is no doubt legitimate, but at this point the method remains the only viable empirical approach whereby further relevant data may be generated. Caution must be exercised in viewing the discharge data obtained as accurate but because the technique is consistant, it does provide some notions of relative discharge, albeit in degrees if not in fact, which are critical to any further study of the problem.

CHAPTER III

THE IMPLICATIONS OF MISFITNESS

3:1 INTRODUCTION

Although it has been established that the features under study are indeed misfit or underfit streams, such information does little to describe the processes involved in their formation or to differentiate this group of misfit streams from other similar features. The questions which Dury(1964b) suggests need to be answered in the application of general misfit stream theory to specific examples remain unanswered. Of particular importance, as part of establishment of cause, is the determination of the major temporal specifications in the development of an underfit stream such as when was the cutting of the channel initiated and when was the large channel abandonned?

To facilitate their solution, several further pieces of research were conducted. At eight of the eleven segments, soil samples were gathered to determine the nature of the sub-surface sediments. A simple hand auger was used with samples being taken at one foot intervals from one to five feet below the valley floor and from one to five feet below the level of the surrounding land. Augering locations are illustrated in Figs. 3 - 11. Samples were taken for only one of the segments of Mill Creek, on fork of Hillman Creek and not taken at all at the Cedar Creek Tributary. Redundancy was the problem in the first (i.e. sample already taken from Mill Creek), high water levels in the second and inaccessability in the third. The samples were then examined by the use of an hydrometer test[5] to determine the sand, silt and clay contents, the median grain sizes and the sorting coefficients.[6] Twenhofel(1939) and Weller(1960) provide reasonably good descriptions of the various indicators which may be used to recognize sediments. Till, for example, is usually identified by its poor sorting and the angularity of stones found in it. An alluvial sediment, on the other hand shows a tendency toward better sorting while alluvial gravel is usually well-rounded. A lacustrine sediment is well sorted, contains few, if any, grains above 2 mm. in size and is often laminate in nature. The laminate nature, a result of differential settling rates, is not always present. Evaluation of the samples, combined with the more comprehensive data of Vagners(1971), provided a useful picture of the nature of the sediments in and surrounding the former valleys.

3:2 DIVERSION

It is doubtful that the misfit streams studies here were the result of river capture or diversion as postulated by Davis (1895, 1896). It has been noted (Chapter I) that for such an explanation to prove adequate in general terms, diversion would have to exist region wide as the phenomena are regionally distributed and this, of course, is not possible. Although, therefore, diversion may serve as

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[5] see procedure in Sabey(1967). This procedure produces far from accurate results but is adequate considering the resources available and the data required.

[6] see Appendix B for method of calculation and results.

an explanation for isolated and independent examples, because of the regionally-distributed nature of the phenomena investigated, this does not provide a satisfactory explanation for the study area. Despite this, it would appear that diversion, in a very loose sense, does play a minor role in the definition of the present drainage characteristics of the area and therefore may be secondarily related to the degree of misfitness in some cases. As has been previously noted, because of the extremely low relief, drainage area boundaries lack clarity and so the events necessary to alter such drainage patterns need not be very great. Although it is clear that there has been a regional reduction in discharge, it is equally certain that this reduction has varied widely between streams. Presumably, if the cause of the reduction in discharge was universal for all examples, the effect would also be reasonably constant. That it is not constant leads to the conclusion that alteration in drainage patterns, which is in effect diversion, has channeled the discharge formally flowing through one stream into another. Thus, one stream appears more misfit than another.

3:3 GLACIAL DERANGEMENT

The second hypothesis of formation, originally postulated by Davis(1909) and discussed by Dury(1964a), was that of glacial derangement. Two possibilities exist; a channel cut by the overflow of a glacial lake or; a channel cut by the meltwaters of an ablating glacier. That misfit streams exist where no glaciation has taken place effectively rules out glacial derangement as a general explanation although the existance of obviously underfit streams in meltwater channels such as the Maumee River in Ohio or the Grand River in Michigan provides such an answer to some individual cases.

Glacial lobes are commonly served by many proglacial meltwater channels, providing the possibility of regionally-distributed meltwater channels. It might, therefore, be possible to have underfit streams regionally distributed as a result of cessation of the flow of meltwater. Since the area in which the underfit streams being studied are situated came under the influence of continental glaciation, the possibility of their being caused by glacial derangement must be considered.

Proof or disproof of the glacial derangement hypothesis must rely heavily on the glacial history of the late Pleistocene events in this area. Although the Pleistocene was a complex series of glacial advances and retreats extending back perhaps 1,000,000 years, most researchers tend to agree that the surficial features of Essex and Kent Counties are the result of the Cary-Port Huron substage of the Wisconsin stage, and subsequent events. Flint(1957), Hough(1958) and Prest(1968) agree that the Carey-Port Huron advance last impinged upon the area approximately 14,000 years B.P., while Dreimanis(1969) suggests that perhaps 13,500 years B.P. would be more accurate although the deviating opinion makes little difference. It is thought that the glacial till underlying most of the area was deposited by the ice which formed the Leamington Moraine (Chapman and Putnam, 1966).

Subsequent to the retreat of the last glaciers, a series of glacial or post-glacial lakes alternately inundated and exposed the area in a combination of events associated with the formation of the Great Lakes. Work by Hough(1963,1966), Wayne and Zumberge (1965), Chapman and Putnam(1966), Prest(1968), Dreimanis(1969) and

Lewis(1969) indicates that there is not consistant agreement by researchers on Great Lakes chronology and sequence. Prest(1968,728) has attempted to "harmonize viewpoints" presented up until the time of his work and thus his sequence and chronology will be relied upon. The later work by Lewis(1969) and Driemanis(1969) differ only slightly and will be the subject of some discussion below.[7]

Glacial Lake Maumee was the first in a series of glacial lakes covering the area circa 14,000 years B.P. It appears to have had three different stages with maxima at 800 feet, 760 ft. and 780 ft. above sea level. It also had two different outlets through the previously mentioned Wabash and Grand Rivers. Continuing glacial recession had changed the shape and level of the lake by 13,600 years B.P. into Lake Arkona with levels at 710 ft. and 695 ft. a.s.l. The area remained inundated.

Rising to a maximum height of 738 ft. a.s.l., post glacial Lake Whittlesey (13,200 years B.P.) was the next lake in the series. Although for most of its tenure, Lake Whittlesey covered the area, there is evidence presented by Vagners(1971) that shoreline remnants from the Lake Whittlesey stage do exist in southern Essex County near Ruthven indicating a fluctuating level. The same is true for Lake Warren (12,900 years B.P. - 670 ft. a.s.l.), Lake Grassmere and Lake Lundy (12,800 - 12,700 years B.P. - 620 to 670 ft. a.s.l.) Lakes Warren, Lundy and Grassmere were all associated with the constant retreat of the glaciers and probably alternately covered and exposed the area.

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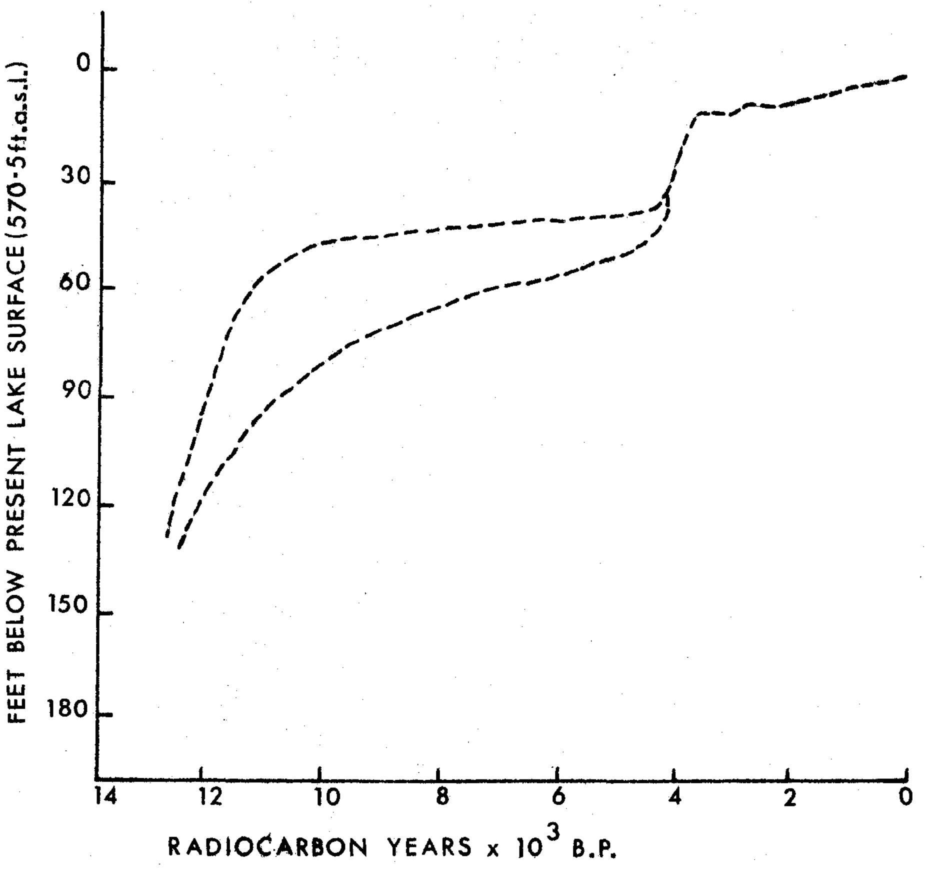
[7] accompanying maps are found in Appendix C.

Around 12,500 to 12,400 years B.P., the continuing retreat of the Lake Ontario and Simcoe lobes opened up the Nipissing outlet which allowed the meltwater access to the Ottawa drainage system. This, combined with the depression of the outlet at Buffalo, caused the lake levels to decline to approximately 465 ft. leaving water in only a small portion of the present Lake Erie Basin and initiating the stage known as early Lake Erie. Differential isostatic rebound caused a gradual rise in early Lake Erie levels to the point where, by approximately 9,000 to 9,500 years B.P., the level was about 30 feet below that of the present.

C.F.M. Lewis(1969) has analyzed cores taken from the central and Pelee Basins of western Lake Erie and, through the use of radio-carbon techniques, come up with more precise dates of this latter phase and the immediately subsequent events (Fig. 18). The existence of two layers of rich dark brown plant detritus dated to 11,140±160 years B.P. and 12,650±170 years B.P. indicate the presence of a low energy paludel or lacustrine environment in the Pelee Basin during this period. The more recent date may be associated with the last low water phase of early Lake Erie while the earlier date is postulated to coincide with the inception of that stage. Lewis also found an upper level contact point between two different sediments and dated this to 5,750± 180 years B.P. This, he suspected, was the approximate date for the opening of the third Nipissing phase outlet through the Lake St. Clair system. Opening of this outlet caused a rapid rise of Lake Erie levels to a point where, by 4,200 years B.P., they were approaching their present levels. Lewis'(1969,267) findings are summarized in Figure 18. The shaded area represents the findings of other investigators while



POST-GLACIAL LAKE LEVELS : ERIE BASIN

SOURCE : LEWIS (1969)

FIG. 18

NOTE: the lower dotted line represents the extent of other analysis while the upper line is Lewis' findings.

Lewis' own conclusions are shown by the upper line.

The submergence of the area by glacial lakes resulted in the laying down of lacustrine sediments throughout the study area with varying intensity. Vagner(1971) found pockets of reasonably thick lacustrine sediments, while Chapman and Putnam(1966) and Coakley(1972,331) describe the area as being "veneered with a thin layer of lacustrine clay and silt formed under glacial lakes Whittlesey and Warren." If the underfit streams in the area were the result of glacial derangement due to meltwaters, it is apparent that some lacustrine sediments will be found below the valley floors as well as below the surface of the surrounding land or, in other words, the sediment profile will be continuous. If, however, the lacustrine sediments were laid down prior to the cutting of the former valleys, the sediments will be truncated at the valley sides. To test this, several valley side walls were cleaned and examined for truncation. Valley sides capable of being studied in this manner were difficult to find as most are vegetation-covered and disturbance of the vegetation might result in serious erosion. In four locations however, (Cedar Creek at Highway #18, Wigle Creek near its headwaters, Mill Creek approaching its mouth, and Wheatley East near Highway #3) the stream had undercut the valley side making examination possible. At all four locations, truncation of the sediments was in evidence. At Cedar Creek, Wigle Creek and Wheatley East, a thin layer of laminate lacustrine material 4 to 6 inches thick was particularly apparent.

On its own, sediment truncation provides clear evidence that the former valleys must have been cut well after the recession of the glaciers and thus could not be the result of glacial meltwater.

There is, however, one other piece of conclusive evidence on this point. The analysis of the sub-surface sediment samples taken at the Wheatley 2 example show a startlingly high sand content in those samples taken below the level of the surrounding land while similar sampling below the valley floor indicate that the stream is cutting into till below the two foot level. Examination of the sides of the stream channel show the till overlain by layers of lacustrine sediments and subsequently by alluvium. This evidence would indicate that the former valley was cut through a remnant shoreline probably, on the basis of the formerly outlined sequence, from the Lakes Grassmere and Lundy stage with the present stream now cutting through the lacustrine sediments laid down by Lakes Whittlesey and Warren. If this interpretation of the evidence is correct, then clearly initiation of the cutting of the former channel began after the recession of Lake Lundy and could not possibly be related to glacial activity.

On the basis of the above findings, it is now possible to make one conclusion of temporal significance. The first chronological specification outlined by Dury(1964b,25) is the initiation of cutting of the large meanders or channels and he suggests that this may be dated "to the gross surface - the erosional platform or depositional spread," or at least to the latest date possible for that surface. This, he says, would set limits before which valley meander trains could not have existed. It is therefore possible in this case to conclude that, because of the truncation, the cutting of the large channels could not have started before the end of the Lake Lundy phase approximately 12,400 to 12,500 years B.P.

3:4 AN ALTERNATE THEORY

Before proceeding to the final hypothesis of formation by climatic change offered by Dury(1964a - Chapter I), it is necessary to comment on a more recent proposal regarding the nature of misfit streams in southern Ontario. R.W. Packer(1973,3), in attempting to construct a model for valley development suggests that most topographic maps and studies of meandering rivers refer to rivers at low flow stages and

> thus do not reflect the conditions of the river from the energy and erosional point of view. The use of the terms misfit and underfit as applied to the rivers of most of eastern Canada, which during the snowmelt season occupy the whole of the valley floor over frozen subsoil, surely cannot be distinguished from those of the immediate post-glacial melt period.

It seems apparent that Packer is proposing that streams in southern Ontario which are described as misfit are actually not but rather the larger valleys are the product of increased discharge and thus increased erosion during the snow melt season.

In the course of this investigation, considerable overbank flooding was observed during the 1973 snowmelt period in some of these segments. The valleys were studied after the recession of the floodwaters and the following conclusions were reached: (1) despite ideal conditions for overbank flooding including high water levels, frozen subsoil, and saturated surface soils, such flooding was not universal throughout the area nor did the floods inundate the entire lengths of the segments which were flooded; (2) in those segments which were subject to overbank flooding, there was no evidence of valley wall erosion and; (3) a thin layer of alluvium was deposited from the swollen streams which covered the floors of the flooded valleys. It would therefore appear that Packer's challenge to misfitness in southern Ontario, although worthy of consideration, is not relevant to the examples in the study area.

3:5 CLIMATIC HYPOTHESIS

If the various hypotheses of derangement are to be discounted as they have been in this study, the regionally-distributed nature of the phenomena leaves only the possibility of reduction in discharge due to climatic change. Dury(1964c,15) has suggested that the former discharges "presumably represent the sum effect of a combination of causes" including:

1. reduced air temperature
2. increased total precipitation
3. changed regimen of precipitation
4. increased extent of frozen ground
5. changed regimen of runoff
6. increased size of individual rains
7. increased frequency of storms
8. increased wetness of soil
9. changed vegetation cover

Dury(1964c,15-29) has provided an excellent discussion of these factors and their possible contributions to the problem of accounting for former discharges and it will therefore not be repeated here. However, Dury's ultimate conclusions on the subject are important. He discovered, for example, that "reduction in air temperature of the order reconstructed for glacial maximums, combined with increases in precipitation above present day values by 50 - 100 percent are capable of increasing mean annual runoff by factors of 5 - 10 within a wide range of existing climates." (Dury, 1964c,39) It was also Dury's finding that frost or frozen ground played little or no part in the generalized explanation of misfitness or do changes in the annual regimen of precipitation and runoff. Higher frequency and intensity of rainfall add to the total runoff but in themselves do not add enough, within the physical limits of probability, to account for the features. Finally, Dury(1964c,39) concluded that "the necessary changes in total precipitation that are required to account for the former discharges are not greater than the season to season variations in some regions at the present time."

A question raised from time to time in the discussion of former discharges suggests that perhaps the large channels were formed during extremely dry conditions subject to high intensity rainfall. The proposal here is that the former channels are, in effect, the remnants of emphemeral streams. Dury's conclusions above would clearly seem to show that, in his opinion, the resulting runoff would be insufficient to account for the magnitude of discharge indicated by the wavelength analysis.

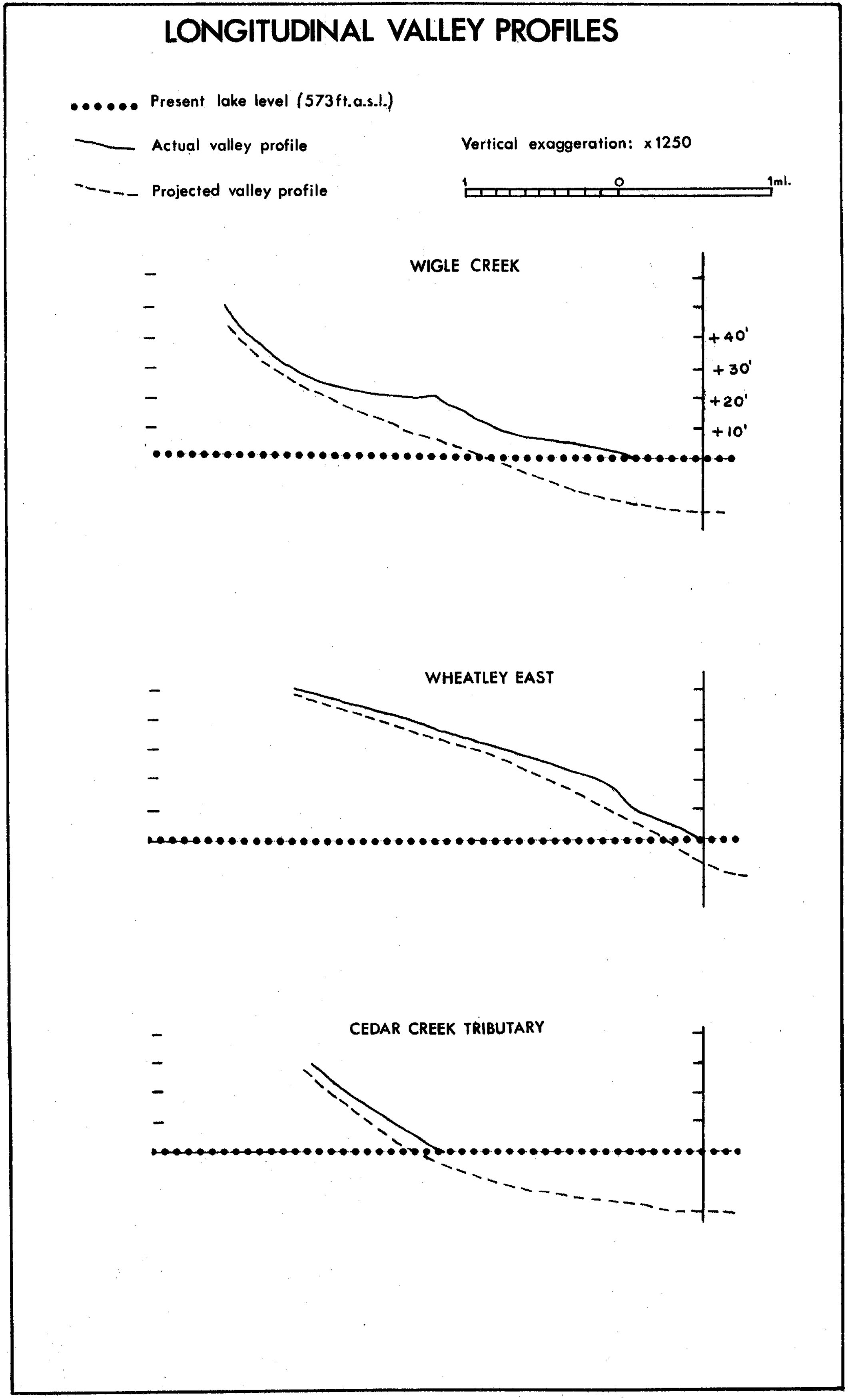
If it may be assumed that conditions of formation of the larger channels are those of reduced temperature and increased precipitation, or some combination of the two, the problem of this study then becomes one of application to the present examples. In precise terms, the problem is one of establishing the approximate dates of initiation and abandonment of the large meanders and the attempted reconciliation of those dates with known post-glacial climatic sequences. Such a procedure would provide either some substantiation or some challenge to Dury's conclusions regarding necessary conditions.

Obviously, the simplest and most precise technique to use in dating is the radiocarbon method, however that procedure is not available to this study. Dating must therefore be accomplished by the less precise technique of logic and elimination applied to existing structure and its comparison to other landforms for which the dates are known. An illustration of this approach has already been put forth above in the sediment trucation analysis. Although the results to be gained from such an approach can only be considered tentative at best, examination of longitudinal profiles, Lake Erie levels, sediments and pollen profile analyses carried out in adjacent areas should provide some indication of the chronology of formation of these landforms.

The temporal context within which the underfit streams must be viewed is extremely broad. As has been shown previously, initiation of the large channels could not have occured before approximately 12,400 years B.P., while Dury's(1964b) studies have found that the latest known date for abandonment in this part of North America was 2,000 years B.P. The result is a period of 10,000 years of possible activity.

Unfortunately, there are few dominant features in the study area which date later than 12,000 years B.P. and thus few features to which the landforms may be correlated. The only palynological studies (analyses of organic materials) carried out in the immediate area, with the exception of those mentioned previously by Lewis(1969), have been analysis and dating of marsh deposits by J. Terasmae(1973, personal communication). Terasmae indicated that the records found in the Pelee marshes dated back to less than 5,000 years B.P. This information is critical as it provides reasonably conclusive supporting evidence to Lewis(1969) and his assumption of lake levels shown in Fig. 16. Coakley(1972, Fig. 4) shows that the Pelee marshes overly undifferentiated glacial material, presumably the Pelee-Loraine Moraine, which rises to within three or four feet of the present lake levels. Terasmae's

FIG.19



LONGITUDINAL VALLEY PROFILES

FIG.19(cont'd)

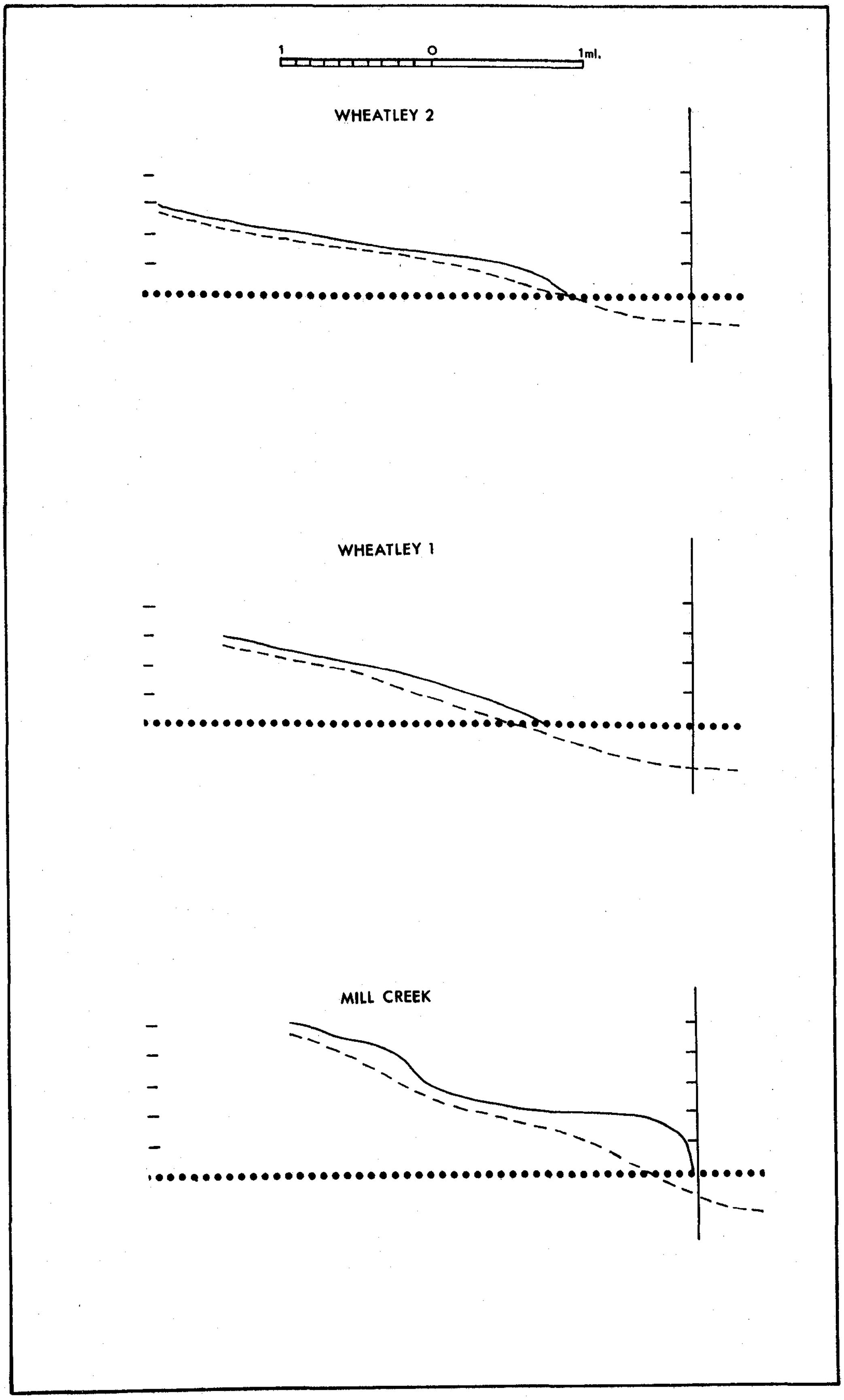
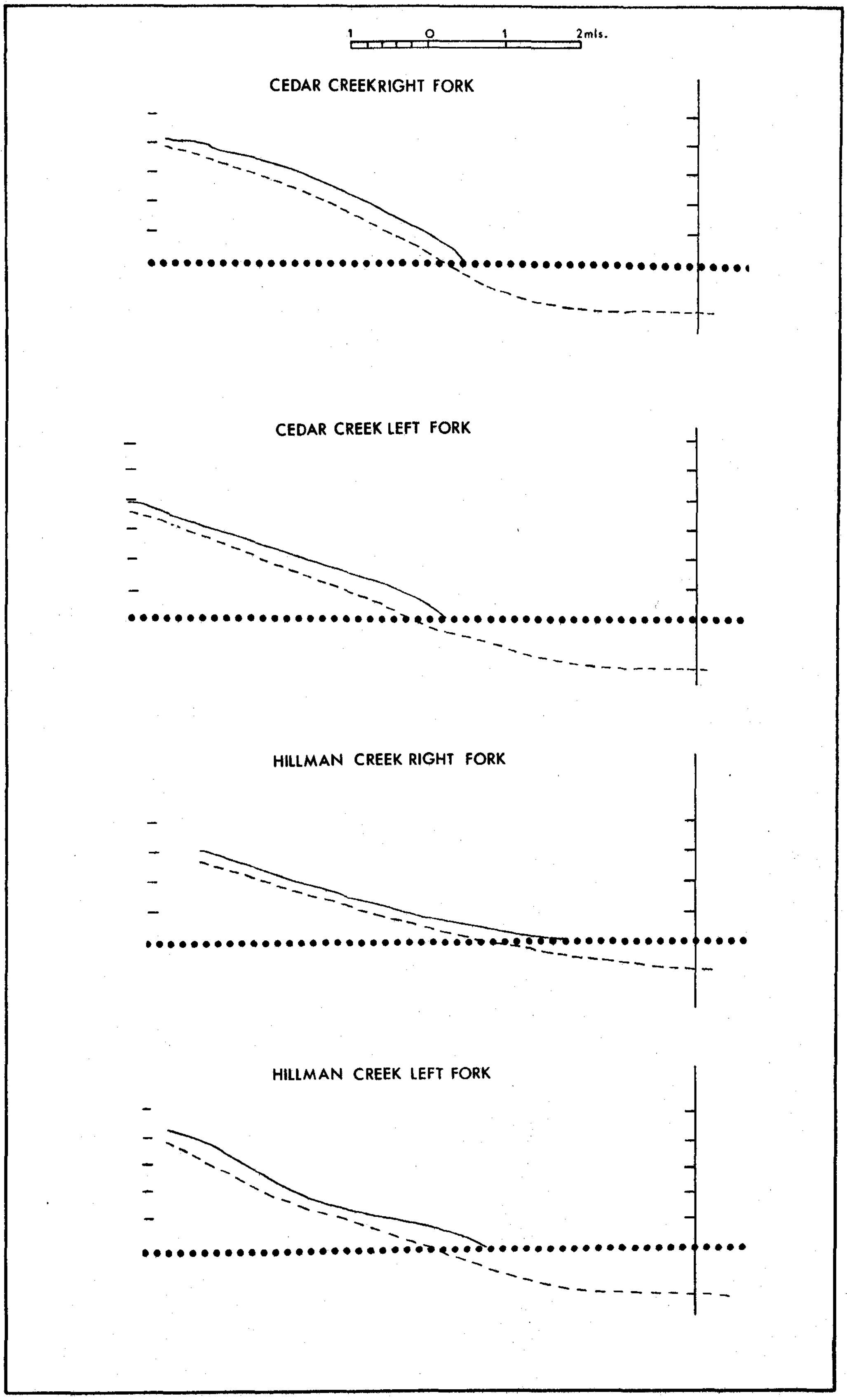


FIG.19 (cont'd)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CEDAR CREEKRIGHT FORK
CEDAR CREEK LEFT FORK
HILLMAN CREEK RIGHT FORK
HILLMAN CREEK LEFT FORK

dating of less than 5,000 years B.P. would appear to be reconcilable with the opening of the third Nipissing outlet and thus with Lewis' projection of lake levels approaching very close to their present height at that time. It was then that the bog was flooded. In addition to the flooding of the Pelee marsh, it might also be presumed that much of drowning in evidence at the mouths of Cedar Creek, Hillman Creek, Wigle Creek and others took place during this rise in lake levels.

Following the work of Hack(1960) on longitudinal profiles and the comments of Leopold, Wolman and Miller(1964) on the same subject, it is known that a "graded" stream should have an increasingly concave profile toward its lowest reaches. The actual longitudinal valley profiles of the ten segments show clearly that, in most instances, this is not the case. The indications from the profiles (Fig. 17:1-11) are that the valleys were cut off at some point in the past, probably by flooding. It has been found by various researchers and summarized in Leopold _et. al._(1964) that the reaction ot an active stream to rising base levels is to once again work toward a graded longitudinal profile. This is accomplished through increased sedimentation or alluviation at the lowest reaches initially and then successively upstream. This being the case, then the profiles of the study segments should show some indication of movement toward a graded profile. That they do not would indicate either of two possibilities; that the former stream to which the profiles belong was not active for long after the base levels had risen to their present height or; that the former stream had ceased to be active at some point prior to the increase in base level.

Analysis of the deposits found below the present valley floors indicated that, where it was determinable, the depth of alluvium overlying glacial till was 2.5 to 3.5 feet. This suggests that the depth of the stream responsible for cutting the former meanders would be in the neighbourhood of three feet below the present valley floor. Assuming that and assuming that the former streams had reached a graded profile, a hypothetical or projected profile of the former stream has been drawn (Fig. 19:1-10). These projected profiles indicate that the mouths of the former streams were between ten and fifteen feet below the present lake levels and found a considerable distance off the present Lake Erie shoreline. The latter point is not irreconcilable with the conclusions reached by Coakley(1972) on the rates of erosion of the Lake Erie shoreline.

Because of the significant divergence between the theorized and actual profiles, the possibility of extensive post-base level change toward grade in the former streams seems remote. It should then perhaps be concluded that former stream was inactive at the time when Lake Erie began to approach its present height. If that is the case, then it may be concluded that the abandonment of the stream took place prior to 5,000 years B.P.

Given the conclusion that initiation and abandonment took place between 12,000 years B.P. and 5,000 years B.P., the problem then remains to establish when the most optimum conditions for these two chronological specifications to occur. Vagners(1973), in a personal communication, offers the conjecture that downcutting of former streams began immediately after the retreat of post-glacial Lake Lundy. In a general sense, Vagners is correct, but there is reason to believe that discharge through the former channels of the magnitude necessary to cut the large meanders did not begin until some time later. Paleo-ecologists, -limnologists, and -climatologists usually tend to subscribe to the basic post-glacial climatic succession offered by Sears(1942) and repeated by Potter(1947,396) for central North America:

V The present - probably cooler with more available moisture

IV A warm dry period

III A warm period but more humid than II

II A dry period probably warmer than I

I A cool moist period

The climato-vegetative succession put forward by Deevey(1953) is slightly more complex than the above but basically follows the same general trends. Deevey also suggests possible dates which would correspond to the Sears-Potter climatic zones:

V present - 2,5000 B.P.
IV 2,500 B.P. - 5,000 B.P.
III 5,000 B.P. - 7,000 B.P.
II 7,000 B.P. - 8,000 B.P.
I 8,000 B.P. - 12,000 B.P.

Within the general context of these zones, Vagner's suggested initiation of the former streams would take place in the immediate post-12,500 B.P. period. However, Cushing(1965) and more recently Ogden (1967) offer strong evidence of a dramatic climatic change approximately 10,000 years B.P. in which it became wetter and cooler than the post-glacial period that it followed. Such conditions, it would seem, appear to satisfy the conditions of cooler air and higher precipitation postulated by Dury(1964c) as being ideal in accounting for the former high discharges. Thus it may be concluded that initiation of the cutting of the larger channels in this study occurred approximately 10,000 years B.P.

According to the climatic scheme outlined above, the conditions during which large enough discharges probably occurred came to an end during the Pine period 8,000 - 7,000 years B.P., because the combination of higher mean annual temperatures and lower precipitation are totally antithetical to the required circumstances postulated by Dury. The conclusion that abandonment had to have taken place prior to the post-glacial "climatic optimum" period 7,000 - 5,000 years B.P. appears to conflict somewhat with previously given lake level evidence. Lewis(1969) suggested that lake levels were between 30 and 60 feet below present levels at that time (Fig. 18). If that was the case, then it might be suspected that downcutting of the former valleys would have been much greater than in fact it had been. This, however, presumes constant downcutting which may not necessarily be presumed. Dury(1964a) found that, in most cases, the former valleys were the result of a series of events rather than one single and continuing event or, in other words, the area was subjected to a time of successive eroding and aggrading and if that is the case, then downcutting would not be so great.

3:6 CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

In general terms, this study seems to have demonstrated, that the discharge through certain existing streams in southeast Essex and southwest Kent Counties is considerably less than the discharge which would have been necessary to cut the valleys in which these streams flow. Climatic alteration, which was found to be the cause of this reduction in discharge, did not result in a proportional reduction over all the examples probably because of the low relief and the ease by which drainage patterns could be altered.

The use of the technique of Power Spectrum Analysis applied to the problem of demonstrating degree of misfitness was less than successful, probably because of inadequacies in the program used. Further experimentation with this procedure is a necessity particularly with a view to solving some of the problems caused by aliasing. A suggested approach to this problem might involve the construction and application of a low frequency filter.

As previously stated, the methods used to date the initiation and abandonment of the large channels lacks precision. Two separate approaches might shed further light and precision on these dates. The resources of this study prevented the use of extensive sub-surface analysis, particularly at the mouths of those segments affected by drowning. Data on the depth of alluvium and on other sub-surface sediments would provide valuable indications of the nature of the former profile. Such evidence might support or reject some of the conclusions made here based on projected profiles. Finally, the obvious technique for dating is the radiocarbon method but because of its expense, it also was beyond the resources of this study. The considerable expanse of marshland as well as the waterlogged sub-surface throughout the area should yield generous amounts of analyzable material for use in such a method.

APPENDIX A

FREQUENCY - WAVELENGTH RELATIONSHIPS

In order to derive the data for use in the power spectrum analysis, the stream segments were traced from air photographs and enlarged. The wide variation in size of the features necessitated different degrees of enlargement and as a result, the scales for the example segments differ and thus the relationship between frequency and wavelength also differs. The following provides a Table of frequency/wavelength relationships.

Table of Frequency - Wavelength Relationships (Wavelength in Feet)

	Frequency									
Segment	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
C.C.Lt.Fk.	1620	810	540	405	324	270	231	203	180	162
C.C.Rt.Fk.	1440	720	480	360	288	240	206	180	160	144
C.C. Trib.	1036	518	345	259	207	173	148	130	115	104
Hillman Lt	1728	864	576	432	346	288	247	216	192	173
Hillman Rt	1728	864	576	432	346	288	247	216	192	173
Wigle Cr.	1802	901	601	451	360	300	257	225	200	180
Mill Cr.A	664	332	221	166	133	111	95	83	74	66
Mill Cr.B	700	350	233	175	140	117	100	88	78	70
Wheatley 1	1080	540	360	270	216	180	154	135	120	108
Wheatley 2	1788	894	560	447	358	298	255	224	199	179
Wheatley E.	1080	540	360	270	216	180	154	135	120	108

Source:Author

APPENDIX B

MEDIAN GRAIN SIZE AND SORTING COEFFICIENTS OF SUB-SURFACE SEDIMENTS

(a) Method of Calculation(Carver,1971)

(1) Sand, silt and clay plotted on cumulative percentage curve

(2) Median Grain Size = grain size of 50th %ile

(3) Sorting Coefficient = grain size(25th%ile)/grain size(75th%ile)

(b) Results

Top = level of main surface
Bottom = level of valley floor

Location	Depth	Median Gr. Size	Sorting Coeff.
Wheatley 1 Top	1	.29	1.183
	2	.28	1.706
	3	.285	1.355
	4	.275	2.678
	5	.275	1.786
Wheatley 1 Bottom	1	.245	2.143
	2	.175	3.300
	3	.165	3.478
	4	.255	3.508
	5	.290	1.393
Wheatley 2 Top	1	.120	6.96
	2	.066	5.118
	3	.08	4.021
	4	.046	6.138
	5	.150	4.039
Wheatley 2 Bottom	1	.190	4.827
	2	.180	3.671
	3	.235	3.783
	4	.043	6.976
	5	.024	7.687
Wheatley East Top	1	.265	5.563
	2	.041	5.542
	3	.082	5.134
	4	.150	3.528
	5	.050	6.210
Wheatley East Btm.	1	.170	2.578
	2	.078	4.640
	3	.255	2.981
	4	.265	3.186
	5	.082	4.000

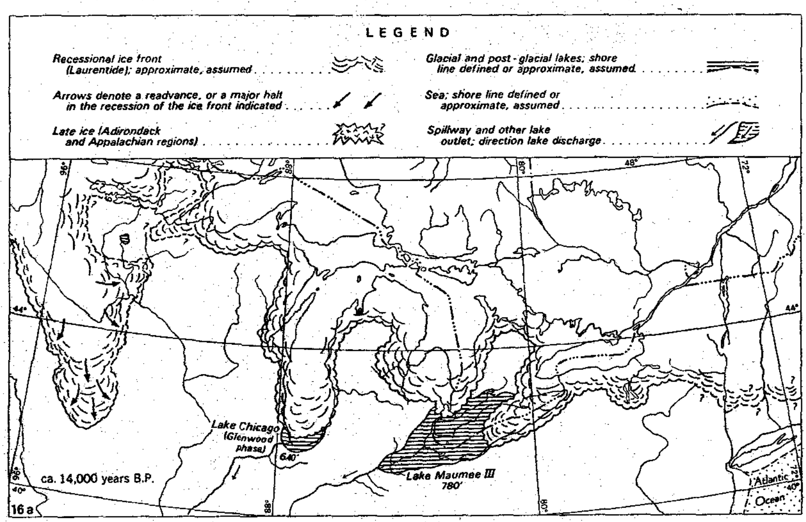
APPENDIX B - continued.......

Location	Depth	Median Gr. Size	Sorting Coeff.
Cedar Cr. Rt. Top	1	.105	3.807
	2	.052	6.614
	3	.047	7.328
	4	.035	6.681
	5	.012	5.182
Cedar Cr. Rt. Btm.	1	.160	3.521
	2	.150	3.631
		Lag Gravel	
Cedar Cr.Lt. Top	1	.100	4.803
	2	.042	7.328
	3	.061	6.342
	4	.045	7.071
	5	.016	5.000
Cedar Cr.Lt. Btm.	1	.185	3.888
	2	.086	6.123
	3	.140	3.333
	4	.090	4.551
	5	.042	4.749
Mill Crrek Top	1	.105	2.534
	2	.082	2.360
	3	.079	2.124
	4	.052	2.188
	5	.071	3.380
Mill Creek Bottom	1	.195	2.509
	2	.125	3.027
	3	.140	2.707
	4	.230	2.886
	5	.140	2.440
Hillman Lt. Top	1	.044	4.113
	2	.072	6.123
	3	.072	6.123
	4	.012	4.677
	5	.072	5.255
Hillman Lt. Btm.	1	.100	3.476
	2	.027	4.452
	3	.058	5.755
	4	.048	7.184
	5	.053	3.619

APPENDIX B - continued.......

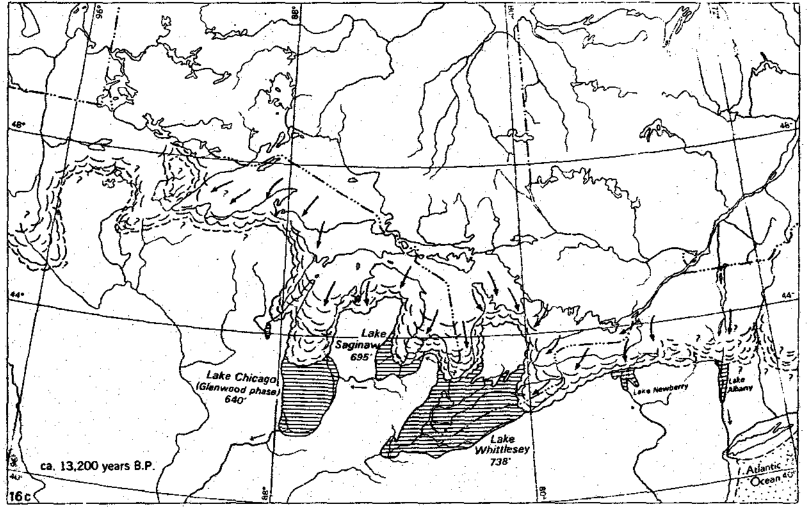
Location	Depth	Median Gr. Size	Sorting Coeff.
Wigle Creek Top	1	.250	1.978
	2	.052	4.629
	3	.060	4.954
	4	.120	4.082
	5	.084	4.472
Wigle Creek Bottom	1	.260	1.943
	2	.260	2.556
	3	.082	5.590
	4	.070	4.320
	5	gravel	

APPENDIX C – Formation of Great Lakes



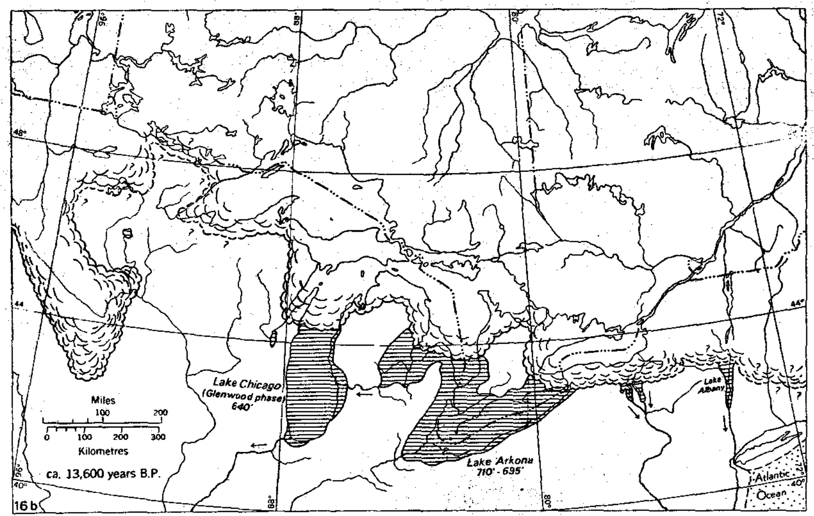
16 a

ca. 14,000 years B.P.



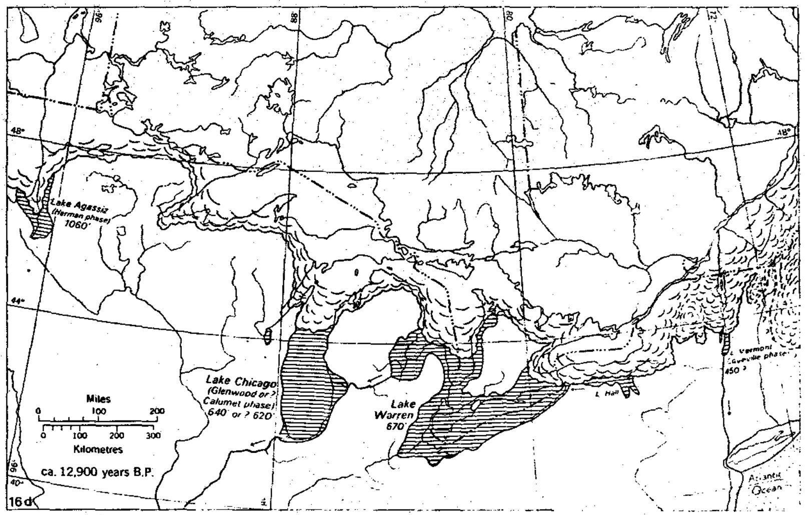
16 c

ca. 13,200 years B.P.



16 b

ca. 13,600 years B.P.



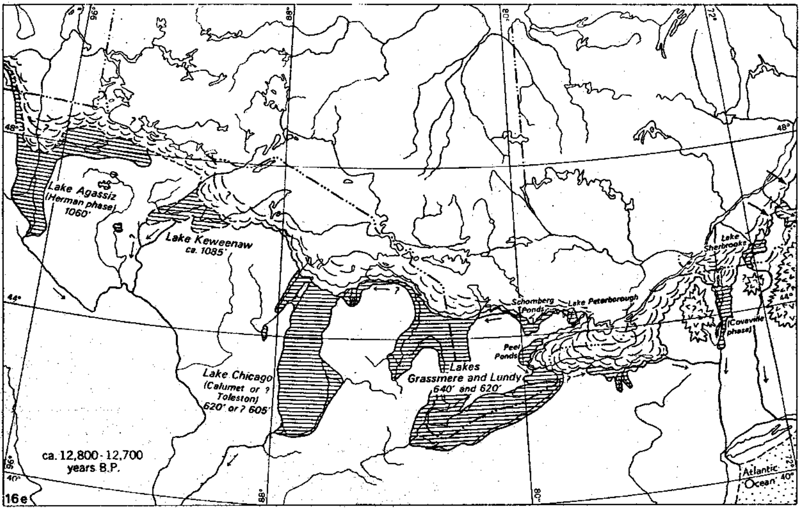
16 d

ca. 12,900 years B.P.

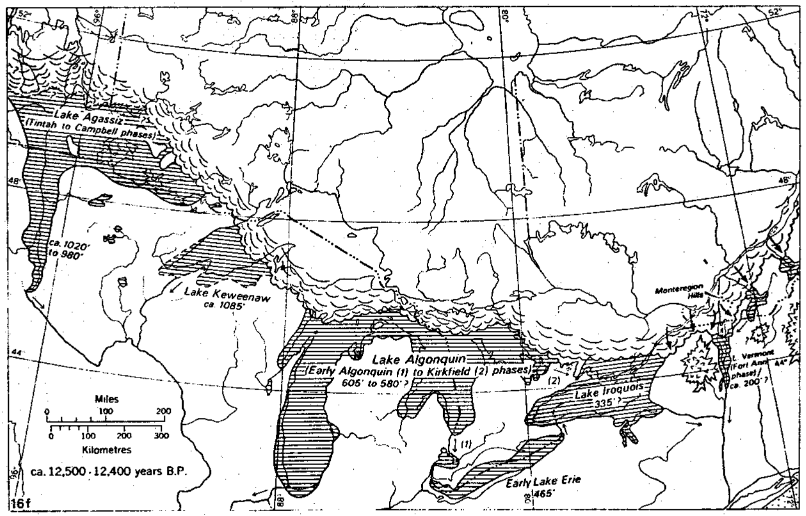
Prest (1968)

APPENDIX C – cont'd ----

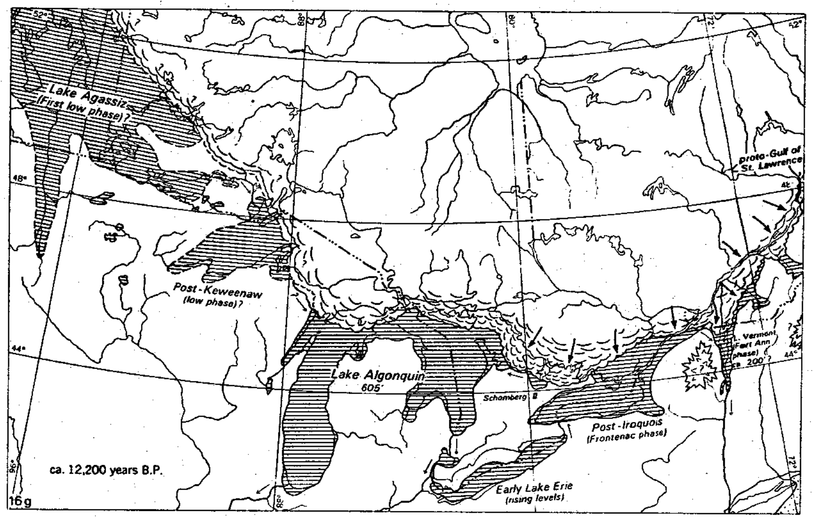
APPENDIX C - cont'd



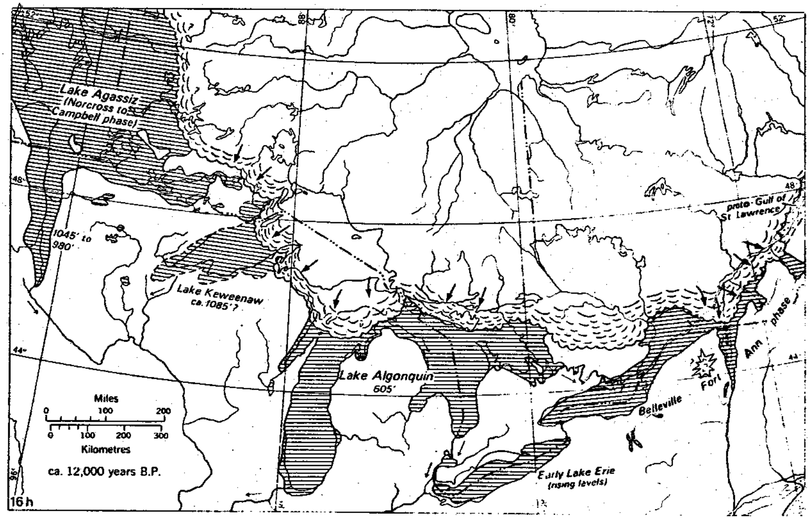
16e



16f

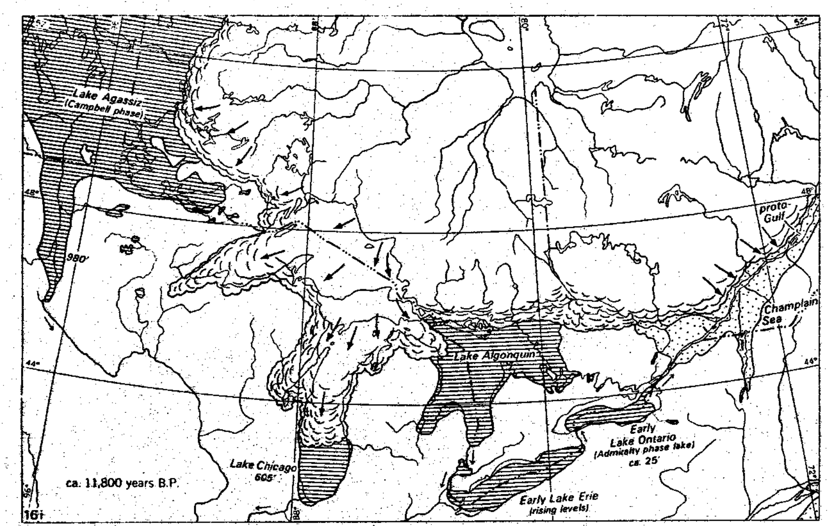


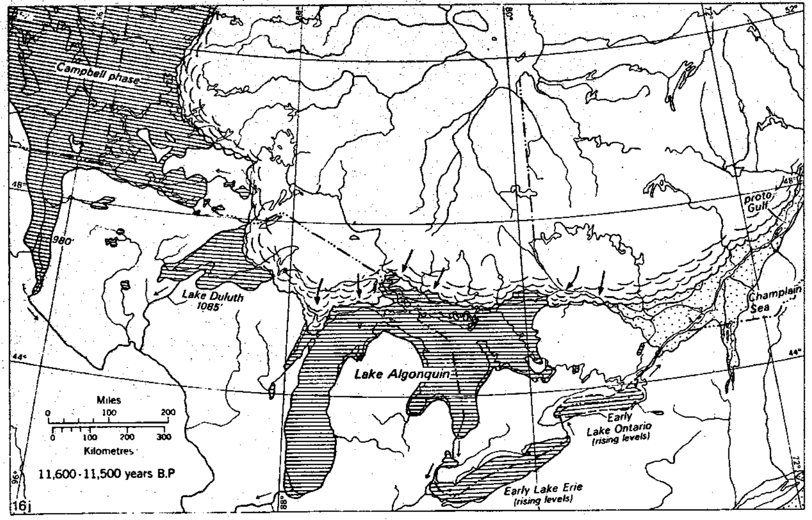
16g



16h

APPENDIX C – cont'd ____


16i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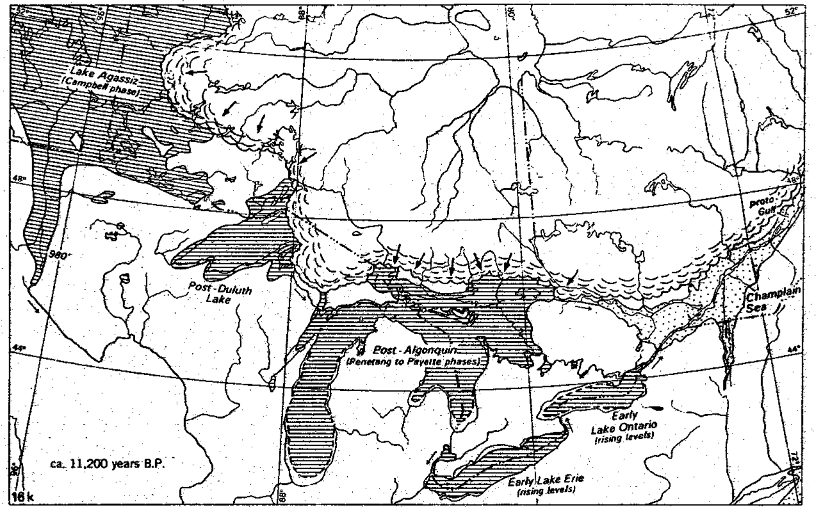
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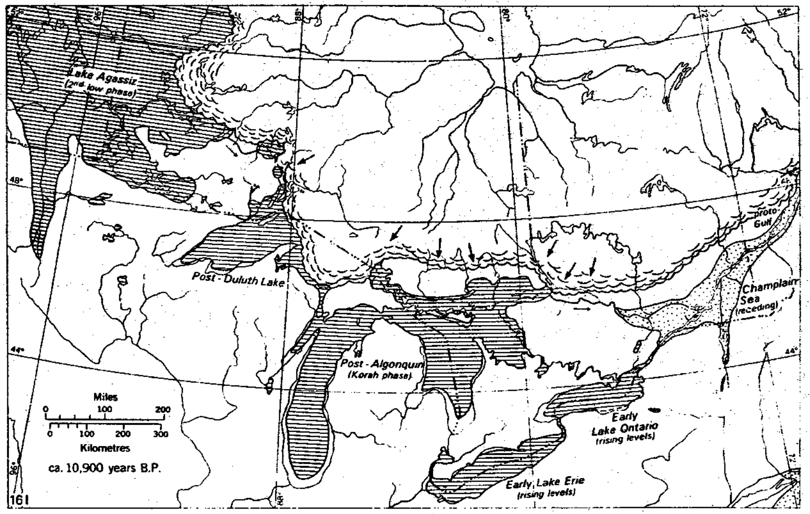
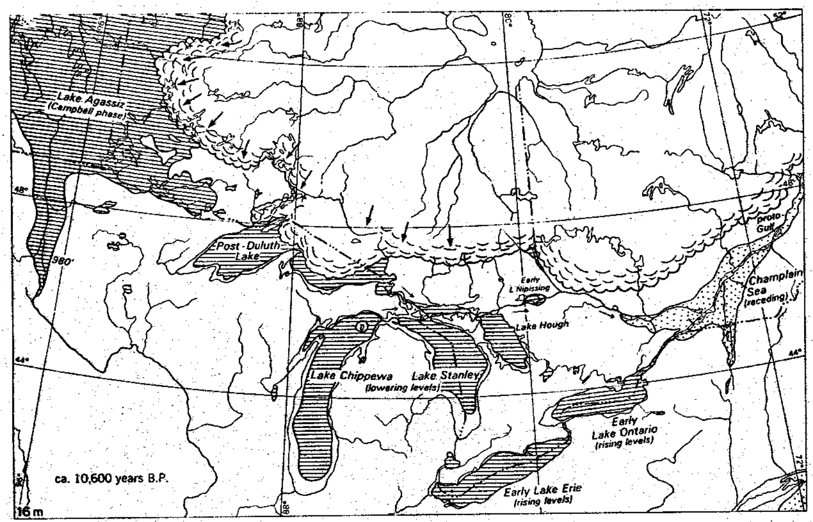
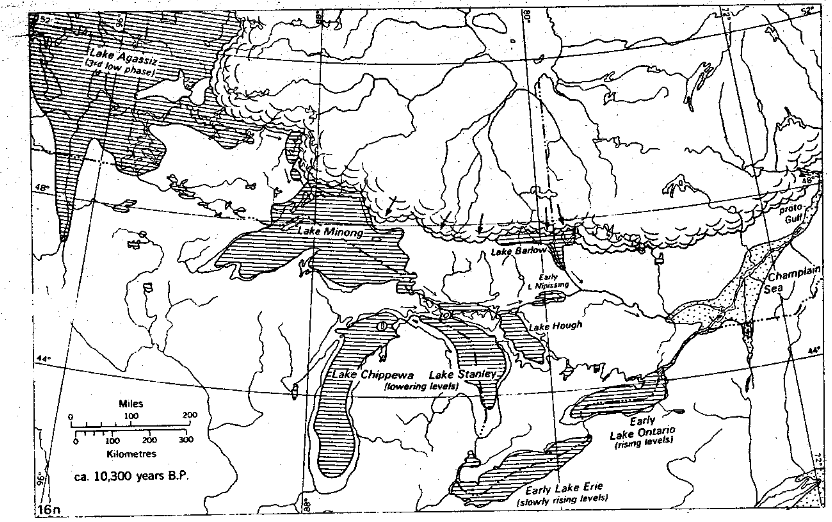

16l

APPENDIX C - cont'd ----



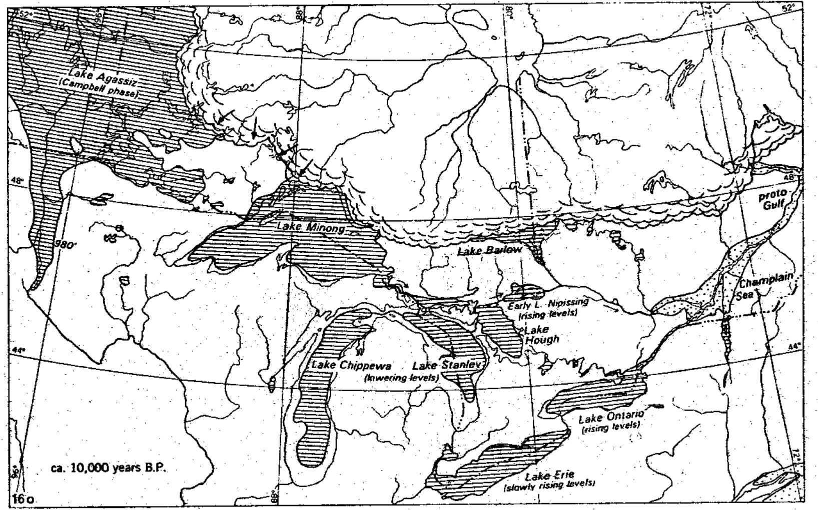
ca. 10,600 years B.P.

16m



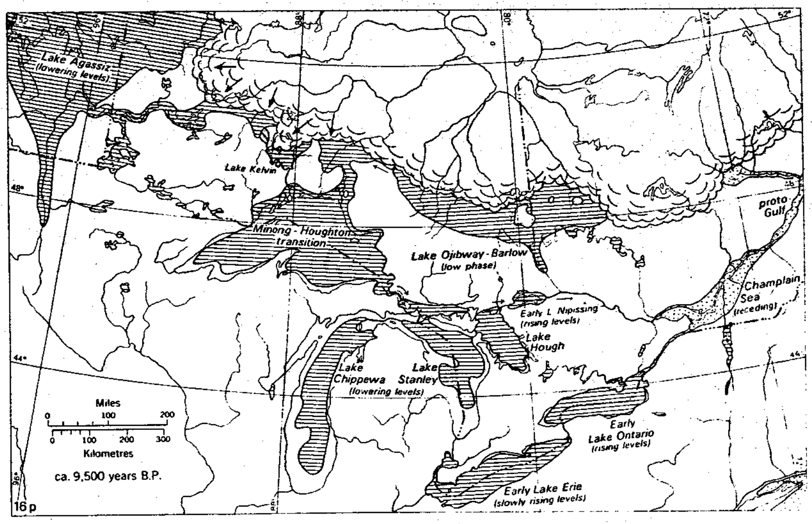
ca. 10,300 years B.P.

16n



ca. 10,000 years B.P.

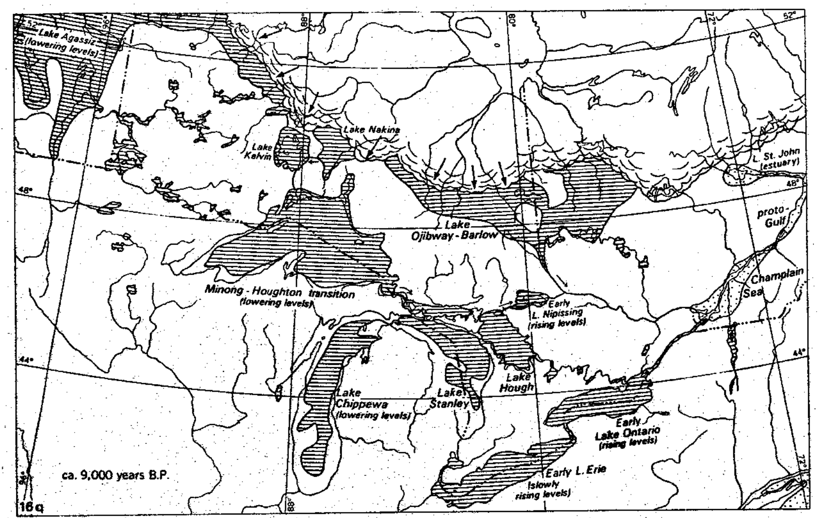
16o



ca. 9,500 years B.P.

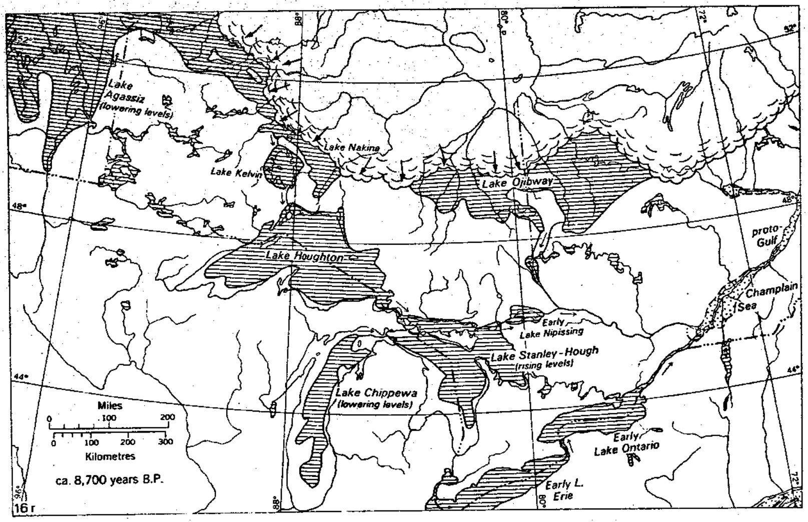
16p

APPENDIX C – cont'd ----



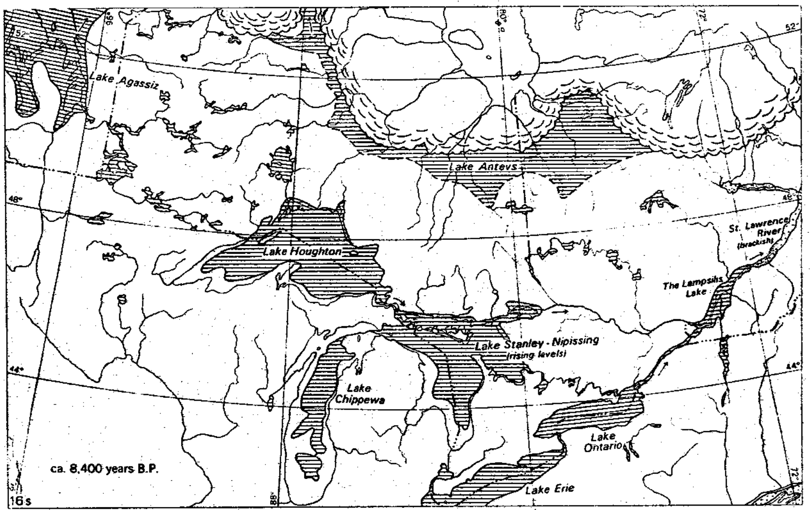
ca. 9,000 years B.P.

16q



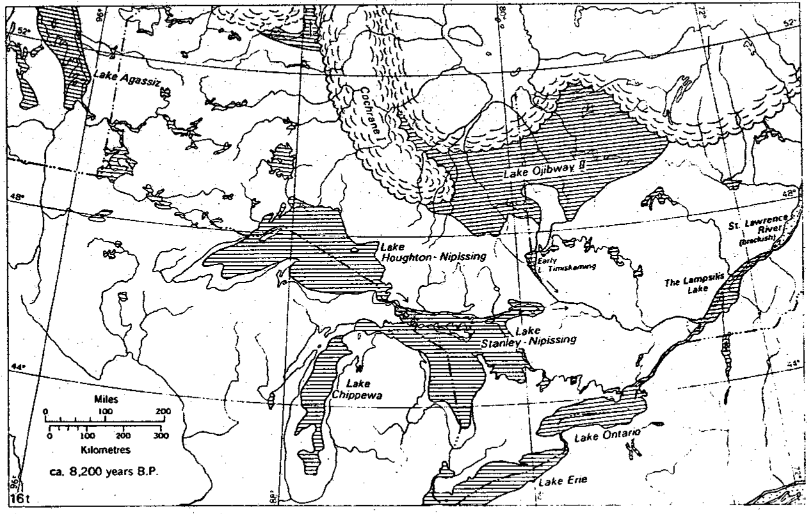
ca. 8,700 years B.P.

16r



ca. 8,400 years B.P.

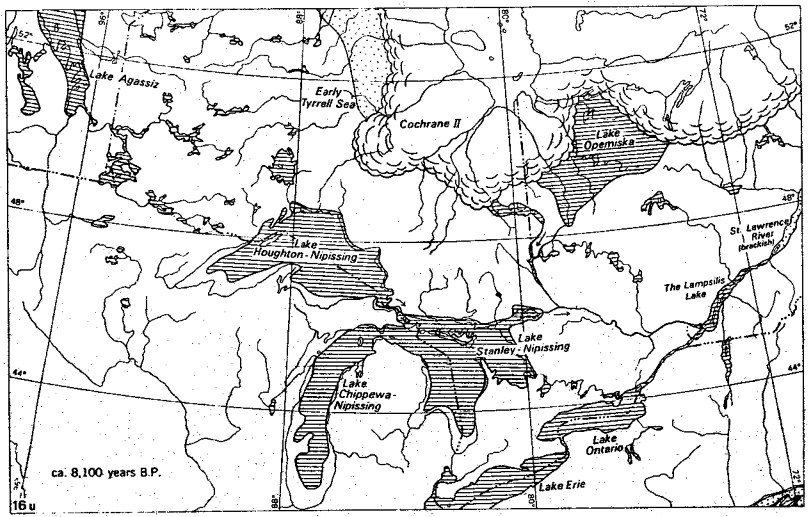
16s



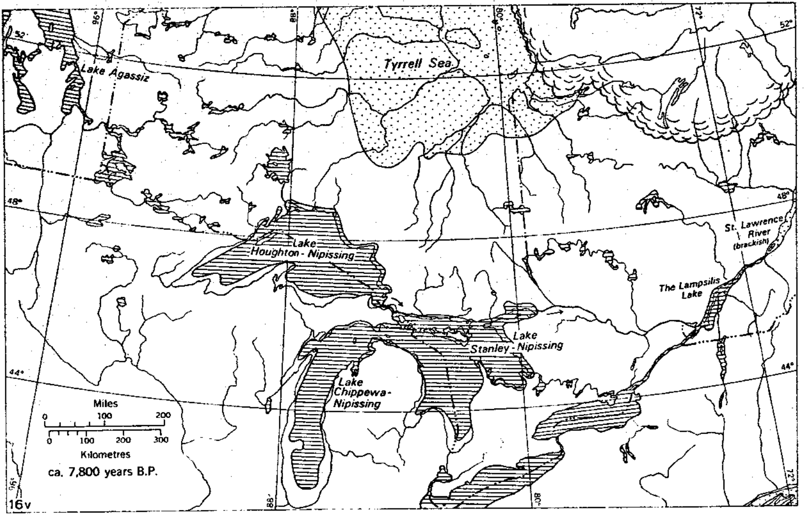
ca. 8,200 years B.P.

16t

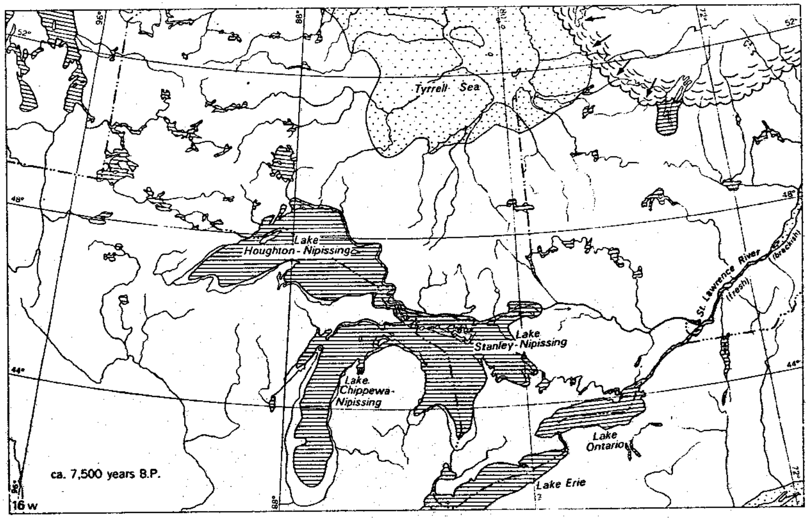
APPENDIX C - cont'd ____



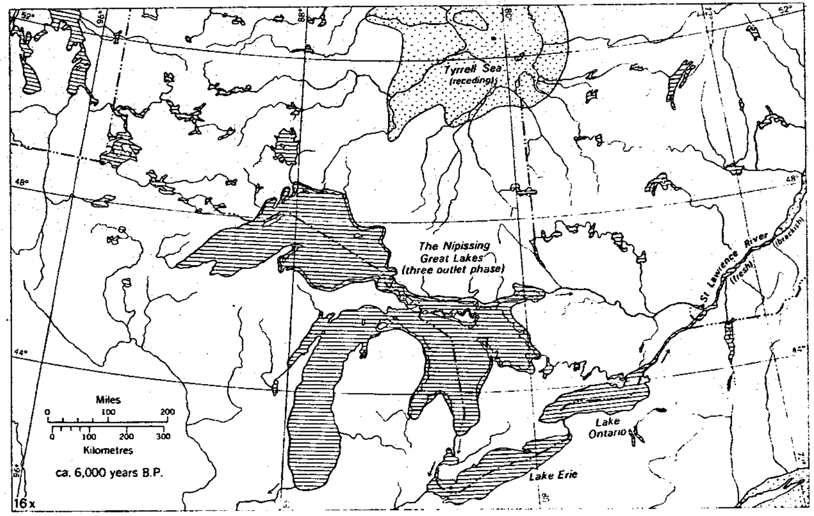
16u ca. 8,100 years B.P.



16v ca. 7,800 years B.P.



16w ca. 7,500 years B.P.



16x ca. 6,000 years B.P.

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