ABSTRACT

A Geomorphological Study

of the lower Souris River Valley, Manitoba,

with special reference to the diversion

by

D.R.J. Brooks

The fact of the diversion of the Souris River from the Pembina Trench across the Tiger Hills is well known, but when and why this happened has not been clarified. The main objective of this essay is to answer these two questions.

A brief survey of the surficial deposits, especially their relation to the preglacial bedrock topography, and a review of the evidence for the diversion are made. Two means of diversion, other than the process of capture, are considered. A critical line of enquiry as to the time and cause of the diversion proved to be the chronology of events in that section of the Souris Valley north of the Tiger Hills.

It was found that diversion occurred earlier than was formerly believed, perhaps as early as glacial Lake Brandon, but, in any case, very early in the history of glacial Lake Agassiz I. A lowering of the level of the latter was evidently not required in order to initiate headward erosion of a tributary of the Assiniboine, if capture were the process involved.

Circumstances were such that capture was distinctly possible and in the writer's opinion the balance of evidence actually swings slightly in its favour.

The chronology of the Souris Valley also has application to post-glacial variations in discharge and present underfitness, as well as rates of river cliff recession and the operation of geomorphological processes.

A GEOMORPHOLOGICAL STUDY
OF THE LOWER SOURIS RIVER VALLEY, MANITOBA,
WITH SPECIAL REFERENCE TO THE DIVERSION

A Thesis

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Master of Arts

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by

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PREFACE

The valley of the Souris River between Bunclody and the confluence with the Assiniboine was examined in the belief that a wide variety of evidence might be brought to reveal the cause of the diversion through the Tiger Hills. Conclusive evidence is still not available to the writer and the cause of the diversion remains unknown for certain. Further study of the same area in greater detail using a wider range of techniques, in addition to the use of certain information from the surroundings should increasingly focus attention on both the critical factors involved and that period during the evolution of the drainage pattern when conditions led to the diversion.

The Souris Valley, downstream from Bunclody, is divided for convenience into three sections (see Fig. 7a) described as the Pembina Trench, Tiger Hills, and Wawanesa Embayment Sections. It is considered that the mode of presentation of the problem in this essay is the best that could be employed, in spite of the necessity to fragment descriptive passages and repeat some discussion. Closely located surficial deposits may be discussed in different sections on rather more distantly related themes. On the other hand, discussion has sometimes been repeated to give immediate significance or coherence. A few surficial deposits and post-diversion modifications are only indirectly related to the main theme.

An American Paulin System Terra Model T - 2 Altimeter with 2 feet graduations was used for measurements of altitude. It was

generally found that over short periods of time (e.g. 15 minutes or less) and small changes of altitude (less than 150 feet), due to the difficulties of measuring meaningful temperatures quickly, corrections for temperature differences were negligible in contrast to the corrections necessary for changes in atmospheric pressure. It is unlikely that more than a very small minority of individual measurements is more than 3 feet in error. However, because of the sparse distribution of bench marks and spot elevations it proved necessary (for example, across the terraces at the south end of the Wawanesa Embayment Section) to use successive altimeter measurements as bases on later occasions, as many as five times. The cumulative error involved here could unfortunately be of the order of the topographic maps' 25 feet contour interval, or at least as inaccurate as some of the contours themselves. However, it is quite impracticable to try to improve upon this state of affairs without motorised transport. Dr. W.J. Brown went out of his way to help make some accurate measurements, along neighbouring highways, in his car.

I owe thanks to Dr. T.R. Weir, but for whom the study would not have been made. Also, I am especially grateful to Dr. W.J. Brown for his continuous help and interest, his personal assistance in the practicalities of fieldwork, and for his always making time freely available for discussion. I have benefitted from discussion with Prof. E.I. Leith, S. Zoltai, and C.T. Shay, and from field visits with Dr. J.A. Cherry and S.J. Simpson. I am grateful to the

Departments of Soil Science and Geology, University of Manitoba, and the Geography Department, University of Brandon, for the use of equipment and facilities.

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CHAPTER I

THE GEOLOGICAL CONTEXT

Pleistocene Geology: Previous Work

Upham, having travelled throughout the region (see Figs. 1 and 6 for location maps) by horse and cart, was able to state in his classic monograph (Upham, 1896, pp. 268 - 272) that

> The glacial Lake Souris occupied the basin of the Souris or Mouse River from the most southern portion of this river's loop in North Dakota to its Elbow in Manitoba, where it turns sharply northward and passes through the Tiger Hills. . . . .
>
> Until the ice-sheet west of Lake Agassiz had receded so far as to uncover Turtle Mountain the glacial lake in the Souris basin continued to outflow by the Sheyenne and build up its delta. Next its outflow passed north of Turtle Mountain by the Pembina, perhaps after taking for a brief time the course of the Badger Creek, Lac des Roches, and the Mauvais Coulee to Devils Lake and the Sheyenne. The channel of outlet by the Pembina, extending about 110 miles from the elbow of the Souris to the Pembina delta of Lake Agassiz is eroded 100 to 300 feet in depth, ...

He mentions that the Pembina Trench is cut into the plateau of Fort Pierre (the name of the corresponding Cretaceous formation in North Dakota) shale and, without referring to any specific section of the valley, that it contains a considerable thickness of till. When the channel of discharge of Lake Souris

> was transferred to the new course by Pelican Lake and along the Pembina, the Lake Souris was suddenly lowered about 125 feet to the level of the top of the bluffs of Langs Valley, and a further lowering of a 110 feet was afterward effected by the gradual erosion of this valley. The lake was wholly drained by this outlet, for the general level of the land adjoining the Souris in the vicinity of the mouth of Plum Creek, which is the lowest portion of the lake bed, is about 20 feet above the present divide in Langs Valley. Since the waters of the Souris ceased to

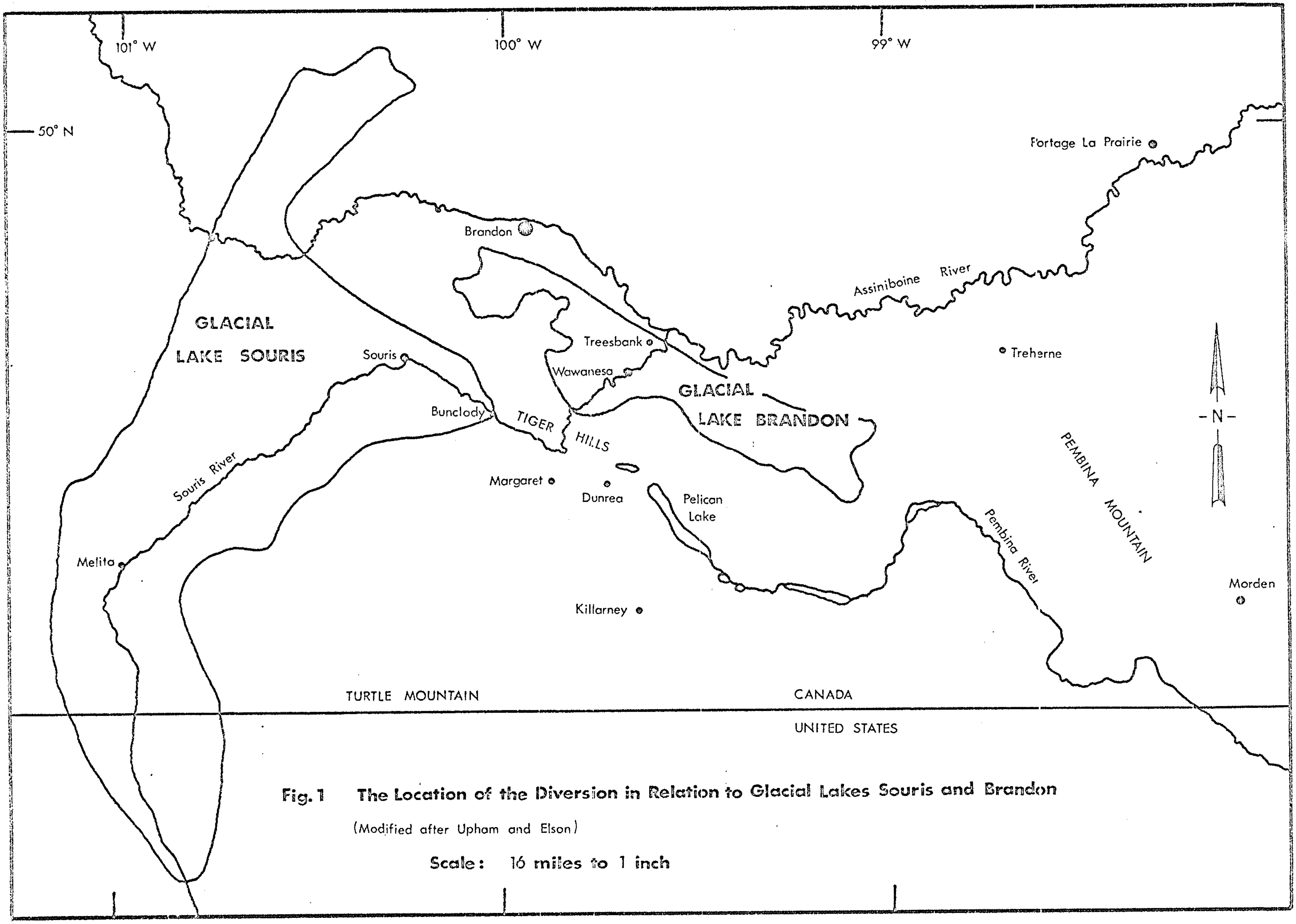


Fig. 1 The Location of the Diversion in Relation to Glacial Lakes Souris and Brandon

(Modified after Upham and Elson)

Scale: 16 miles to 1 inch

flow along this course the sediments of gravel and sand brought by tributaries have filled portions of the Pembina Valley 10 to 20 feet, forming the barriers of its shallow lakes; and the divide in Langs Valley has been raised probably 10 feet by the deposits of Dunlops Creek.

. . . . . . A width of only 3 miles of the morainic belt of the Tiger Hills, extending along the north side of the Langs Valley and the elbow of the Souris, intervened between that stream and an expanse of till whose surface is lower than the bottom of Langs Valley and descends with northeastward slope to the Assiniboine. The crest of this moraine rises about 200 feet above Langs Valley, but it had probably been cut through nearly or quite to the level of that valley by drainage southward from a small lake formed between the moraine and the receding ice within the angle between the east-to-west range of the Tiger Hills and the north-to-south range of the Brandon Hills. With the withdrawal of the ice front across the Assiniboine this gap through the moraine was soon channeled deeper, and the Souris turned northwards at its elbow, leaving its old channel of Langs Valley and flowing with more rapid descent to the Assiniboine in its present course. The gap has been since eroded to a total depth of 350 feet; and thence northward the Souris has cut a channel about 140 feet deep, chiefly in till . . . . . .

Antevs (1931) discusses the late-glacial history of Manitoba in a general context, correlating it with events in the rest of North America and Europe. Johnston (1934) provides a brief description of the surface deposits in south western Manitoba, including Map 254A which shows their general distribution in relation to glacial Lake Agassiz. Ellis and Shafer (Ellis, 1938, Ellis and Shafer, 1940, Ellis and Shafer, 1943) show how surficial geology is reflected in soil types. Ehrlich, Rice, and Ellis (1955) have made a more specific study of this aspect. Pratt and Ellis (1954) discuss the nature and distribution of saline soils in the Souris Basin. Ellis and Pratt's (1953) outline of the source and nature of regolith in southern Manitoba is, on the other hand, highly generalised.

Elson (1955) has reconstructed the chronology of events in the area between latitudes 49° and 50° north and longitudes 98° and 101° west, including the Tiger Hills and the basins of glacial Lakes Souris and Brandon. Much of this mapping, however, was still of 'a strictly reconnaissance nature'. In contrast to Upham, who envisaged the ice as receding in a general direction towards the north east, Elson explained observed features in terms of three ice lobes, the Red River Lobe, the Assiniboine Sublobe, and the Northwestern Ice, the latter receding in a north westerly direction (Elson, 1958). Halstead (1959) refers to certain aspects of the geology of the Brandon map-area. This publication contains Geological Survey Sheet 62G, Map 1067A, showing the surficial geology as mapped by Elson.

Klassen, of the Geological Survey of Canada, has made a study (1966) of the Riding Mountain area and is currently engaged in a study of the south west corner of the Province. Elson (1956, 1961a) has published maps of part of that area. Lemke (1960) has completed a survey of the area, crossed by the Souris River and formerly occupied by glacial Lake Souris, in North Dakota. Elson (1957) offers a brief review of data on Lake Agassiz in the light of radiocarbon dates, and (1961b) gives a summary, with a useful bibliography, of the properties of the surficial deposits in the Lake Agassiz basin. The proceedings (Mayer-Oakes, 1967) of the 1966 Conference on Environmental Studies of the Glacial Lake Agassiz Region offer the most recent and comprehensive survey, but do not consider the Souris Valley in any detail.

The Cretaceous Bedrock

Wickenden (1945, Table of Formations, p. 7) lists the names and thicknesses of all the formations found in south west Manitoba. Elson (1955) gives a summary of the characteristics of the Cretaceous shales found in the Tiger Hills region. He refers to the work of Kirk (1930) and Kerr (1949) but compiles a map (1955, Plate 2) using information obtained mainly by Tovell (1951) and Wickenden (1945). Table 1, herein, is compiled from Elson (1955) and Wickenden (1945).

The Cretaceous strata dip gently to the west and southwest at about 5 or 6 feet to the mile over most of the region. Outcrops of formations toward the north or north east, therefore, become progressively older. Elson's map (1955, Plate 2) shows where the Riding Mountain Formation and the Pembina, Boyne, and Morden members of the Vermilion River Formation lie in the Souris Valley.

Where the Odanah shale of the Riding Mountain Formation outcrops it is generally brittle. Although it can maintain steep slopes it offers little resistance to erosion. In numerous localities near Wawanesa the soft clay of the Millwood phase is exposed. All rock beneath the surficial deposits is described, for example when encountered in wells, by the local inhabitants as 'blue clay'. The actual distribution of the Millwood phase, therefore, is not known with certainty. It is exposed in river cliffs immediately on the north and south sides of the town of Wawanesa, under the apex of the

Table 1 Bedrock Formations

<table>
<tr><td colspan="2">RIDING MOUNTAIN FORMATION (1100 feet +)</td></tr>
<tr><td colspan="2">Marine. Hard, greenish-gray siliceous shale, upper (Odanah) phase. The most competent rock in the area - constitutes bulk of shale in till and water-worked deposits. Massive beds break into fissile fragments when weathered. A few bentonite beds. Lower soft clay (Millwood) phase (65 feet thick). Rapid slumping south of Wawanesa destroys exposures. Waxy greenish-gray clayey shale with a few thin bentonite beds. Ironstone concretions up to 1.5 feet.

<u>Description by Kirk near centre of sec.23, tp.7, rge.17</u>

10 ft. shale, medium to light gray, in bands 2 to 6 inches alternating with soft greenish-gray shale.
1 ft. greenish-gray shale, with two bentonite bands.
14 ft. shale, alternating hard and soft, as above.
48 ft. soft greenish-gray shale; some layers of concretions with fossils including Baculites, Inoceramus, Dentalium.</td></tr>
<tr><td colspan="2">VERMILION RIVER FORMATION</td></tr>
<tr><td>Pembina Member</td><td>80 feet ± . Series of dark gray to black non-calcareous shales with numerous bands of bentonite near the base. Upper part rarely exposed because overlying Riding Mountain Formation slumps easily.</td></tr>
<tr><td>Boyne Member</td><td>140 feet ± . Includes both calcareous shale with a few beds of bentonite and dark gray, non-calcareous shale. The most complete section described is in S.W. ¼ sec.4, tp.1, rge.6.</td></tr>
<tr><td>Morden Member</td><td>190 feet ± . In N.E. ¼ sec.36, tp.2, rge.6, near Morden, soft, somewhat fissile, dark gray, non-calcareous shale containing large ellipsoidal septarian concretions. Exposures limited.</td></tr>
</table>

meander core one mile to the north east, at some points near the present river channel, and in the roadcut for the new Highway 2. This clay is *in situ* together with both ironstone concretions and bentonite beds, and has the same distinctive bedding and jointing patterns as the shale of the Odanah phase.

Bedrock Topography

Well information. The configuration of the preglacial bedrock surface is only known in very broad outline (see Halstead, 1959, Fig. 2 and Elson, 1955, Plate 2). Generally speaking, sufficient accurate information is just not available to improve upon these maps significantly. Elson (1955, p. 41) obtained his data 'from oral statements by well-owners and from information from electro-logging and seismic operations kindly made available by the California Standard Oil Company'. However, the contours are very generalised, based on sparse data, and show many discrepancies in detail.

Geological Survey of Canada Map 1066A (Halstead, 1959) incorporates some well information selected from the original data from which the Geological Survey of Canada Water Supply Papers (Elson, 1949, Elson and Halstead, 1949, and Halstead, 1954) were compiled. Water Supply Paper No. 301, although listing detailed well information, does not actually state the depths to the bedrock surface. R.G.Pearce of the Hydrology Division of the Department of

Energy, Mines and Resources, Ottawa, kindly supplied as much of this information as was available, as well as the list of wells which is omitted from Water Supply Paper No. 302. None of the wells in tp.7, rge.18, covered by Water Supply Paper No. 326, reach bedrock.

Bedrock altitudes from all the water-well information available, over a zone extending four to six miles on either side of the Souris River, are included in Fig. 2 (supplemented by surface observations).

Oral comments by well-owners are sometimes difficult to interpret. One well in Langs Valley was said to pass through 60 feet of blue shale and end in gravel. It was maintained that another well five miles to the north reaches 10 feet of sand after passing through 70 feet of blue clay (shale?) and ends in another 35 feet of blue clay.

Surface observations. The several exposures of shale in the Souris and Langs Valleys can only be considered as minimum preglacial bedrock altitudes. This applies to the tops of the shale river cliffs cut into the main composite terrace upstream from the Elbow. On the other hand, just upstream from the Elbow where Highway 346 crosses the river, till is exposed in a roadcut (Plate 2) such that the maximum possible height of the bedrock here is about 1275 feet. The most useful exposures show surficial deposits (other than river gravels) *in situ* lying on the shale bedrock. These are found in roadcuts on the north and south sides of Souris and Langs Valleys and

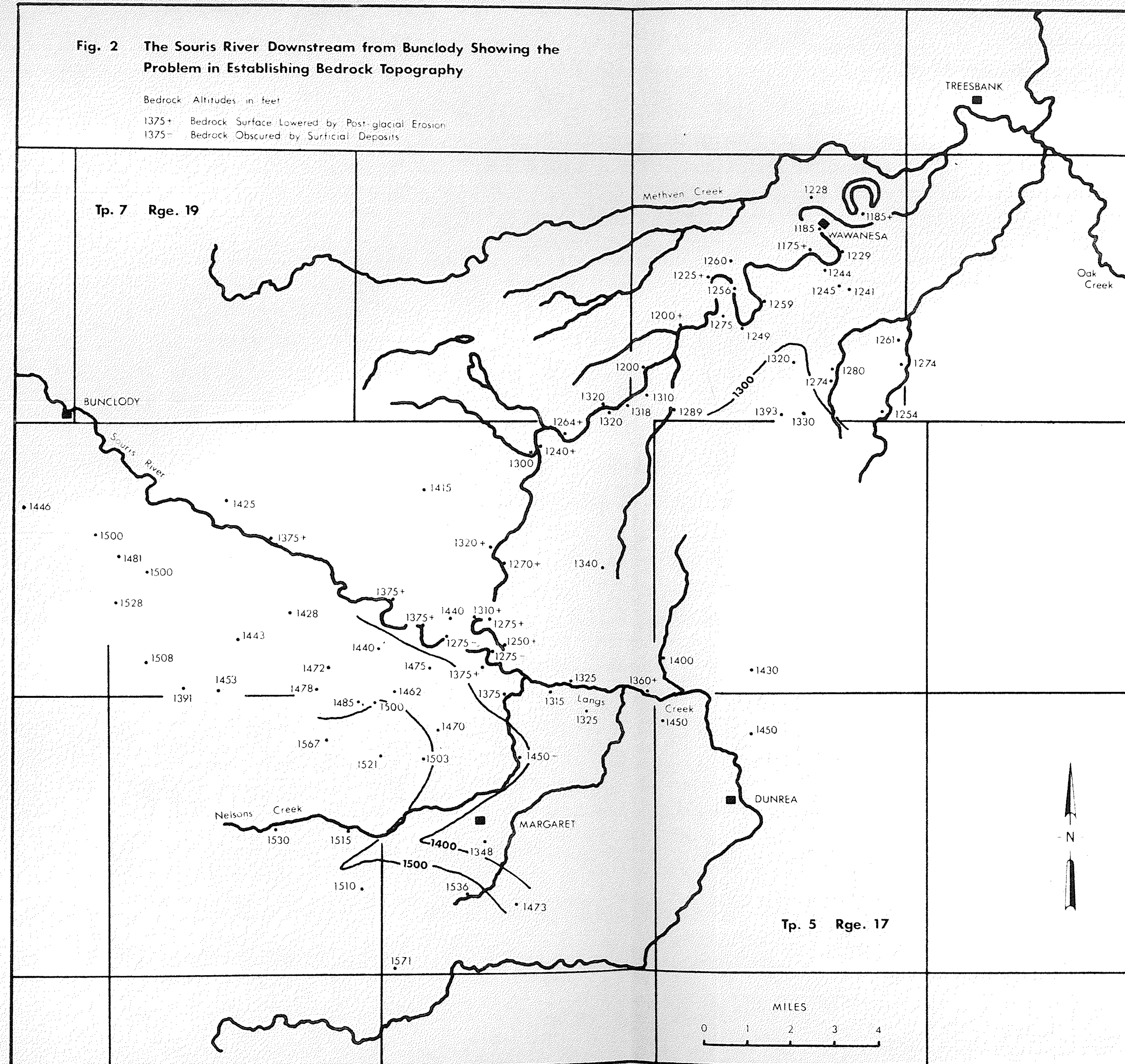


Fig. 2 The Souris River Downstream from Bunclody Showing the Problem in Establishing Bedrock Topography

confirm the presence of a south-north depression in the bedrock surface (shown in Fig. 2, Halstead, 1959) between Highway 10 and Ninette. Shale is exposed north of Dunrea and west of the Elbow and in the west side of Nelsons Creek, but only till and water-worked deposits are exposed in secs.2 and 3, tp.6, rge.18, and secs.34 and 35, tp.5, rge.18, and in the east side of Nelsons Creek. However, shale exposed in the floor of Langs Valley in sec.1, tp.6, rge.18, together with the altitudes of the shale in the roadcuts immediately to the east demonstrate that the axis of this depression is to the west of the position indicated. A new well in S.E. $\frac{1}{4}$ sec.3, tp.6, rge.18 fixes the height of the shale there at approximately 1315 feet. The precise course of this supposed depression northwards under the Tiger Hills, however, remains unknown. It is generally assumed that the bedrock topography is controlled by a former integrated drainage network. In this case the low level of the bedrock surface in sec.8, tp.6, rge.18 can only be explained in terms of an undetected intricate system of preglacial valleys.

Fig. 2 (Halstead, 1959) shows the floor of the general depression or valley in the bedrock surface crossing the present Souris Valley in sec.1, tp.7, rge.18 at an altitude of almost exactly 1200 feet. However, shale is exposed here along the eastern side of the valley at altitudes higher than 1300 feet. On the other side of the valley shale is exposed at a similar height near the centre of sec.1, tp.7, rge.18, but there is no shale at all at the base of the river cliff in S.W. $\frac{1}{4}$ sec.7, tp.7, rge.17, nor at river level in N.W. $\frac{1}{4}$ sec.8, tp.7, rge.17.

Within and just south of the Tiger Hills there are few continuous exposures of the contact between bedrock and the surficial deposits. This not the case, however, upstream from Wawanesa in some of the river cliffs where the contact can be traced for considerable distances. In some cliffs where shale cannot be seen it is difficult to be sure that it is not obscured by slumping. Along most visible contacts the shale generally shows no pronounced variations in height or disturbances which could be attributed to ice movement, and the contacts are virtually parallel to the bedding.

West of the Elbow where Highway 346 crosses the south side of the valley (see Plate 23) a steep preglacial bedrock surface coincides with the steep side of the present valley and the shale is evidently very unstable. A roadcut here reveals many local disturbances including very minor folds of small amplitude. Weathered shale near the surface has been subject to considerable movement. On the north side of the valley at this point another roadcut has exposed a more complex structure just below the level of the high outwash terrace (Plate 23) near its southern edge. At the southern end of this exposure horizontally bedded shale lies in situ. However, just to the north, at a slightly higher altitude, a large mass of shale lies on a till with its bedding undisturbed and appears to have been moved en bloc by ice. Dr. J.A.Cherry (University of Manitoba) has commented that, although it would seem surprising that this mass of shale could be moved without any disruption of the bedding, similar occurrences have been observed in Saskatchewan.

The Relation of Surficial Deposits to the Bedrock Topography

A general idea of the relation between surficial deposits and the bedrock topography can be had by carefully studying Geological Survey Map 1067A (Halstead, 1959), such maps of bedrock topography as are available (Fig. 2, herein, Fig. 2, Halstead, 1959), and the appropriate topographic maps.

Map 1067A states that most of the area under consideration is covered by ground and end moraine. Since local relief is a principal criterion for distinguishing between these two types, however, being based on reconnaissance, the map is not definitive. The highest altitudes are reached within the belt of the Tiger Hills shown as end moraine. Immediately south of the Pembina Trench the ground moraine is covered by outwash material and lag concentrate. Some of this gravel is now being taken off for commercial purposes three miles north of Margaret. North of the Tiger Hills the surficial deposits are described by Elson as 'deltaic and offshore'.

The Pembina Trench. On the north side of the Trench, two miles east of the Elbow the high outwash terrace is capped with a distinctive flat-topped mass of gravel (Plate 1) in secs.2 and 11, tp.6, rge.18. In Figure 7a this mass of gravel is enclosed by the 1475 feet contour.

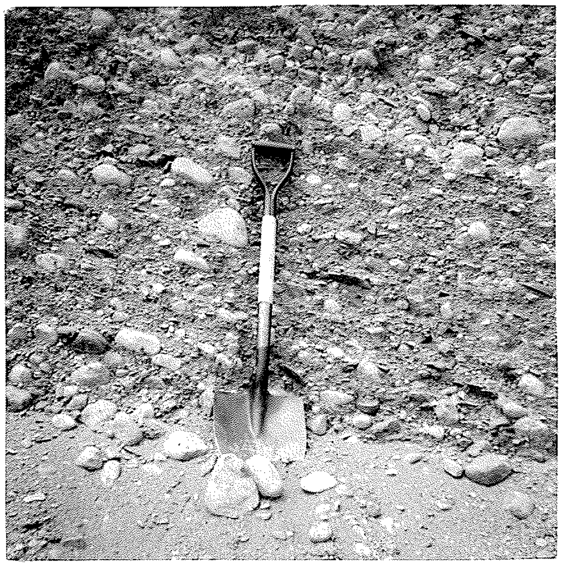


PLATE 1. GRAVEL ON THE HIGH OUTWASH TERRACE IN THE PEMBINA TRENCH.

Looking north eastwards at a section in the gravel pit in N.W. $\frac{1}{4}$ sec.2, tp.6, rge.18. This exposure is near the abrupt north edge of the flat-topped mass of gravel whose position is enclosed by the 1475 feet contour in Figure 7a.

An interpretation of its origin must explain its position in relation to the high terrace, its abrupt margins (it does not appear to have been isolated by recent fluvial erosion, being set back from the front edge of the terrace), the characteristics of the gravel itself, and the direct ions of dip of the stratification (a gravel pit cuts through the eastern end of the gravel and shows near the centre stratification which is almost horizontal, but towards the north (see Plate 1) and south sides the dip becomes almost as steep as the actual margins of the feature). A poor exposure beneath the floor of the gravel pit suggests that the entire gravel mass is lying on finer material of different origin.

Elson describes the deposits on the floor of the Trench as colluvium, alluvium, and lag concentrate. Lag can be seen resting on shale bedrock in S.E. $\frac{1}{4}$ sec.1, tp.6, rge.18, and in the road cut close to the point where Highway 346 crosses the Souris River (Plates 2 and 23). Langs Valley farm, sec.35, tp.5, rge.18 is built on an alluvial fan.

However, because of the diversion of the Souris and the resulting incision of this river and Langs Creek (Fig. 2) other kinds of deposits have also been exposed. Plate 2 shows a till exposed in the road cut west of the Elbow. This has a much smaller gravel cont ent than the Tiger Hills end moraine. From its position Dr. R.W. Klassen (personal communication) inferred that the till is older than the moraines north and south of the Trench. Exposures between Highway

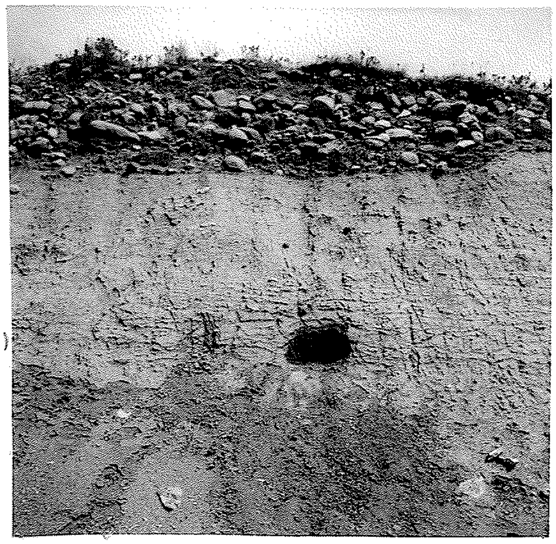


PLATE 2. TILL AND LAG CONCENTRATE IN THE PEMBINA TRENCH

The east side of the road cut in S.W. $\frac{1}{4}$ sec.8, tp.6, rge.18. The lag concentrate is about 6 feet deep and lies near the front edge of the main composite terrace. Gravel is sparse in the till which is weathered along a fine network of joints. A pit has been dug in the till near the centre of the photograph.

346 and the Elbow are poor but a similar material may be exposed in the S.W. $\frac{1}{4}$ sec.9, tp.6, rge.18 and shale in situ on the north bank of the Souris in N.W. $\frac{1}{4}$ sec.4.

Immediately east of the Souris near the Elbow a small road cut exposes a mixture of shale blocks and small rounded igneous gravel. The shale blocks have also been rounded, deposited at all angles, and weathered in their present positions, thus revealing the parallel lines of weakness along which they easily shatter. The exposure, therefore, has a distinctive 'mosaic' appearance. Eastwards, good exposures are limited, but although the constituents are considerably smaller similar material seems to occur under the composite terrace throughout secs.2 and 3, tp.6, rge.18, north of Langs Creek. An example of it can be seen under the alluvial fill in Plate 10.

South of Langs Creek the surficial material is in marked contrast (Plates 3 and 4). A gulley beside the road along the west side of sec.2, tp.6, rge.18 exposes stratified sand, silt, and gravel. This is of interest because it lies below the level of the original floor of the Pembina Trench and therefore must predate its use as spillway and presumably also the last ice advance.

The 2 feet of convoluted silt shown in Plate 4 could have had a simple fluvial origin. Similar convolutions have been described (McKee, Crosby, and Berryhill, 1967) from modern flood deposits in Colorado. It is suggested that there they 'were developed during a

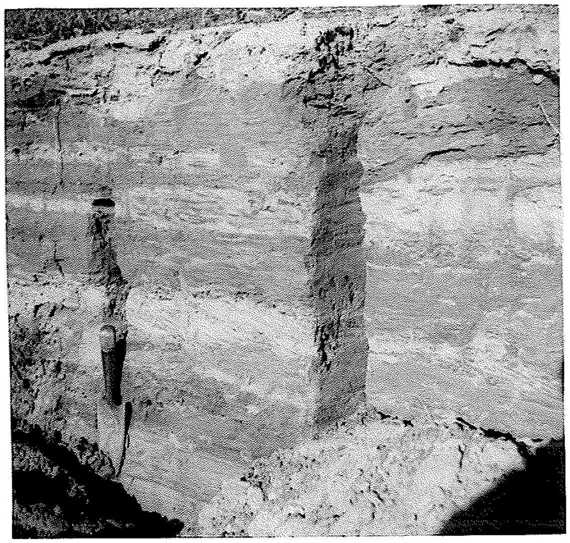


PLATE 3. STRATIFIED SAND AND SILT IN THE PEMBINA TRENCH

PLATE 4. CONVOLUTED SILT IN THE PEMBINA TRENCH

Two exposures in a gulley at about 1340 feet above sea level in S.W. $\frac{1}{4}$ sec.2, tp.6, rge.18. The stratified deposits lie at a higher level than the convoluted silt and are seperated from it by the gravel shown overlying the latter.

late stage of the flood when current velocities had slowed down materially and sediment was in the condition of a quicksand'.

During the summer of 1967 a sand pit was opened at the same leve l on the other side of the road. This deposit consists mainly of sorted sand and fine gravel but is evidently a continuation of the same deposits. The sand is generally cross-bedded.

Nelsons Creek. Another interesting exposure lies on the east side of Nelsons Creek at its easternmost bend in sec.28, tp.5, rge. 18 (Plates 5 and 6). Elson (Geological Survey Map 1067A) does not distinguish between this deposit and the surrounding outwash. Even though it is higher than the floor of the Pembina Trench it is still about 50 feet below the level of the Killarney Plain and the 10 feet of sorted sand and gravel are overlain in ascending order by 5 feet of poorly sorted sand and gravel, 3 fe et of mainly sand, and at least 12 feet of unsorted fine material.

Wawanesa Embayment Section. It is in this section that fresh exposures of the surficial deposits and their contact with the shale are most continuous. Elson (1955, Plate 3) describes those on the west side of the Souris Valley as delta and lake deposits, coarse well-sorted sand and coarse silt. These overlie silty sandy ground moraine in the south. On the east side of the valley, with the exception of a small area of similar delta and lake deposits near Wawanesa, he describes the surficial material as poorly-sorted very

PLATE 5. NELSONS CREEK

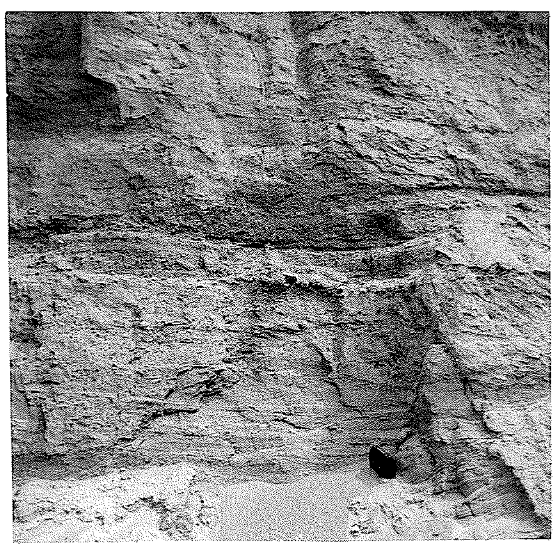


PLATE 6. WATER-WORKED DEPOSITS, NELSONS CREEK

The deposits in Plate 6 are located near the centre of Plate 5, at the easternmost bend in Nelsons Creek, sec.28, tp.5, rge.18, at an altitude of about 1450 feet.

fine sand and silt with rare pebbles and of problematic origin (outwash or aeolian ?). Most of the material, examined by the writer, exposed in all the large river cliffs in the Wawanesa Embayment Section of the Souris Valley is unsorted and contains angular rock fragments. Its general character is wholly consistent with an origin as till.

Of particular interest is the lag (Plate 7, herein, and Elson, 1955, Fig. 3-18) near the top of the cliff on the west side of the valley in sec.34, tp.6, rge.18 (see Plate 24 for location). The lag can be traced for at least a mile, 2 to 3 feet down from the top of the cliff. It lies on till and is under a sandy silt (lake sediment ?) and soil. The lag varies from coarse sand and gravel to large boulders. The top of the cliff is not level but the lag tends to remain at a constant depth below the surface. Its continuation north and westwards is suggested by the existence of a scattering of boulders on the surface. Elson proposed that the lag was formed in the shallow water of glacial Lake Brandon. Unfortunately, a deep tributary valley enters the Souris Valley at the point where the termination of the lag against the Tiger Hills moraine may have given the precise altitude of the lake when it was at its maximum extent, at this stage. Even so, its present distribution has a direct bearing on the evidence for a spillway, along the line of the Souris Valley, southwards through the Tiger Hills from glacial Lake Brandon, first intimated by Upham.

A similar lag concentrate is preserved just below the top of

PLATE 7. LAG CONCENTRATED IN SHALLOW WATER OF GLACIAL LAKE BRANDON

The top of the 150 feet cliff in N. $\frac{1}{2}$ sec.34, tp.6, rge.18 (see Plate 24 for location). Here the lag includes a limestone boulder.

the cliff at 1350 feet (the same altitude as Dry River spillway, Elson, 1955, p. 235a) near the centre of sec.6, tp.7, rge.17. There is some more lag 1 mile south of Wawanesa, 8 feet below the top of the cliff at an altitude of 1270 feet, which is higher than the cross -bedded sand and stratified silt ½ mile to the north north east (Fig. 3). This lag is somewhat higher than the Treherne spillway which is about 1250 feet above sea level.

Figure 3 shows a section through the river cliff just south of the town of Wawanesa. The upper part of this cliff is to be seen in Plate 8, and Appendix I contains the results of particle size analyses of these deposits.

There are nine distinct strata which can be traced for about ½ mile. At one steep section the deposits are well exposed but difficult to approach. Northwards, near the school in Wawanesa the sands and silts are replaced by till. Similarly, southwards, till re places them such that the north-facing section of the cliff is entirely in shale and till, being capped by the lag mentioned above. Unfortunately there are no extensive fresh exposures revealing the manner in which the sands and silts peter out.

Both the bedding and the upper surface of the shale are nearly horizontal and was evidently not disturbed by the ice. The lower 22 feet of till in contact with the shale has a high percentage of sand and silt (Appendix I). Since only a small sample was analysed the gravel portion may not be well represented.

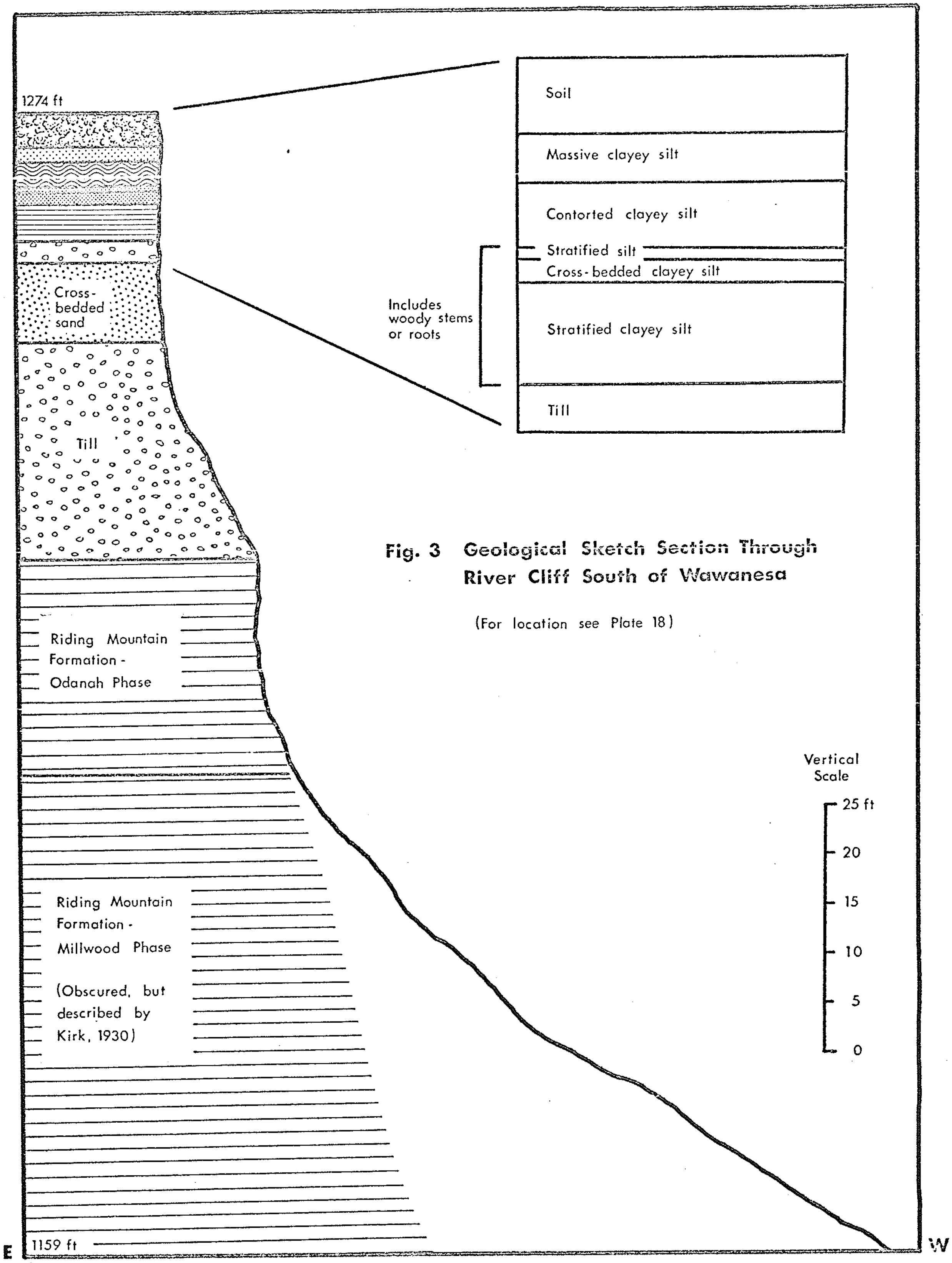


Fig. 3 Geological Sketch Section Through River Cliff South of Wawanesa

(For location see Plate 18)

Stratified
clayey
silt

till

cross-
bedded
sand

PLATE 8. THE WAWANESA RIVER CLIFF

(See Fig. 3 and Plate 18)

The cross-bedded sand is notable for its vertical thickness and continuity along the face of the cliff. Its extent in from the face of the cliff is unknown. It has not been found on the other side of the valley. The sand is ve ry fine (Fig. 8). The individual beds are of the order of 1 inch thick. There are included a small number of silt beds and a scattering of granules. This sand is at the same altitude as the Treherne spillway such that it could have been deposited in shallow water representing the Treherne Phase of glacial Lake Brandon (Elson, 1958, Fig.8). This, however, would require a later readvance of the ice to explain the thin (2 feet) layer of till on top of the cross-bedded sand. It seems likely that Lake Brandon had a complex history. Actual correlation of deposits with spillways is made difficult by two complications. Firstly, due to post-glacial tilt ing, re lative to the Treherne spillway these deposits were formerly about 20 feet higher (see the section on the 'Level of Lake Agassiz I at Wawanesa and the Effect of Tilting'). Secondly, the floor of a spillway is lowered by an unknown amount during the time of its use.

The thin upper till also has a small percentage by weight of gravel and a substantial amount of clay. The top beds of the cross-bedded sand are quite undisturbed. The stratigraphic position, stratification, and continuity of the clayey silt above the till are consistent with an origin in a glacial lake. The lake evidently became shallower when the cross-bedded silt was deposited over it. This latter silt both looks and feels coarser than the underlying stratified silt but the only significant difference revealed by particle size analysis (Appendix I) is a small increase in the size of the sand fraction. Above this again is a thin layer of stratified silt.

The deposits which are still higher must be younger and therefore worthy of closer study because they may be as recent as the diversion of the Souris River itself, or even younger. The contorted clayey silt is difficult to explain. L. Clayton (oral statement, Winnipeg, 1967) has shown that in western North Dakota a considerable area has been cove red with 5 feet of silt, the product of soil erosion, since the 1920's. More recent gullies reveal sections through the silt which can be seen to bury a soil. The massive silt at Wawanesa could have had a similar origin, but in the absence of a buried soil horizon it is more likely that both the massive and the contorted silt were deposited early in post-glacial time.

At the southern e nd of this Wawanesa cliff is another massive clayey silt above the lag concentrate having a somewhat similar particle size composition but a distinctive greenish hue.

At the point where the section in Figure 3 was measured a concentration of remains of woody stems or roots was found in the stratified and cross-bedded silts. If it could be proved that they are stems then it would follow that they are of the same age as the silts. Their date then would be of considerable interest. However, although at least some of them are almost certainly roots their interpretation is difficult and they are discussed in further detail in Appendix II.

Figure 4 is a section through the next river cliff to the south of Wawanesa on the east side of the valley. This second cliff bears some resemblance to the one just considered but it is only the lower till which is possibly continuous from one to the other.

The most interesting part of the section is shown in the photograph in Figure 4. Here, there is an abrupt change from the till to $1\frac{1}{2}$ feet of stratified clay, silt, sand, and gravel. The narrow dark bands in the photograph are finely laminated clay. The central band of dark laminated clay (just below the trowel) encloses a deposit of much different composition (Appendix I), consisting mainly of silt and clay but also including sand and some gravel. There is also some varved clay just below this central band of laminated clay (which can be faintly discerned in the photograph to the right of the trowel). The composition of the remainder of the stratified material ranges from silt and clay to coarse gravel. This stratum can be traced for about $\frac{1}{2}$ mile before it is obscured and its characteristics are consistent with an origin in a glacial lake, the gravel having been dropped by melting floating ice. At one point a cobble at the bottom of the stratified deposits lies in a small depression in the till. This draws attention to the radical changes in properties of the surficial deposits with time.

These lake deposits are at a higher elevation than the top of the cliff at Wawanesa. It seems likely that they are highly localised

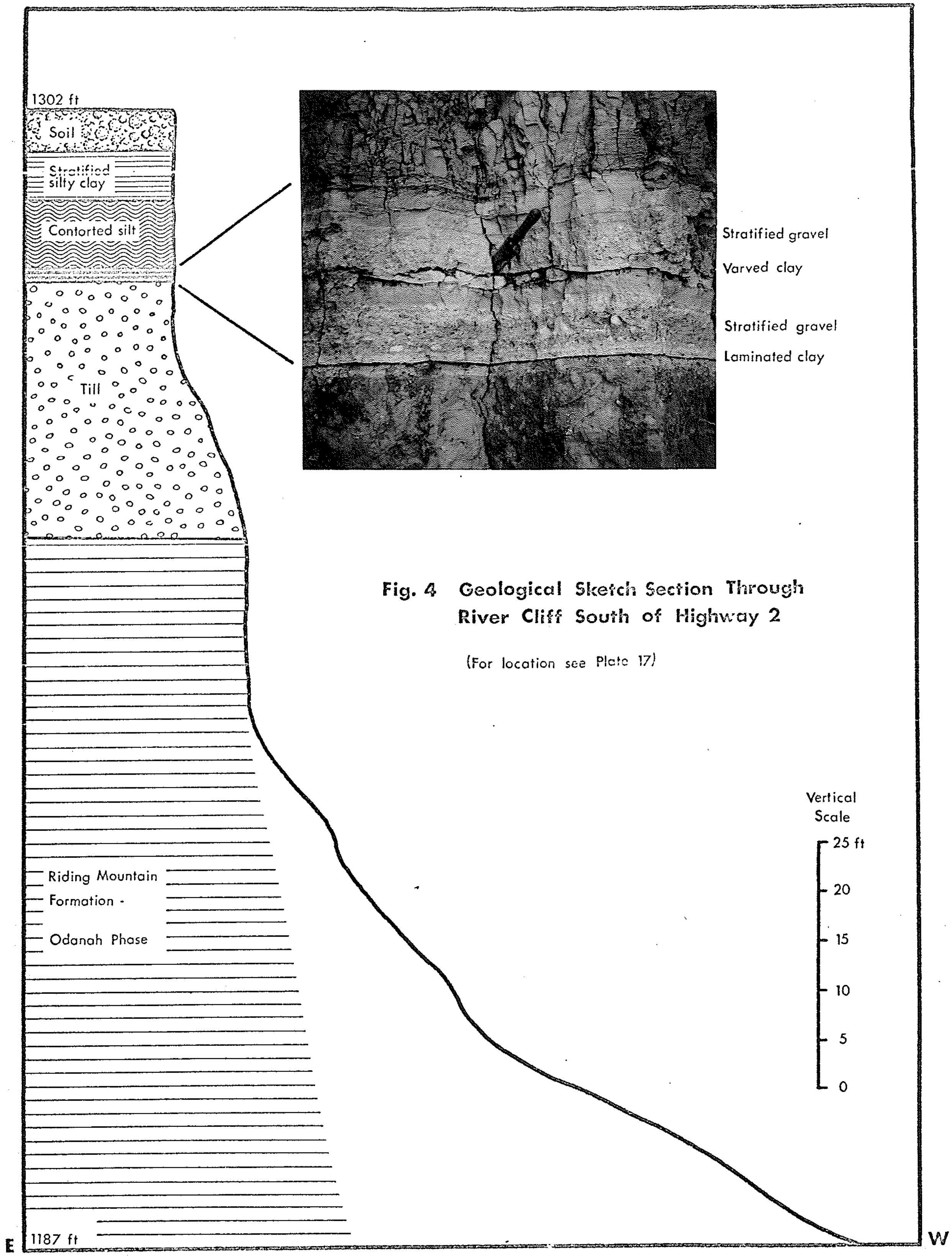


Fig. 4 Geological Sketch Section Through River Cliff South of Highway 2

(For location see Plate 17)

and perhaps formed when the ice front lay somewhere between the two cliffs.

The contorted silt can be seen at the top of the photograph in Figure 4 although it is not apparent therein that it is very contorted. Neither the deposits already described nor the stratified silty clay above the contorted silt show any signs of disturbance. The silt is somewhat variable in size composition (Appendix I).

Slopes, Processes, and Climate

Fluvial and slope processes. Yatsu (1966) has made a timely plea for the placing of geomorphology on a sound scientific basis. Since geomorphology is essentially the study of landforms (p. 102)

> slope problems are the focus of interest because any topographic feature is composed merely of two elements, slope and altitude. (Consider slope S, altitude A and position P, then, topography = f(S,A), where A = f(P), S = dA/dP. This is a fundamental geomorphological concept). Thus mass wasting on slopes should have been a matter of primary concern for geomorphologists. However, they have indulged in their fantastic imagination about slopes, saying convex, concave, aufsteigende Entwicklung, absteigende Ent wicklung, retreat of slopes, and so on. This approach has had its time.

He calls for a rejection of circular reasoning (pp.4 - 11) and advocates rigorous studies of the mineralogical, physico-chemical and mechanical properties of rock involved in all erosion and mass wasting processes, studies as have been attempted so far almost exclusively by students of soil mechanics and certain aspects of geology. From this standpoint the present thesis is mainly irrelevant. However, it is worth emphasizing as a basis for future work on processes in the Souris Valley since it is only with such an understanding that really satisfactory inferences can be made about processes operating in the past.

The fluvial processes of the present Souris River have not yet been the subject of any particular study, although patterns of groundwater flow at three locations in the valleys of the Rivers Cypress, Pembina, and Assiniboine have been established (Meyboom, van Everdingen, Freeze, 1966). Inferences were made on the possible effects groundwater has on channel flow and changes in erosion and sedimentation patterns.

The Souris Valley is particularly notable for the development of river cliffs. Typically, a river cliff is not being eroded by the river along its entire length, due to the shifting of the channel away from its base. This is evident both at the present river level as well as at higher levels on terraces. Generally, where the river cliff is not being eroded, that is undercut, its overall gradient declines with time, often gradually becoming less and less steep (possibly regularly) with increasing distance from the present position of the channel. Shale scree has accumulated at the bases of many cliffs. Dr. W.J.Brown (pe rsonal communication) has examined and mapped a large number of these features between the town of Souris and the confluence with the Assiniboine.

River cliffs formed by the Souris River are subject to modification by mass wasting. S.J.Simpson (personal communication) has identified and located a number of slope processes or the specific features formed by them. He has recognised soil creep, slope wash, basal sapping, a group of processes under the general heading 'biotic' as well as slumps (both stable and potentially unstable), sheet slides, bowl slides (distinguished by crescentic head scarps), clitter (the concentration of boulders being attributed to the washing away of fine material, both at and away from the present river channel), sheet scree or talus, scree cones, rills and gullies. He has also started a skeleton programme designed to obtain information on the rates at which some processes are operating.

These processes are functions of local relief, the properties of the rock involved, and climate. Local relief is a function of the post-glacial development of the Souris Valley (see Chapter 3). The relation of these processes to the mineralogical, physico-chemical, and chemical properties of the local shale and surficial deposits, for which Yatsu calls, has not been attempted. Elsewhere in Manitoba Warkentin (1961) has ascertained that the clay minerals of landslip areas consists of illites and montmorillonites. Table 2 provides an illustrative summary of some features of the climate which would be expected to have some control over rates of processes and their seasonal variations.

Since processes operating at present are marginal to the main problem of this essay it is not proposed to discuss them in any detail. In any case this could only be done by conjecture. In general, processes are sensitive to changes in temperature and precipitation

Table 2 Selected Climatic Data

(From records of the Meteorological Division, Department of Transport, Canada, 1947, 1954, 1956)

Jan.	Feb.	Mar.	Apri	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
The monthly averages of daily maximum and minimum temperatures at Ninette (Over 25 years)											
11 -8	17 -3	30 10	50 27	66 39	74 49	80 54	77 51	66 42	53 31	34 16	18 1
Average monthly total precipitation in inches for Ninette and Souris, in order (Over 25 years)											
0.80 1.08	0.65 0.71	0.84 1.09	1.41 1.37	2.01 1.56	3.09 3.09	2.10 2.49	2.31 2.18	1.48 1.55	1.30 1.31	1.04 1.02	0.77 0.87
Average monthly snowfall in inches for Ninette and Souris, in order (Over 25 years)											
8.0 10.8	6.5 6.9	7.7 10.3	5.7 4.2	0.3 0.1	- -	- -	- -	0.2 0.1	4.4 5.1	6.7 8.5	7.1 8.5
The average number of days per month with measurable rain (top line) and snow (bottom line) at Minnedosa (Over 10 years. Figures not available for Souris and Ninette)											
- 8	- 8	- 8	4 3	10 1	11 -	11 -	9 -	8 1	3 2	1 6	- 8

Frost data for Ninette (Over 36 years). There are an average of 102 frost-free days each year.

LAST FROST			FIRST FROST		
Average	Earliest	Latest	Average	Earliest	Latest
May 31	Apr. 30	July 3	Sept. 10	Aug. 20	Oct. 13

which are obscured by the averages in Table 2. Rates of processes would be most usefully measured in very close conjunction with detailed local meteorological observations. Most processes are likely to be rapid during the spring thaw. Summer rain is responsible for soil erosion and the quantity and movement of groundwater must exert a strong control over mass wasting. None of these problems have been investigated in the Souris Valley. Baracos and Bozozuk (1958) have made accurate measurements of up and downward movement only in Agassiz clays related to season and dry/wet periods.

A general study of processes in the Souris Valley also requires that distinctions be made between those operating at present and those which ceased to operate at some time in the past. The writer does not know of any features in the Souris Valley which have been shown to be, for example, periglacial in origin. If periglacial processes operated mainly immediately after the deglaciation of the area, given the nature of the development of the valley, within the actual valley only the 'high bluffs' (delimiting 'Stage 1', Chapter 3) are as old as this. However, Elson (1955, p. 138) has inferred that ice wedges, stone polygons, and involutions were formed in the Tiger Hills region during or after the final subsidence of Lake Agassiz from the Campbell strandline. He further suggests (p. 179) that small ice wedges are forming during the winter seasons at present. This is obviously a matter for investigation. Given the chronology as outlined in Chapter 3 the maximum age of a deposit or feature can be inferred on the basis of position or altitude.

Large slumps occur particularly in the Tiger Hills and Wawanesa Sections of the valley. Just south of Wawanesa (Plates 17 and 18), according to local inhabitants some slumps are very recent. Others have probably occurred within a few hundred years. It is considered, however, that large stable slump complexes in the Tiger Hills Section are much older. Their distinctive character is shown in air photographs (Plate 24). The slumps sometimes hold up lakes. Bessants Lake (Plate 24) is the largest of such lakes. The distribution of slump complexes is shown in Figure 7a. Each complex is outside a pronounced bend in the river channel on the concave side. The river, in eroding vertically, also moved laterally, creating well-defined slip-off slopes. Large scale slumping occurred due to undercutting during this process. The maximum age of the slumps in N.E. $\frac{1}{4}$ sec.28, tp.6, rge.18 (south west segment of Plate 24) can be related to a small terrace just to the south (near the southern edge of Plate 24). This terrace, about 10 feet above the present river channel, is crossed by a number of arcuate ridges and swales, ending abruptly against the slump complex. From this juxtaposition it might be inferred that the slumping occurred during or since the formation of the terrace.

A pit dug on top of one of the ridges showed that the predominant granular sized gravel consists of rounded shale fragments. Fragile unbroken shells of molluscs are abundant. Because of the broad similarities between the slump complexes it is conjectured that they were all subject to some general control, perhaps merely a limiting relief, some general causal factor relating to groundwater, or a change in physical conditions due to a change in climate. This topic is considered further in the section on 'Climate and the Chronology'.

Accelerated erosion. Soil erosion is a direct effect in many cases of man's activities. The soil is sensitive to the changes in surface resistivity and infiltration capacity brought about by deforestation, grazing, and cultivation. Gulley erosion and aggradation are more manifest than sheet erosion. Gullies are generally of the discontinuous type (Leopold, Wolman, and Miller, 1964, p. 448). Two of the largest gullies in the area are those cutting back into the main terrace, north of the river, ½ mile north east of Bunclody.

The small gullies or valleys along the south edge of the main composite terrace in secs.2 and 3, tp.6, rge.18, possibly began to develop immediately after the diversion of the Souris River, as soon as Langs Creek began to lower the local base level. Plates 9 and 10 show what recent processes have been operating in one of these valleys as the result of the cultivation of the terrace.

The V-shaped valley-fill shown in Plate 10 is about 10 feet wide and consists of twenty bands of silt sand and gravel. Buried cans farther upstream demonstrate its recent origin. To the left of

PLATE 9. A DISCONTINUOUS GULLEY IN THE PEMBINA TRENCH

PLATE 10. VALLEY-FILL REVEALED IN THE GULLEY

The abandoned farm is located in S.E. $\frac{1}{4}$ sec.3, tp.6, rge.18.

the shovel the darker deposit consists mainly of rounded pebbles and thin shale fragments with their flattest sides parallel to the side of the valley. These are located on the inside of a bend in the valley. The exposure was very considerably modified even within two weeks of the photograph being taken, after the snow had melted. Similar valley-fills and discontinuous gullies are to be seen in the two ravines in sec.34, tp.5, rge.18.

CHAPTER II

EVIDENCE FOR THE DIVERSION

Evidence in General for Diversions

The diversion of the Souris River from its Elbow in sec.4, tp.6, rge.18, northward through the Tiger Hills to the Assiniboine River is, locally, both well-known and well-established. This chapter will be concerned with the evidence for it.

Rivers may be diverted from their original courses either by the process of capture or piracy, or by the blockage of its valley for example by mass movement or an ice or lava flow, or by some more or less catastrophic event destroying the side of the valley at some point causing the river to follow a new course. Conceivably, some agent such as an ice flow could cause a diversion and then disappear, perhaps leaving no evidence, after the new course had become established.

The hypothesis of river capture has been invoked frequently to explain given drainage patterns. Generally speaking the greater the period of time which has elapsed since capture the less conclusive is the evidence. Then if the problem is to be pursued, other conditions have to be reconstructed such that the probability of occurrence can be postulated. This might require that geological structure be demonstrated to be, or have been at some time in the past, favourable, and that the probable drainage characteristics before capture could allow that capture was possible. Another line of reasoning has depended on a supposed imminent capture within a regional drainage network (Wooldridge, 1954, p. 235). The distribution of fresh water fauna is another kind of evidence which has been used to reconstruct former lines of drainage. Although not with reference to river capture Mozley (1934) has considered the changes of drainage patterns associated with glacial Lake Agassiz in explaining the post-glacial distribution of fresh water molluscs.

The questions which these methods raise is not so much their general validity as some order of priority. Given a particular problem it is possible to reject all ambiguous evidence. However, in trying to elucidate a chronology, for example, this action would almost certainly lead to an impasse. Alternatively, the initial question may be posed in such a way that minimal consideration need be made of ambiguous evidence. This latter is a significant, if not fundamental, aspect of recent trends in geomorphology (Chorley, 1965).

However, the present discussion is concerned with the consistency of existing evidence, incomplete as it is, with the hypothesis of river capture in the context of the Pleistocene history of south west Manitoba.

Features generally associated with, and taken to be evidence of, capture may be listed as follows :

I. A distinctive drainage pattern.

a) A conspicuous bend or elbow in the captured stream at the point of capture.

b) An alignment of the beheaded stream with the valley upstream from the elbow.

II. A wind gap.

III. An underfit (beheaded) stream which is

a) small in relation to the dimensions of the valley,

b) possibly incapable of removing all the material brought into the valley by its tributaries.

IV. A correlation of long profiles and terraces and terrace deposits upstream from the elbow and in the underfit valley.

V. Incision of the captured stream below the level of the wind gap.

VI. A reversed tributary at or near the elbow.

When observed in isolation, each of these features should only be looked upon as an indication that capture may have taken place, not as proof. Even long profiles are best looked upon as permissive rather than substantive evidence (Brooks, 1965). In this particular case, however, it will be shown in following sections that all six features are very much in evidence and are best explained by invoking the diversion of the Souris River, the term 'diversion' being used because all these features could be consistent with the types of diversion other than capture.

Most of these lines of evidence are apparent from topographic maps and air photographs and, indeed, the drainage patterns and general trends in the topography are much more difficult to ascertain in the field. On the other hand, terraces and surficial deposits require close first hand inspection.

Evidence and Post-Diversion Modifications in the Pembina Trench

The Souris Elbow is conspicuous on topographic maps, both on a regional scale and at, say, a scale of 1 : 50,000. The shape of the Elbow in detail has been due to the gradually increasing sinuosity of the river since diversion took place.

Upham (1896, see p. 1 above) described the general evidence such as the alignment of the Souris Valley with Langs Valley and the Pembina Trench as well as the striking wind gap, Langs Valley, even though it does not conform to the more common conception of a wind gap as being a col in the crest of a homoclinal ridge. These latter features are actually more apparent on topographic maps than in the field.

Upham also described the ponding up of Lakes Bone, Overend, and Pelican by colluvium from the sides of the Trench, there being no sufficiently powerful stream to remove it. Since the Pembina Trench originally carried the overflow from both glacial Lakes Souris and Regina (Johnston and Wickenden, 1930) the Souris River itself, upstream from the Elbow, is also underfit.

The main composite terrace. Before its diversion the Souris River flowed through the wind gap at an altitude of about 1370 feet. Plate 11 is a view to the west from the wind gap near the centre of sec.3, tp.6, rge.18, showing part of the cross profile of the Trench west of the Elbow and the continuation of the main terrace across the Souris River. Elson (1955, Plate 5b) has drawn the long profiles of

PLATE 11. THE VIEW TO THE WEST FROM THE WIND GAP

The profile of the Pembina Trench west of the Elbow as seen from the dissected edge of the main terrace near the centre of sec.3, tp.6, rge.18. The south end of the Tiger Hills Section of the Souris Valley and the rise from the main composite terrace up to the higher outwash terrace are seen behind the horses.

the Souris River and Pembina Trench. The channel of the present Souris River only reaches the altitude of the wind gap south of the town of Souris, some 25 miles upstream from the Elbow. However, this long distance is due in part to the level of the floor of glacial Lake Souris basin being at a lower altitude than the head of the spillway from the Lake at Bunclody.

Throughout Langs Valley the edges of the Trench floor, although obscured locally by colluvium (except along the shores of Pelican Lake), are clearly discernable. There is no doubt about the altitud inal relationship between this supposed wind gap and the main composite terrace in the Souris Valley upstream from the Elbow (Fig. 7a). The rear edges of this terrace increase gradually in height at le ast as far as Bunclody and were traced in the field on b oth side s of the valley almost continuously between Langs Valley and Hi ghway 10. They can also be clearly identified on air photographs and topographi c maps at a scale of 1 : 50,000. On the National Topographic Series map 62G/5W the position of the rear edge of the terrace is marked by the 1375 contour, in the vicinity of the Elbow. Between Highways 346 and 10 the 1400 feet contour marks the edge. Between these two highways the rear edge of the terrace on the north side of the valley is much more precise and continuous than is suggested by the contours. In certain localities it is emphasized by cultivation as in Plate 13 in which a remnant of a higher discontinuous terrace can be clearly seen.

The area was originally traversed for the main purpose of

PLATE 12. THE MAIN COMPOSITE TERRACE IN THE PEMBINA TRENCH

The view from the N.W. $\frac{1}{4}$ sec.22, tp.6, rge.19. The storage bin in the distance is beside Highway 10. The vertical range of the terrace here is at least 50 feet. Igneous boulders lie in the foreground.

PLATE 13. THE NORTH SIDE OF THE PEMBINA TRENCH

Small t ributary valleys graded to the main terrace in sec.21, tp.6, rge.19. The Tiger Hills rise slightly above a higher terrace.

mapping a supposed terrace sequence in detail. However, it soon became apparent that apart from low terraces less than 25 feet above the river channel this westward extension of the Pembina Trench is dominated by the main terrace shown in Figure 7a, which, although composite, cannot be easily subdivided. In places the terrace has almost a stepped appearance. Elsewhere, as in Plate 12, it has a continuous slope and considerable range in altitude. The abrupt incision of the river within a relatively narrow belt, below the lower or front edge of the terrace marks a distinct phase in the later history of the valley. This main terrace is cut almost entirely in shale which is exposed in the large number of river cliffs formed during this more recent phase.

The chief interest, therefore, in the composite nature of the terrace is that it may be inconsistent with the hypothesis of river capture since it would be expected that a retreating nickpoint would c reate a nar row gorge incised in the near-level former Trench floor. (See the section on 'The Relationshi ps between Features in the Wawanesa Embayment Se c tion and those Upstream').

Plate 13 also shows the manner in which the side of the Trench is dissected. Some of the se small valleys end abruptly at the rear edge of the terrace without a trace of an extension, but the majority continue across the terrace in shallow inactive depressions. Others are still being eroded and cut deeply into the terrace. Whereas the front edge of the terrace often terminates at an undercut river cliff its position is sometimes indicated by a slightly steeper gradient crossed by small dry valleys, as in S.W. ¼ sec.13, tp.6, rge.19, which do not extend across the lower terrace. These dry valleys could have been formed either when the water table was higher, before the Souris River had eroded to its present depth, or during a recent phase when the climate was different from that of the present.

The two gullies in the terrace at Bunclody can be seen on an air photograph to be integral parts of a small drainage system. Bunting (1961) has described subsurface seepage lines in Scotland. There, however, they have no topographic expression and are recognisable by their occasional moistness at the surface. At Bunclody there is a network of small linear depressions but no evidence of surface flow. This explains why the two anomalous gullies are downstream from relatively small features in the side of the valley, their initiation and development being controlled by subsurface seepage. This is one of the few areas where the main terrace is not cut in shale. Near the rear edge of the terrace a layer of gravel is exposed in the side of the gulley about 6 feet beneath the surface. Finer material above this gravel is stratified and cross-bedded.

Leopold and Miller (1954, pp. 76 - 83) have discussed the relative ages of erosion features in the present topography of alluvial valleys in Wyoming, with reference to terraces and sequences of events in the master streams.

Terrace deposits. If it can be demonstrated that the only source for fluvial deposits in the underfit valley is within the present catchment area of the river which is supposed to have been diverted, then their distribution is explained by invoking a continuous line of drainage between them and their original source. Since most of the fluvial deposits in this case are derived from glacial deposits or the local bedrock, this kind of evidence has not been established. However, it will be shown that the deposits on the main composite terrace may have some bearing on the process by which the Souris River was diverted.

Between Highways 346 and 10 there are no extensive terrace deposits exposed. Vertical sections through the terrace cut by river cliffs show a soil profile and a few isolated boulders in contact with the shale bedrock.

The gravel near the south end of the Tiger Hills Section of the Souris Valley, in sec.8, tp.6, rge.18, shown in Plate 14, is at least 10 feet deep but evidently only of limited horizontal extent (a pit, 6 feet deep, a few yards to the south of the gravel in Plate 14, reveals mainly silt). The gravel is mainly small with a large proportion of sand. Pebbles of strongly weathered igneous rock and rounded blocks of crumbly shale are common. In the west side of the gravel pit sorted sand and gravel dip southwards at an angle of about 20°. It could have been deposited at the end of the spillway southwards through the Tiger Hills, first intimated by Upham (see p. 3). That high part of the Trench floor, in N. ½ sec.2, tp.6, rge.18,

PLATE 14. GRAVEL ON THE MAIN COMPOSITE TERRACE

The south side of a gravel pit near the rear edge of the terrace, at the top of the river cliff, in E. ½ sec.8, tp.6, rge.18, at about 1370 feet (located in Plate 23).

which is above 1375 feet may have been formed by deposition at the southern end of such a spillway. The surficial material here is not exposed.

There is a thick lag concentrate at the front edge of the main terrace in the road cut shown in Plate 2 and located in Plate 23. On the other side of the road at the same elevation, finely bedded sand underlies small shale fragments. Plate 23 also shows the location of an exposure of very fine cross-bedded sand (Appendix I). It seems likely that this was deposited by a small tributary entering the valley from the north at some time in the past. Eastwards, along the edge of the terrace, boulders lie scattered on the surface. They are to be seen concentrated in an area 100 yards long within the Elbow in sec.4, tp.6, rge.18, as well as in the N.E. ¼ of this section.

The main terrace between Highway 346 and the Elbow is covered with a variety of deposits which change their character abruptly over short distances. The significance of their interpretation will be shown later in the section on 'The Relationships between Features in the Wawanesa Embayment Section and those Upstream'.

The reversed tributary. A reversed tributary near points of capture is generally characteristic. Figure 2 shows that more than 50 square miles are drained by Langs Creek and its tributaries. All tributaries to the Trench, before diversion, must have joined the main stream and flowed towards the east. The reversal was presumably effected by headward erosion by Langs Creek from the direction of the Elbow, first capturing Nelsons Creek and then proceeding for another 4 miles. This is surprising because of the presence of the raised Trench floor in N. ½ sec.2, tp.6, rge.18, and because the present gradient of the reversed stream to the east of this is very slight. In fact, over a distance of 3 miles, although micro-relief is considerable it is difficult to detect the trend of the Trench floor. Part of the course of Langs Creek lies over the preglacial depression in the bedrock surface (Fig. 2) and the surficial deposits (including the kinds shown in Plates 3 and 4) may have offered little resistance to erosion. However, shale appears at the surface from the centre of sec.1, tp.6, rge.18, eastwards. In its lower mile Langs Creek has laid down at least 6 feet of floodplain deposits and a delta at its confluence with the Souris River (on the sharp concave bend of the Elbow).

Post-diversion modifications. There is an interesting contrast between the tributary valleys on the north and south sides of the Pembina Trench. This is due mainly to two related factors : the degree of drainage integration and the size of catchment areas. The basin around sec.27, tp.6, rge.19 is exceptionally large for the end moraine, and, from their appearance, all the main tributaries probably carried a very large discharge soon after the retreat of the ice.

On the south side of the Pembina Trench tributary basins are much larger due to the regional slope of the land towards the north east and to the relatively smooth surface of the moraine and outwash. Streams developed early and presumably kept pace with the downcutting of the Trench spillway waters until after the diversion when the Souris River and its reversed tributary perhaps began to erode more rapidly. It was anticipated, therefore, that these tributaries would offer ideal circumstances for a study of nickpoint behaviour, particularly the extent to which they maintain their identity during recession.

Many tributaries have cut deep valleys in the main terrace. Others cross it in, at most, a shallow depression. At the Elbow itself one or two tributary valleys hang, showing no signs at all of recent modification. The valley in the W. ½ sec. 36, tp.5, rge.18 was graded to the main terrace such that the latter extends up the valley as a small floodplain. However, the present channel is incised 15 feet below this at the edge of the Trench but there is no conspicuous nickpoint upstream. The valley in the E. ½ sec.34, tp.5, rge.18 extends across the main terrace in a shallow depression.

Only Nelsons Creek was studied in detail. Its long profile was measured over a distance of 2½ miles downstream from Margaret cemetery using a steel tape and an abney level. Near the cemetery the river has a floodplain up to 300 feet wide with stratified deposits. Upstream it is clearly underfit and has a very gentle gradient. The measured profile was found to be surprisingly uniform. The only slight irregularity was at an elevation of 1390 feet which only showed after the profile had been plotted. But here the maximum gradient was less than 2°. It is located just south of the section line and upstream from the two low terraces shown in Plate 15. This local increase in gradient could therefore be a nickpoint which has receded upstream from Langs Valley. Although the left bank tributary in N.W. ¼ sec.33, tp.5, rge.18 was not accurately surveyed there is a more marked change of gradient in the valley floor at about the same altitude. There are several other terrace remnants in the main valley including the distinctive amphitheatre-like hollow in N.E. ¼ sec.33, tp.5, rge.18. The small tributary valley at the south end of sec.4, tp.6, rge.18 hangs 18 feet above the channel of Nelsons Creek. Its floor is very broad and three gullies dissect this edge where bedrock is exposed.

Another result of the diversion has been the dissection of the composite terrace by short tributaries of Langs Creek in secs. 2 and 3, tp.6, rge.18 in a manner somewhat similar to that envisaged for the Farmington River, Connecticut by Carter and Chorley (1961).

These gullies or small valleys (Plates 9 and 11) raise at least three problems : their age, reasons for a preferred orientation, and asymmetry. A large number of maximum valley-side slope angles were measured in preparation for a quantitative study. There seemed to be systematic variations in slope angles (of the kind detected by Carter and Chorley) but they were unrelated to stream order as defined by Strahler, although the relationship to stream order as defined by Scheidegger (1965) may be a closer one. There are no

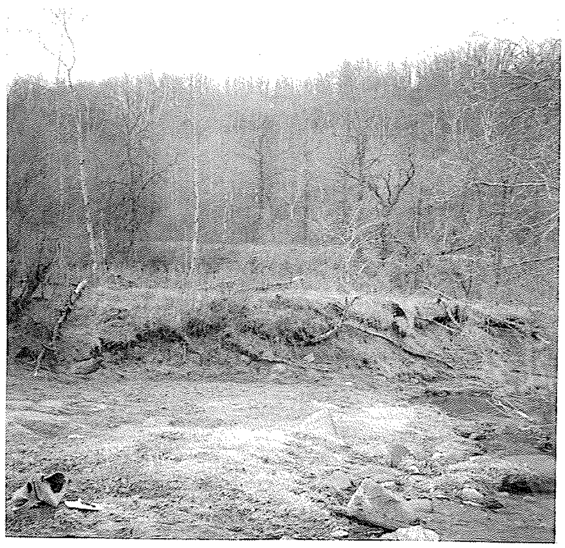


PLATE 15. TERRACES IN NELSONS CREEK

In S.E. ¼ sec.33, tp.5, rge.18, downstream from the nickpoint in the long profile of Nelsons Creek.

permanent streams in these gullies and they all have at least a small valley-fill. The terrace surface is irregular, first order channels are difficult to define both on air photographs and in the field, and it is impossible to define watersheds precisely, although the point from which the drainage seems to diverge, towards the west, south, and east is near the track junction half way along the north side of sec.3, tp.6, rge.18.

Other features relating to the history of the diversion lie to the north of the Elbow, in the Tiger Hills and in the Wawanesa Embayment between the Tiger and Brandon Hills.

Evidence North of the Tiger Hills for the Occurrence of the Diversion

Several minor features in tp.7, rges.16, 17, and 18 are consistent with the discharge of what is now the Souris River having increased dramatically at some time after the formation of the Wawanesa Embayment and after the establishment of a local drainage pattern. In other words it is likely that a small stream, comparable in size to Methven and Oak Creeks, developed at an early stage along the line of this Section of the present Souris valley, and that its discharge subsequently increased due to the addition of that of the upper Souris.

Throughout the area streams are typically underfit. By their very nature, therefore, some evidence of their earlier appearance remains. On the other hand the Souris River, in the above context, is overfit such that direct evidence of its predecessor is obliterated. Terraces, meander scrolls and cut-offs merely provide evidence of its development.

Four observations need be made. Firstly, the line of the Souris is an integral part of the Embayment drainage pattern. Secondly, there is a distinct change in the orientation of the valley near the point where it is later inferred that a stream consequent on the newly exposed floor of glacial Lake Brandon had its headwaters. That is, in the Tiger Hills the orientation of the valley is from the south south west to the north north east, for a distance of 5 miles. From the north side of the Tiger Hills to the confluence with the Assiniboine, throughout the Wawanesa Embayment, for 13 miles, the orientation is from the south west to the north east. Thirdly, the contours crossing the Embayment have a distinctive pattern and suggest that it is only the Souris River which has modified the surface of the former significantly. Between 1200 and 1300 feet the general trend of the contours ignores the Souris Valley completely (Fig. 7a). The contours from 1300 up to about 1400 feet, however, change direction where they would have crossed the valley, suggesting that this may have been the longest axis of the Embayment after the fall in level of glacial Lake Brandon. Fourthly, with the enlargement of the meanders in the main valley small streams have been abstracted or captured, in secs.7 and 18, tp.7, rge.17. In one or two cases the process is imminent or at least has been thwarted (see north west corner of Plate 19).

Alternatives to Capture as the Cause of the Diversion

Some alternatives to capture as means of diverting streams were mentioned at the beginning of the chapter. There is no indication that any catastrophic event, involving, for example, earth movement, was responsible for this particular diversion. Another possibility, the temporary blockage of the Trench, by, for example, an ice lobe, might be expected to leave some evidence, such as a moraine. Although the Trench floor rises considerably higher than 1375 feet in sec.2, tp.6, rge.18, the nature and origin of the underlying material is unknown, there being no natural exposure. No other supporting evidence has been found.

Ellis and Shafer (1943, p. 23) did not give any support for their claim that

> When the ice had cleared from the northern point of the Pembina Hills, the lower-lying land of the Assiniboine delta area was covered by a bay of glacial Lake Agassiz, and the waters in the deeper ravines on the left bank of the Pembina channel could flow northward. This reversal of drainage by the uncovering of the lower-lying land in the north, and the dammimg of the waters of the Pembina channel by sedimentation from the streams that flowed in from the south, forced the waters which entered the channel from the west to turn northward through the ravine in Township 6, Range 18, thus diverting the flow of water in the main channel and determining the present course of the Souris River and Oak Creek.

R.W.Klassen (personal communication) has suggested that diversion may not have required headward erosion by a tributary of the Assiniboine but that the re-establishment of the general trend of drainage towards the north was permitted at an early stage by the formation of a low col in the Tiger Hills by an ice lobe.

In this case, implicitly, either an ice lobe from the north effectively blocked a gap in the north wall of the Trench such that the base of the ice was at least as low as the floor of the Trench, getting lower towards the north, or, a readvance of the ice eroded a northward-sloping depression through the Tiger Hills, presumably just not reaching the Trench. Both of these hypotheses would seem to require very peculiar local conditions, and no supporting evidence is known to the writer, although the general characteristics of the area are not necessarily inconsistent with such explanations. Klassen specifically called for a general lowering of, or depression in, the Tiger Hills at this point. Plate 16, together with topographic maps, indicate that this is not the case. Given all the evidence provided by Elson (1955) a break through the Tiger Hills is most likely to have been achieved by the spillway first intimated by Upham. This is consistent with the profile of the Tiger Hills as seen in Plate 16.

On the other hand, deductively, if headward erosion from the north took place, since the wind gap is at about 1370 feet one would expect evidence of a relatively steep-sided valley, both upstream and downstream from the Elbow, immediately below that altitude. There is no direct evidence for such a valley especially upstream from the Elbow. Here, a broad terrace was formed just after the diversion. Incision below this terrace came later. Within the Tiger Hills six major bends have developed in the channel of the Souris River since the diversion. From the attitudes of their slip-off slopes it can be deduced that the channel was formerly straighter. In sec.16, tp.6,

PLATE 16. THE TIGER HILLS FROM THE KILLARNEY PLAIN

The farm on the left is in the S.W. ¼ sec.32, tp.5, rge.18. The Pembina Trench lies out of sight just below the skyline on this side of the Tiger Hills, sloping down from west to east, from left to right. The Souris Valley where it cuts through the Tiger Hills can be seen near the centre of the photograph.

rge.18 the rear edge of the slip-off slope is just below the level of the Trench floor. There are a number of small tributary valleys behind this slip-off slope which do not continue across it and which therefore were formed at or before the time of the diversion. (See the reference to this general problem in the section on 'The Relationships between Features in the Wawanesa Embayment Section and those Upstream'.)

Level of Lake Agassiz I at Wawanesa and the Effect of Tilting

The general absence of beach ridges makes the level of Lake Agassiz I (or what Elson, 1958, Fig. 10, calls Early Lake Agassiz) at Wawanesa difficult to fix precisely. Some approximate idea of its height above sea level can be got from Geological Survey of Canada Map 1067A (Halstead, 1959) by Elson. The southern boundary of the Assiniboine deltaic and offshore deposits from the neighbourhood of Oak Creek past Banting towards Martinville always lies above the 1200 feet contour. It is usually between 1225 and 1250 feet except north west of Banting where in secs.29 and 33, tp.8, rge.17 there are two beach ridges. One is about 1200 feet above sea level, surrounded by deltaic deposits, and the other, in an area of lag concentrate, is at approximately 1230 feet. South of this line any lacustrine deposits were supposedly associated with glacial Lake Brandon.

It is also possible to infer the level of the former Lake in this area from Johnston's map and profile of the Lake Agassiz beaches (Johnston, 1946, Figs. 1 and 2). Wawanesa lies near the extension of isobase 4 as drawn in his Figure 1, between isobases 4 and 5 such that the level of the highest, Herman, beach in this vicinity would be perhaps 1245 feet. The average gradient of the Herman Beach between isobases 4 and 5, due to tilting, according to Johnston, would be about 75 feet in 60 miles. Upstream from the Elbow the Souris River is roughly parallel to the isobases so tilting did not have any significant longitudinal effect on the river. However, over the 18 miles between the Elbow and the confluence with the Assiniboine the river is almost parallel to the line of maximum tilt. Over this distance, therefore, the vertical fall of the river has been reduced, *in toto*, by 22 feet, say 1 foot per mile. Elson (1955) calculated that the southward tilt in the basin of glacial Lake Souris was 40 feet in 85 miles.

It should be pointed out, of course, that Johnston's longitudinal beach profiles may be so inaccurate as to make such inferences and calculations worthless. For example, Nikiforoff (1947) can find no evidence for differential uplift at all. He explains the vertical divergence of the beaches towards the north by a mechanism in operation during the retreat of the ice front. However, this mechanism does not seem to be entirely plausible and is made cumbersome by the need for an ice front retreating southwards.

The questions raised by Kupsch (1967) are more timely, even if extreme. He outlined the well-known problems of relating the beach ridges to precise lake levels and with specific reference to

Johnston's (1946, Fig. 2) diagram of the beach profiles proposed that at least some of the hinge lines could be eliminated on the basis of inaccurate fieldwork. Does the crust really behave in the way suggested by this diagram? Are the dots showing beach levels accurately correlated with the correct lake levels?

However, on the basis of the above deductions the level of Early Lake Agassiz near Wawanesa (Fig. 7b) will be taken to lie between 1225 and 1250 feet (compare 'about 1250 feet', Elson, 1962, p. 8).

The Time of the Diversion

The question of underfitness. Elson (1955, p. 25) describes the Tiger Hills Section as a V-shaped gorge, saying that paired terraces have not been recognised and that other terraces are sparse. The term 'gorge' is best reserved for valleys deep in relation to their width. Here, cross-sections of the valley tend to be dominated by the long, wide, gently-sloping spurs covered by river gravels.

Later, Elson (1955, p. 237) continues that 'the lack of stream terraces and alluvial fans of tributary gullies in the gorge suggests (1) that downcutting has been almost continuous, and (2) that discharge was never much greater than it is at present'. Although downcutting may well have been continuous it is very unlikely to have been at a constant rate. It will be shown that, since diversion, discharges have varied between wide limits.

One of the most comprehensive discussions of underfitness in rivers has been by Dury (1964a, 1964b, 1965). In referring to his sketch (1964a, p. A18, and Fig.16) of the Souris River at Minot in North Dakota he reconstructed a sequence of three events. The first was the 'cutting of a very large meandering channel by meltwater' (this channel can be most clearly seen in Lemke, 1960, Plate I, East Half), then the 'cutting of large meanders, equivalent to valley meanders in unglaciated regions, by an ordinary stream', and, thirdly, 'the cutting of the present meanders by the reduced stream'. The history of the Souris River in North Dakota is not strictly paralleled by its history in Manitoba because of the nature of the deglaciation of the area as a whole and the formation of glacial Lake Souris (Lemke, 1960). It has already been pointed out in an earlier section that the present Wawanesa Embayment Section of the river is manifestly underfit (Dury, 1964a, p. A1) because it meanders within the meandering course of the valley. This same observation will be taken up again later.

The Two Creeks Interval. With reference to the neighbourhood of Wawanesa, Elson (1955, p. 248) stated that the

> meander scars of Souris River have about the same radius as the present meanders, hence, the discharge of Souris River was about the same at the time of capture as it is now (Dury, 1954). The capture must have occurred after glacier drainage in Saskatchewan began to discharge through the Qu'Appelle - Assiniboine River system. The meander cores have about the same altitudes as the adjacent uplands; it is believed that the meanders were established very early in the development of the valley, shortly after deposition of the adjacent part of the Assiniboine delta, and before Assiniboine River had incised the delta very deeply. The former gradient of Souris River, represented by the terrace (at

> 1180 feet) a few feet below the upland surface south of Treesbank correlates with terraces in the Assiniboine valley that represent the Tintah phase of Lake Agassiz I.

It has already been shown that the first sentence of this quotation is incorrect. Because of this, the reasoning about the time of the diversion is probably not entirely correct. In the following chapter an early stage in the development of the Souris Valley is reconstructed (see Figs. 5 and 7a, Plates 17, 18, 19, and 22, and Table 3). Given the problem of reconstruction of former discharges, the discharge at that time <u>could</u> have been of the same order as the maximum discharge down the Pembina Trench. Thus diversion could have occurred <u>before</u> glacier drainage in Saskatchewan began to discharge through the Qu'Appelle - Assiniboine River system. (Johnston and Wickenden (1930) have described glacial Lake Regina itself.) This is unlikely, however, because of the similarity of 'Stage 1' at Wawanesa and the post 'outspill of meltwater' stage at Minot (Dury, 1964a, Fig. 16). This problem might ultimately be resolved by relating the mineral assemblage in terrace gravels at Wawanesa to catchment area.

The second half of the above quotation quite correctly emphasizes, however, the early development of the meanders near Wawanesa, and therefore, implicitly, the early occurrence of the diversion. Furthermore, since the 'terrace (at 1180 feet)', which Elson correlates with the Tintah phase of Lake Agassiz, must post-date the diversion, implicitly, the diversion occurred before Lake Agassiz I was drained. However, this is contradicted by the more recent quotation given later in this section.

Upham (1896, pp. 268 - 272) did not state explicitly that in order for the diversion of the Souris to take place, given a southward sloping spillway through the Tiger Hills (for which he provided no conclusive evidence) formed by the outflow from a lake dammed north of the Hills, the direction of slope of this spillway had to be reversed. He merely stated that the spillway was so deep that when the lake drained, the Souris River was diverted northwards. Elson (1955, p. 237) pointed out that this was not possible because, however deep, the north end of the spillway had to be higher than the south end. Headward erosion by a tributary of the Assiniboine, however, could have reversed the gradient and he suggests (1958, pp. 70 - 71) that conditions were favourable for this during the Two Creeks interval.

> Ice recession during the Two Creeks interval (about 11,000 (plus) years ago) lowered the level of Lake Agassiz to 830 feet or less. Valleys were initiated in the comparatively steep foreset slope of the Assiniboine delta and Assiniboine River cut deeply into the delta. This delevelling gave impetus to the headward growth of a small tributary of Assiniboine River that grew southwestward towards the channel across the Tiger Hills moraine that was eroded early in the history of the Brandon Lake.
>
> Advancing Valders ice closed the eastern outlet of the Agassiz basin and Lake Agassiz II was formed. Radiocarbon dates of alluvial fills in Assiniboine and Pembina valleys (Preston, Person, and Deevey, 1955; Barendsen, Deevey, and Gralenski, 1957) indicate that the lake attained a level of about 1140 feet about 8,000 years ago. Increased precipitation accompanying the Valders ice advance caused the small tributary of the Assiniboine at the west end of the Tiger Hills to erode headward. Lake Agassiz II existed until perhaps 5,000 years ago.

Even though Elson (1967) has revised the Lake Agassiz chronology (see Table 3, herein) he is suggesting above that headward erosion and capture occurred primarily as a response to the lowering of the local base level caused by the fall in level of Lake Agassiz I down to 830 feet. However, that this was not necessary is demonstrated by the observation that immediately after diversion (i.e. even before 'Stage 1 ') no part of the Souris Valley, at least south of Wawanesa, could have been at a lower level than about 1224 feet (see Fig. 7b). This is not even significantly lower than the highest level reached by Lake Agassiz I near Wawanesa which, as deduced in an earlier section, lay between 1225 and 1250 feet.

The basis for this argument is developed in the next chapter where 'Stage 1' in the development of the valley is defined. This stage which clearly post-dates the diversion is represented by bluffs whose bases lie between 1224 and 1280 feet above sea level and the apex of the meander core north of Wawanesa which is 1241 feet above sea level.

Thus, if capture resulting from headward erosion were the process involved a base level lower than 1224 feet was evidently not required. This means that diversion did not necessarily occur during or since the Two Creeks interval.

<u>The necessity for an early diversion</u>. Meander development near Wawanesa post-dates 'Stage 1' and from a consideration of altitude alone evidently relates to Lake Agassiz I. Elson (1955, see above) did believe that the meanders were established shortly after the deposition of the adjacent part of the Assiniboine delta. This is consistent with the occurrence of meander scrolls and river gravels

up to at least 1241 feet north east of Wawanesa. Rather than capture it is more likely that the ingrowth of meanders down to almost 1150 feet was associated with the drop in lake level during the Two Creeks interval (Lake Agassiz II only reached the height of 1140 feet). Unless the correlation be a chance one due to altitude the 'terrace (at 1180 feet)' could still relate to the Tintah phase of Lake Agassiz I as assumed by Elson (see above, and Fig. 7b, and Table 3).

Diversion, then, must have preceded or have been contemporary with Lake Agassiz I, since the meanders could not have developed before diversion because the local catchment area could not have contributed a large enough discharge. Thus diversion could have occurred between the Dry River or Treherne and Lake Agassiz I phases (Elson, 1958, Figs. 7 - 10).

The levels of glacial Lake Brandon during the Dry River and Treherne phases stood at about 1420 and 1270 feet respectively. As the lake level fell from 1420 feet, consequent streams presumably developed on the exposed lake floor (see north west quarter of Plate 19) and as the result of chance distribution, or local conditions, one of them could have immediately started to erode headwards southwards to the point where the spillway across the Tiger Hills had been formed earlier.

Mineralogical analysis of the surficial deposits on the floor of the Wawanesa Embayment (Fig. 3) might prove that the Souris River was diverted into glacial Lake Brandon.

CHAPTER III

THE POST-GLACIAL CHRONOLOGY

The Development of the Wawanesa Embayment Section since Diversion

<u>Stage I</u>. Further clues as to the nature of the diversion would be available if it proved possible to reconstruct with confidence the lower Souris Valley at the moment of diversion or very soon afterwards. Because the valley is so precisely incised beneath the floor of the Wawanesa Embayment such evidence must be sought on the present valley-sides.

The stage, described here as 'Stage 1', which can be identified on air photographs, topographic maps, as well as from a number of good vantage points in the field, is the earliest, that is the highest, stage recognised, but it may post-date the diversion considerably.

The course of the valley at that time is now delimited by at least nine bluffs (Figs. 7a, 7b, and Plates 17, 18, 19, and 22). Their bases lie between 1224 and 1280 feet above sea level, between 43 and 56 feet below the Embayment floor, and of the order of 85 feet above the present elevation of the river. Specific height measurements are considered to be accurate within ± 2 feet but typically the bases are gently concave and are irregular, locally, along their lengths. Figure 7b shows the heights of the bases of the bluffs and their relationship to the Embayment floor (not highly accurate having been


STAGE 1
STAGE 3
STAGE 2
1266 ft
1265 ft

generalised from topographic maps).

These nine bluffs are all cut in surficial deposits. There is no bedrock at all for at least 80 feet below the bluff in the extreme S.W. ¼ sec.17, tp.7, rge.17. In the S.W. ¼ sec.16, tp.7, rge.17, the bedrock is clearly exposed in the adjacent river cliff at the same height as the base of the bluff. Elsewhere the bedrock is just at or below the level of the bluff bases, although it is not exposed in every case.

The bluff bases mark the upper limits of extensive deposits of river gravels. Whereas there is no gravel in the bluffs themselves there is some exposed on the crest of the meander core 1 mile north east of Wawanesa (Plate 18) at an altitude of 1241 feet which is about 10 feet higher than the bases of the bluffs immediately upstream and downstream. The break of slope parallel to the 1225 feet contour in S.W. ¼ sec.6, tp.8, rge.16 may represent another bluff at 1215 feet but gravel can be seen scattered on the field above this level.

Just less than 1 mile south of Treesbank there is another well-defined bluff. At the west end of the terrace below it a river cliff exposes several feet of river gravels overlying sand (Assiniboine delta?) similar to that in which the bluff itself is cut. Since the terrace is 80 feet above the present river channel it is likely that this feature is related to this sgate.

Upstream, remnants of bluffs relating to this stage are less

Plate 18 Air Photograph of Wawanesa and Vicinity

certain. One may be preserved two fifths of a mile south south east of the pond in sec.18, tp.7, rge.17, and another one and one tenth miles due south of the pond on the opposite side of the river.

From the positions of the bluffs some idea of the width, direction, and shape of the valley at that time can be gained. Its width varied between 400 to 700 yards. Its course was gently sinuous and turned through a sharp bend in sec.18, tp.7, rge.17 (Plate 19).

Now, was this valley formed during and immediately after the diversion? Could it possibly have been formed before the diversion? Or did some time elapse after diversion before such a deep wide valley could be eroded? What was the discharge of the river at that time? Was it manifestly underfit? Did the river ever fill this valley, making it in effect its channel? Few of the answers to these questions can be other than surmise.

Almost the entire valley surface below the levels of the bluffs is covered with terrace gravels. As far as can be determined no such gravels lie above the bases of the bluffs. This suggests that this stage was preceded by a period of erosion during which there was no abundant supply of gravel and/or during the erosion of the 50 feet deep valley the sides were always undercut, or at least those parts of them which have been preserved, such that no gravel was deposited on them.

Eight miles north of the Pembina Trench the floor of the valley under discussion was almost exactly 100 feet below the level of the Trench floor. Thus headward erosion southwards was possible within this vertical range of 100 feet. Since this stage is cut entirely in surficial deposits it would seem on this account that bedrock had no control over the course of events at all.

Stage II. This arbitrary stage was selected to demonstrate the manner in which meanders developed. The reconstruction was based on the height of meander scrolls above the present channel. Generally the scrolls are continuous across each slip-off slope and can be traced on air photographs without difficulty. However, the method is not sensitive to the precise altitudinal relationships between the scrolls and the former associated positions of the channel. An accurate long profile of the present channel is not available and specific scrolls on different slip-off slopes have not been correlated. Despite this, it is considered that, on the scale plotted, the largest errors do not invalidate the general conclusions reached.

By the time this stage was attained the amount of vertical erosion achieved was approximately half of that achieved between 'Stage 1' and the present. It can be seen (e.g. in Fig.7a and Plate 17) that by now, throughout much of the valley, the meander belt was only a little wider than the valley at 'Stage 1'. The exceptional areas were north east of Wawanesa, where the early development of large meanders was the prime cause of their eventual abandonment, and in secs. 7 and 8, tp.7, rge.17, where a pronounced meander was the legacy of the only major bend in the valley at 'Stage 1' (Plate 19).

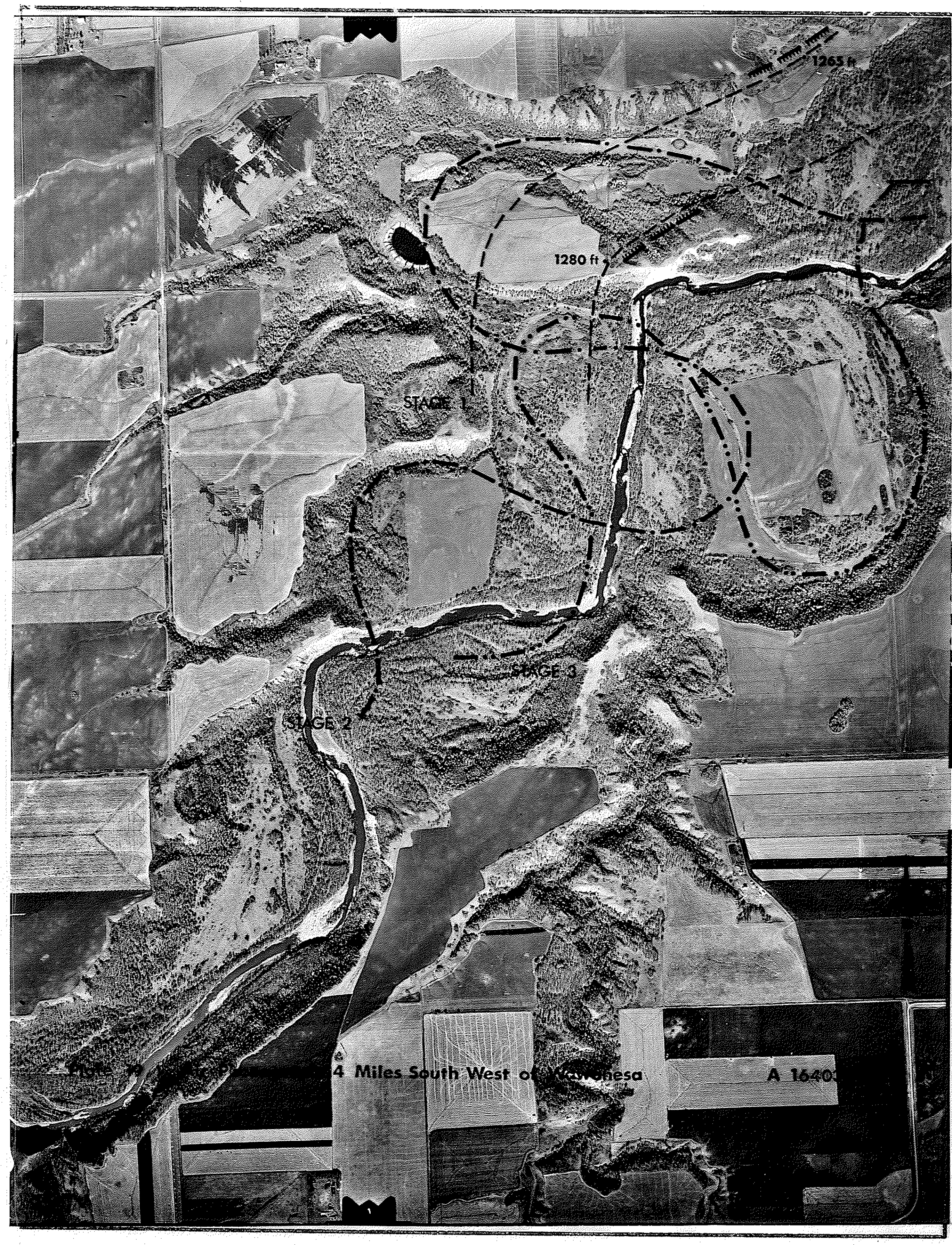


Plate [illegible] 4 Miles South West of [illegible]   A 1640[illegible]

Meander scrolls in sec.8, tp.7, rge.17 are taken as evidence for the 'Stage 2' meander shown in Plate 19. Immediately to the west and south west the foot of the old river cliff is 36 feet above the present river channel at the former's south end. Elsewhere in the valley points 40 feet above the present channel were located on the upstream and downstream sides of each slip-off slope. Scrolls were taken to indicate the direction in which the river formerly flowed across the slip-off slopes between these points but elsewhere, of course, the location of its channel had to be interpolated, sometimes over rather long distances.

Since 'Stage 1' the Souris River has deposited vast quantities of sand and gravel (Plates 20 and 21). There are eight good exposures of these river gravels in gravel pits on the slip-off slopes, but very few points where the total depth of the gravels can be measured. Likely sites on the eroded sides of the slip-off slopes are usually vegetated or the shale is obscured by slumping. On the other hand, in Wawanesa there are a large number of privately-owned wells which typically end 2 or 3 feet below the top of the shale (known locally as 'blue clay'), the aquifer being gravel immediately on top of the shale. It appears from discussions with well-owners that the whole town is underlain by 22 to 28 feet of very variable sand and gravel. The bedrock topography under Wawanesa corresponds closely with that of the surface since all wells are approximately the same depth. With regard to the sand and gravel itself the only valid generalisation seems to be the tendency to finer material at the

PLATE 20. FLUVIAL DEPOSITS NORTH EAST OF WAWANESA

The south side of the gravel pit south of the track along the north side of sec.25, tp.7, rge.17. The pencil is 8 inches long. The dark bands just below the gravel consist of silt.

PLATE 21. FLUVIAL GRAVEL NORTH EAST OF WAWANESA

Gravel in the pit about ½ mile to the south south west of that in Plate 20. Note the tendency to imbricate structure.

PLATE 22. TWO OF THE HIGH BLUFFS AT WAWANESA

The view from the school at the east end of Wawanesa looking north towards the bluff on the other side of the valley, surmounted by the road.

lower level north of the town ('Stage 3'and later).

Stage III. It is of intrinsic interest to reconstruct the Souris Valley at the time when the two large, now abandoned, meanders were approaching their maximum development. Using an altimeter, the water surface at the downstream end of the abandoned meander in Plate 18 was found to be 17 feet above the present level of the Souris. The undissected floor of the downstream end of the other abandoned meander to the north is 18 feet higher.

'Stage 3' is represented by the 24 feet terrace on the north west side of Wawanesa and therefore just predates the actual abandonment of the two meanders. The method of reconstruction was the same as for 'Stage 2'.

Figure 7a shows the change in channel pattern between stages 2 and 3. This takes the form mainly of an enlargement of the amplitudes of the meanders and a slight downstream shift of their axes. The only drastic change took place in secs.7 and 8, tp.7, rge.17 (Plate 19). The upstream end of the abandoned channel in sec.8 is 24 feet above the Souris River and was therefore occupied at this stage. Since the former channel in the S.W. ¼ sec.18, tp.7, rge.17 is only slightly higher than this at 28 feet it is evident that it was abandoned only shortly before 'Stage 3', after the formation of the related scrolls in sec.8.

There are many striking similarities between that section of the Souris Valley shown in Figure 19 and that section of the Pembina River Valley in Alberta described by Crickmay (1960, Fig.3).

Of particular note are the gentle slip-off slopes which culminate in steep river cliffs at their eastern ends, for which Crickmay suggested the term 'pembina'. Descriptive details in several other respects are very similar and a comparison of rates of vertical and horizontal or lateral erosion in the two valleys are made in a later section on climate and the chronology.

By this stage then the present familiar configuration of the Souris Valley had been reached. However, in addition to the meanders being smaller than they became still later, the river cliffs were lower, ranging in height from about 75 feet north east of Wawanesa to 120 feet in sec.8, tp.7, rge.17.

If the meander pattern at this stage be compared with that of the present Red River the striking similarity in size of amplitude and wavelength suggests that the discharge of the Souris River then was of the same order as that of the Red River now.

Stage IV. This is taken to be the stage of maximum river cliff development, the next stage being the present period of underfitness involving the radical modification of the cliffs by vegetation and the accumulation of the products of mass movement at their bases.

It will be noticed that given a vertical fall in level of only 24 feet, the interval since 'Stage 3' has been associated with a very large proportionate increase in the amplitudes of the meanders (see Fig. 5). It is likely, however, that since the meanders have been

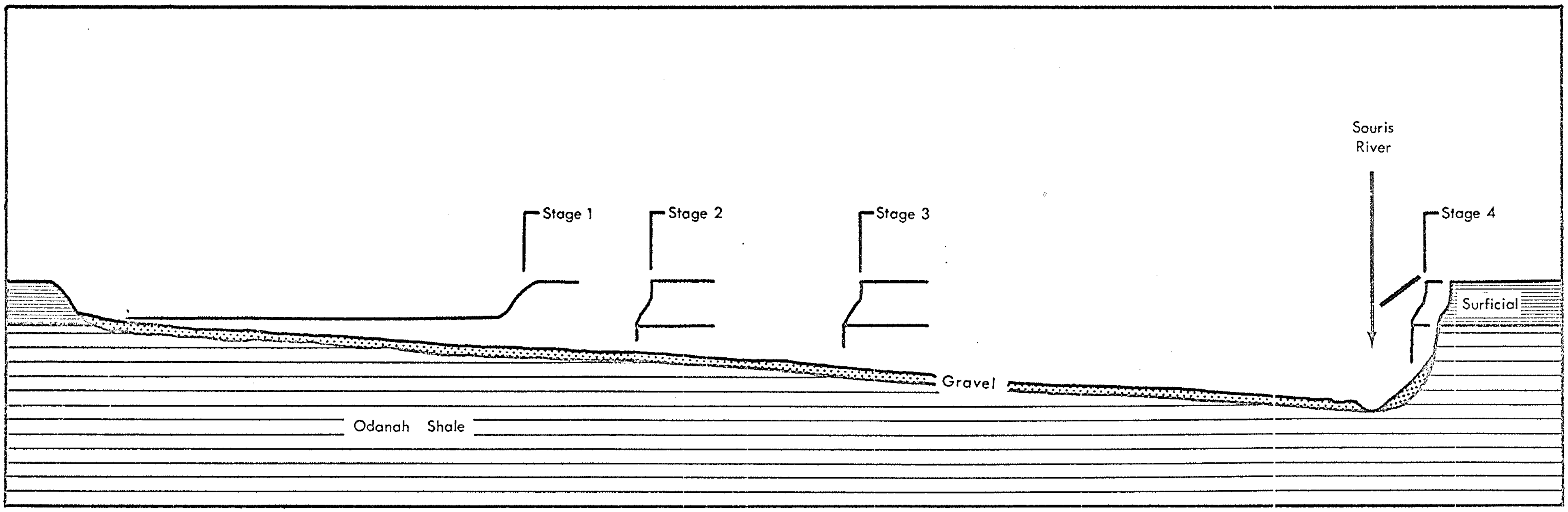


Fig. 5 Generalised Section across the Souris Valley near Wawanesa to Show the Main Stages in Development

Not to scale. See Plate 17 for a typical location generally cut in bedrock subsequent to 'Stage 1', discharge and meander dimensions are not necessarily simply related because of the time taken for adjustment between changes in discharge and channel parameters. This increase in amplitude plus the ever increasing height of the river cliffs required the removal of enormous quantities of material. The downstream shift of the axes observed in 'Stage 3' continued at least until 'Stage 4' and has led to the undercutting of the upstream sides of the slip-off slopes.

Inside all the major convex bends of the present river, around and south of Wawanesa, below the level of 'Stage 3' there are ridges and swales having amplitudes up to 10 feet. They are generally left uncultivated.

Stage V and underfitness. This final stage is distinguished from 'Stage 4' on the basis of manifest underfitness. Nowhere is this more apparent than in secs.3 and 4, tp.8, rge.16. Recent point bar deposits are closely related to the development of the small meanders along the more amply meandering course of the river. Two other specific localities are the two large meanders south and south west of Wawanesa in secs.23 and 16, tp.7, rge.17. Because the Souris River is underfit it is believd that the two river cliffs are, strictly speaking, relic features undergoing modification by mass wasting.

It may be argued that mass movement has been directly responsible for the formation of the small meanders taken to be an indication of manifest underfitness. In one or two cases, for example in Plate 17, along the high river cliffs, this seems to be the case, in others, especially where there is no adjacent cliff, it is not. In any case, the removal of the products of mass movement on the cliffs is generally so slow as to be inconsistent with a continuous parallel retreat of the cliffs as was evidently happening up to 'Stage 4'. Only exceptionally does the river flow against shale in situ. Just south of Wawanesa accumulated material is vegetated. The steep shale cliff section which does exist is being oversteepened by slumping marked by large fractures along the top of the cliff.

The large size of some river gravels and more particularly the enormous size of many igneous and limestone erratics presently found in the main river channel as well as in most minor tributaries do not necessarily demonstrate underfitness. Although there are recorded instances in other parts of the world of large boulders being moved during floods, their widespread occurrence in the Souris Valley is adequately explained by supposing that they are locally derived from the surficial deposits. They need have suffered no horizontal component of movement downstream.

Oak and Methven Creeks and their tributaries are clearly underfit but the temporal relationship between their underfitness and that of the Souris is uncertain. Because of the different sizes of their respective catchment areas the controlling factors could have been quite different.

A small meandering channel within a meandering valley are characteristic of both Oak and Methven Creeks. For 2 miles north of

Highway 2, the Oak Creek channel meanders within the meandering course of the Creek, crossing the floor of the shallow valley which also meanders. In several localities, abandoned meanders can be found on low terraces. Their chief interest lies in their shape and size in comparison with meanders in the present channel. Their height above the present channel gives some indication of the time which has elapsed since they were abandoned. Many of them are poorly preserved or obscured by trees, but one worth examining is located in N.E. ¼ sec.33, tp.7, rge.17. It is about 300 yards long and fits into the pattern of 'river course' meanders immediately to the south, there being a slip-off slope on its south flank. However, the smooth outline and wide channel of the abandoned meander is in marked contrast to the sinuous narrow channel superimposed on the pattern of 'river course' meanders and demonstrates a large reduction in discharge. The present channel is incised at a lower level and has exposed a section at right angles to the long axis of the abandoned meander, showing at least 5 feet of stratified sandy and silty alluvium (containing fresh water molluscs) under the former channel on both sides of the unsorted material of the meander core. The upstream end of the abandoned channel is 13 feet above the present Creek and the downstream end is 8 feet above it.

A gravel pit, in the slip-off slope on the south flank of the cut-off, just below the side of the valley, shows at least 6 feet of stratified but poorly sorted sand and gravel up to 9 inches in diameter. This deposit is comparable with the Souris river gravels.

The highest gravel exposed is 19 feet above the abandoned channel. A poor shallow exposure (a former gravel pit) on the slip-off slope of the meander core, at exactly the same height, shows the wider extent of this gravel. Here it also includes some large boulders.

Just south west of Banting, in S. ½ sec.2, tp.8, rge.17, there is a somewhat more complex area of cut-offs. There are at least two small cut-offs within the large abandoned meander whose floor is 13 feet above the present channel. Methven Creek also seems to have abandoned a channel along the south side of the isolated hill south west of Banting.

The Development of the Tiger Hills Section since Diversion

Three factors militate against the effective study of this section, firstly the absence of rapid approaches for the efficient use of an altimeter, secondly an almost continuous dense tree cover, and thirdly a lack of exposures. For the most part therefore this section is only known in very general terms.

The features essential to an elucidation of its history can be seen in Figure 7a. These are six large slump complexes and six spurs within convex bends in the river. The one spur which is cleared of trees, accessible, and open to study is in sec.16, tp.6, rge.18. Here the spur is seen to be a wide, gently inclined, slip-off slope or composite terrace. Its altitude falls from 1369 to 1301 feet over a distance of 550 yards making its mean gradient 1 in 24, being actually concave in profile. A narrow terrace lies 10 feet below the front edge.

Shale is exposed at the upper margin and in a small river cliff under the low terrace. River gravel is exposed at the front edge of the slip-off slope.

The other spurs are heavily wooded and have not been studied in detail. Low terraces and ridges and swales are developed in some localities. The spur in the S.W. ¼ sec.28, tp.6, rge.18 has a stepped profile. The slump complexes were mentioned in Chapter 1 in the discussion of processes. There evidence was presented for the suggestion that slumping occurred when the Souris River was flowing at a level 10 feet higher than it is at present. From the broad similarities between all six complexes and their present evident stability they are probably all nearly contemporaneous. One of the few exposures in a slump complex area is in an 80 feet high river cliff in the S.W. ¼ sec.21, tp.6, rge.18. At the north east end of this cliff the shale dips at an angle of 30° in a direction which is consistent with the slump being rotational.

In this section of the valley, when the river was flowing at the level of the tops of the main slip-off slopes, its course was much less sinuous than it is today. After a period of lateral and vertical erosion a critical stage was reached at which slumping occurred. It is reasoned later that the date of slumping was during the wetter climate of Sub-Boreal times (Table 3).

The Relationships between Features in the Wawanesa Embayment Section and those Upstream

The three sections (Pembina Trench, Tiger Hills, Wawanesa Embayment) of the Souris Valley each have very distinctive characteristics (compare Plates 17, 23, and 24). This is true even of those parts of the valley which are at a lower altitude than the 1375 feet contour level and the floor of the Embayment itself, and which demonstrably developed since the diversion. Broad sequences of events can be recognised in each section. If especially the early stages could be correlated the chronology would have a greater bearing on the solution to the problem of the cause of the diversion.

Figure 7b shows the relation between certain features and the long profile of the Souris River. The profile was obtained from topographic maps and therefore cannot be considered as being highly accurate. Therefore, for example, little significance can be attached to the steeper gradient of the river both on the north and south sides of the Tiger Hills. The profile shown also follows the axis of the valley and so is considerably steeper than the actual thalweg. The vertical exaggeration is some forty two times.

One factor making correlations on the bases of terraces difficult is the hiatus of more than 2 miles at the south end of the Wawanesa Embayment (see the south half of Plate 19). South of sec.7, tp.7, rge.17, the Souris flows through one of the narrower sections of the valley. At its narrowest point (south west corner of Plate 19)

TIGER
HILLS
High Outwash Terrace
Main Composite Terrace
Fine Sand
New Road Cut
N
H16/85-104

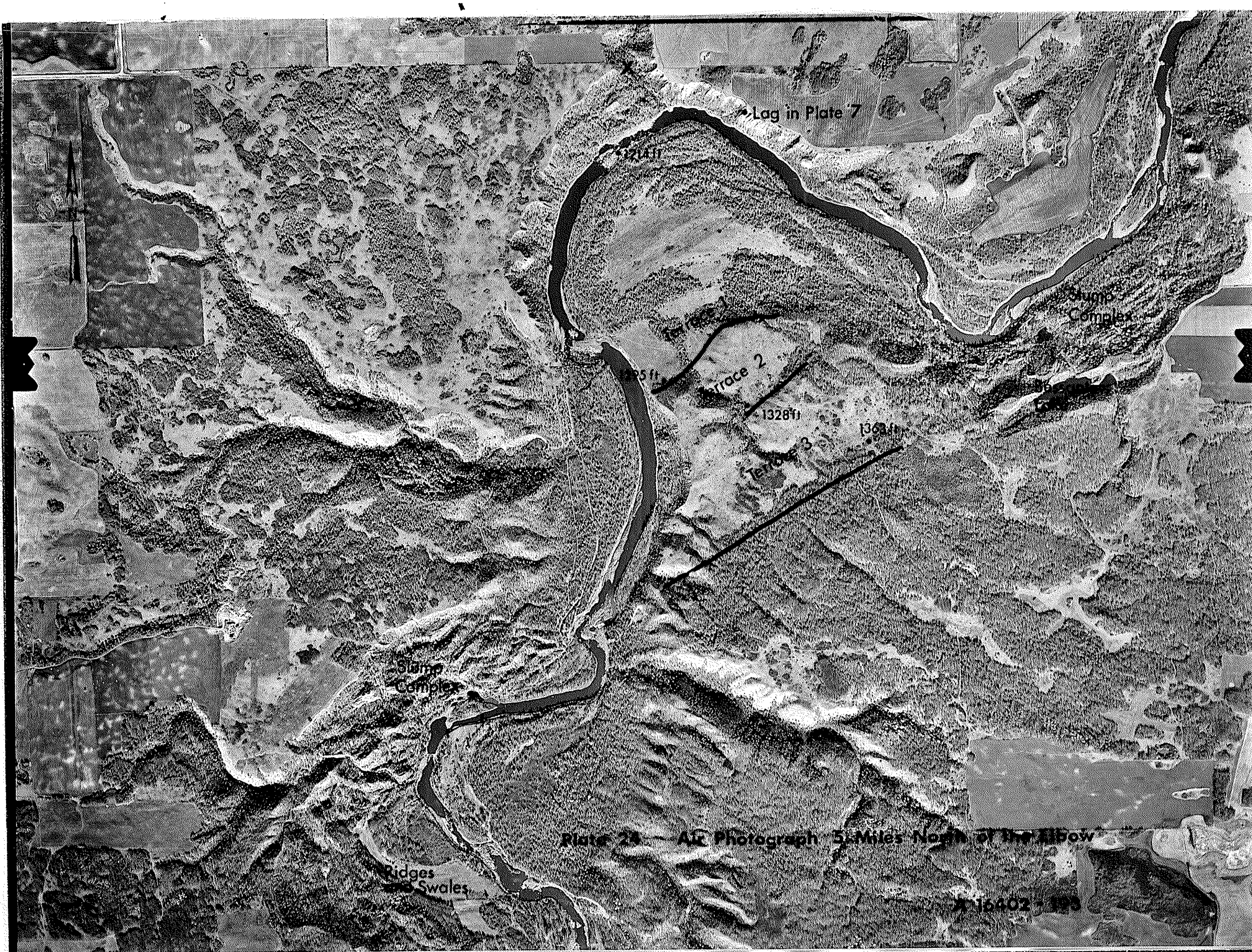


Plate 24 — Air Photograph 5 Miles North of the Elbow

it is less than 500 yards wide, bounded by steep walls 150 feet high, and cut 109 feet into the shale bedrock. The river is at its least sinuous here and no terraces higher than 30 or 40 feet above the present channel have been preserved. However, three areas of low terraces, on alternate sides of the river, are well developed and bear traces of former channels, ridges and swales, and sand and gravel containing, in places, molluscs.

The terrace sequence within the large bend in the river in sec.34, tp.6, rge.18 (Plate 24) is a 'key', but unfortunately also an ambiguous, site. Altimeter readings of some twenty four points on the three terraces were taken in an effort to establish actual heights above sea level, heights above the river channel, and the directions in which their rear edges slope.

The rear edge of terrace 3 is 1363 feet above sea level, 149 feet above the present Souris, and a little lower (Fig. 7b) than lag and lacustrine deposits (Plates 7 and 24) at the top of the cliff on the opposite side of the river. The rear edge of this terrace could possibly mark a former margin of glacial Lake Brandon. The rear edge of terrace 2 is between 111 and 114 feet above the present channel, sloping very slightly down towards the north east, 1328 feet above sea level. Although rather high to be correlated with 'Stage 1', on the basis of altitude alone it is the most likely, that is if one of the three terraces is related to it. Detailed analysis of surface deposits may demonstrate that this terrace represents an earlier stage. Two points at the rear edge of the composite terrace 1 are 70 and 81 feet above the present channel at 1284 and 1295 feet above sea level. This is probably too low to be correlated with 'Stage 1' as it would require that the gradient of the valley, then, between this terrace sequence and sec.7, tp.7, rge.17, was less than its gradient to the north.

The five stages recognised in the Wawanesa Embayment Section are not evident in the Tiger Hills Section except in an even more general way based on the altitudes of the less well developed terraces and slip-off slopes. In the Pembina Trench Section correlations must be even more tenuous. However, one observation on the (slender) basis of Figure 7b can be made. It is distinctly possible that the main composite terrace in the Pembina Trench was formed between the time of the diversion and 'Stage 1', since on the basis of altitude alone 'Stage 1' correlates with the front edge of this terrace. This is logical in the light of earlier comments on discharge at 'Stage 1' because incision below the front edge of the terrace can then be attributed to a change of regime (actually involving a decrease in discharge).

If the Souris River were diverted by the process of capture, immediately after it was effected a nickpoint and gorge would be expected to retreat upstream from the Elbow. The tops of the sides of such a gorge would be at an altitude of about 1375 feet, so it should not be confused with the more recent incision below the main terrace. Thus an elucidation of the origin of the main composite terrace is critical. For example, was it eroded by the Souris River or is it the degraded side of such a gorge as that postulated above? What was the discharge in the Pembina Trench at the time of the diversion? Interpretations of the composite terrace deposits are the most likely sources of evidence for the answers to these questions. The deposits were briefly referred to in Chapter 2.

Climate and the Chronology

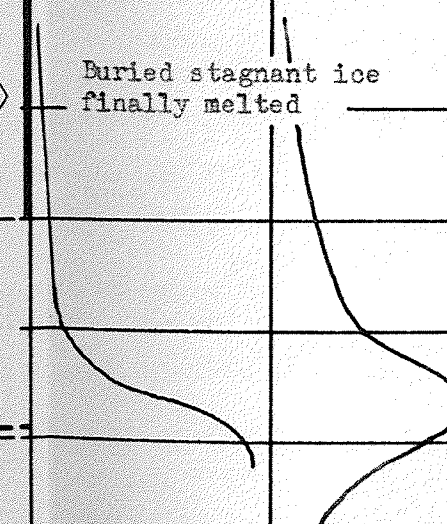
A review of sources. Literature pertaining to post-glacial climate generally is voluminous. Even that concerned with north-central America (with the possible exception of Manitoba) is abundant. Inferences have been drawn variously from work done in botany, zoology, geology, and archaeology, as well as climatology. A post-glacial geomorphological chronology must necessarily be concerned with the parallel changes in climate.

Table 3 has been assembled as a convenient means of summarising some representative findings relevant to the Souris Basin (Fig. 6). It is apparent that climatic inferences range from reasonable qualitative descriptions almost to fiction. However the consensus of opinion lends itself to a comparison with Dury's (1964a, 1964b, 1965) discussions of post-glacial underfitness in streams. Leopold and Miller (1954, pp. 53 - 75) considered the chronology of climatic events and paleohydrology in relation to post-glacial chronologies of alluvial valleys in Wyoming.

Post-glacial climate is of importance for two reasons. Firstly, it has controlled variations in river discharges and regimes.

...episodes in history of Lake ...gassiz (Elson, 1967) plus ...elected radiocarbon dates.	Bryson and Wendland (1967, N.B. Fig. 70)	Ritchie (1967), consistent with (1964) — Climate - Tiger Hills		Years B.P.	Brooks — SOURIS VALLEY	Dury, (1964a, b, 1965) — Pollen Zones		
				1,000	Stage V All mass movement on Wawanesa Cliff.			
	Return to conditions similar to Atlantic.			2,000	Stage IV	IX	Sub-Atlantic	
Y-11 * Climate more moist than present.	Much wetter. Change in circulation. Winters stormier.			3,000				
	More meridional circulation.	Marked increase of deciduous. Slightly cooler and/or less dry.	Increase in deciduous elements in southern Lake Agassiz basin (Shay, 1967)	4,000	Slump complexes in Tiger Hills	VIII	Sub-Boreal	
				5,000				
				6,000		VII	Main Atlantic	Increased temps. and runoff (Sn. England).
Change in regimen of Red River. Aggradation began (Elson, 1962).	Rapid in situ wasting. Rel. high temperatures.	Speculate : Summer - precip. decrease temp. increase; Winter - temp. decrease precip. increase	Arid (McAndrews et al. 1967). Dessication of Devils Lake (Callender 1967).	7,000	Large meanders cut off.	VI	Early Atlantic	
	Cochrane moraine. Ice thinner than Valders.		Maximum aridity (Shay, 1967).	8,000	Stage III Discharge of Souris reduced.			
	Less 'mountain effect'. Arctic air in winter. Subsident Pacific air in summer. Dry grassland climate.			9,000		V	Boreal	Reduced precip. counteracted reduced temps. runoff decreased. (Sn. England)
I ... Drier climate.		Warm - dry	(Ritchie and De Vries 1964)	10,000	Stage II	IV	Pre-Boreal	
...a S-41 * Kupsch (1960) Wetter and colder than present.	Grassland. Abrupt change in circulation	Abrupt change to grass (typical of W. Canada)	Climate-induced slope instability. SOURIS CAPTURE (Elson, 1958)	11,000		III	Younger Dryas	July temps. lower than II in New England. Increase in precip.
W-542 * Moir (1958) Cooler and moister than present.	Less severe winters than present. Less cloud cover. Very low rel. humidity. Strong westerlies in summer.	Mixture of boreal and temperate. Only moderately cold.		12,000	Terrace at 1180 ft. Treesbank. Discharge reduced.	II	Allerød (Two Creeks)	Wisconsin meanders abandoned
Glacial Lake Brandon			Temp. fell. Precip. increased. Long series of dull cold summers with much precip. (Manley, 1955)	13,000	Stage I DIVERSION OF SOURIS.	Ic	Oldest Dryas	Wisconsin meanders post-date meltwater.
Y-165 * Terasmae in Rowe (1956). Colder than present.				14,000		Ib	Bolling	
				15,000		Ia	Oldest Dryas	

Table 3 Post-Glacial Climate and Chronology

Years B.P.	Cooper (1958) Pollen Zones	Provis. Time Units	Love (1959) Elson Ice	Elson Lakes	Climate	Clayton (1967) Per cent of surface water from ice melt (0 → 100)	Mass movement (Relative scale)	5 episodes in hi… Agassiz (Elson, … selected radioca…
						Missouri Coteau (North Dakota)		
1,000	IX	Hypo-thermal						
2,000					Woodland animals at Lockport.			
3,000	VIII		All ice disappears					Y-11 * Cli… moi… pre…
4,000				North Outlet	Decrease in temps.			
5,000					'Long Drought' Temperatures higher than today.	Compaction of tills due to dessication and low water tables.		
6,000	VII	Hypsi-thermal			Heat-loving and drought-requiring plants.			
7,000				East Outlet				Change in re… River. Aggra… (Elson, 1962…
8,000	VI		Retreat	Lake Agassiz II	Man - winters severe, but tolerable summers ?			IV
9,000	V		Valders Ice	South Outlet	Y-415 : warm for deciduous colonisation	Buried stagnant ice finally melted		III
10,000	IV	Ana-thermal			Ground frozen and wet.			IIa S-41 * Ku… (1…
11,000	III		Advance	East Outlet	Riverine parkland Marsh-grassland			
12,000	II	Valders	Two Creeks Interval	Lake Agassiz I				II W-542 * Co… th…
13,000			Mankato Port Huron Ice	Ice	No flora			I Glacial Lake…
14,000		Interstadial		?				Y-165 * T… (… t…
15,000			Late Cary Ice	Ice				

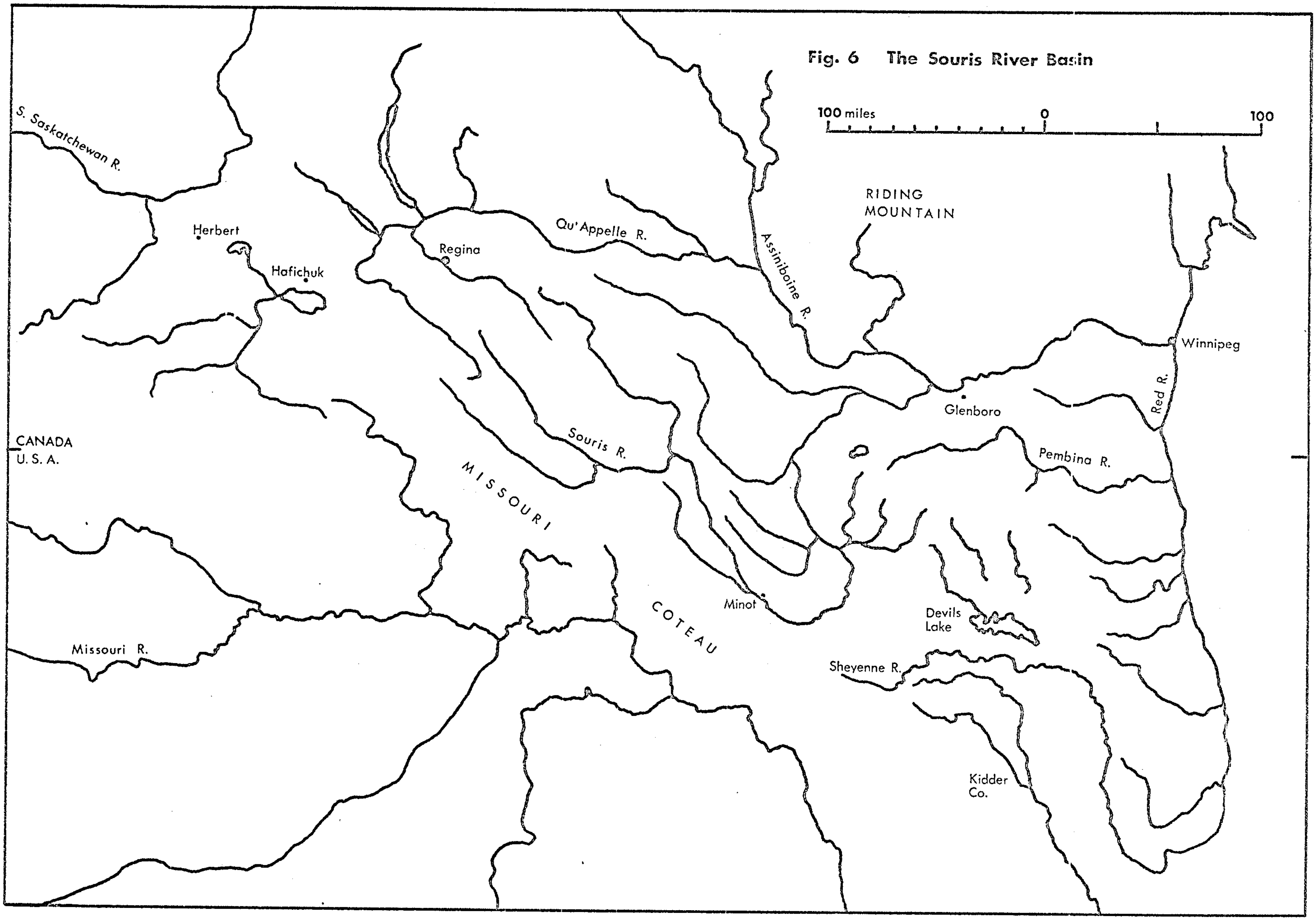


Fig. 6 The Souris River Basin

Secondly, it has had a direct influence on a wide range of geomorphological processes.

Two notable discussions from the climatological standpoint have been by Manley (1955) and Bryson and Wendland (1967), but their concern with broad generalities is an early warning of the problems involved. Manley, for example, tried to reconstruct actual mean temperatures for North America generally. Bryson and Wendland had a different objective in presenting 'a few tentative reconstructions of past airmass regimes'.

Ritchie (1967) has made some tentative climatic inferences from pollen analysis at a site in the Tiger Hills, relatively near Wawanesa. There is usually general agreement between the findings of pollen analysis at different sites (e.g. compare Klassen, Delorme, and Mott, 1967), but early discharges of the Souris River necessarily depend on climatic conditions over an even wider area (see Fig. 6).

Naturally, from a botanical standpoint the main emphasis is on plant assemblages and migration. Often, climate is of secondary interest. If not, then since a given plant assemblage at a given point in time is the end result of a whole complex of factors and processes of which the availability of plant species is not the least important, climatic inferences cannot be rigorous. An example of the type of discussion involved is given by Rowe (1956, p. 27). He refers to an earlier acceptance of the 'idea of forest retreat before the ice and of advance in its wake' and to the suggestion that 'during the latter movement a fragment of the spruce forest remained on the

(Assiniboine) delta (in the Spruce Woods Forest Reserve) where local edaphic conditions proved favourable for its survival. He then points out that

> it is significant that no relict spruce community occupies the similarly formed sandy deposits in the Souris basin, and a glance at the drainage patterns of the two areas immediately suggests the reason for the difference in vegetation. The Assiniboine River flows to its old delta from a forested zone in the northwest, while the Souris River approaches its old delta from a prairie zone in the southwest. It seems likely therefore that white spruce arrived at the Assiniboine delta via what the writer believes was a main route of migration of boreal species, namely a southeastward and eastward-trending river valley.

Love (1959) agrees with this argument and suggests that the plants contemporary with radiocarbon date Y-165 (Table 3) migrated to the area in this fashion.

It comes as no surprise that there is not unanimous agreement amongst the different workers represented in Table 3. There are a number of reasons for this. Firstly the research was done at different times and in some cases later work may be considered as an advance on earlier work. Discrepancies will naturally occur when inferences are made on the bases of different methods or criteria. Also, different studies have been concerned with different sites or general areas. At any given time, climate over an area as small as the Souris basin could have varied considerably especially perhaps when in the neighbourhood of an ice front. Lastly, all evidence relating to former climates is to some extent ambiguous.

Having said this, however, a number of observations can be made from Table 3 and its sources with a sufficient degree of certainty to provide a basis for discussion.

1. Permafrost has not been a general cause of large discharges.
2. Some large discharges post-date and are independent of meltwater.
3. There is complete agreement on the general aridity and relatively high temperatures obtaining during the Atlantic period.
4. Between 14,000 and 9,000 B.P. the climate was variable. Discharges at times were very high. Geomorphological processes on unvegetated slopes in recently deposited, unconsolidated, wet material must have been rapid.
5. There is agreement that the climate became wetter and cooler during and at the end of Sub-Boreal times.

<u>The chronology</u>. The following criteria are available to date the stages in the evolution of the lower Souris Valley:

1. The date of the diversion (see above).
2. The relation of 'Stage 1' to the Treesbank 1180 feet terrace.
3. Amount of material removed which is a function of (a) total vertical erosion, and, more significantly in this case (see Fig. 5), (b) the extent of lateral erosion.
4. Rates of fluvial erosion are functions of discharge and therefore climate. Dury (1965, p. C15) listed the 'seperate factors most likely to have operated in former times to promote high discharges' as follows:

   Reduced air temperature
   Increased total precipitation
   Changed regimen of precipitation
   Increased extent of frozen ground
   Changed regimen of runoff
   Increased size of individual rains

Increased frequency of storms
Increased wetness of soil
Changed vegetation cover

Each of these factors is not necessarily independent of the others. Contemporary variations in the different factors could either work together in augmenting the total effect or counteract, thus minimising change.

5. Geometry of meanders as functions of discharge and climate.

The following reasoning was employed in establishing the chronology as shown in Table 3.

1. Since 'Stage 1' is everywhere higher, and since there is no evidence to the contrary, it is older than the 1180 feet Treesbank terrace, that is the Tintah phase of Lake Agassiz I.
2. 'Stage 1' was related to a high discharge which was not derived in the main from meltwater from an ice sheet (see section on 'The Two Creeks interval). Immediately after diversion a large quantity of surficial material must have been removed in a short period of time (see Fig. 7b). At that time the deposits were probably wet and relatively unconsolidated.
3. 'Stage 2' was reached early because of (a) the activity of geomorphological processes, and (b) the relatively small volume of material which had to be removed (Fig. 5). This is the case even though at the same time discharge was reduced (compare Black Earth Creek, Wisconsin, Table 3). Evidence for this is indicated by the horizontal floor (in cross-section) of 'Stage 1' (suggesting that the section in Figure 5 constituted the channel) compared with

the gravel-covered slip-off slope formed between stages 1 and 2, at which latter stage the river occupied a relatively small channel at the foot of a river cliff, in the manner it does today. There was a considerable decrease in meander wavelength between stages 1 and 2 (Fig. 7a).

4. 'Stage 3' is harder to date. This stage was attained after the removal of a smaller volume of material than had to be removed between stages 3 and 4. Given, therefore, what must have been small discharges during Atlantic times, 'Stage 3' must have been reached at least before the Early Atlantic in order that enough time was available between stages 3 and 4.

5. From the geometry of the meanders at 'Stage 3' (and the evidently well-preserved channel in the cut-off immediately north east of Wawanesa) it would seem that the discharge then was of the same order as that of the present Red River at Winnipeg. From the climatic data in Table 3 this is questionable. However, study of the slightly irregular plans of the two cut-offs north east of Wawanesa suggests that the river became underfit before the meanders were actually abandoned, which was in any case some time after 'Stage 3'. This could have been contemporary with the change of regimen of the Red River (Table 3, herein, Elson, 1962). The Cochrane readvance 8,000 years ago is most likely to have been associated with higher precipitation and runoff.

6. Between stages 3 and 4 the meanders must have been reduced in size (there is no direct evidence for this) due to general aridity and

therefore underfitness. Aggradation might also be expected and it seems from verbal comments by local inhabitants that the north west corner of Wawanesa is not underlain by coarse gravel but by up to 25 feet of sand. However, C.T. Shay (personal communication) has drawn attention to the general absence of evidence for aggradation in the Souris Valley, at any stage, which is in conspicuous contrast to other parts of north central America (Elson, 1962; Leopold and Miller, 1954; Brophy, 1967, p. 105). R.W. Klassen (unpublished) has commented on the occurrence of wood buried 20 - 26 feet below the present surface near the south shore of Lake Manitoba, representing a lower lake level. This wood has been dated at 3375 $\pm$ 250 B.P. In the Souris Valley changes in level of Lake Agassiz appear never to have had a direct effect on events upstream from Treesbank.

7. Lateral erosion must have been slow until discharges increased after 4,000 B.P. Much of the total erosion between stages 3 and 4 was probably achieved after this date.
8. The slump complexes and low terraces in the Tiger Hills (see the section dealing with fluvial processes) must have formed before 'Stage 4' was reached, which was, in a sense, the stage of maximum 'scouring' of the valley.
9. The onset of the present underfitness was recent, dating from the return to conditions 'similar to the Atlantic', 1,500 years ago. The channel at Wawanesa is on bedrock so underfitness has evidently not been accompanied by aggradation.

Rates of processes. In an earlier section attention was drawn to the similarities between the section of the Pembina River Valley in Alberta described by Crickmay (1960) and the Souris Valley near Wawanesa, especially that reach shown in Plate 19. Their ages are similar (less than 14,000 years). They are both about 150 - 200 feet deep. The widths of the two valleys are of the same order. Both their areas consist mainly of extensive slip-off slopes. There are, on the other hand, two important differences which should be borne in mind when making a comparison of rates of erosion. Firstly the Pembina River is cut into Cretaceous sandstone with some thin shale and coal beds whereas the two large left bank river cliffs in Plate 19 are cut entirely in till. Secondly, the mean annual discharge of the Pembina River is 687 cusecs compared with 48.2 cusecs for the Souris River at Wawanesa during 1961/62 (Dept. of Northern Affairs and Natural Resources). However, given basic similarities in age and valley geometry, average rates of erosion are necessarily of the same order. Crickmay has calculated that the rate of lateral erosion this century, at a specific location, has been slightly less than 1 foot per year. The rate of post-glacial vertical erosion has been 1 foot in 90 years. (He also observed that a nickpoint receded 1,050 feet in 10 years.)

The calculation of the rate of vertical erosion is merely an average and ignores variations of discharge with time. Comparison of the two valleys on the basis of present discharge is made difficult because of ignorance as to the degree of present underfitness which is likely to be different in the two cases.

In the Wawanesa section of the Souris Valley the river has eroded vertically approximately 85 feet since 'Stage 1', that is in about 12,000 years. That is at an average rate of 1 foot in 140 years. The average maximum recession of valley sides (river cliffs) since 'Stage 1' has been about ½ mile (see Fig. 7a). This amounts to recession of the large river cliffs at an average rate of about 1 foot in 4½ years. In reality this recession must have varied between a rate of many feet in some particular years and prolonged periods of standstill, say during Atlantic times. Also, the average rate does not take into account the increasing height of the cliffs (Fig. 5) and therefore the increasing quantity of material which had to be removed for each successive foot of recession.

The large cut-offs, having been abandoned for about 7,000 years offer a situation in which the nature and extent of cliff modification, after undercutting has ceased, can be assessed. A minimum age for these cut-offs could possibly be derived independently by pollen analysis of the sediments in the ox-bow lake. Had the meanders not been cut-off there would have been further cliff recession and the cliffs themselves would have become higher.

The nature of the chronology requires that <u>all</u> mass movement on the concave river cliffs near Wawanesa (apart from in the cut-offs) is very recent, having occurred within the last 1,500 years.

On the other hand, the slump complexes in the Tiger Hills are relic features. For reasons considered in the section on fluvial processes they post-date a low terrace, predate 'Stage 4', and are approximately contemporaneous. A date of about 3,000 B.P. is made likely since a large increase in precipitation could have been a critical factor in causing failure, given an earlier period of oversteepening of the sides of the valley.

The Necessity for an Explanation

Evidence for a former spillway. The early timing of the diversion deduced in another section has two possible implications. Either, it requires that the process of headward erosion leading to capture was very rapid, probably due to the necessary removal of a minimal quantity of unresistant material. Or, the divide was so low that something less than a catastrophic event was capable of sparking off an overflow to the north. A low col or an early spillway would be a concomitant of either hypothesis.

With Upham, Elson (1955, p. 235a, Table 5 - 2) assumes that such a spillway existed and he suggests that it was formed in two stages (Fig. 7b, herein). Firstly when its south end was at an altitude of 1490 feet it was up to 4 miles long and its source of water was the actual ice margin. Later it became the spillway of glacial Lake Brandon, its floor was lowered to 1380 feet at the south end, and its length increased to 5 miles. Three miles to the east one of the several spillways southwards through the Tiger Hills is preserved.

After studying topographic map 62G/12W and air photographs covering the area south of Nesbitt, east of Highway 10, and north of the Tiger Hills, it was hoped that supporting evidence could be found there. Geological Survey Map 1067A shows that the most recent direction of ice movement was from the north east to the south west, and that washboard moraines (formed parallel to the ice front) trend from the north west to the south east.

Methven Creek and its tributaries must have extended across the floor of glacial Lake Brandon when the lake drained to the north or east. The sub-parallel drainage pattern is distinctive. Since the two tributaries of the Souris on the north margin of the Tiger Hills (X and Y in Plate 24) are at a higher altitude than the floor of the Pembina Trench near the Elbow, and parallel to the washboard moraines, it is suggested that they may have been ice-margin features whose waters flowed southwards down the spillway, perhaps before glacial Lake Brandon began to form.

Elson presumably took the high outwash terrace (Fig. 7a) as evidence for the first stage in the development of the spillway at an altitude of 1490 feet. Since the topography of the Tiger Hills and the Wawanesa Embayment has been so little modified since their formation there is no reason to suppose that such a feature was longer than just over 3 miles. A lengthening to 4 miles and the development of the tributaries mentioned above could then have accompanied the retreat of the ice margin northwards, the formation of glacial Lake Brandon, and downcutting of the spillway itself to the level of the floor of the Pembina Trench. The position of the margin of the lake at this stage is indicated by the lag in sec.34, tp.6, rge.18 (Plate 7).

There are no exposures in the high outwash terrace. Its surface is somewhat irregular being dissected by a number of shallow valleys, and small dry valleys in the Tiger Hills are sometimes graded to it. East of the Souris River the terrace has a gentle gradient down towards the east. Near its east end lies the gravel deposit shown in Plate 1.

Although the nature of the material under the anomalous high part of the Trench floor (above 1375 feet just east of the Elbow) is unknown, its position is consistent with an origin as a delta at the mouth of the supposed spillway.

The search for evidence for a spillway within the Tiger Hills was, not surprisingly, with one exception, unsuccessful. In sec.9 and the S. ½ sec.16, tp.6, rge.18, on the east side of the valley there are a number of small features such as small cols, terraces, and breaks of slope, but there are no exposures and they may have no chronological significance.

On the other hand, beside the small track leading down to the broad slip-off slope in N.W. ¼ sec.16, tp.6, rge.18, at an altitude of about 1400 feet, that is just above the altitude of the rear edge of the main composite terrace and the wind gap, lies a small obscure deposit of stratified sand and gravel (Plate 25). Its altitude and its position within one of the large bends in the Souris River are both significant. The concave (in plan) sections of the valley-sides

PLATE 25. STRATIFIED SAND IN THE TIGER HILLS SECTION OF THE SOURIS VALLEY

This deposit is in sec.16, tp.6, rge.18, above the level of the main composite terrace in the Pembina Trench, at about 1,400 feet. Refer to Figure 9 for size analyses of <u>a</u> (gravelly sand), <u>b</u> (sand), and <u>c</u> (coarse sand).

have been modified too much (mainly by slumping), since diversion, for such evidence to survive. Whether or not this deposit was formed on the floor of the postulated spillway remains doubtful. It may be related to a small tributary stream entering this section of the Souris Valley from the west, or it could even be a localised water-worked deposit within the Tiger Hills end moraine, exposed here by chance.

The site of the Souris Valley for a spillway across the Tiger Hills is possible, and even likely, on the grounds of the number of others which can be shown to exist. An examination of the north end of the spillway just 3 miles to the east of the Souris Valley demonstrates that headward erosion, southwards, for a short distance along its length has actually been achieved in a situation analogous to that obtaining before the diversion of the Souris River. This spillway therefore is of intrinsic interest.

The spillway is 3½ miles long and up to 100 yards wide except in its lower mile where it is both deeper and narrower. Over a distance of 2 miles it decreases less than 25 feet in altitude. Headward erosion has occurred southwards along it, at its north end, for about 600 yards. A small stream flows northwards from just north of the track along the south side of sec.30, tp.6, rge.17 where the track crosses the spillway.

Although it can be seen from air photographs that this stream cuts through a small morainic ridge 700 yards north of the track, its valley to the north becomes very shallow. Followed further it can be seen that it is a part of the underfit drainage network. Headward erosion has not been associated with any incision in its lower course. It would also seem that headward erosion is no longer active, and might therefore have been in progress at the time of diversion.

Thus it is quite possible that the Souris Valley was the site of a spillway which effectively reduced the total quantity of surficial rock which had to be removed by the process of headward erosion in order for capture to take place. But conclusive evidence may never be found.

The influence of bedrock topography. Elson (1955, p. 24) stated that 'the spillway north of Ninette might have developed into the cross-axial channel of the Souris River but for a bedrock sill at its north end' and also that 'three miles east of the Souris gorge a small cross-axial channel may have drained a small glacial lake before downcutting was retarded by a bedrock sill'. Whether this refers to the distn ct spillway along the west side of tp.6, rge.17 or the low divide in the S.W. ¼ sec.13, tp.6, rge.18 is not clear from his map of the bedrock topography especially as it shows the surficial deposits as being about 100 feet thick in the north west corner of tp.6, rge.17 and much thicker beneath the divide in sec.13, tp.6, rge.18.

Elson's map (Halstead, 1959, Fig. 2) showing the relation between present surface relief and the bedrock topography strongly suggests that the latter may have had a significant control over the diversion. Firstly, in its general context, the diversion may be seen as one event in the re-establishment of the former trend of drainage from south to north. Secondly, the Tiger Hills Section of the Souris Valley supposedly almost coincides with, crossing at a small angle, a preglacial valley which may therefore have been directly responsible for guiding the direction of headward erosion and/or underground seepage (see Howard, 1938, for an example of what has been described as an 'underground' diversion).

There are a number of reasons for supposing that the matter is not as simple as this. That the bedrock could have guided headward erosion completely is not tenable because the correspondence between the present Souris Valley and the preglacial valley is not a complete one as shown by Elson's map itself. Figure 2 of this present essay shows that, in fact, more realistically, the details of the bedrock topography are just not known. Furthermore, underground seepage along preglacial valleys in Manitoba to a pronounced degree, over long distances, is virtually unknown due to the nature and irregular composition of the surficial deposits. L.Gray (personal communication) has pointed out that this fact is a major barrier in the prediction of successful sites for wells most likely to tap water resources within the surficial deposits. Finally, it is now known that immediately after capture (i.e. 'Stage 1') no part of the Wawanesa Embayment Section of the Souris Valley had yet reached bedrock.

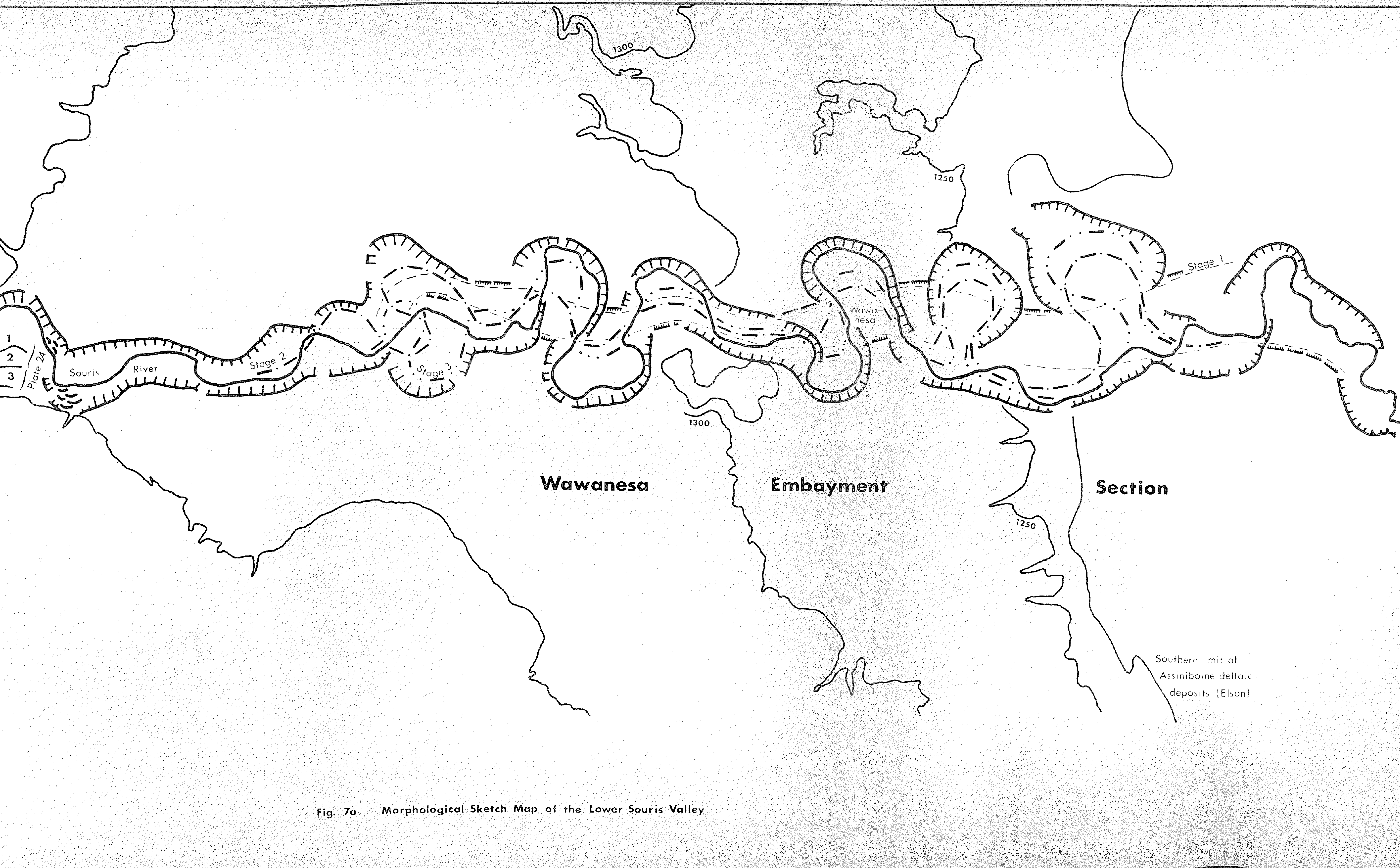
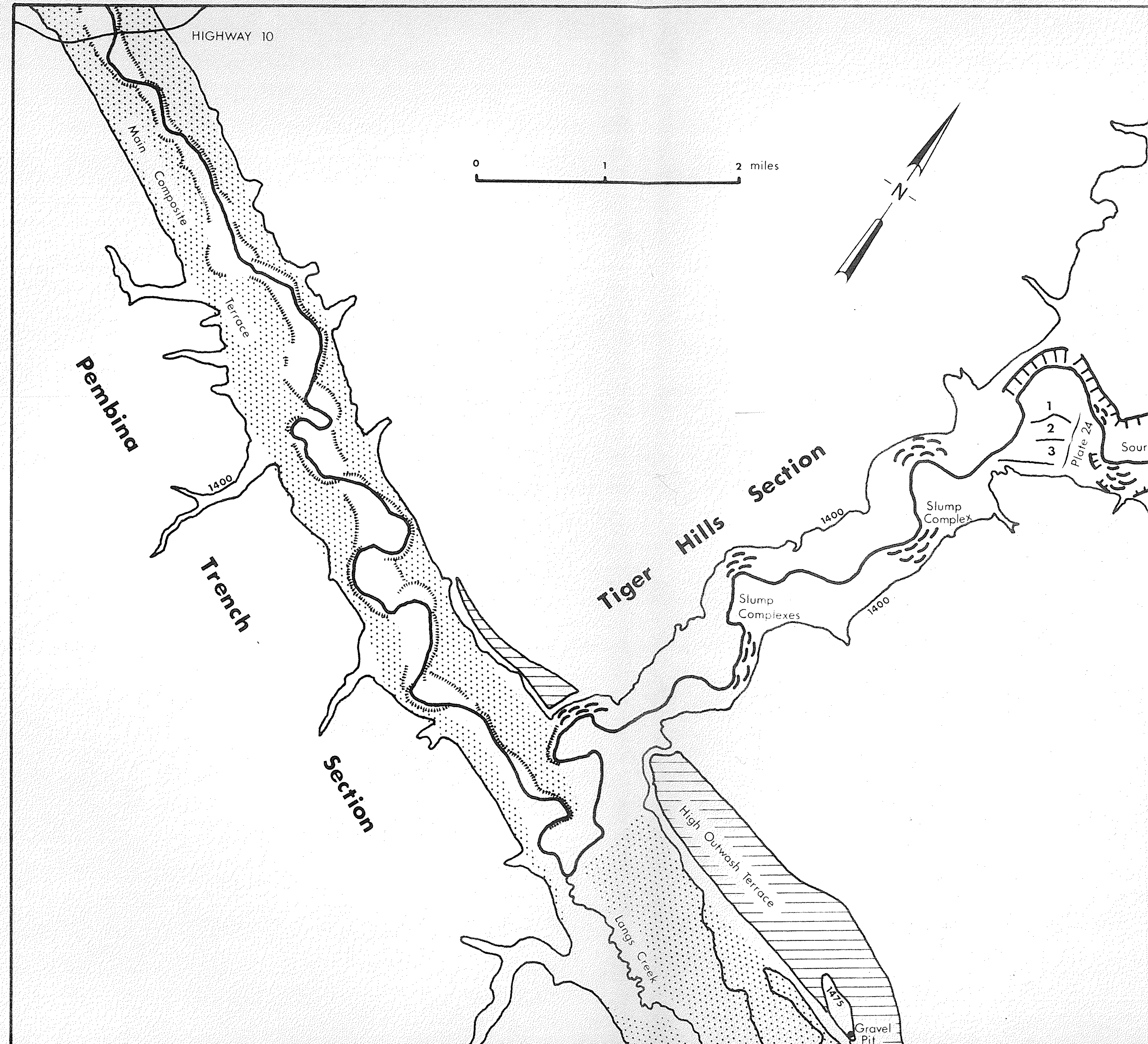


Fig. 7a Morphological Sketch Map of the Lower Souris Valley


HIGHWAY 10
0
1
2 miles
N
Main Composite Terrace
Pembina Trench Section
1400
Tiger Hills Section
Slump Complex
Slump Complexes
1
2
3
Plate 24
High Outwash Terrace
Langs Creek
1475
Gravel Pit

uris Valley

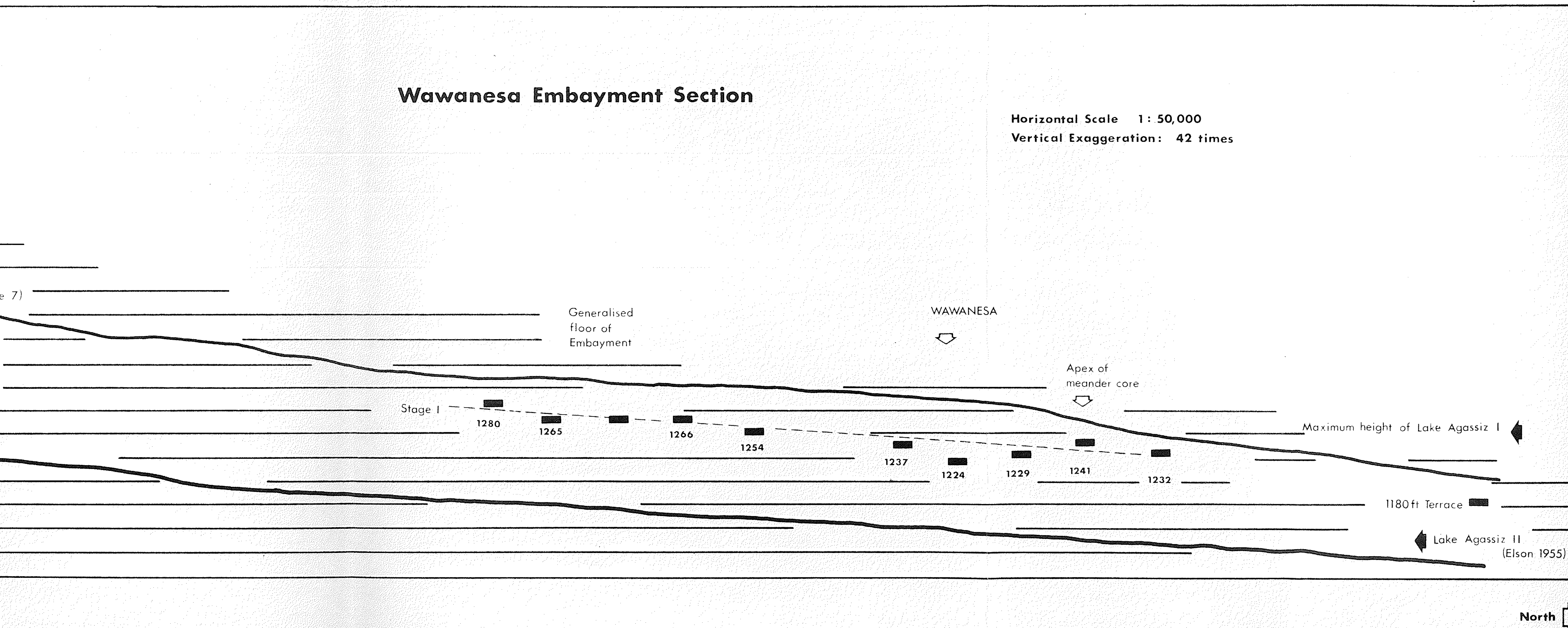
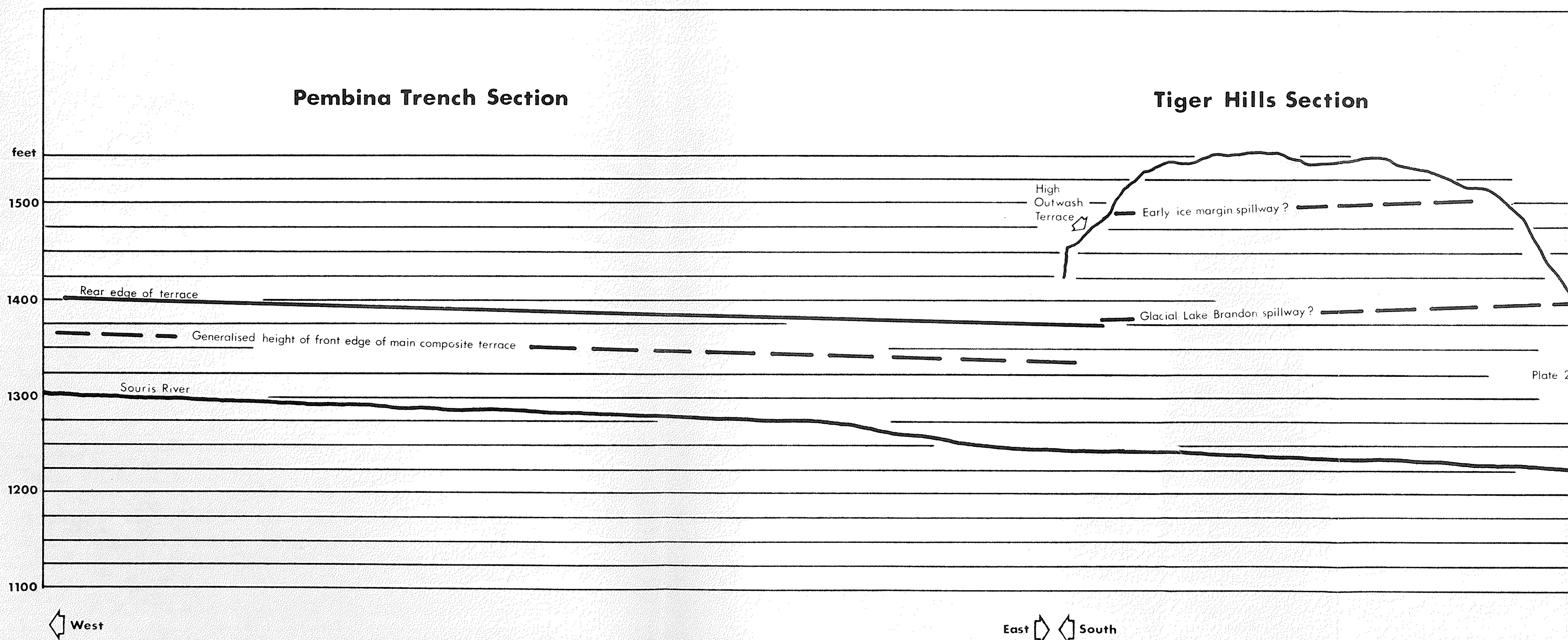

Wawanesa Embayment Section
Horizontal Scale 1 : 50,000
Vertical Exaggeration: 42 times
e 7)
Generalised floor of Embayment
WAWANESA
Apex of meander core
Stage I
1280
1265
1266
1254
1237
1224
1229
1241
1232
Maximum height of Lake Agassiz I
1180 ft Terrace
Lake Agassiz II (Elson 1955)
North

Fig. 7b Generalised Long Profile of



CHAPTER IV

CONCLUSIONS

It is impossible to reconstruct the bedrock topography accurately because of the general lack of sufficient information on depths of surficial material. This is especially so in the Tiger Hills Section where such information would be most relevant to the problem of the diversion. There is evidence in the Pembina Trench to suggest that surficial deposits (Plates 2, 3, 4) older than the last major glacial advance are preserved in preglacial hollows.

Five stages in the development of the Wawanesa Embayment Section can be recognised. 'Stage 1' post-dates the diversion. Most of the surficial material into which the valley here is incised must predate the diversion. However the localised, uppermost lacustrine sediments are probably associated with glacial Lake Brandon, and there is no evidence to show that the Souris River was not diverted into late Lake Brandon. The diversion, therefore, could possibly be contemporary with these sediments.

Identification of these five stages also permitted approximate estimates of absolute dates of all large river cliffs north of the Pembina Trench to be made. Thus, information relating to rates of cliff recession and lengths of time for which specific processes have operated was obtained. Assembled data on post-glacial climate showed that, in very general terms, inferred variations in river discharge can be related to terrace and river cliff development.

Summary of Evidence for the Diversion

The evidence for the diversion having taken place is conclusive. No features in the entire area studied are inconsistent with this hypothesis. No other hypothesis can be contrived to explain this distinctive assemblage of landforms so well. However, the problem of the cause of the diversion remains. It is concluded that the diversion was due either to the process of capture or to a simple spilling of the Souris River northwards as the result of an exceptionally high water level in the Pembina Trench and/or the existence of a particularly low col across the Tiger Hills. In the writer's opinion the balance of evidence swings very slightly in favour of the process of capture. There follows a summary of the evidence which supports one or other of these two hypotheses.

The orientation of the Tiger Hills Section of the valley is consistent with its having been the site of a spillway, discharging water southwards from a glacial Lake Brandon. Other possible evidence for this spillway includes outwash at its south end, a small deposit on the side of the present valley, and certain elements of the tributary pattern at its north end. The valley is cut abruptly into both the Tiger Hills and the Wawanesa Embayment and follows no general depression in them. From the height of the lag (Plate 7), formed in shallow water of Lake Brandon, it is apparent that the gradient of the spillway could have been very small indeed, perhaps being less than a vertical drop of 25 feet in 4 miles. Such a vertical height is of the same order as the annual range of depth of the present Red River. Thus, the north end of the spillway was possibly low enough for water to spill northwards into the Wawanesa Embayment after an initial fall in the level of glacial Lake Brandon. Alternatively, the quantity of material to be removed by the process of headward erosion, thus reversing the gradient of the spillway, leading to capture, could have been very small.

Eight miles north of the Pembina Trench the floor of the valley representing 'Stage 1' was 100 feet below the floor of the Trench. This, apparently, would have been ample to permit headward erosion since the small stream which has successfully eroded headwards into the spillway 3 miles to the east of the Souris Valley is not even incised into the Embayment.

Details of the main composite terrace in the Pembina Trench and of the slip-off slopes in the Tiger Hills indicate that there might not have been any rapid downcutting by the Souris River immediately after the diversion as would be expected had capture been responsible. However, if, as seems likely, capture could have been achieved with only a very small altitude difference between the Trench and the stream crossing the Embayment, then the associated downcutting would have taken place, its amplitude being too small to be detected in the present morphology of the terraces, these having been subsequently modified by mass wasting.

A more complete correlation of events and landforms in the three sections of the valley, than has been given, would require, as a basis, an accurate long profile of the Souris River for assessing the validity of heights of terraces and meander scrolls above the present channel as evidence for relative age.

Evidence has been presented to demonstrate that the diversion occurred during or soon after the fall in level of glacial Lake Brandon from the lag on the north margin of the Tiger Hills. This early date increases the likelihood of a simple spilling northwards as it reduces the length of time available for headward erosion leading to capture.

The history of Lake Brandon is evidently not at all simple as shown by the occurrence and localised distribution of lag, varved clay, stratified silt, cross-bedded sand, and overlying unsorted massive material.

It has not been demonstrated that bedrock had any direct control over either the course or the cause of the diversion. Biological, archaeological, and geological evidence for deducing precise climatic conditions at the time of the diversion are ambiguous (Table 3), but there is little doubt that processes were active then especially as recently deglaciated slopes must have been unvegetated.

Further Comments

A certain amount of useful information could be obtained by drilling; for example, the depth to bedrock and the nature of the surficial material in the Pembina Trench 2 miles east and west of the Elbow. Within the Tiger Hills this would be more difficult because of the greater depths involved and problems of access. In the Wawanesa Embayment the lateral extent of the sand, silts, and clays, shown in Figures 3 and 4, are relevant to an interpretation of them, and could be detected by drilling. A systematic analysis of the river gravels in this section would require objective sampling by drilling and avoidance of gravel pits which probably do not reveal representative gravels. The abandoned meanders north east of Wawanesa are likely to be worthy of further investigation. Drilling would provide information on the nature and location of the former river bed. The ox-bow lake sediments might provide a pollen sequence which could give a minimum age for the lake.

A somewhat varied fluvial history has already been inferred, mainly on the basis of (ambiguous) morphological and climatological evidence. One would expect this history to be recorded in the extensive river gravels (Plates 20 and 21). Visher (1965) has interpreted fluvial processes from ancient fluvial deposits. Plumley (1948), Lapinsky, Revell, and Winters (1958), and Nossin (1959) have made systematic studies of terrace deposits which, however, were generally of a much greater age range and which could be more clearly distinguished on the basis of their characteristics due to their glacial or interglacial age.

The problem of the stage at which the Qu'Appelle Valley was first exposed and diverted water from glacial Lake Regina, and the question of the source area of the 'post-till' deposits in the Wawanesa Embayment (i.e. were they deposited in Lake Brandon by the already-diverted Souris River?) may be resolved by petrographic analyses. Further deposits of interest are those on the composite terrace in the Pembina Trench between the Elbow and Highway 346, and those on the terrace sequence shown in Plate 24.

What could be inferred from a long profile of the Souris River more accurate than the one shown in Figure 7b is questionable. However, it would serve as a better basis for the chronology as well as for specific studies of fluvial processes and general relationships to features in plan, such as the large and underfit meanders.

Lastly, the Souris Valley offers particular scope for the study of contemporary processes of mass wasting as well as the distinction between them and those processes which have operated in the past.

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APPENDICES

APPENDIX I

Results of particle size analyses by the hydrometer method.

(sand: 2.0 - .05mm; coarse silt: .05 - .005mm; fine silt: .005 - .002mm; clay: less than .002mm in diameter)

Wawanesa Cliff (see Fig. 3)

Massive clayey silt:

sand	1.1%		
silt	73.2%	coarse silt	67.0%
		fine silt	6.2%
clay	25.7%		

Contorted clayey silt

sand	1.0%		
silt	68.4%	coarse silt	64.1%
		fine silt	4.3%
clay	30.6%		

Cross-bedded clayey silt

sand	3.1%		
silt	79.1%	coarse silt	76.0%
		fine silt	3.1%
clay	17.8%		

Stratified clayey silt

sand	0.5%		
silt	79.7%	coarse silt	71.9%
		fine silt	7.8%
clay	19.8%		

Upper till

gravel	12.6%		
sand	34.6%		
silt	36.2%	coarse silt	30.6%
		fine silt	5.6%
clay	16.6%		

Cross-bedded sand (see Fig. 8)

Lower till

gravel	6.7%		
sand	50.8%		
silt	35.1%	coarse silt	32.4%
		fine silt	2.7%
clay	7.4%		

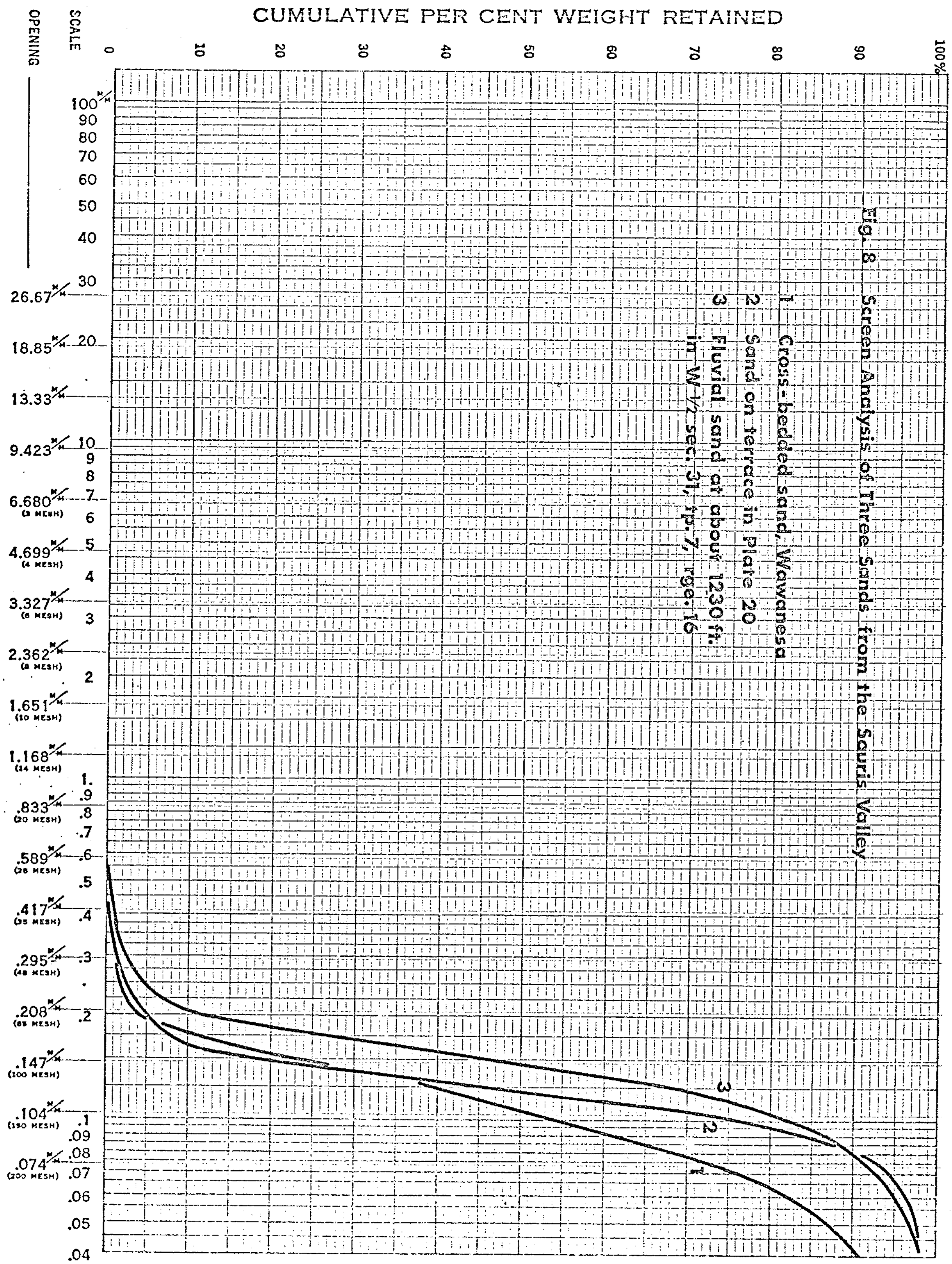

Fig. 8 Screen Analysis of Three Sands from the Souris Valley
1 Cross-bedded sand, Wawanesa
2 Sand on terrace in Plate 20
3 Fluvial sand at about 1230 ft. in W 1/2 sec. 31, tp. 7, rge. 16

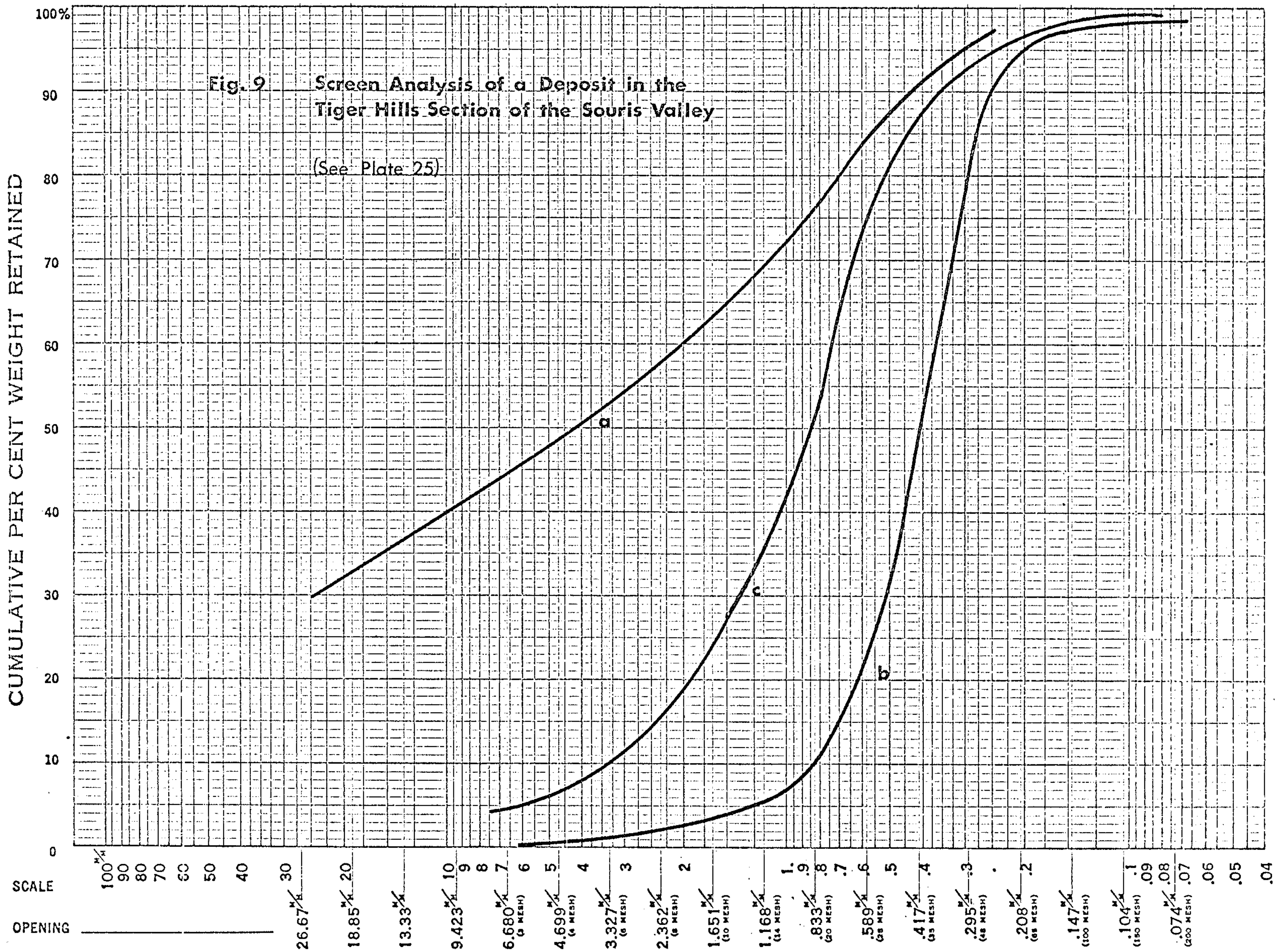
Fig. 9 Screen Analysis of a Deposit in the Tiger Hills Section of the Souris Valley
(See Plate 25)
CUMULATIVE PER CENT WEIGHT RETAINED
100%
90
80
70
60
50
40
30
20
10
0
a
b
c
SCALE
OPENING
26.67 M/M
18.85 M/M
13.33 M/M
9.423 M/M
6.680 M/M (3 MESH)
4.699 M/M (4 MESH)
3.327 M/M (6 MESH)
2.362 M/M (8 MESH)
1.651 M/M (10 MESH)
1.168 M/M (14 MESH)
.833 M/M (20 MESH)
.589 M/M (28 MESH)
.417 M/M (35 MESH)
.295 M/M (48 MESH)
.208 M/M (65 MESH)
.147 M/M (100 MESH)
.104 M/M (150 MESH)
.074 M/M (200 MESH)

Clayey silt above lag at south end of the cliff

sand	5.0%		
silt	66.3%	coarse silt	57.8%
		fine silt	8.5%
clay	28.7%		

<u>Cliff south of Highway 2 (see Fig. 4)</u>

Stratified silty clay

sand	0.4%		
silt	27.8%	coarse silt	17.7%
		fine silt	10.1%
clay	71.8%		

Contorted silts:

In gulley in photograph

sand	0.3%		
silt	69.2%	coarse silt	62.2%
		fine silt	7.0%
clay	30.5%		

50 yards south of the gulley

sand	0.5%		
silt	83.2%	coarse silt	76.5%
		fine silt	6.7%
clay	16.3%		

100 yards south of the gulley

sand	6.7%		
silt	89.8%	coarse silt	87.0%
		fine silt	2.8%
clay	3.5%		

Varved clay

sand	5.4%		
silt	17.3%	coarse silt	8.8%
		fine silt	8.5%
clay	77.3%		

Clayey silt enclosed by finely laminated dark clay (near centre of photograph)

gravel	4.1%		
sand	12.4%		
silt	47.0%	coarse silt	40.0%
		fine silt	7.0%
clay	36.5%		

<u>Fine sand on main composite terrace (see Plate 23)</u>

sand	79.3%		
silt	16.7%	coarse silt	15.1%
		fine silt	1.6%
clay	4.0%		

APPENDIX II

Woody Stems or Roots from the Wawanesa Cliff

At the point where the section in Figure 3 was measured the remains of several woody stems or roots were found concentrated at the level indicated. They range in diameter from about one tenth of an inch to about 3 inches. The patterns of annual growth rings are very well preserved but it seems that most of the organic matter has been replaced by iron.

The main point of interest is whether or not they are contemporary with the material in which they are buried. There are a number of observations which seemed at first to make it likely, or at least possible, that they were. Firstly, they are restricted to the stratified and cross-bedded silts between 7½ and 13 feet beneath the top of the cliff. It so happens, also, that they were not found in the face of the cliff, along its length, outside a small area of a few square feet. Secondly, some lay horizontally, parallel to the stratification, and ended abruptly as if they were broken before they reached these positions. Others rested at different angles but there was a clear absence of growth relationship between some particular specimens. If it were demonstrated that they are the remains of stems and not roots, then it could be stated with confidence that they were contemporary with the silts. If they be the remains of roots they could be either this same age or younger, and therefore of limited interest even if they could be dated and identified.

S.Zoltai, after examining the specimens briefly, observed that several of the smaller ones are nearly vertical, slightly sinuous, and similar to roots he had seen elsewhere. The larger ones, however, could be stems and even of a different age. He also pointed out that some of the larger ones were surrounded in section by concentric dark rings, apparently homogeneous silt, exactly the same as that without any remains of wood, up to 4 inches in diameter. These rings gradually become faint away from the centre and probably do not represent the original size of the wood. Zoltai also commented that both root concentration at this level and the availability of iron would be consistent with a high water table maintained by the (clayey) till underneath the silt. In one specimen there was some indication, in section, of a radial structure. If this were a hardwood it must be younger than the surficial deposits because hardwoods migrated into the Province at a later date (Shay, 1967, p. 250) than when it is supposed the silts were deposited (in glacial Lake Brandon).