Hydraulics Research
Wallingford

CHANGES IN THE TIDAL CAPACITY OF THE RIVER MERSEY

Report on studies made in 1984-85

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SUMMARY

This study has been undertaken to identify changes in estuarine sediment distribution and assess the factors responsible in a multi-channel system as represented by the inner estuary of the River Mersey.

A report produced in March 1983 (IT 244) examined changes in the tidal capacity of the estuary between 1861 and 1977 and concluded that there were three distinct periods of change. It also concluded that the major decline in capacity between 1911 and 1961 was concentrated in the wide, shallow inner estuary between Seacombe and Hale Head.

In this second stage, the study has been directed towards establishing the reasons for the changes, differentiating between periods of relative stability in estuary capacity and periods of rapid decline. Changes in the hydraulic characteristics which influence the tidal capacity of the system - tidal flow, river flow and sediment supply - have been examined and identified with civil engineering practice since the final decades of the last century. Paramount among the works were construction of the Manchester Ship Canal and the River Weaver diversion scheme which modified the exchange of flow between estuary and tributaries from the 1890's; training of the sea channels in Liverpool Bay which increased the supply of sediment to the inner estuary between the 1900's and the 1930's; slag tipping below Widnes which pinned the low water channel to the Lancashire shore above Hale Head in the upper part of the inner estuary since the end of the last century; progressively intensive maintenance dredging in the Eastham Channel up to the early 1960's which inhibited changes in channel position below Mount Manisty in the lower part of the inner estuary.

Investigation of the relationship between position and movement of the low water channel and loss in capacity involved an analysis of information extracted from 1200 charts shewing the monthly channel position since 1867. A computer program producing a schematized outline of the estuary was used to plot the location of channel intersections with standard survey section lines.

The study revealed three main phases of low water channel behaviour roughly coincident with the three periods of capacity change identified in report. IT244 - fifty years of relatively high channel activity with the system near a state of long-term dynamic equilibrium; fifty years of reduced activity during major readjustment to large-scale civil engineering works; twenty-five years of increasing activity with the approach of a new state of dynamic equilibrium.

The findings of this strategic research project have particular relevance in the context of development projects for the Mersey estuary eg present land reclamation proposals, the possibility of a Mersey barrage, the development of leisure activities. They provide an understanding of morphological changes in the system in the light of which the results of studies on the recently completed physical model of the Mersey may be assessed.

CONTENTS

1 INTRODUCTION

In the first report on this study of changes in the tidal capacity of the River Mersey (Ref 1), it was established that the period for which regular surveys are available falls into three district periods. From 1861 to about 1911 wide fluctuations were experienced, the barely discernable trend being very gradually downward. By comparison, events during the next half century until the early 1960's were quite clear-cut, taking the form of a rapid reduction which resulted in the loss of $70 \times 10^6 m^3$ of tidal storage. From the early 1960's to 1977 there was an apparent levelling off with the possible establishment of a new dynamic equilibrium.

The report also found that the very significant decline in estuary capacity between 1911 and 1961 did not occur evenly over the whole estuary but was concentrated in the wide, shallow part between Seacombe and Hale Head, the cross-sectional area having fallen by 25% between Stanlow Point and Hale Head (Fig 7).

It was recommended that a study be made of the relative significance of factors having an influence on tidal capacity, regretting the fact that although isolated parts of the estuary are regularly surveyed by different authorities, the Mersey Docks and Harbour Company (MDHC) are now no long able to carry out regular comprehensive surveys of the Mersey, 1977 being the last occasion when one was made.

This second report gives an account of the work carried out since 1983. It describes the findings of an examination of the possible reasons for the capacity changes and assesses their relative significance. It also presents the results of an analysis of changes in the position of the main low water channel and suggests a possible connection between civil engineering activity and channel position.

2 FACTORS AFFECTING TIDAL CAPACITY

The tidal volume of an estuary like the Mersey is prevented from rapid deterioration by the ability of the low water channel to migrate across the area lying between the high water mark of ordinary spring tides (Ref 2). During this process, the meandering channel is continuously eroding and depositing material, the working and re-working of the sediments interrupting the growth and consolidation of inter-tidal banks. Where meandering is suppressed, either through natural causes or man's intervention, the erosional process is suppressed. Silt, deposited on the surface of the banks during slack high water of tides, remains undisturbed due to the inability of the low water channel to "fret" into the banks by undercutting. The result is a gradual increase in bank height, consolidation of deposited sediments, and colonization by vegetation. Eventually that part of the estuary occupied by the bank is lost to the system, being covered by water on only the very highest of spring tides.

There are numerous examples where this process has been accelerated by man's intervention.

In the Dee, the course of the river below Chester was diverted from the much lower north side of the estuary to the south side by excavating a new channel through well-consolidated saltings and restraining its movement by the construction of training walls. By 1916, 26% of the total area of the estuary at high water had been lost by reclamation of the bed between the new, trained channel and the Cheshire shore. By 1938, deterioration due to loss of tidal storage had been so severe that efforts to maintain navigation depths in the upper estuary were abandoned.

In the Ribble, the low water channel was trained over a distance of 15 miles with the result that extensive siltation occurred on either side. In the upper estuary the saltings advanced from the original bank line almost up to the training walls, depriving the estuary of tidal storage. This process gradually progressed down-estuary accompanied by reclamation as saltings became established.

In the Mersey, various civil engineering works could have led to the suppression of channel movement. In the outer estuary the approach channel was trained between 1909-1936 and in the inner estuary a variety of engineering works (listed in Ref 1 and repeated below for convenience) are also likely to have reduced low water channel activity:

(i) the River Weaver diversion scheme, completed in 1896;

(ii) the construction of piers for the Runcorn railway bridge, completed in 1865;

(iii) the construction of piers from the Runcorn transporter bridge, completed in 1902;

(iv) the tipping of slag to form an embankment on the north-east side of the estuary between Widnes and Hale Head, completed in 1896;

(v) the construction of the Manchester Ship Canal with its associated reclamation and diversion of river and tidal water, completed in 1894;

(vi) the dredging of estuary channels, carried out intermittently from the 1890's and culminating in the average annual extraction of $2.75 \times 10^6 m^3$ from the Eastham Channel during the latter half of the 1950's.

Although it is not possible to isolate the effects of these various activities, it was concluded in Ref 2 that the training walls constructed in Liverpool Bay had contributed to inner estuary siltation by altering the circulation in the bay in such a way as to increase the amount of sediment arriving at the entrance to the Mersey. Measurements in the field and on a hydraulic model established the existence of salinity/density currents which provided a mechanism for transporting this additional material into the inner estuary.

It was also shown in Ref 2 that whereas the low water channel between Widnes and Hale Head could be found in any position between the Lancashire and Cheshire banks until the early 1890's, thereafter it moved across to the Lancashire side of the estuary and has remained there ever since - an event attributed mainly to the tipping of the inerodible slag embankment along the Lancashire shore below Widnes.

The other civil engineering activities most likely to have affected the inner estuary between Seacombe and Hale Head, where most of the deterioration in capacity occurred, were the construction of the Manchester Ship Canal and associated River Weaver diversion scheme, and the recurrent maintenance dredging undertaken in the Eastham Channel approach to the canal.

The direct effect of the construction of the Manchester Ship Canal and River Weaver diversion scheme on the tidal capacity of the estuary (defined as the volume of water between the river bed and the highest level reached by a spring tide rising to a level 9.45m above Liverpool Bay Datum at Princes Pier) was to reduce it by an estimated $5.2 \times 10^6 m^3$. Although this represented less than one percent of the tidal capacity at the time of construction, it could have had a significant effect on local flow patterns and on the behaviour of the low water channel.

Before construction, a considerable volume of tidal water and fresh water flowed across what is now the estuary boundary but was formerly the confluence with the Weaver (Fig 2). The flushing action of the flood and ebb would have maintained a permanent low water channel for the R Weaver linking it with the low water channel of the R Mersey, the location of the junction of the two being strongly influenced by seasonal variations in freshwater discharge down both the Mersey and the Weaver.

The discharge into and out of the River Gowy, Holpool Gutter and Poole Hall Brook, though on a smaller scale, would also have played a similar role. Furthermore, during very high spring tides, the flood plains of all of the tributaries in the surrounding marshy areas would have contributed to tidal storage, extending the range of possible discharge into and out of the estuary still further.

The construction of the Ship Canal and associated works changed the pattern of flow in this part of the estuary, water no longer entering and leaving the mouth of the Weaver and the minor tributaries directly. Instead, entrance to the Weaver was via the canal through the Eastham locks and tended to be bi-monthly rather than semi-diurnal in occurrence. Egress became a function of the prevailing water level in the canal, any excess being discharged through the Weaver sluices. Tidal flow into and out of Poole Hall Brook and Holpool Gutter was completely cut off, the fresh water discharge being passed under the canal through siphons and the flood tide being excluded by tidal flaps. The River Gowy differed from the other outfalls in that the tidal flaps were located about 1km upstream of the culverts carrying the flow under the canal. Some degree of tidal storage was thus provided, albeit on a smaller scale than before canal construction.

The water in the canal is maintained at a level 9.1m above Chart Datum which is below the high water level of some spring tides at Eastham locks. The mitre gates at Eastham are not capable of withstanding a reverse head difference and therefore open on high tides allowing estuary water to enter the canal. When the tide turns and the estuary level begins to fall at Eastham, the lock gates close, trapping the excess water in the canal. To ensure that bridges are cleared by passing ships the canal water level is fairly quickly reduced by discharging through the Weaver sluices. Although this can be expected to affect local circulation in the estuary at the time, it is unlikely to have much influence on the position of the main low water channel since it only occurs for a fairly short period, on only a few tides, and at a time when water levels in the estuary are relatively high.

If carried out on a sufficiently large scale, the continuous maintenance dredging of one particular channel in a multi-channel tidal system tends to concentrate the flow in that channel at the expense of competing channels, with inevitable local stabilization of channel position. In addition, it inhibits the natural tendency of the channel to migrate by the process of lateral abrasion. It is thus likely that in a particular compartment of an estuary, the behaviour of a low water channel whose freedom of movement is restricted, either upstream, downstream, or in both places at once, will be different from that of one having no such constraints.

In order to investigate whether such changes in low water channel behaviour had indeed occurred in the inner part of the Mersey estuary, the study described in the next section was carried out.

3 LOW WATER CHANNEL BEHAVIOUR, 1867-1958

It was shown in Ref 1 that the bulk of the deterioration in the tidal capacity of the Mersey between the second and seventh decades of this century occurred between Seacombe and Hale Head. It was also demonstrated that the maximum loss of 25% in estuary cross-sectional area took place between Stanlow Point and Hale Head (Fig 1).

An examination of the MDHC quinquennial surveys clearly revealed that in this zone, the most pronounced development was the growth and establishment of inter-tidal banks along the Cheshire shore in the vicinity of Ince and Stanlow. It was therefore decided to examine the frequency with which the low water channel has, over the years for which records are available, swept the area now occupied by these banks.

Between 1867 and 1972, the Upper Mersey Navigation Commissioners surveyed and buoyed the low water channel above Eastham approximately once every month. In 1958 the Hydraulics Research Station (as HR was then called) borrowed all of the charts available up to that time and over a period of twelve months each was registered and photographed. A cartoon film made at the time provided the basis for the first part of the analysis.

It should be explained that the buoyed channel was not necessarily the only channel that could have been used for navigation, nor was it always the predominant one. It seems likely that once markers has been placed by the Commissioners, they would have been left in position until surveys showed that a deterioration in channel width and depth dictated a change to a better route. Nevertheless, the data provided a useful guide to the position of what, on most occasions, probably served as the main low water channel.

The method of analysis adopted was to project each frame of the film in turn on to an outlined chart of the Mersey estuary on which all of the estuary sections used by the MDHC were shown. The position at which the buoyed channel intersected each survey section was then measured and tabulated and the information input to a computer file for analysis.

In order to illustrate the position of the channel, a computer program was written to produce a schematised outline of the bank line of the estuary and to plot the locations of the intersections of the low water channel with the survey sections for each decade between the 1860's and the 1950's. The boundaries of the Ince and Stanlow inter-tidal banks as defined by the +9m contour on the MDHC 1977 survey were also reproduced on the image. The result is given in Figs 3-12. It should be noted that any individual point merely indicates that the channel occupied that position at some time during the decade observed: it does not reveal how many times this occurred.

The most important features to emerge from the figures are:

(i) the low water channel encroached on the inter-tidal banks in the four decades of the 1860's, 1870's 1880's and 1900's but never thereafter;

(ii) the course of the main low water channel lay through either the Garston Channel or Middle Deep during the fifty or so years between 1867 and part way through the 1920's, and since then until the end of the period covered by the charts it was consistently located in the Eastham Channel.

It is likely that if the presence of the low water channel adjacent to the Cheshire shoreline were a feature of a regular cyclical change in the channel's position, it would have recurred on a number of occasions since the 1880's (Fig 5). Based on an examination of the monthly charts up to 1958 this did not happen.

4 LOW WATER CHANNEL BEHAVIOUR, 1958 TO DATE

Following closure of the office of the Upper Mersey Navigation Commissioners in Runcorn, HR lost track of the remainder of the monthly charts of the Mersey buoyed channel. It is only in recent months that some of them have been located in the care of the new Liverpool Maritime Museum, and the Director of Museums of Merseyside County Council kindly loaned them to HR to enable this study to be brought further up to date. The charts cover the years 1958 to 1966, the information currently available on low water channel position after 1966 unfortunately being very sparse indeed. However, to give some indication of developments since then, recourse was had, firstly to the last of the surveys carried out by MDHC, secondly to aerial and satellite photographs obtained respectively from the Manchester Ship Canal Company and the Remote Sensing Unit of the Royal Aircraft Establishment, Farnborough, and finally to a survey made in 1984 by HR.

The MDHC surveys, which had formerly been quinquennial, were carried out annually throughout the fifties and sixties, terminating with three in the seventies - one in 1970, another in 1972 and the last in 1977. The only survey of the inner estuary made during the last eight years was that commissioned by Cheshire County Council and carried out by HR in 1984 in connection with a study of the effect of proposed reclamation on the estuary.

The main points to emerge from an examination of the data since 1958 are:

(i) the low water channel moved to the edge of the banks during the first half of the sixties and actually made inroads during the late seventies;

(ii) the main route for the low water channel lay through the Eastham Channel until 1964: thereafter its course became more variable, mostly passing through the Garston Channel.

It thus appears that for the remainder of the fifties and the beginning of the sixties the behaviour of the channel remained much the same as throughout the previous decade. However, there were signs, even as early as 1962, that in the region of Stanlow Point the curvature of the low water channel was increasing fairly rapidly, and undercutting of the outer edges of both the Ince and Stanlow Banks was taking place. This process was halted by the relatively sudden switch in course in early 1964 from the Eastham Channel to the Middle Deep and the Garston Channel, channels which had remained subsidiary to the Eastham Channel in the three-channel system which had prevailed since the 1920's. From 1964 to date, conditions in the inner estuary have been considerably more changeable, the relative mobility of the low water channel being more reminiscent of the period prior to the 1920's than of the years leading up to the 1960's (Ref 3).

The erosion of Stanlow Banks which recurred in the early 1970's culminated, in 1979, with a distribution of inner estuary banks and channels in a two-channel system which, with minor exceptions, appeared to be almost identical to that which prevailed in 1871 - itself not very different from conditions in 1875 (Fig 2). Although it is unfortunate that the 1979 evidence is in the form, not of a hydrographic survey showing bed levels, but of an aerial photograph taken near the time of low water, the position of the main low water channel is quite unmistakable (Plate 1).

One of the minor, though significant, exceptions referred to is in the region of Ince Banks. In 1871, the southern limit of the channel ran virtually parallel to the Cheshire shore of the estuary from Holpool Gutter almost to what is now Mount Manisty before turning northwards through 90 degrees towards the Lancashire shore: between the Gutter and Stanlow Point it lay approximately 200ft (610m) offshore. In 1979, however, although still turning through a 90-degree bend between Stanlow Point and Mount Manisty before crossing to the Lancashire shore, the course of the channel from Hale Head to Stanlow Point lay further away from the Cheshire shore than in 1871. When due north of a point about 4000ft (1220m) west of Holpool Gutter, the edge of the channel was 5000ft (1525m) away from the shore, reducing to about 2000ft (610m) as it neared the Point.

An estimate made by the Manchester Ship Canal Company following some observations and measurements made in 1979/80, indicated that by 1980 the low water channel had moved further away from Stanlow Point. The HR survey of March 1984 showed that although the remains of the channel cut deeply into Stanlow Banks immediately westward of the point (the maximum distance from the shore at any point along the whole length of the banks was less than 1000ft (300m)), the main course of the low water channel had now moved towards the centre of the estuary and lay at least 5500ft (1700m) away from the Cheshire shore.

It thus appears that the low water channel has undergone a partial reversion to pre-1920 behaviour, becoming more active than during the intervening years up to the 1960's. A comparison of Figs 13, 14 and 15 illustrates this change in behaviour. The Figs respectively show low water channel position during the three periods - 1867-1916, 1921-1961 and 1961-1984. It would also appear that periods of little or no decline in estuary capacity tend to be associated with frequent changes in low water channel position, an observation made in Ref 3.

A major consequence of sea channel training was to provide the inner estuary with additional sediment (Ref 2): even so, the low water channel would still have had a natural tendency to make frequent changes in position had it not been inhibited by other works such as the virtually continuous maintenance dredging undertaken in the Eastham Channel, a policy which was not changed until 1962. Although the increased sediment influx would have produced accretion on fringe areas of inter-tidal marsh such as Frodsham Score or Ince Banks, the "pinning" of the low water channel encouraged expansion of the banks into the estuary by leaving large areas undisturbed for many decades.

5 CONCLUSIONS

The second stage of this three-year study of sediment redistribution in the Mersey estuary has identified three main phases of low water channel behaviour which are roughly coincident with the three periods of capacity change described in the report on the first stage:

(i) a period of relatively high channel activity during the first fifty years under review when the system appeared to be approaching a state of long-term dynamic equilibrium;

(ii) a period of reduced channel activity during the next fifty years when hydraulic conditions were undergoing major readjustment to civil engineering works undertaken around the turn of the century;

(iii) a period of increasing channel activity during the last twenty-five years, coincident with the establishment of a new state of dynamic equilibrium.

ACKNOWLEDGEMENTS

The co-operation of the Director of Museums of Merseyside County Council is gratefully acknowledged for the loan of the charts of the buoyed channel surveyed by the former Upper Mersey Navigation Commission. Thanks are also due to the Manchester Ship Canal Company for the provision of copies of aerial photographs and information on their own observations of low water channel behaviour.

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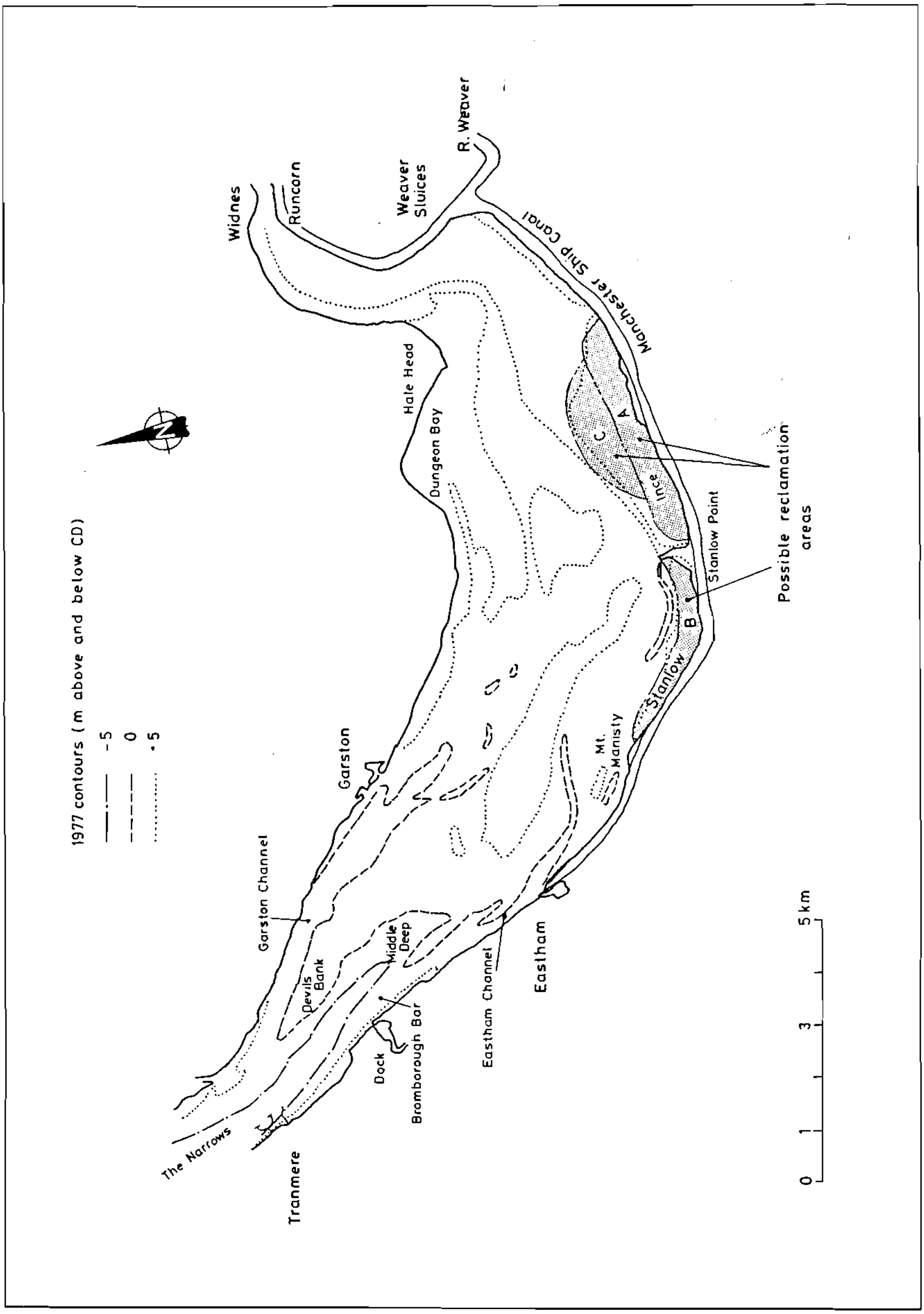

Fig 1 Location plan

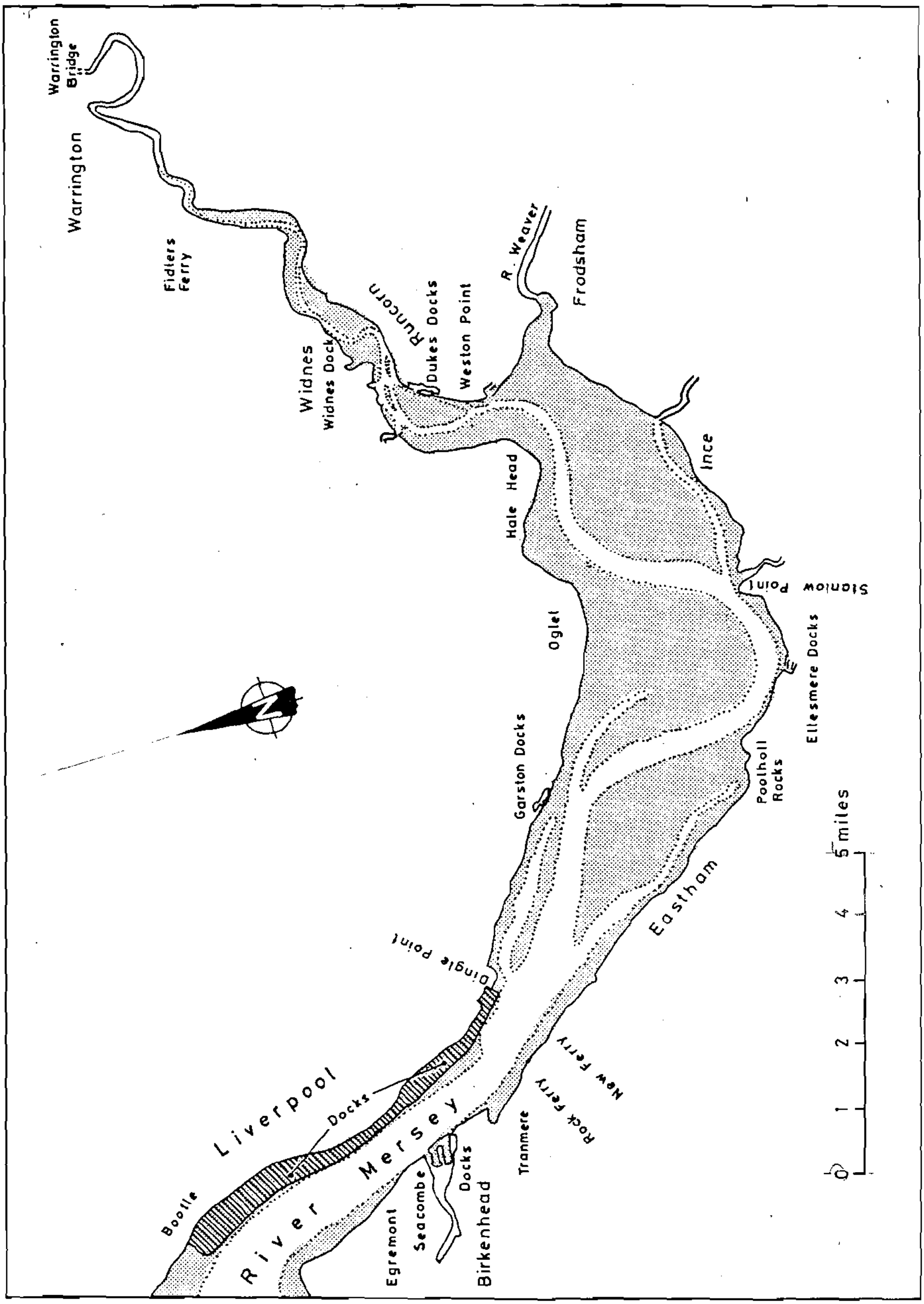

Fig 2 The inner estuary of The Mersey - 1875

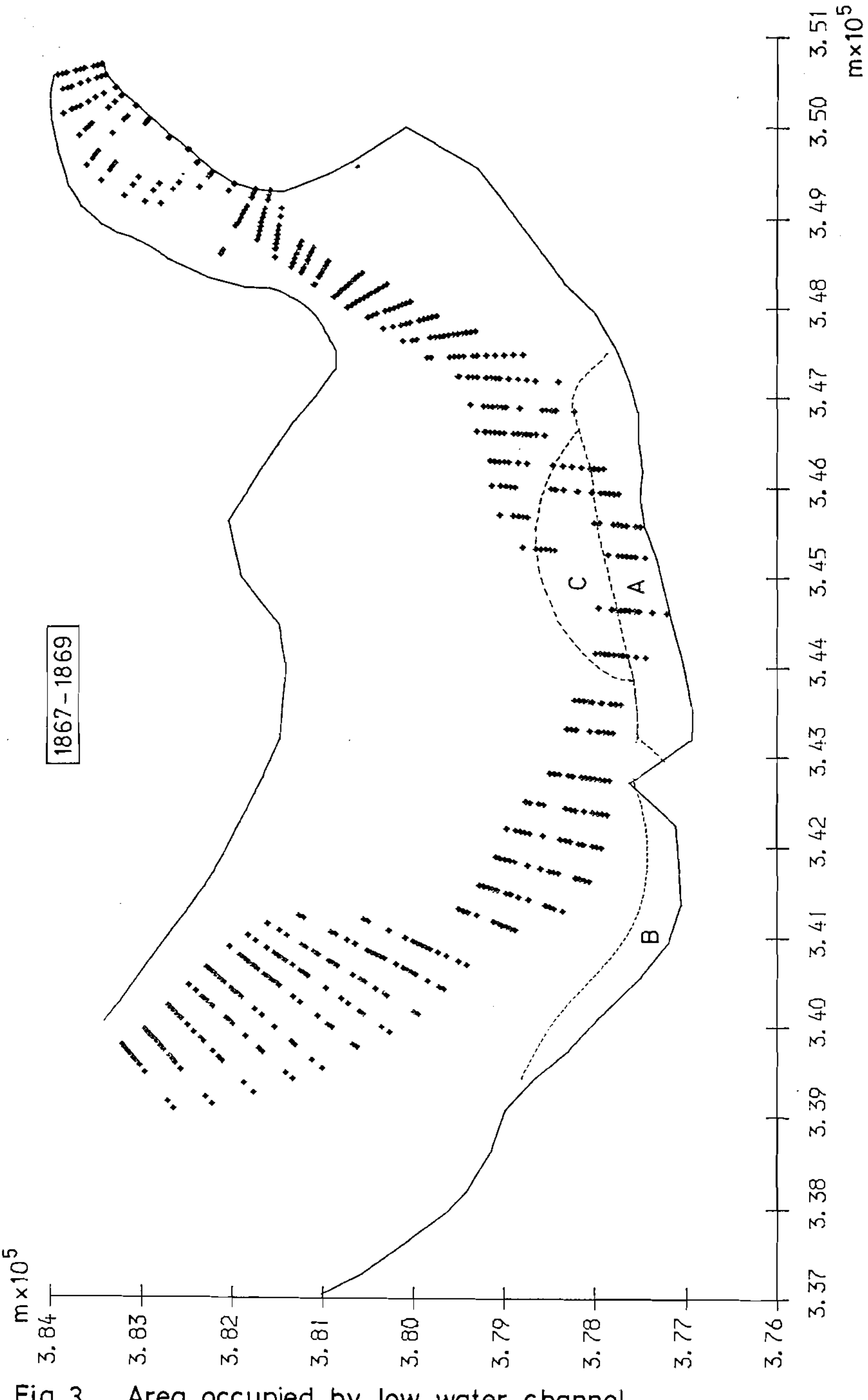

Fig 3   Area occupied by low water channel

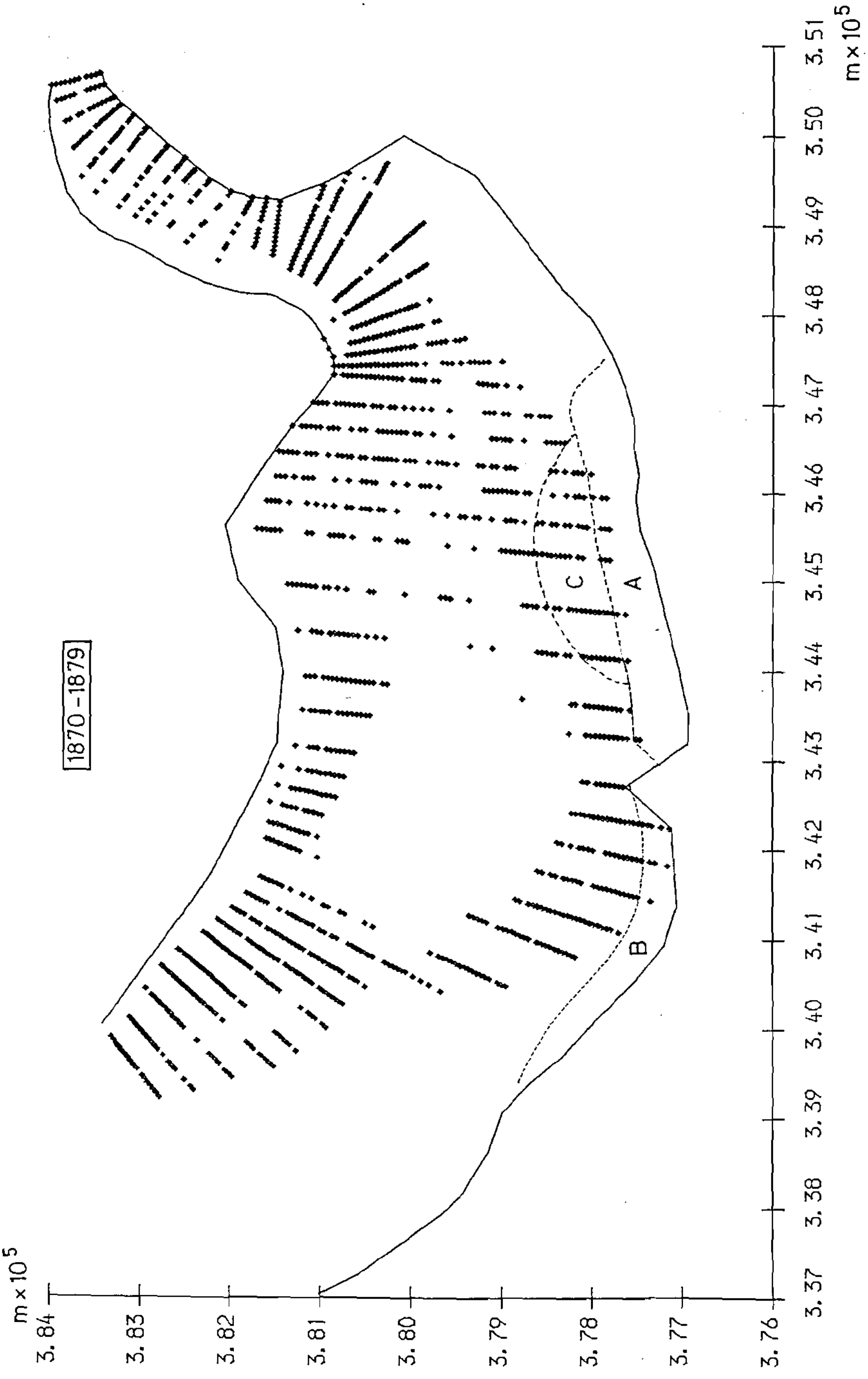

Fig 4 Area occupied by low water channel

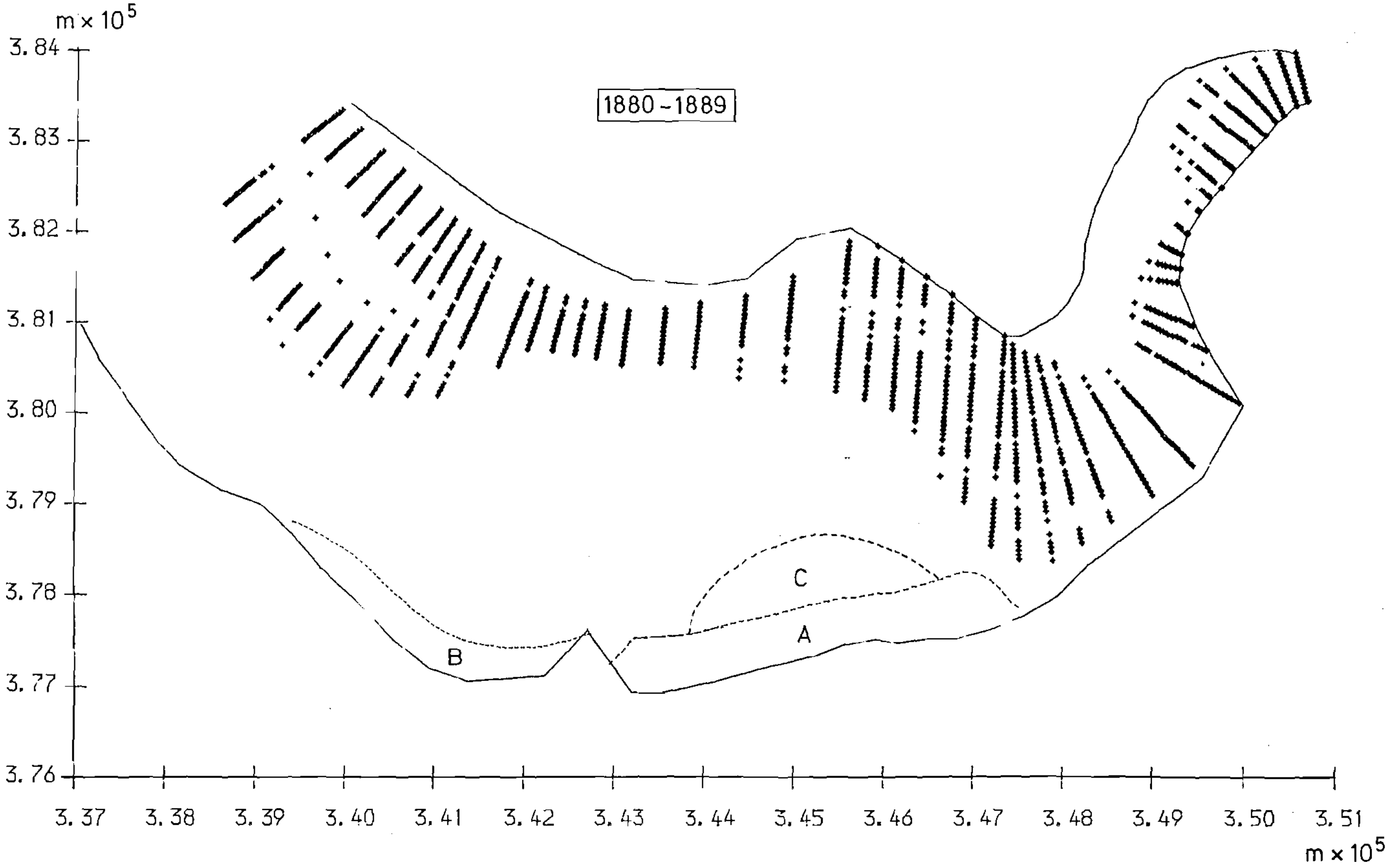

Fig 5 Area occupied by low water channel

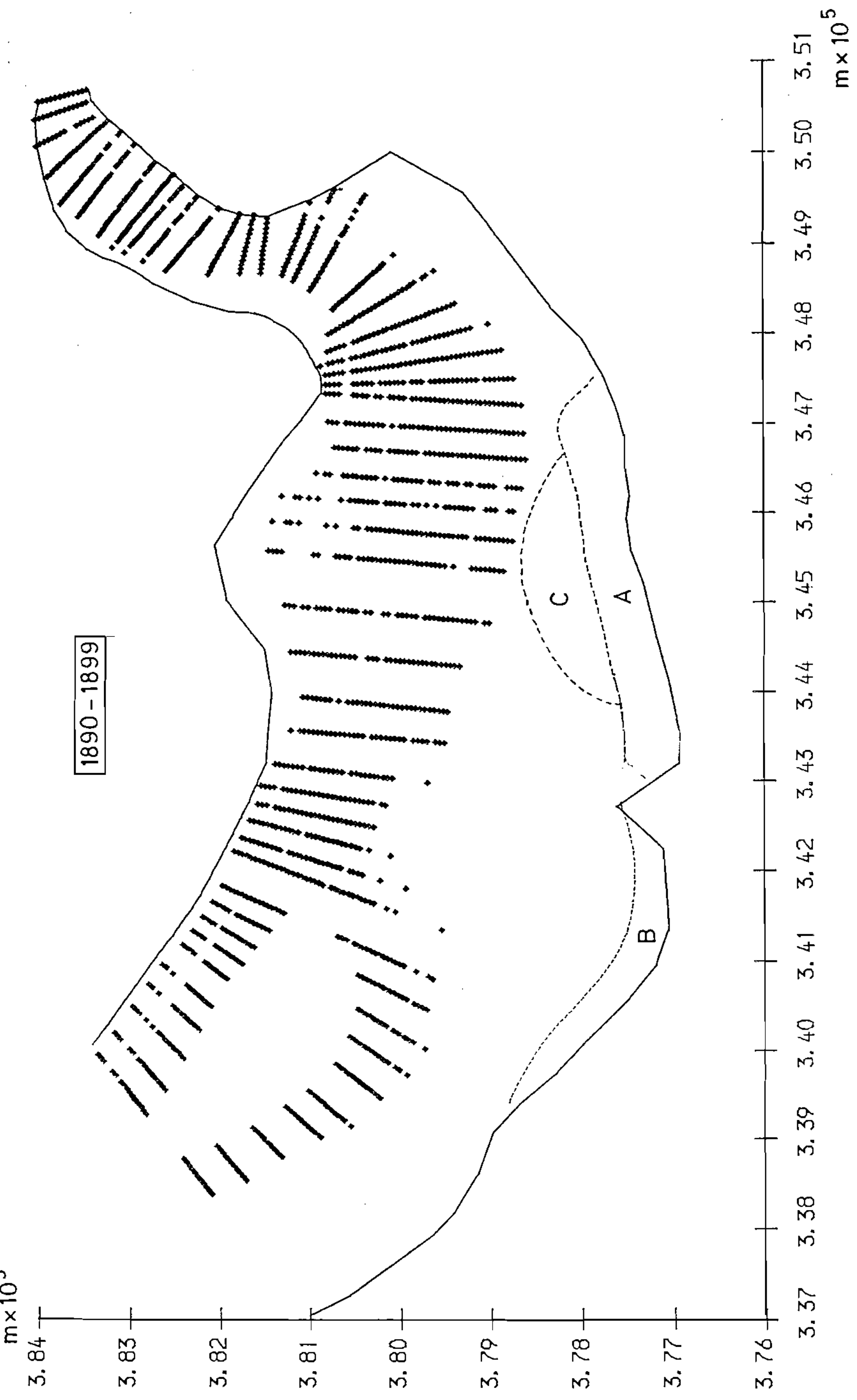

Fig 6 Area occupied by low water channel

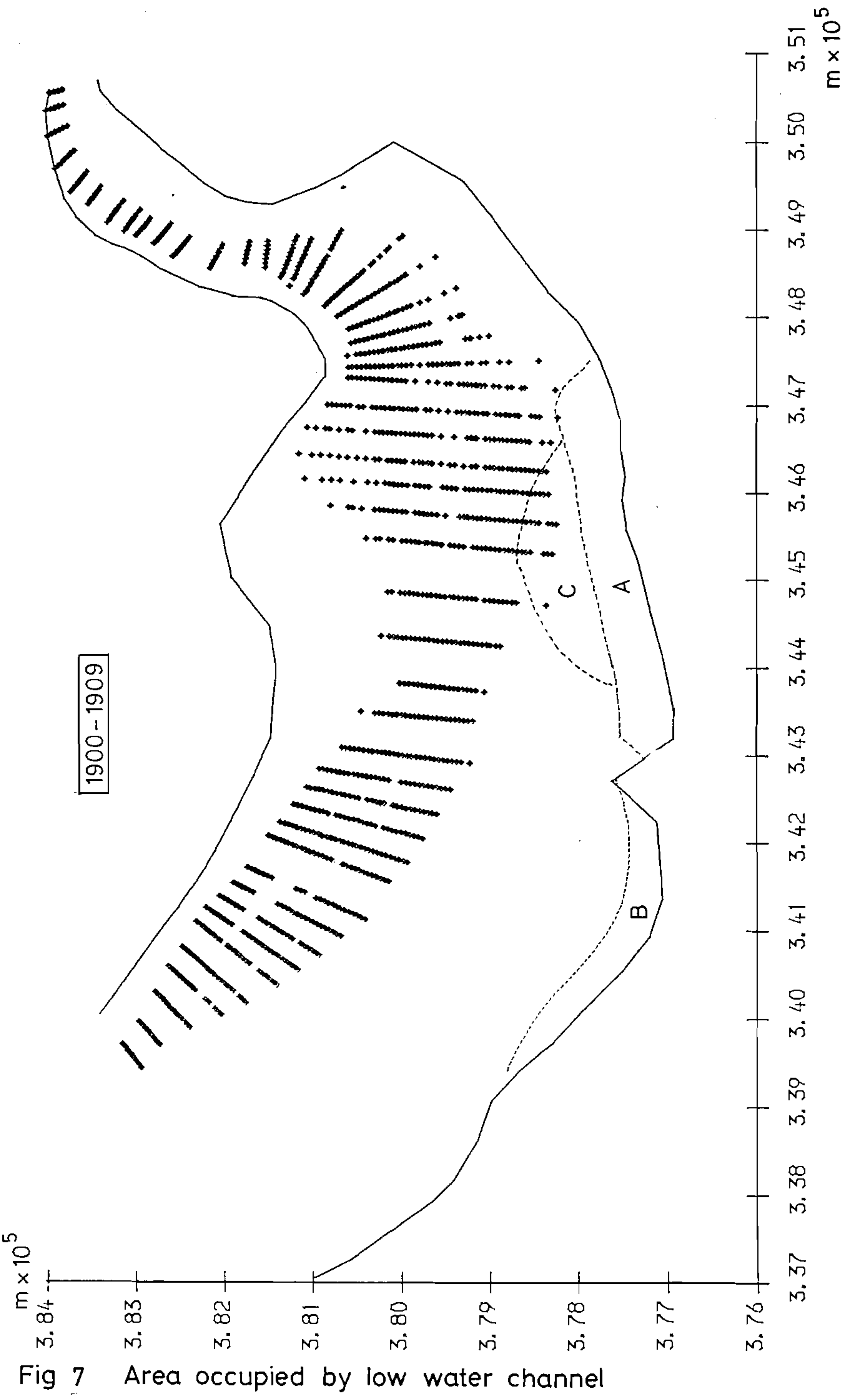

Fig 7 Area occupied by low water channel

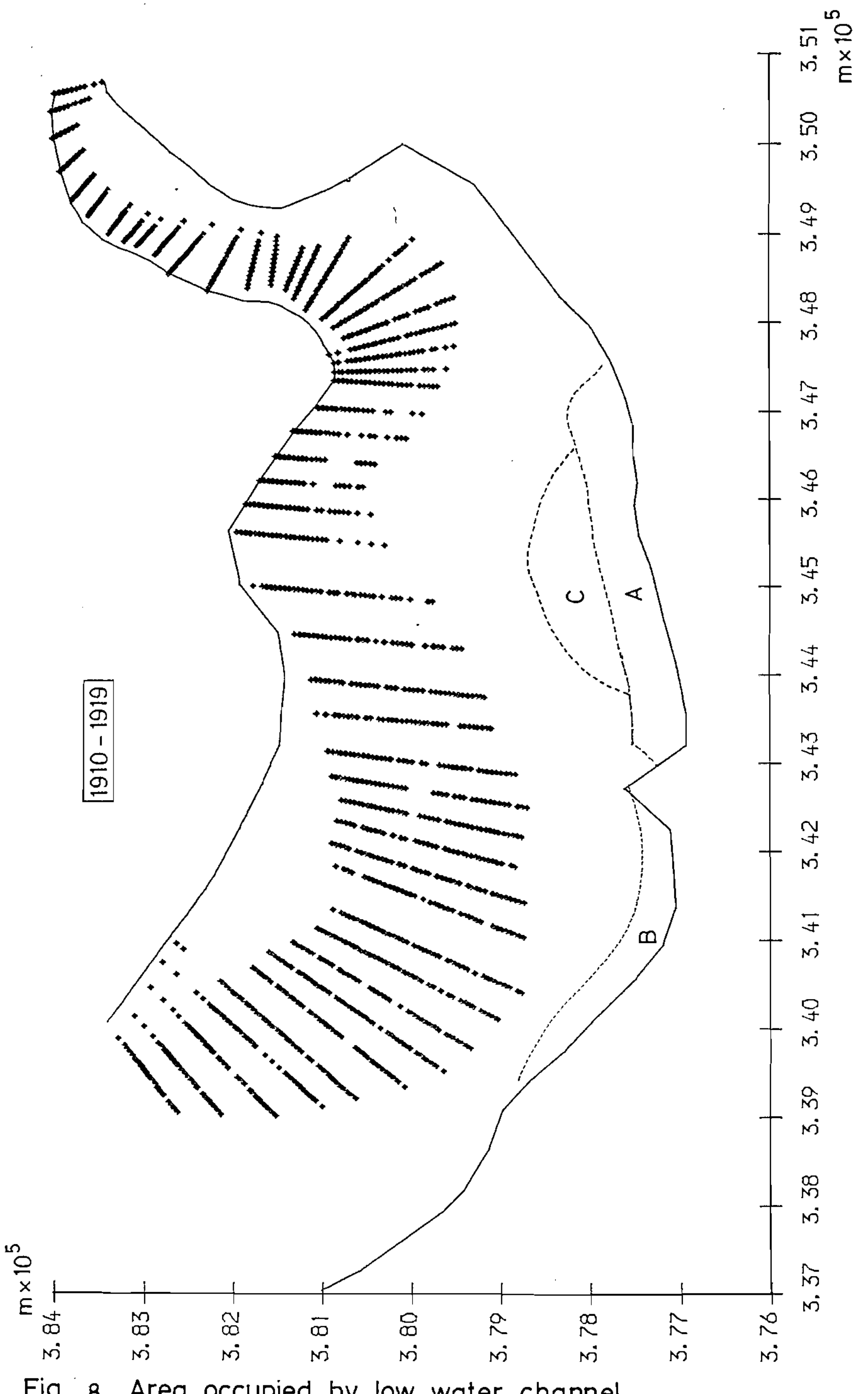

Fig 8 Area occupied by low water channel

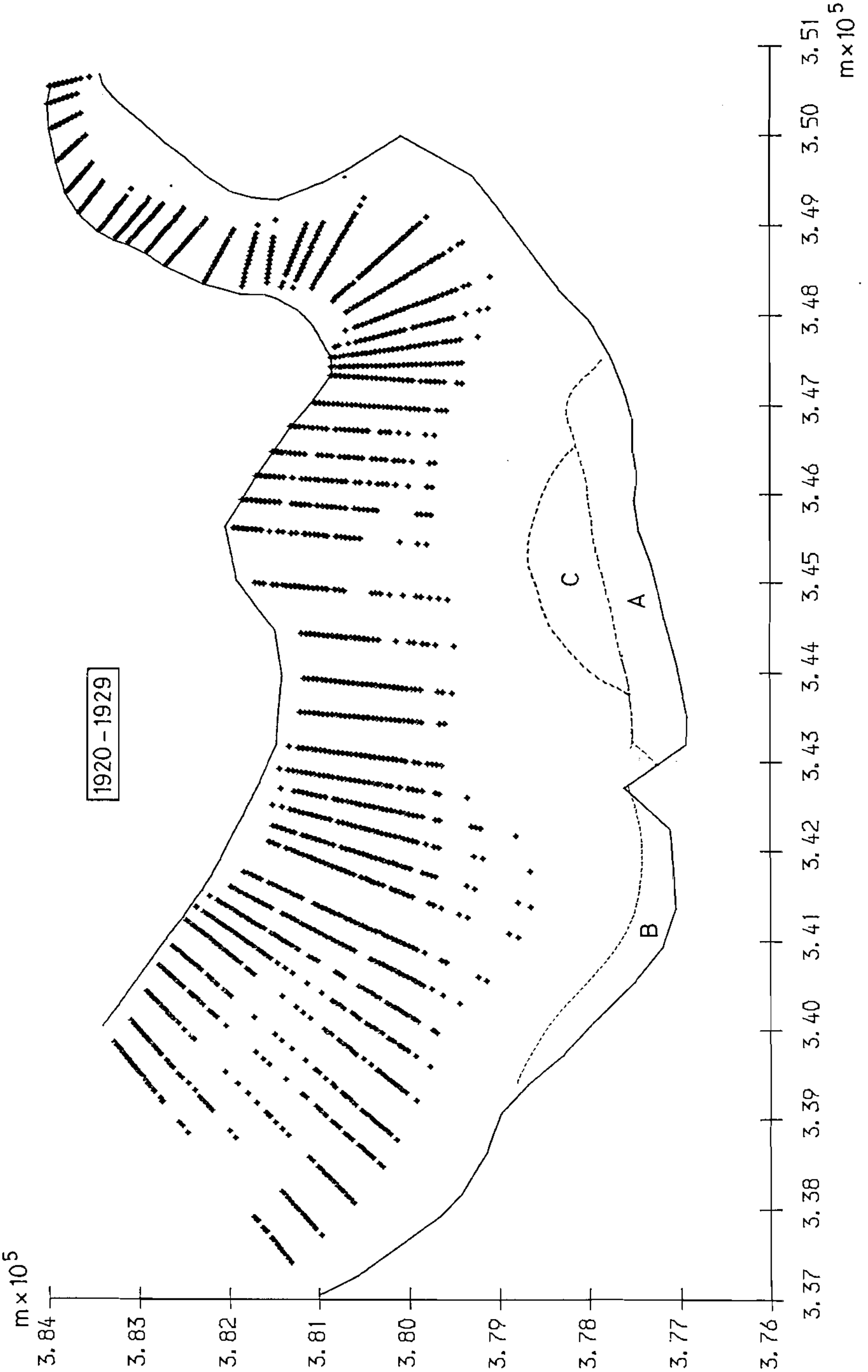

Fig 9 Area occupied by low water channel

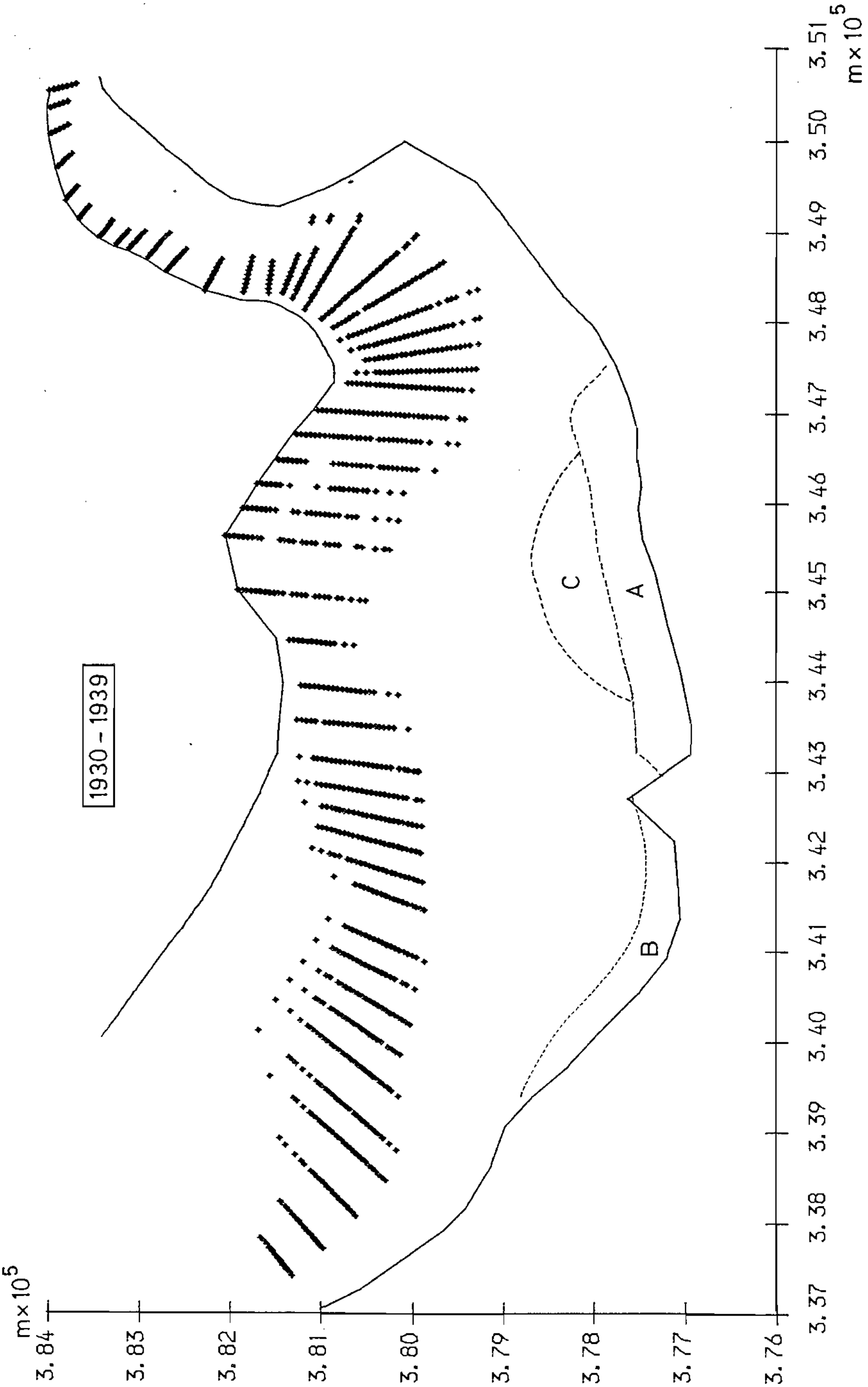

Fig 10   Area occupied by low water channel

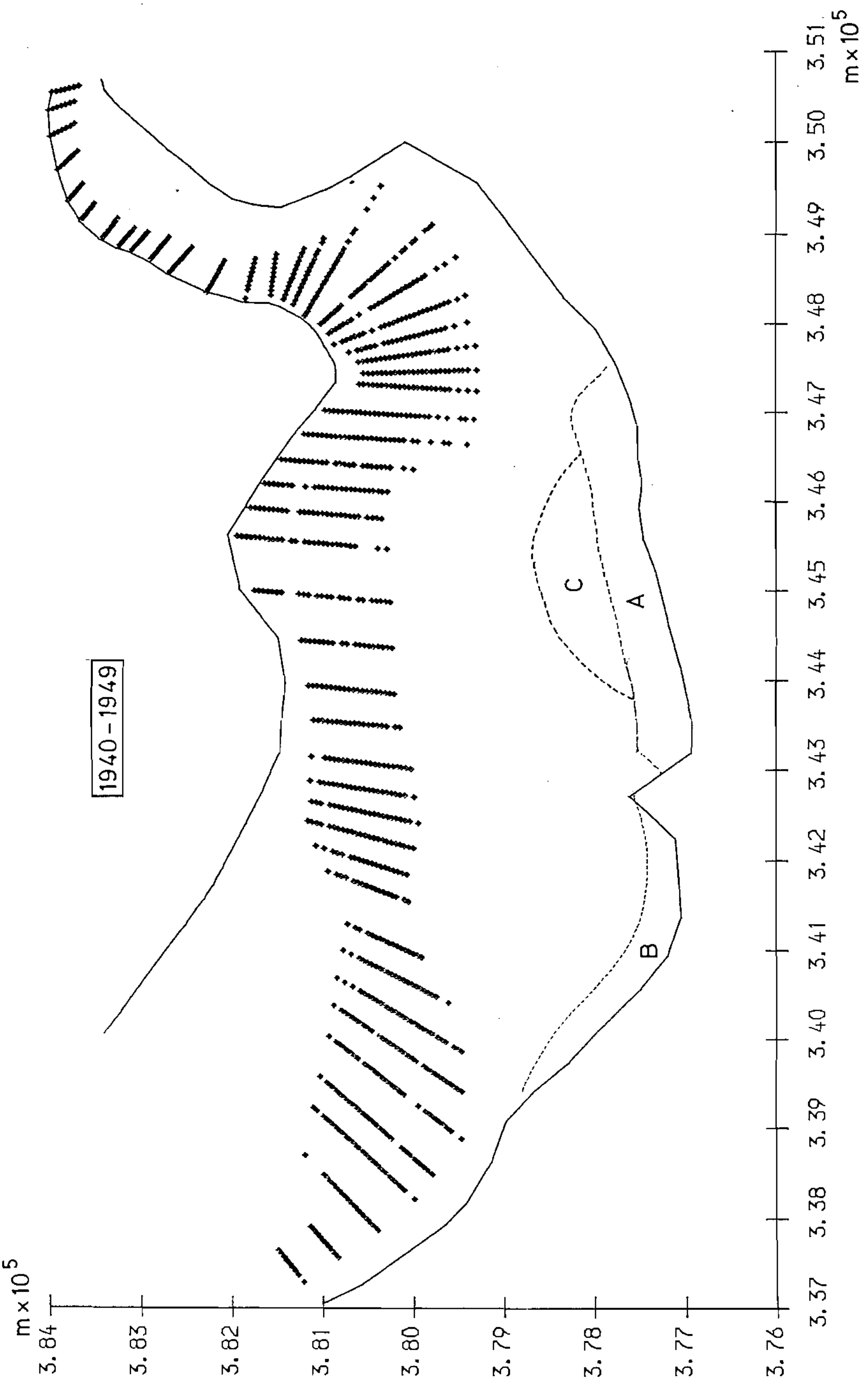

Fig 11 Area occupied by low water channel

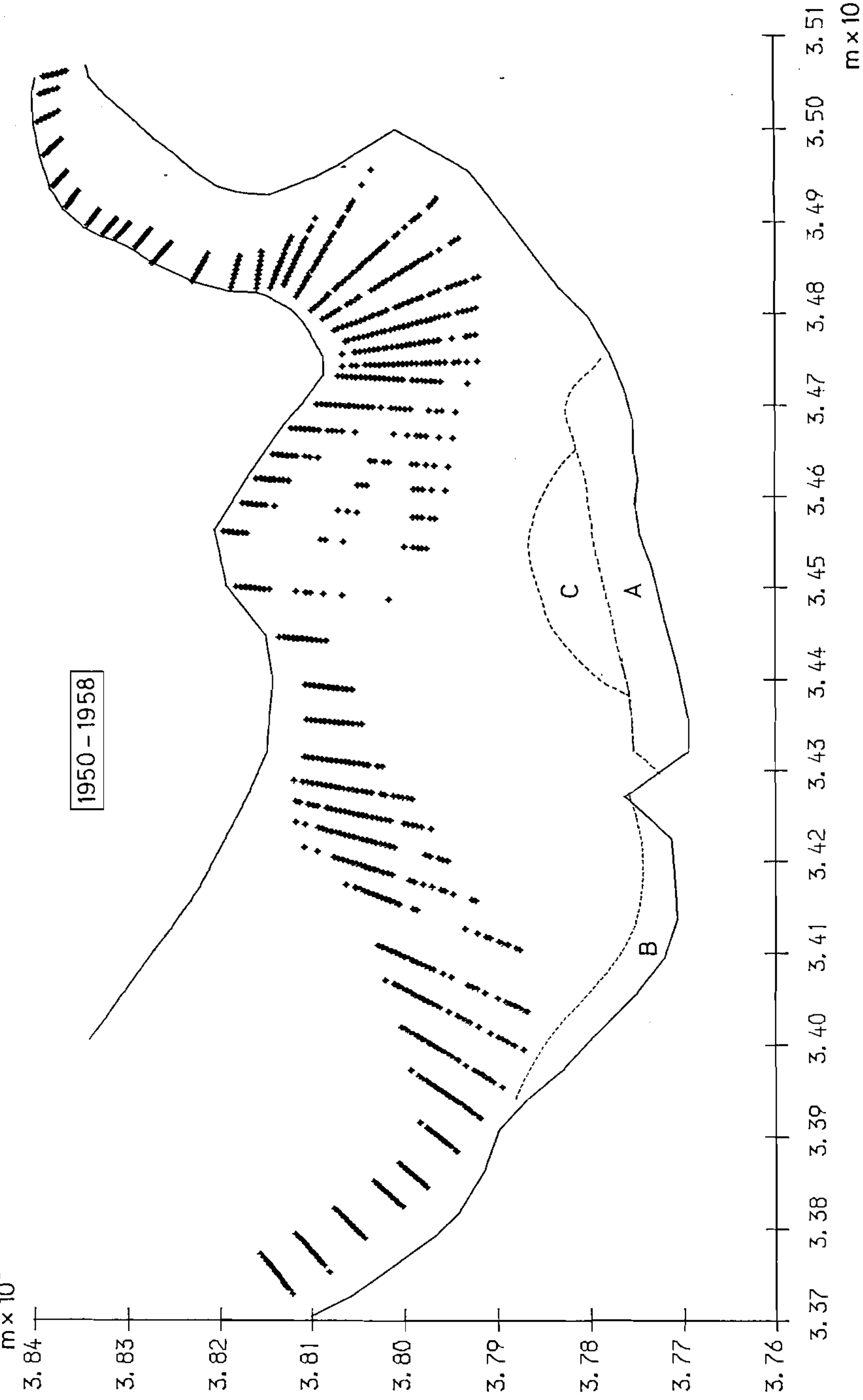

Fig 12 Area occupied by low water channel

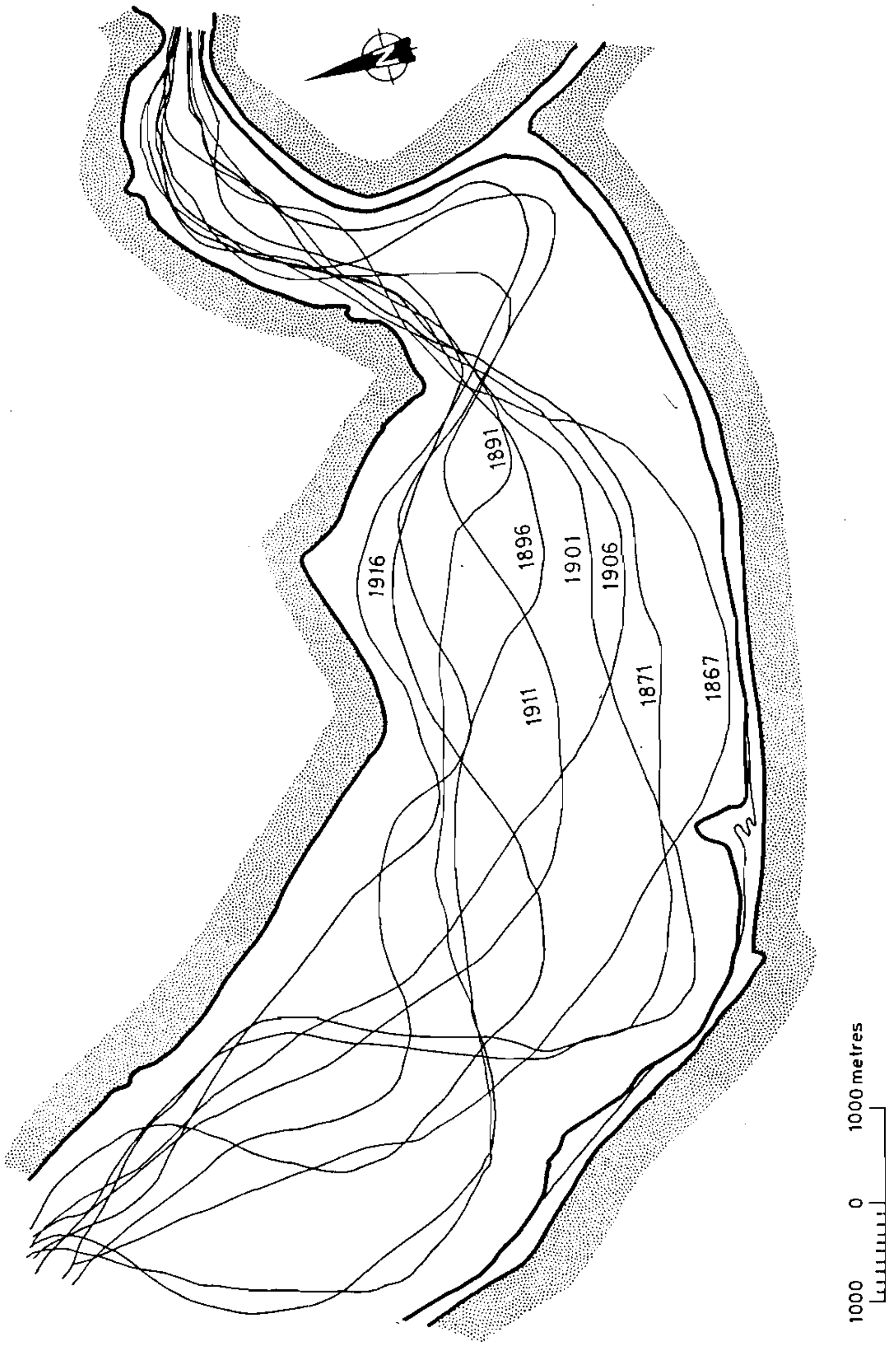

Fig 13 Mersey low water channel 1867 – 1916

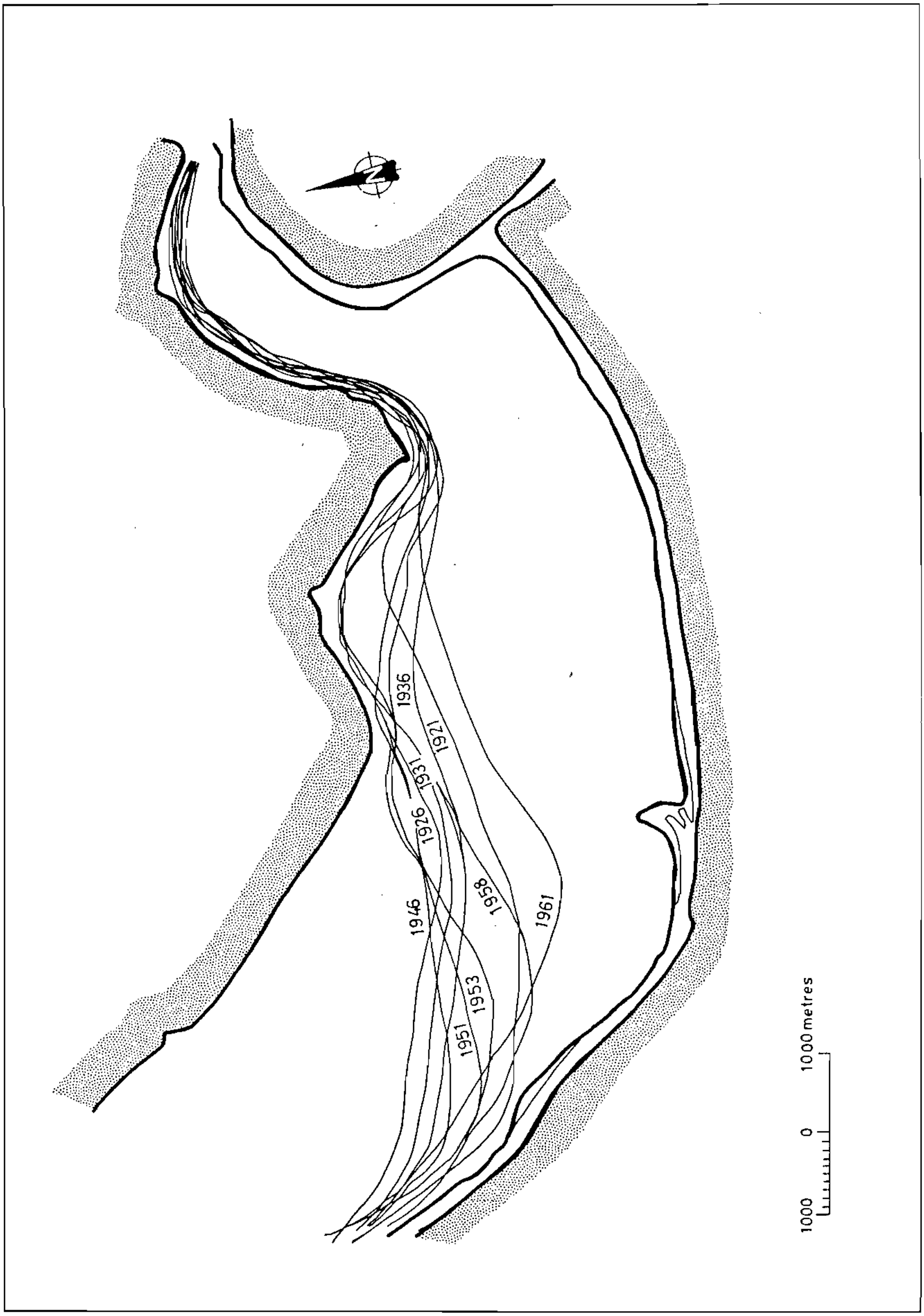

Fig 14 Mersey low water channel 1921 – 1961

Fig 15 Mersey low water channel 1961 - 1984