DETECTION OF CROP MARK CONTRAST FOR ARCHAEOLOGICAL SURVEYS

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16. Abstract

Anomalous growth patterns in vegetation which indicate buried archaeological features such as walls and ditches are called crop marks. These crop marks are visible for only a few weeks during each growth year. Ancient river meanders can also cause crop marks which are visible at the same time as nearby archaeological crop marks. The geological crop marks should be visible in Landsat photographs; a sequence of these photos taken during a crop growth cycle will determine the optimum time for archaeological photography from an airplane.

During the 1975 growing season, cloud cover at the Thames River test site in England has obscured the critical photos of mid-summer. The practicality of this technique has not been proven.

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Preface

Shallowly buried archaeological features such as ditches and walls can cause anomalous growth patterns in the overlying vegetation. These markings in the vegetation are visible for at most a few weeks during the growing season. Ancient buried river channels also cause vegetational growth patterns and they do so at the same time as nearby archaeological features. Landsat resolution appears to be good enough to detect the river channels, allowing the optimum time to be determined for photographing the archaeological marks from an airplane.

Photographic enlargements of the red image (Band 5) provided the greatest amount of information on the growth of the vegetation. Some additional detail was obtained by comparing the red and infrared images (Bands 5 and 7) with color diazo transparencies.

The test site near the Thames River at Dorchester, England, is obscured by clouds or haze in all Landsat photographs taken during the period of critical growth in mid-summer. The 1976 photos should be examined when they become available in the hope of a clear atmosphere. A related test could also be tried in the Mississippi-Missouri river valley.

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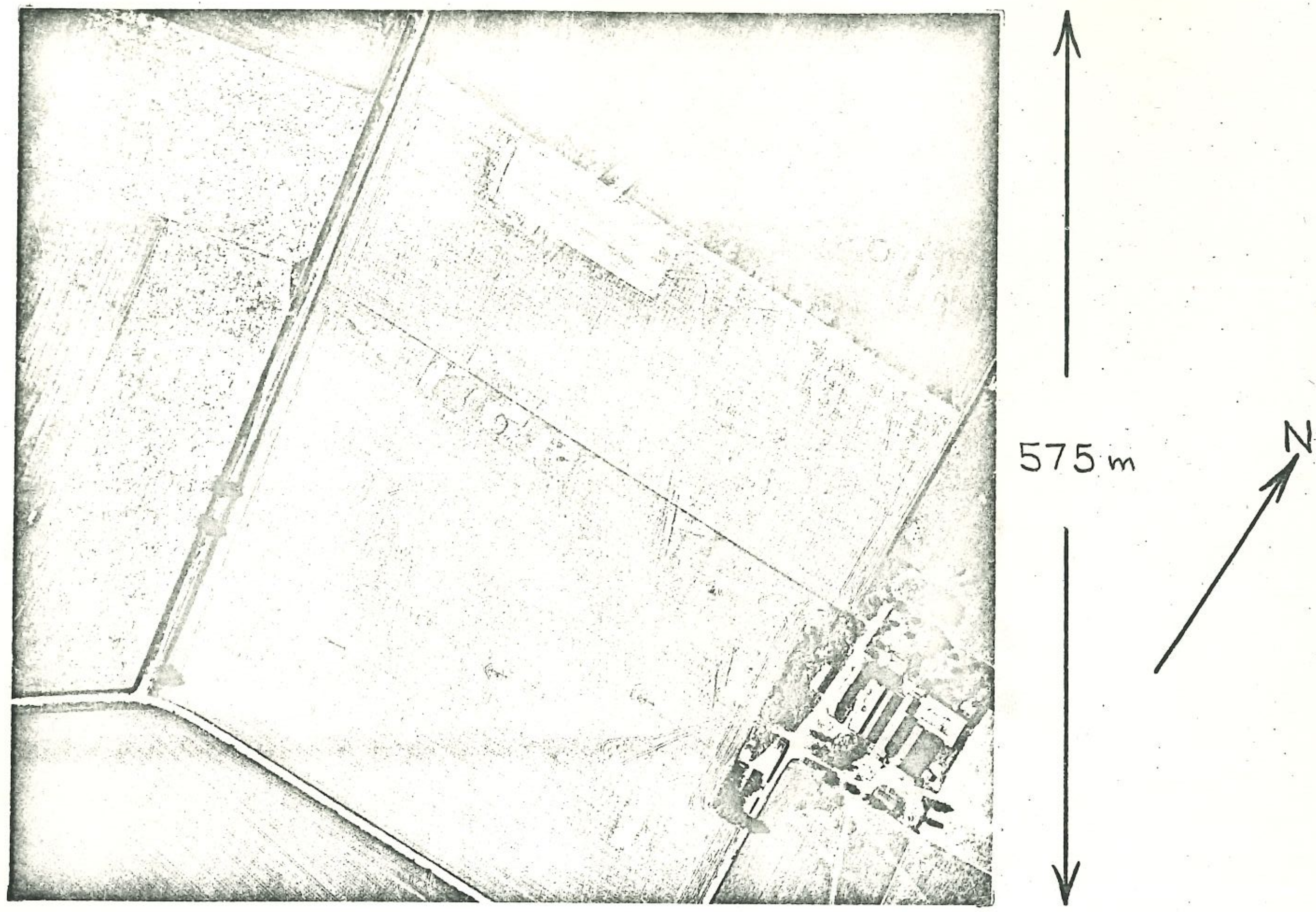
Introduction

The resolution of the photographs from Landsat-1 and Landsat-2 appears to be good enough to detect ancient meanders of the Thames River near Dorchester, England. However, no clear photos are available which show the area at the proper time in early summer during which growth patterns in the crops could reveal the earlier course of the river. Therefore the usefulness of the satellite for determining the optimum time for archaeological reconnaissance from aircraft is as yet unproven.

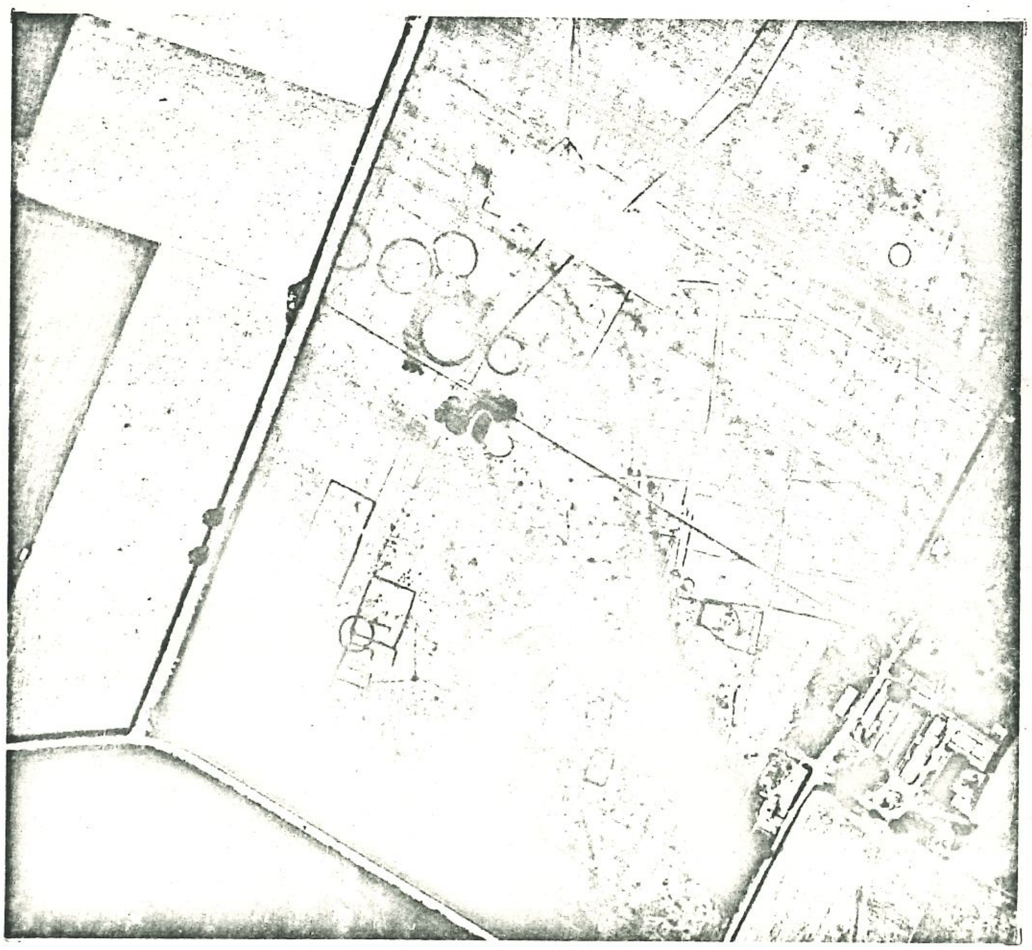
Archaeological Background

Archaeological structures, even those buried at a shallow depth, can sometimes be discovered and mapped with aerial photography. Ancient ditches, refilled by nature or man, and buried walls and roads are often detectable by the patterns of anomalous growth in the overlying vegetation; these patterns are called crop marks(1).

Crop marks indicating refilled ditches and pits are particularly visible in areas which have a thin but rich topsoil which covers barren subsoil. The river valleys in southern England are examples of this. Gravel is often found only a few decimeters under the surface. Early man dug holes through the topsoil into the gravel; when these holes were refilled, a pocket of richer soil would often result. Crops, such as wheat or barley which send their roots into this pocket of rich soil can grow differently than the surrounding crops. The most pronounced effect appears to be due to the greater amount of moisture in the soil of the refilled hole: the crop there can still be green when the surrounding crop is golden and matured. An example of this is given in Figure 1; the many ring-shaped ditches, rectangular enclosures, and other marks in this photo are the result of a long period of occupation by early man from the Bronze Age and Iron Age through the Romano-British Age (2). The camera which took these photos used panchromatic film and a yellow filter.



4 June 1970



19 June 1970

Figure 1. The time factor in crop mark visibility.

One of the big difficulties in archaeological reconnaissance is the short period of time in which crop marks are visible. The two photos in Figure 1 were taken 15 days apart. These marks will vanish when the crops are harvested.

The optimum time for photographing crop marks lasts for only about one week, although sometimes traces are detectable for a month or more. This optimim time varies from year to year primarily because of changing weather; in addition, differences in the soil cause the best time for photography to vary from region to region.

The Dorchester Area

The course of the Thames River in southern England is shown in Figure 2. At Dorchester, the Thames flows around a bend 2km in diameter; a map showing this smaller region is given in Figure 3.

This area is rich in crop marks; the shape and position of many of them are mapped in Figure 4. The line of the Thames is indicated on this map to show the correspondence to the base map in Figure 3.

In addition to the archaeological crop marks, large bands appear in the fields. Some of these bands are shown in Figure 1; the time of their appearance coincides with the time of visibility of the archaeological crop marks. From aerial photographs taken in 1970 and earlier, the shapes of some of these large bands have been mapped (see Figure 5).

The position and size of these bands indicate that they might mark earlier courses of the river; in a flat-bottomed valley like this, river meanders are to be expected. The variable bands of soil left behind by the shifting river cause large geological crop marks; the greener growth of the bands implies that there might be a thicker layer of topsoil over the gravel subsoil.

It is the presence of this gravel which endangers the archaeology in the Thames valley; the gravel is being excavated for industrial use (3). Several gravel pits are located on the northeast side of the map of Figure 3.

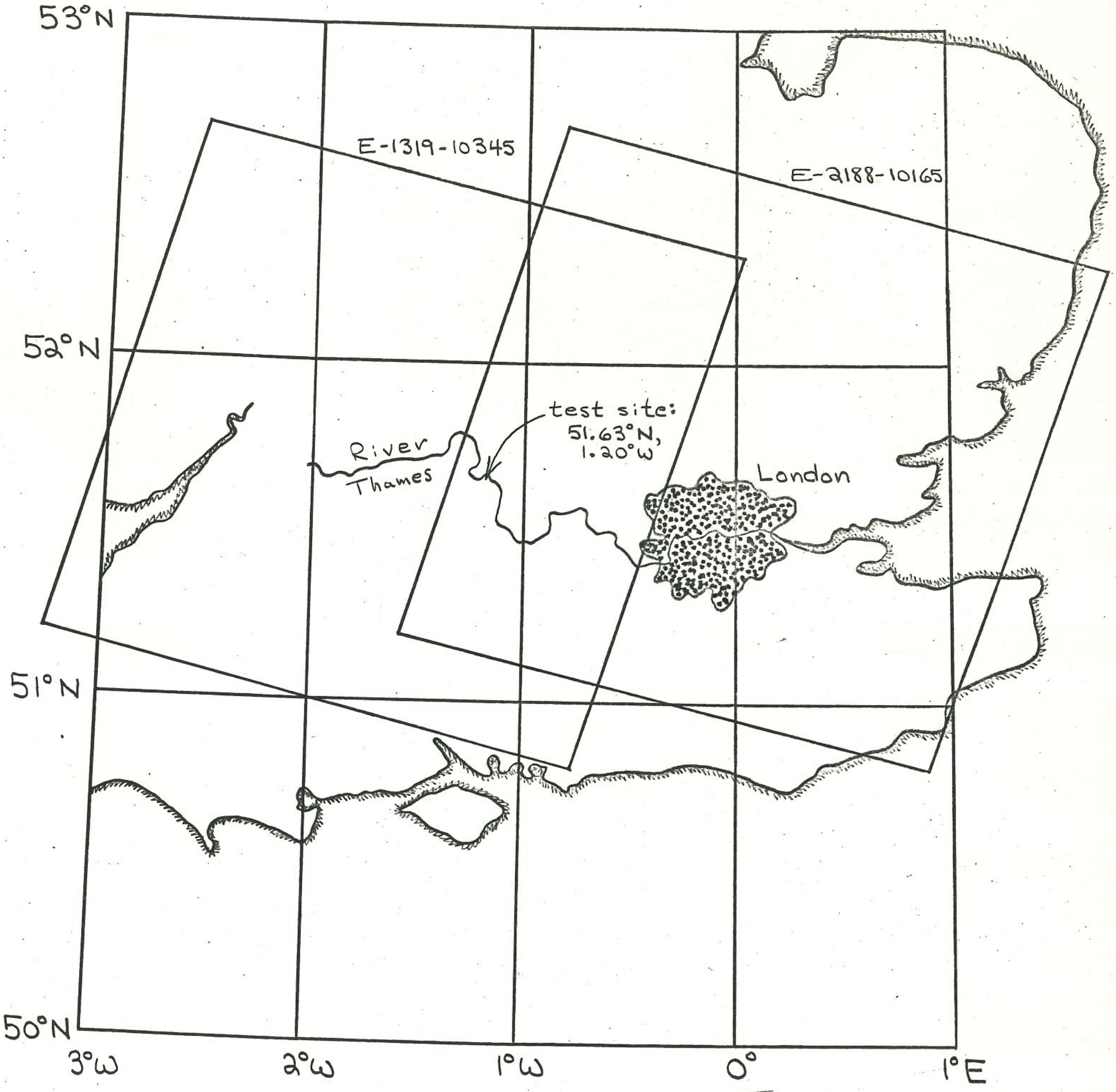


Figure 2. The test site at Dorchester in southern England.

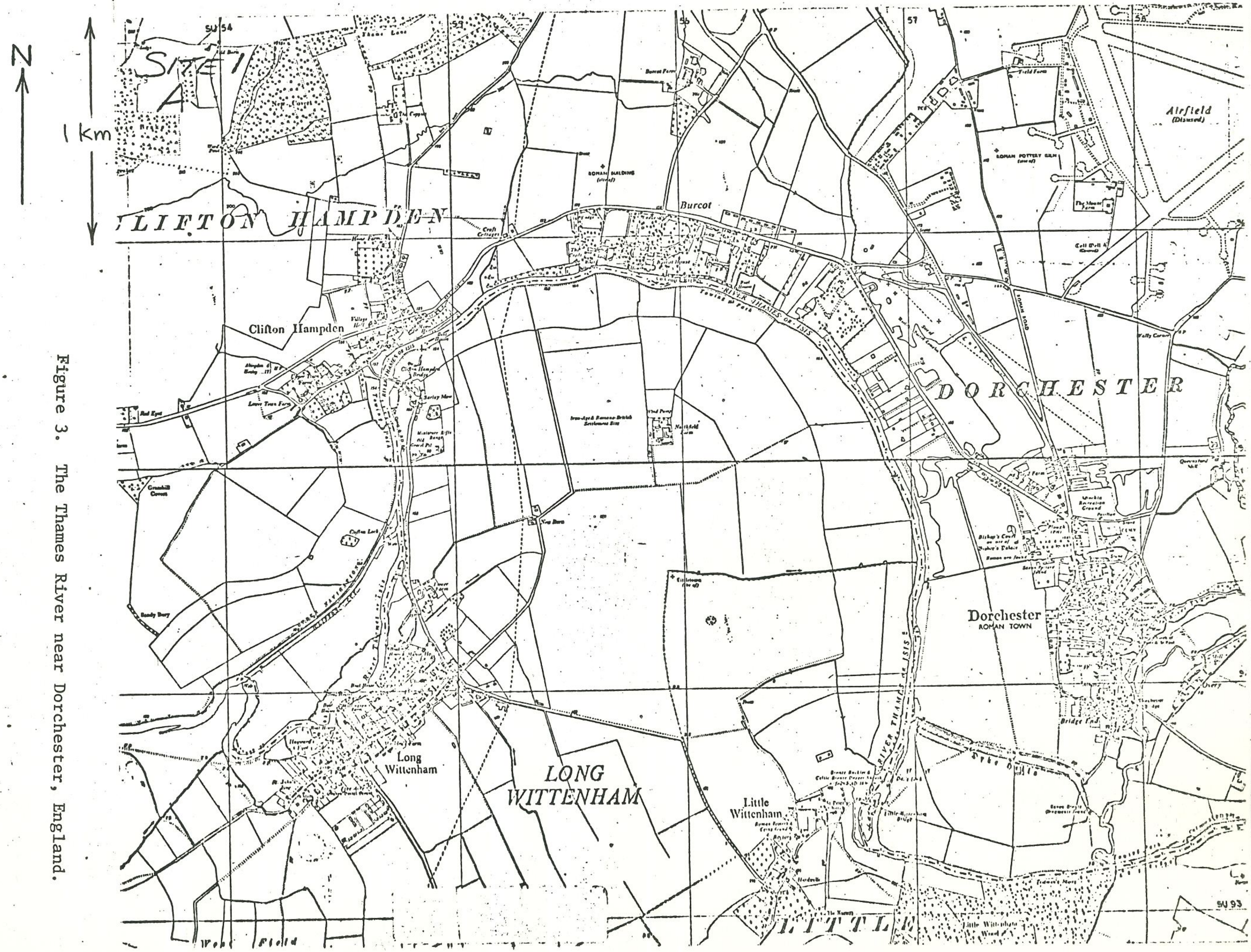


Figure 3. The Thames River near Dorchester, England.

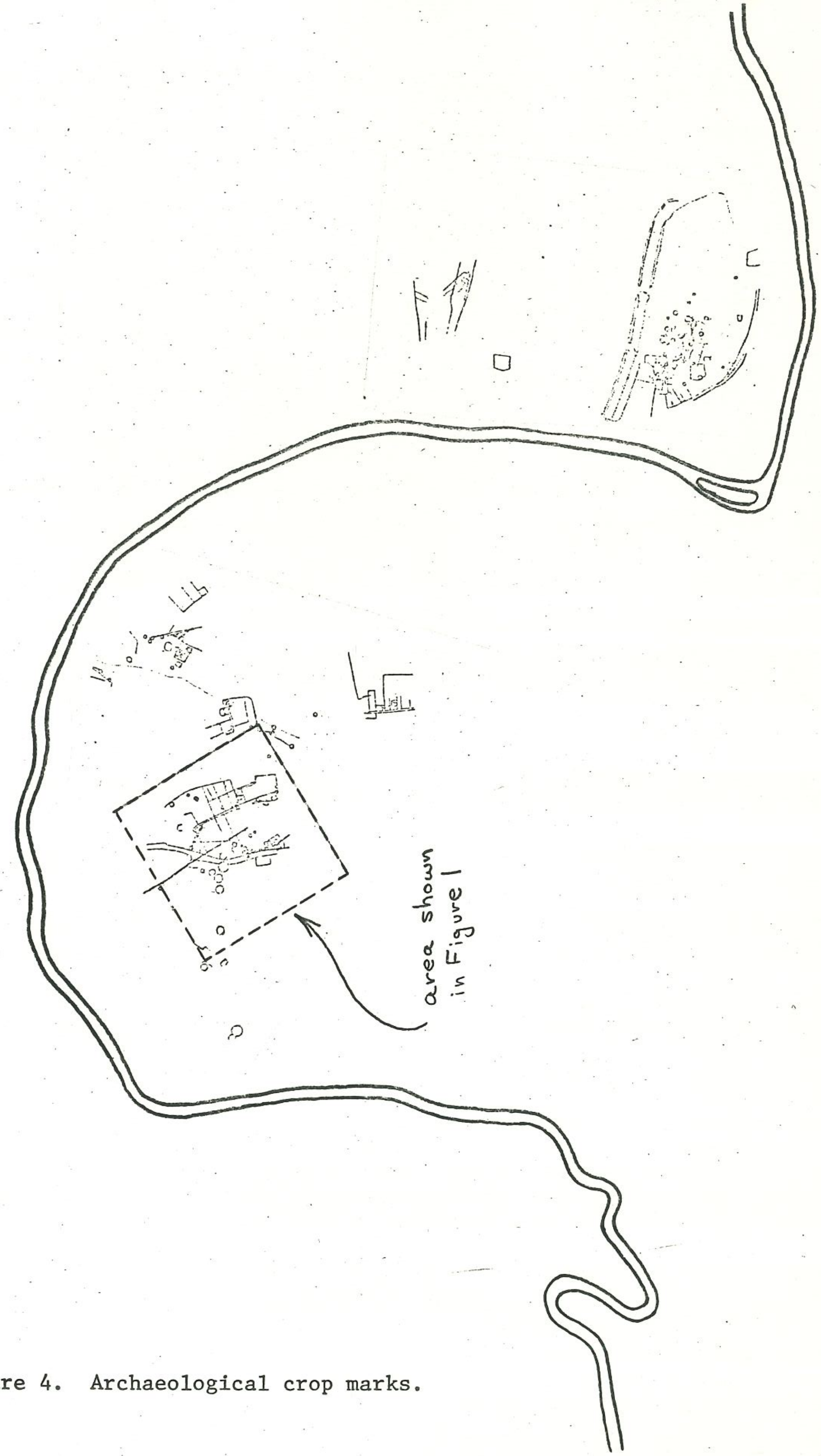


Figure 4. Archaeological crop marks.

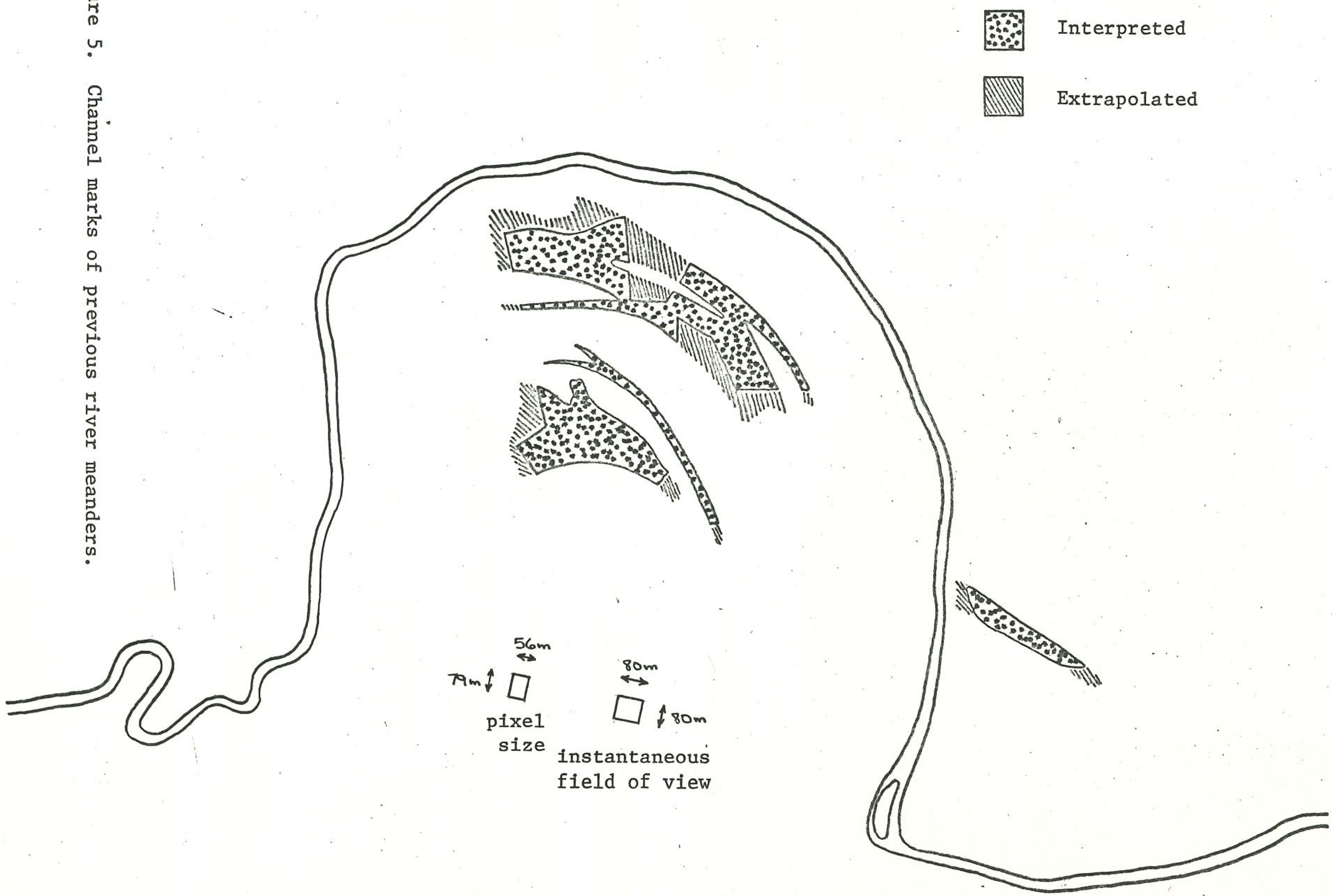


Figure 5. Channel marks of previous river meanders.

The Satellite

Landsat-1 (formerly called the Earth Resources Technology Satellite) was larnched in July 1972; a second satellite, Landsat-2, was launched in January 1975 (4). These satellites have sensors which scan the earth and generate pictures line-by-line, much like the raster on a TV screen. From an altitude of 914km, the width of the strip which is photographed is 185km (100 nautical miles). The orbit of the satellite is synchronized with the rotation of the earth so that the photos are taken at about 9:30 AM local time.

The primary "camera" is called the Multispectral Scanner. It makes four images of each scene in the visible and infrared spectrum. The red image, Band 5 (600 to 700nm), and the infrared image,Band 7 (800 to 1100nm), were the most useful for this project. The green image, Band 4, and Band 6, between Bands 5 and 7, were of lesser value.

On command, pictures are telemetered to earth as a stream of numbers; almost eight million numbers are required to generate each completed photo. The area covered in these photos is illustrated in Figure 2, which outlines two photos used in this project. The image is a parallelogram because of the oblique path of the satellite relative to the earth.

Each satellite can photograph an area once every 18 days. The Thames River at Dorchester is visible in either of two photos taken on consecutive days during each 18-day cycle.

The photographic resolution of the satellites is good enough to allow objects larger than about 100m to be detected. Smaller objects, if they have very high contrast or are long, can also be seen.

Photographic Interpretation

A list of the 19 satellite photos which show the Dorchester area is given in Figure 6. Of the photos taken in 1975, only the one taken on July 29 and the companion photo on July 30 have a small amount of cloud cover. In fact, these are the only clear photos of the test site which have been taken in the summer.

The EROS Data Center furnished these two photos as 9.5 inch positive transparencies. One set of these was enlarged by a factor of about 15.5 and negatives were made of the area of the test site around Dorchester.

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                                    EROS DATA CENTER DATA INQUIRY SYSTEM                  DATE 11/06/75   REFCRT DIJ02
                                         GENERAL LIST (TERMINAL)                          TIME     16:09  PAGE        1
GEOP 8 // N513800 W011200
 19 ACCESSIONS
LIST FOR SMM 511CC159 DORCHESTER

 TYPE COVERAGE      FILM SOURCE  PHOTO/SCENE ID  QUAL CLD  DATE  CENTER/1ST FRAME CTR  SCALE  ALT OLAP  1ST LAST NOF MICROFILM CCT

ERTS-1 (MSS)             B&W-02.2" 81066102825A000  8888 50% 720927 N51 38 46 E000 09 26 3369000 9130 10%               200041698
 SCENE          (N52 10 43,E001 49 37)(N52 35 27,W000 44 13)(N50 41 40,E001 00 47)(N51 05 28,W001 28 26) S11 3806 M5 113   55  53

ERTS-1 (MSS)             B&W-02.2" 81094102855A000  8888 60% 721015 N51 34 59 E000 04 19 3369000 9182 10%               200C51361
 SCENE          (N52 07 07,E001 44 55)(N52 31 59,W000 49 37)(N50 37 34,E000 55 55)(N51 01 28,W001 33 57) S11 3806 M5 113   55  53

ERTS-2 (MSS)             B&W-02.2" 821881016550000  5558 10% 750729 N51 45 59 E000 02 59 3369000 9C94 10%                       0
 SCENE          (N52 17 45,E001 43 07)(N52 42 30,W000 50 30)(N50 49 05,E000 54 12)(N51 12 53,W001 34 48) S11 3806 M5 113   55  53

ERTS-2 (MSS)             B&W-02.2" 822061016250000  8888 60% 750816 N51 42 59 E000 03 59 3369000 9087 10%               200121355
 SCENE          (N52 15 08,E001 43 35)(N52 39 13,W000 50 01)(N50 46 21,E000 55 42)(N51 09 31,W001 33 16) S11 3806 M5 113   55  53

ERTS-1 (MSS)             B&W-02.2" 81228102935G000  8888 10% 730308 N51 40 08 W000 06 10 3369000 9221 10%               200161557
 SCENE          (N52 12 33,E001 34 56)(N52 37 18,W001 00 40)(N50 42 33,E000 45 58)(N51 06 21,W001 44 54) S11 3806 M5 113   55  53

ERTS-2 (MSS)             B&W-02.2" 82152101735000C  0000 90% 750623 N51 26 59 W000 08 59 3369000 9239 10%                       0
 SCENE          (N51 59 31,E001 31 47)(N52 24 14,W001 03 22)(N50 29 19,E000 43 02)(N50 53 06,W001 47 26) S11 3806 M5 113   55  53

ERTS-1 (MSS)             B&W-02.2" 81031103415A000  5555 30% 720823 N51 48 07 W001 19 56 3369000 9141 10%               200020600
 SCENE          (N52 20 18,E000 20 31)(N52 44 45,W002 14 12)(N50 51 03,W000 28 00)(N51 14 33,W002 58 03) S11 3806 M5 113   55  53

ERTS-1 (MSS)             FCC-07.3" 81031103415A200 6BG R 30% 720823 N51 48 06 W001 19 56 1000000 9141 00%               200020600
 SCENE          (N52 20 18,E000 20 31)(N52 44 45,W002 14 12)(N50 51 03,W000 28 00)(N51 14 33,W002 58 03) S11 3808 M5 500  185 178

ERTS-1 (MSS)             B&W-02.2" 81121103505A000  2888 40% 721121 N51 32 54 W001 23 51 3369000 9250 10%               200150417
 SCENE          (N52 04 58,E000 17 40)(N52 30 29,W002 17 41)(N50 34 54,W000 32 22)(N50 59 27,W003 03 03) S11 3806 M5 113   55  53

ERTS-1 (MSS)             B&W-02.2" 81229103525A000  8888 20% 730309 N51 41 49 W001 31 08 3369000 9224 10%               200161653 Y
 SCENE          (N52 14 12,E000 10 05)(N52 39 01,W002 25 37)(N50 44 11,W000 39 01)(N51 08 04,W003 10 00) S11 3806 M5 113   55  53

ERTS-1 (MSS)             FCC-07.3" 81229103525A200 3BG R 20% 730309 N51 41 49 W001 31 08 1000000 9224 00%               200161653
 SCENE          (N52 14 12,E000 10 05)(N52 39 01,W002 25 37)(N50 44 11,W000 39 01)(N51 08 04,W003 10 00) S11 3808 M5 500  185 178

ERTS-1 (MSS)             B&W-02.2" 81247103525G000  8888 10% 730327 N51 37 36 W001 36 23 3369000 9252 10%               200190313
 SCENE          (N52 10 11,E000 04 55)(N52 34 56,W002 31 05)(N50 39 51,W000 44 03)(N51 03 39,W003 15 18) S11 3806 M5 113   55  53

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 SCENE          (N52 18 46,E000 02 06)(N52 42 34,W002 32 16)(N50 49 38,W000 45 26)(N51 12 32,W003 15 07) S11 3806 M5 113   55  53

ERTS-1 (MSS)             FCC-07.3" 81319103455A200 6BG R 10% 730607 N51 46 19 W001 37 41 1000000 9112 00%               200221815
 SCENE          (N52 18 46,E000 02 06)(N52 42 34,W002 32 16)(N50 49 38,W000 45 26)(N51 12 32,W003 15 07) S11 3808 M5 500  185 178

ERTS-2 (MSS)             B&W-02.2" 82027102325N000  5885 90% 750218 N51 27 59 W001 20 59 3369000 9214 10%               200020142
 SCENE          (N52 00 05,E000 15 46)(N52 25 19,W002 14 47)(N50 30 16,W000 29 32)(N50 54 32,W002 59 26) S11 3806 M5 113   55  53

ERTS-2 (MSS)             B&W-02.2" 82045102325N000  5555 90% 750308 N51 35 59 W001 15 59 3369000 9132 10%               200021264
 SCENE          (N52 07 44,E000 24 08)(N52 32 52,W002 09 25)(N50 38 42,W000 24 52)(N51 02 54,W002 53 51) S11 3806 M5 113   55  53

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ERTS-2 (MSS)             B&W-02.2" 821711023050000  8888 90% 750712 N51 39 59 W001 27 59 3369000 9155 10%               200110864
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ERTS-2 (MSS)             B&W-02.2" 821891022450000  8588 20% 750730 N51 45 00 W001 22 59 3369000 9093 10%                       0
 SCENE          (N52 16 53,E000 16 57)(N52 41 24,W002 16 40)(N50 48 10,W000 31 37)(N51 11 46,W003 00 39) S11 3806 M5 113   55  53
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Figure 6. Landsat photos of the Dorchester area.

Contact (positive) prints of the red and infrared imagees are shown in Figure 7. The scale of these photos is about 1:64,300; if the entire satellite photos were enlarged to the same scale, they would be 2.9m wide. The ground area shown in these photos is 6.8km by 5.2km, somewhat larger than the area shown in the map of Figure 3. Band 6 was quite similar to Band 7, but had a lower contrast. Band 4 was very low contrast because of thin haze and atmospheric scattering.

Photographic subtraction of the Band 7 image from the Band 5 image was of no help in interpreting these photos. Instead, it was found that a color composite constructed with diazo film was excellent for comparing Bands 5 and 7 (5). A qualitative map of the ratio of red to infrared brightness as determined from the false color image is given in Figure 8. The key to the symbols shown in that figure is listed in Figure 9, along with the estimated cause for each spectral ratio.

This map and the original photos show no trace of the crop marks due to the river meanders. During 1975, the archaeological crop marks, and the associated geological ones, had their highest visibility during the first week in July and had disappeared by mid-July. On July 29 when the satellite photo was taken, most of the crops were golden or were harvested.

The July 29 photo does show that one field within the bend of the river was still quite green then. This photo also shows that the ponds of water which indicate gravel pits cover a larger area than is shown on the base map of Figure 3.

Two satellite photographs taken in 1973 were also examined to see if there was any trace of the geological crop marks on them. However, it was found that the Band 5 image, by far the most useful for this task, was obscured on both dates. On March 8, a heavy haze was responsible. One June 7, thin cloud cover, at an altitude of about 9km, seriously reduced visibility in Band 5. However, on both dates there was fair visibility of the ground in Band 7 (6). These satellite photos are shown in Figures 10 and 11; the scale is the same as those in Figure 7.

The resolution of these three photos is indicated by the field boundaries which are visible in them (see Figure 12). The crops growing in 1970 in some of these fields are mapped in Figure 13. The broken lines in the figure indicate boundaries which are not shown in Figure 3. Since some of the detectable fields are smaller than the size of the geological

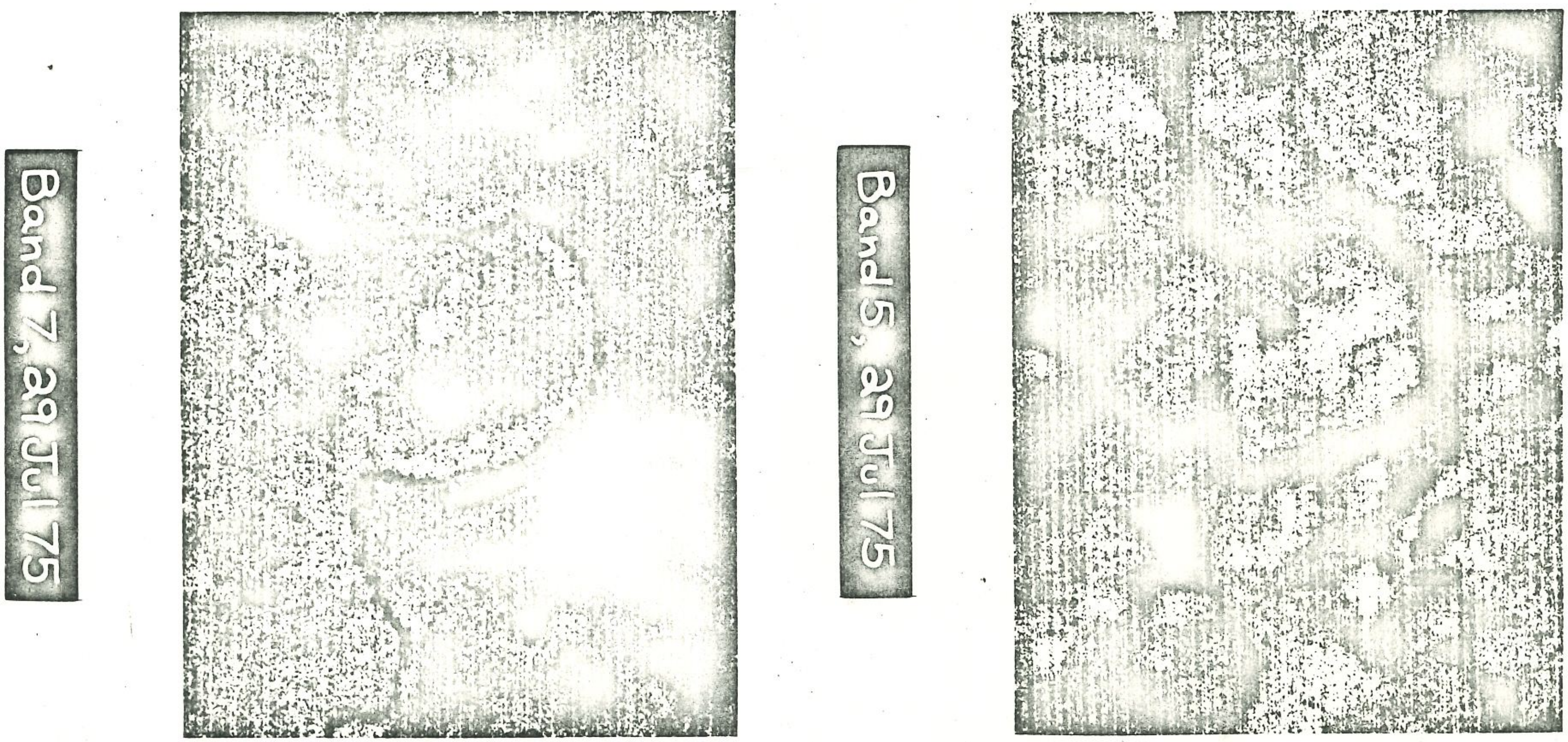

Figure 7. Landsat-2 photograph; red (Band 5) and infrared (Band 7) images are at a scale 1:64,300.

E-2188-10165

Figure 8. Red and infrared brightness of the photos in Figure 7.

SYMBOL	MEANING	POSSIBLE CAUSE
ri	red and infrared low brightness	water
r>i	both low, but red brighter	bare soil?
r<I	very low red brightness, high infrared	lush green vegetation
rI	low red and high infrared brightness	moderately green vegetation
Ri	high red and low infrared brightness	stubble?
R>I	both high, but red brighter	matured field crops

Figure 9. Interpretation key for Figure 8.

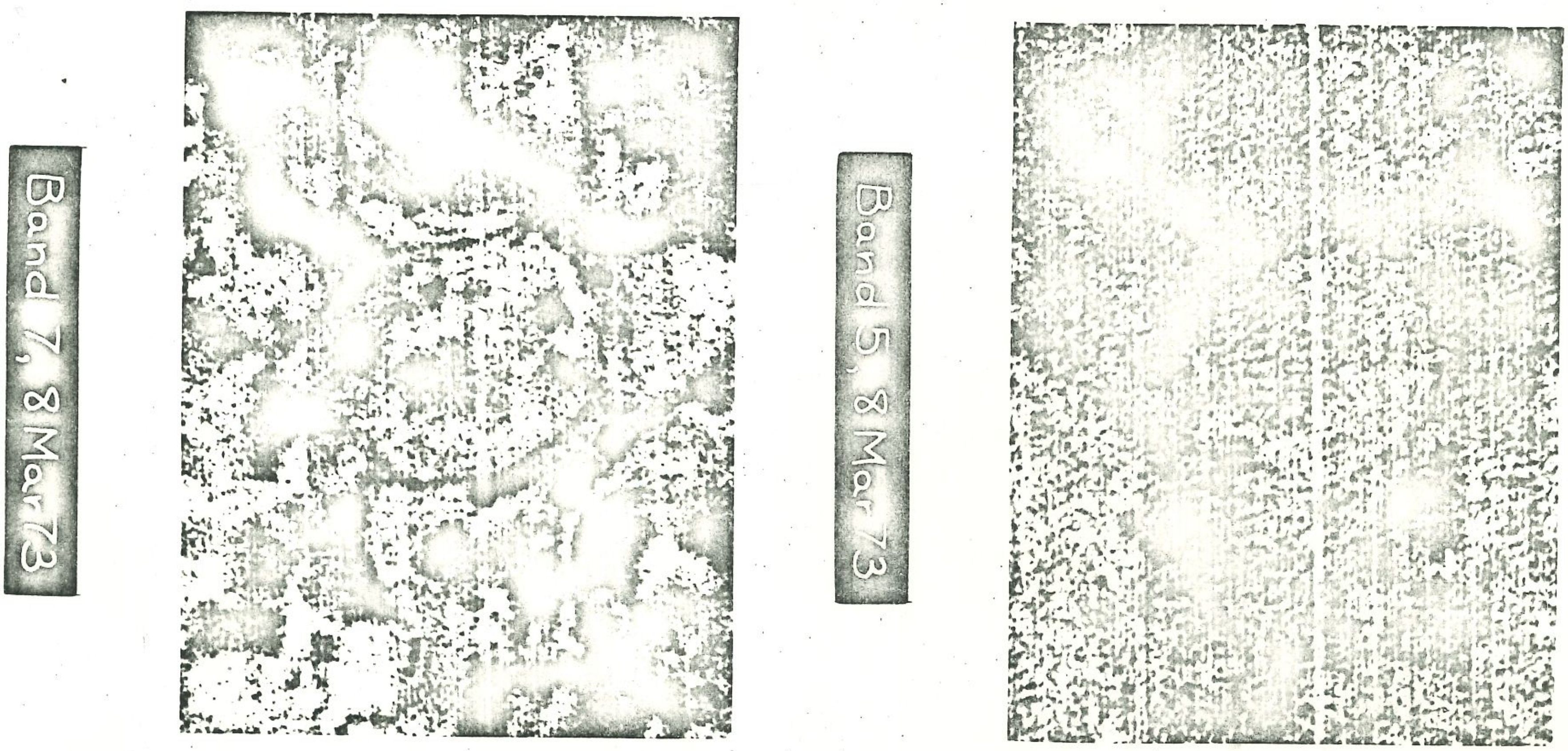

Figure 10. Landsat-1 photograph; same scale as Figure 7.

E-1228-10293

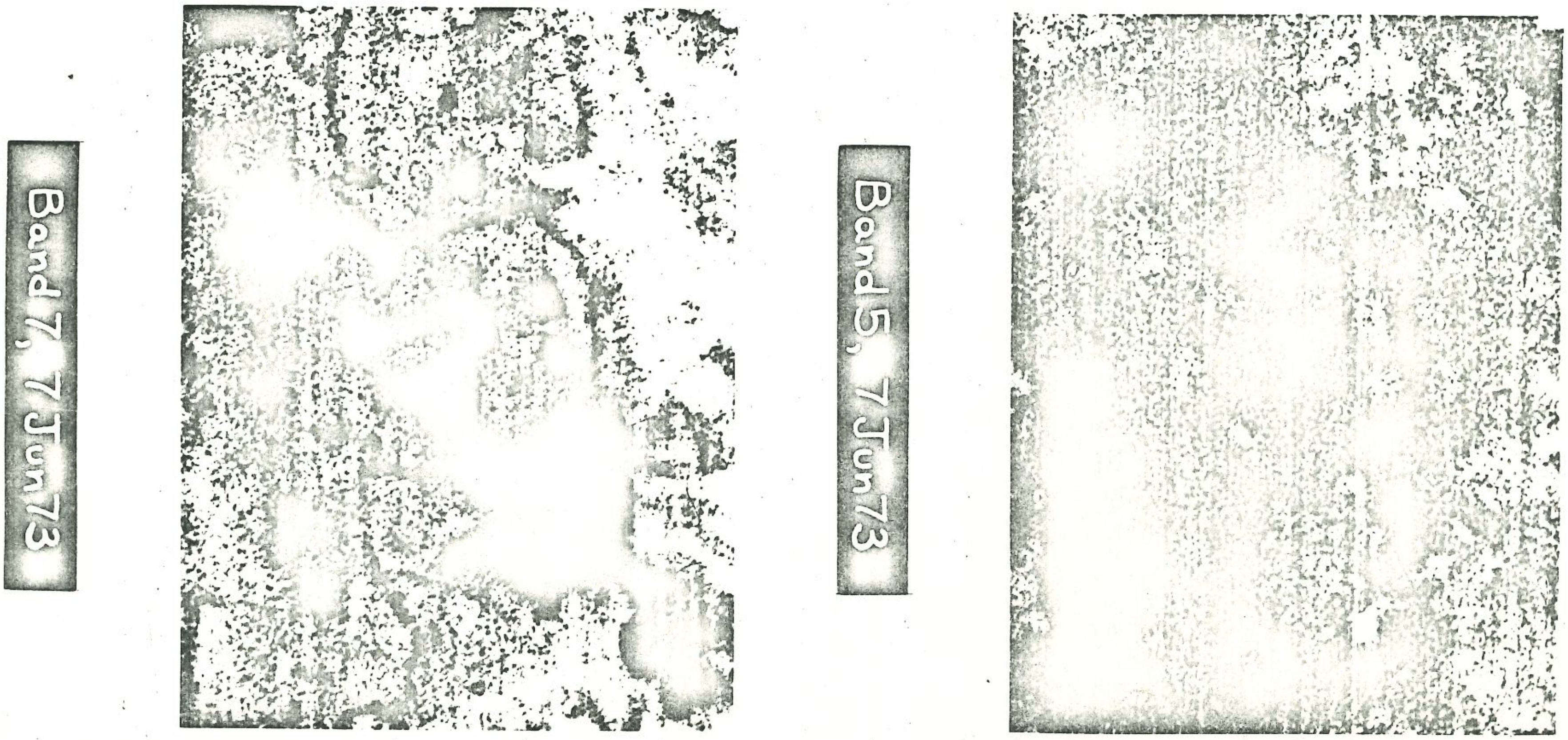

Figure 11. Landsat-1 photograph; same scale as Figure 7.

Figure 12. Field boundaries detected on Landsat photographs.

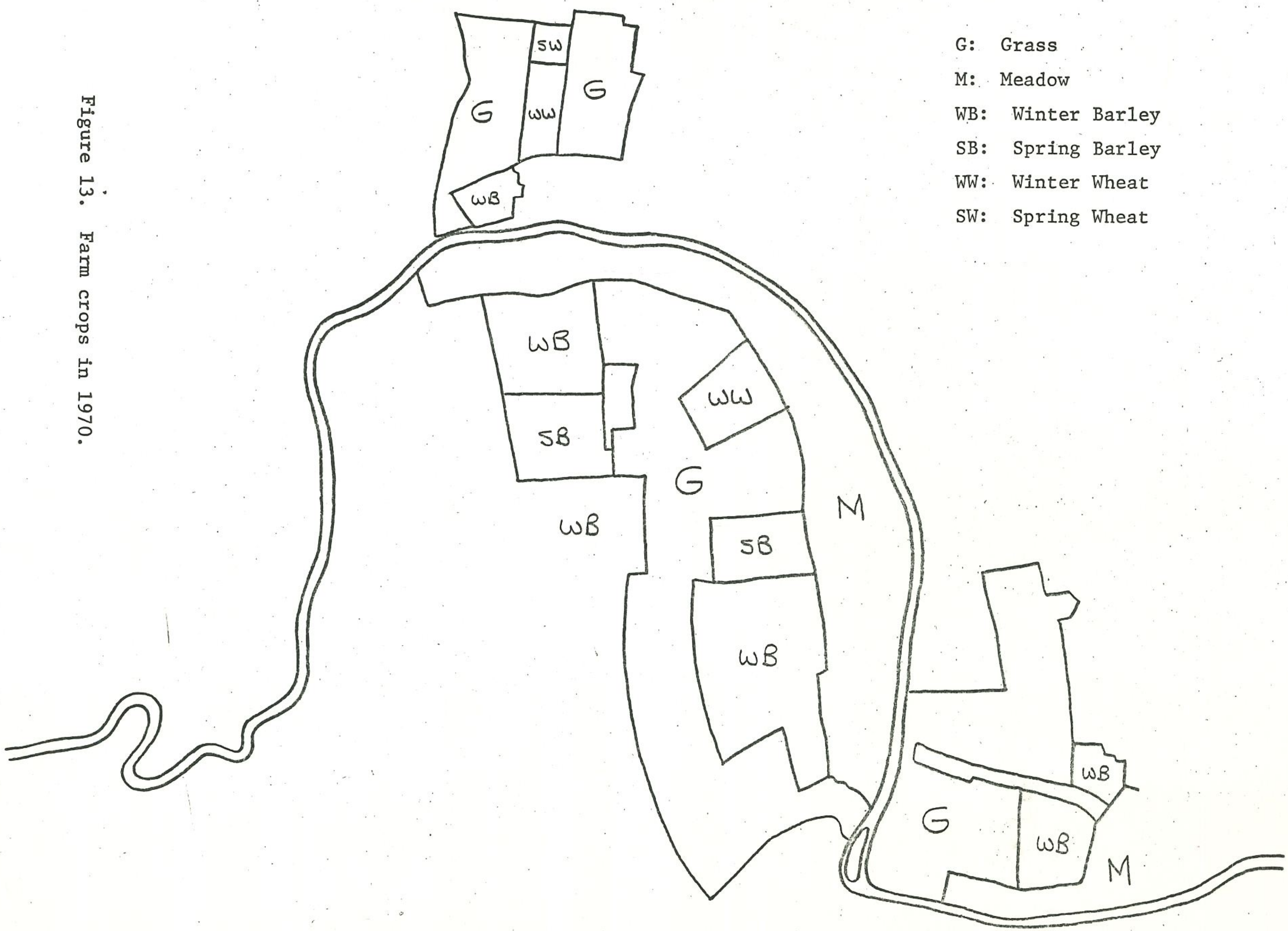

Figure 13. Farm crops in 1970.

crop marks, it is surmised that these geological marks will be visible on photos taken at the right time.

The cloud cover probability for southern England in summer is about 60%. Therefore, it is poor luck that no photos are available from the June 24 or July 12 overflights of Landsat-2, or from the six other times during the period from April through August for which pictures would have been valuable.

Future Work

It is hoped to be able to continue this experiment in the 1976 growing season. If a photo taken at about the right time becomes available, it might be important to get the highest possible resolution from it. As a start, photographic combination of the two pictures taken on consecutive days may decrease the loss of resolution due to film grain and the raster pattern (stereoscopic parallax should be no problem). Also, it might be possible to make a digital contour map of the brightness ratio of Bands 5 and 7; since only about 1000 pixels are necessary, the processing of the Computer Compatible Tapes might not be too difficult.

It might also be possible to examine other areas along the Thames River if a greater selection of June and July photos becomes available. If an anomalous pattern within a known field becomes visible during the growing season, it might indicate the partial maturity of that field's crop; this would mark the best time for aerial photography.

Hopefully, it will also be possible to investigate other river valleys which have a known appearance of archaeological crop marks; the Mississippi-Missouri would be the prime example.

Conclusion

Since the 18-day periodicity of Landsat imagery has a unique capability of aiding archaeological reconnaissance, it is hoped that cloud and haze cover are more favorable in the future. The 9.5 inch positive transparencies of the red and infrared images have been excellent for detecting patterns in the growth of crops.

Acknowledgment

This project was made possible with the help of the National Aeronautics and Space Administration, both for getting the satellite photos taken and in furnishing them for this investigation. A grant from the National Science Foundation, SOC-75-04203, funded the interpretation of these photos and the publication of this report.

References

1. L. Deuel, Flights into Yesterday (St. Martin's Press, New York, 1969).
2. J. N. Hampton, "An Experiment in Multispectral Air Photography for Archaeological Research", Photogrammetric Record 8(43):37-64 (April 1974).
3. Royal Commission on Historical Monuments (England), A Matter of Time (Her Majesty's Stationery Office, London, 1960).
4. T. H. Maugh II, "ERTS: Surveying Earth's Resources from Space", Science 180(4081):49-51 (6 April 1973).
5. O. G. Malan, "Diazo Color Composites of ERTS and Multispectral Photography", South African Journal of Science 70(6):185,186 (June 1974).
6. A. P. Colvocoresses, "Unique Characteristics of ERTS", Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1, NASA SP-327 (U.S. Government Printing Office, Washington, 1973).

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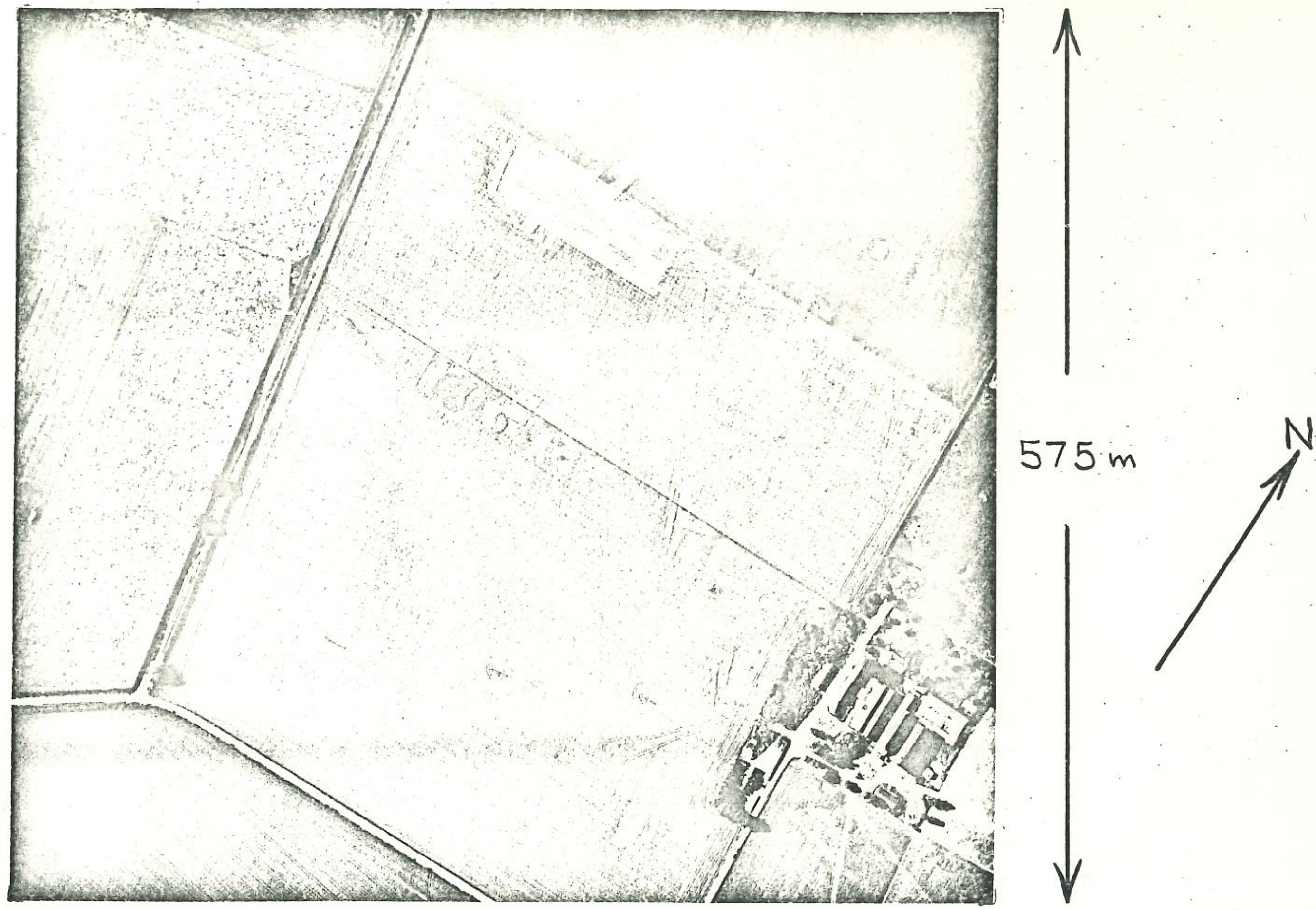
Archaeological Background

Archaeological structures, even those buried at a shallow depth, can sometimes be discovered and mapped with aerial photography. Ancient ditches, refilled by nature or man, and buried walls and roads are often detectable by the patterns of anomalous growth in the overlying vegetation; these patterns are called crop marks(1).

Crop marks indicating refilled ditches and pits are particularly visible in areas which have a thin but rich topsoil which covers barren subsoil. The river valleys in southern England are examples of this. Gravel is often found only a few decimeters under the surface. Early man dug holes through the topsoil into the gravel; when these holes were refilled, a pocket of richer soil would often result. Crops, such as wheat or barley which send their roots into this pocket of rich soil can grow differently than the surrounding crops. The most pronounced effect appears to be due to the greater amount of moisture in the soil of the refilled hole: the crop there can still be green when the surrounding crop is golden and matured. An example of this is given in Figure 1; the many ring-shaped ditches, rectangular enclosures, and other marks in this photo are the result of a long period of occupation by early man from the Bronze Age and Iron Age through the Romano-British Age (2). The camera which took these photos used panchromatic film and a yellow filter.



4 June 1970

19 June 1970

Figure 1. The time factor in crop mark visibility.

One of the big difficulties in archaeological reconnaissance is the short period of time in which crop marks are visible. The two photos in Figure 1 were taken 15 days apart. These marks will vanish when the crops are harvested.

The optimum time for photographing crop marks lasts for only about one week, although sometimes traces are detectable for a month or more. This optimim time varies from year to year primarily because of changing weather; in addition, differences in the soil cause the best time for photography to vary from region to region.

The Dorchester Area

The course of the Thames River in southern England is shown in Figure 2. At Dorchester, the Thames flows around a bend 2km in diameter; a map showing this smaller region is given in Figure 3.

This area is rich in crop marks; the shape and position of many of them are mapped in Figure 4. The line of the Thames is indicated on this map to show the correspondence to the base map in Figure 3.

In addition to the archaeological crop marks, large bands appear in the fields. Some of these bands are shown in Figure 1; the time of their appearance coincides with the time of visibility of the archaeological crop marks. From aerial photographs taken in 1970 and earlier, the shapes of some of these large bands have been mapped (see Figure 5).

The position and size of these bands indicate that they might mark earlier courses of the river; in a flat-bottomed valley like this, river meanders are to be expected. The variable bands of soil left behind by the shifting river cause large geological crop marks; the greener growth of the bands implies that there might be a thicker layer of topsoil over the gravel subsoil.

It is the presence of this gravel which endangers the archaeology in the Thames valley; the gravel is being excavated for industrial use (3). Several gravel pits are located on the northeast side of the map of Figure 3.

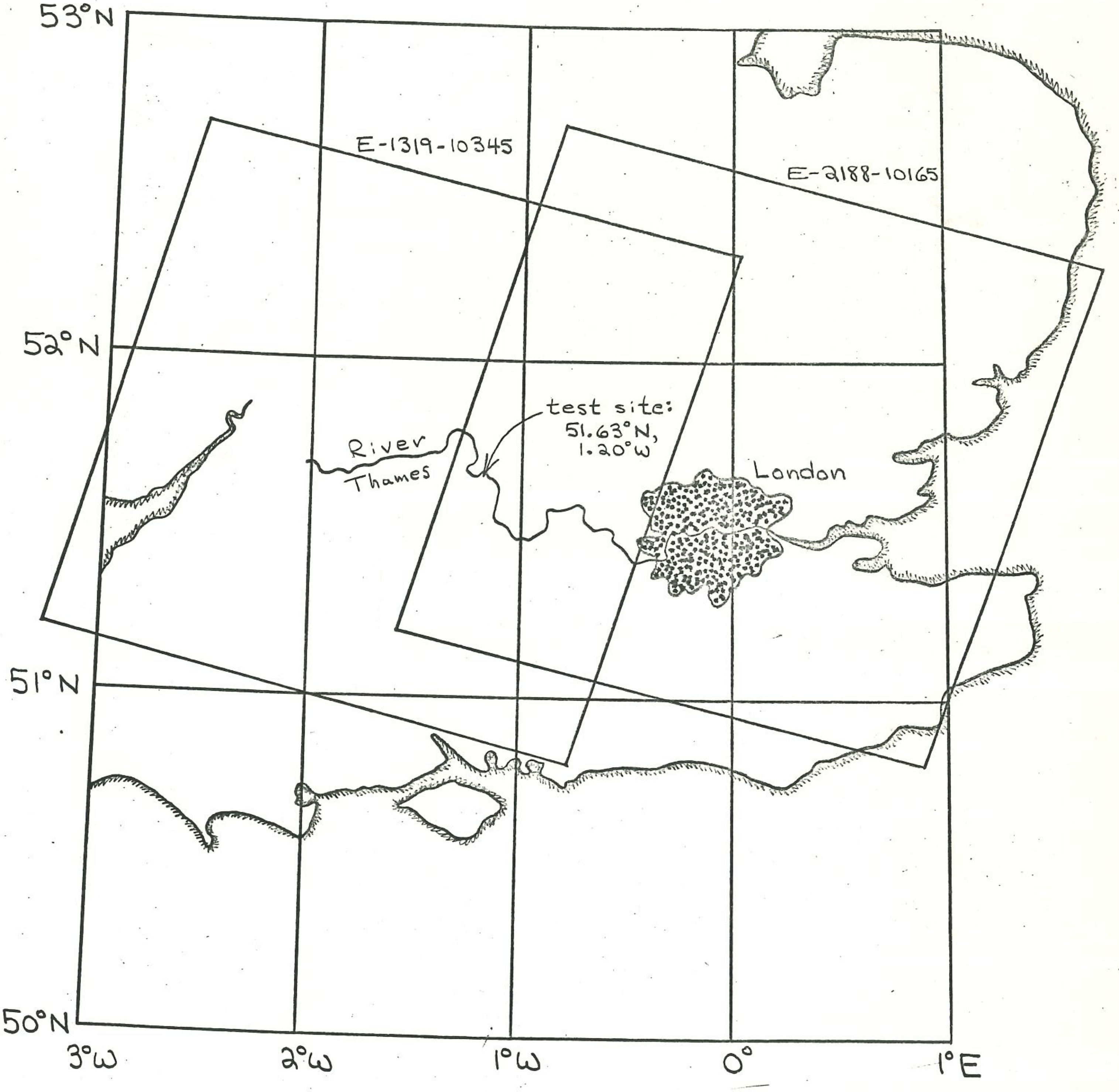


Figure 2. The test site at Dorchester in southern England.

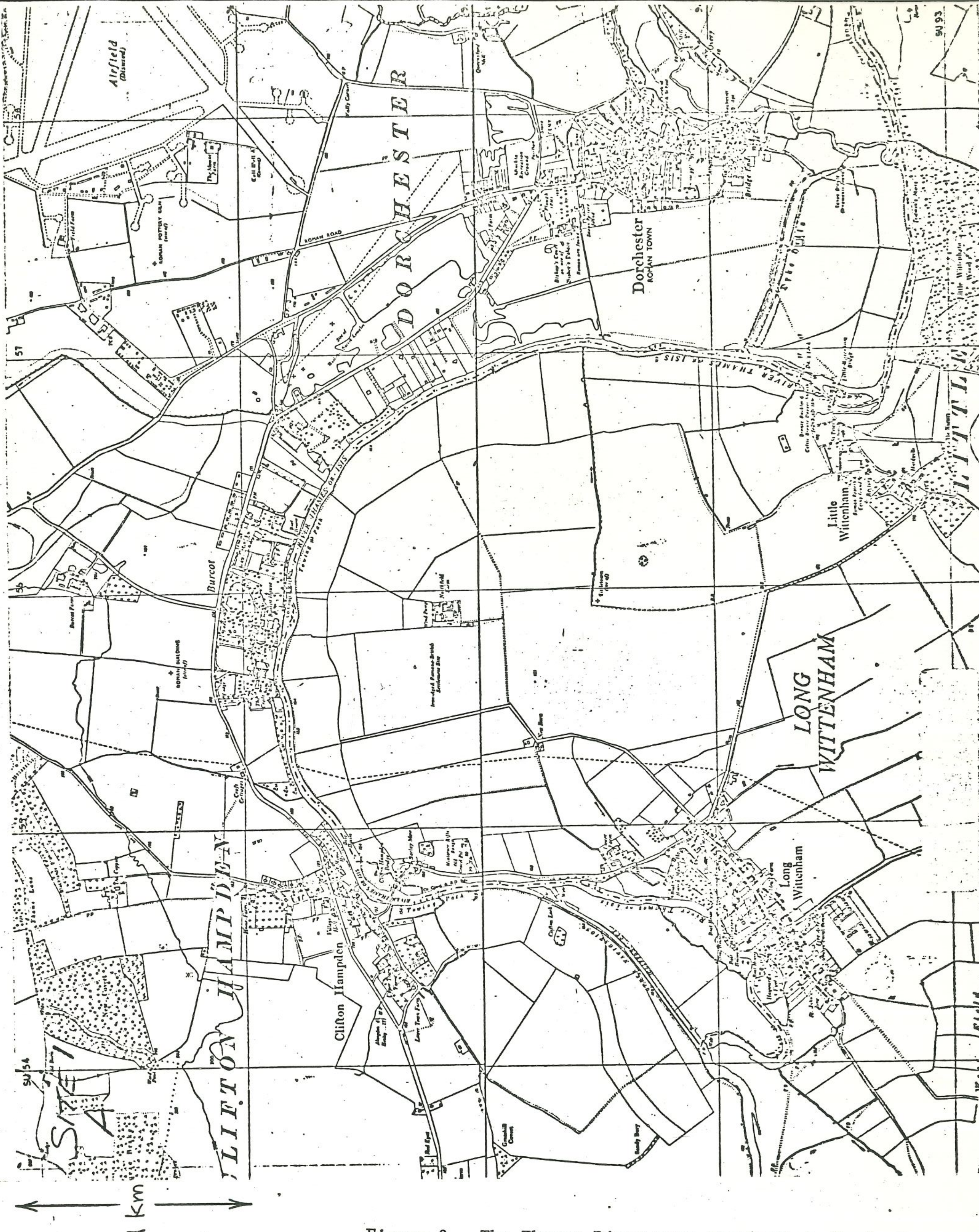


Figure 3. The Thames River near Dorchester, England.

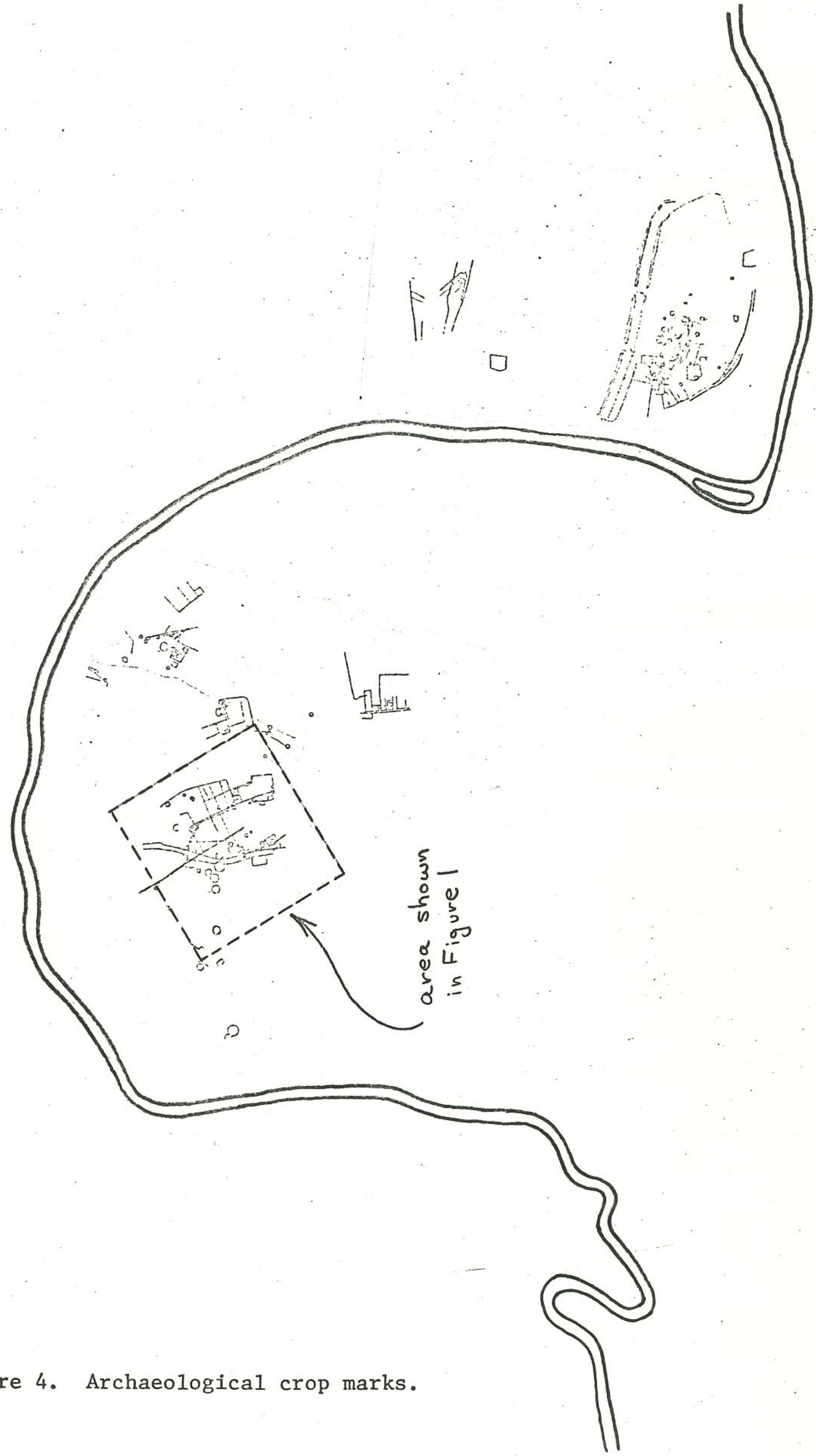


Figure 4. Archaeological crop marks.

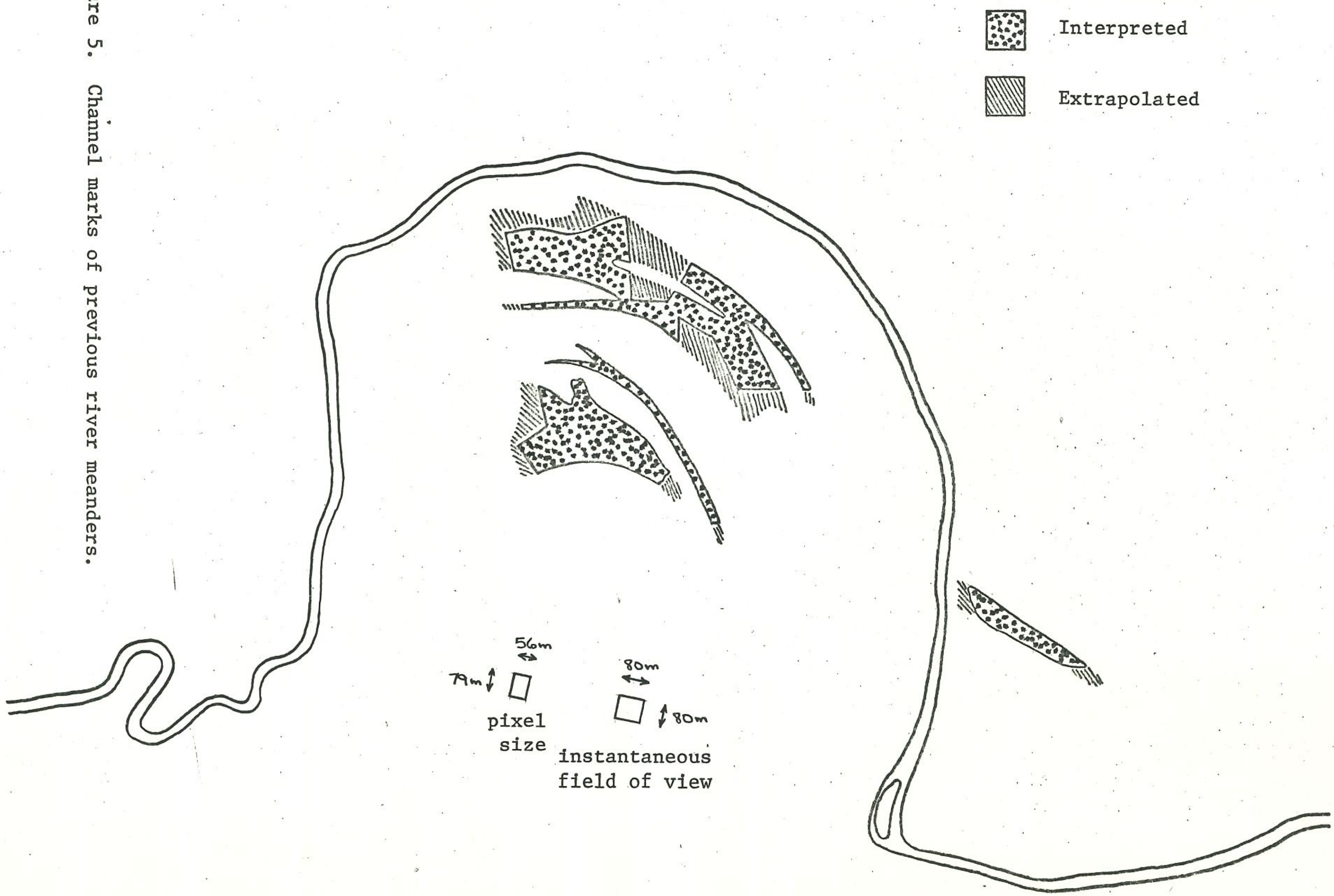


Figure 5. Channel marks of previous river meanders.

The Satellite

Landsat-1 (formerly called the Earth Resources Technology Satellite) was larnched in July 1972; a second satellite, Landsat-2, was launched in January 1975 (4). These satellites have sensors which scan the earth and generate pictures line-by-line, much like the raster on a TV screen. From an altitude of 914km, the width of the strip which is photographed is 185km (100 nautical miles). The orbit of the satellite is synchronized with the rotation of the earth so that the photos are taken at about 9:30 AM local time.

The primary "camera" is called the Multispectral Scanner. It makes four images of each scene in the visible and infrared spectrum. The red image, Band 5 (600 to 700nm), and the infrared image,Band 7 (800 to 1100nm), were the most useful for this project. The green image, Band 4, and Band 6, between Bands 5 and 7, were of lesser value.

On command, pictures are telemetered to earth as a stream of numbers; almost eight million numbers are required to generate each completed photo. The area covered in these photos is illustrated in Figure 2, which outlines two photos used in this project. The image is a parallelogram because of the oblique path of the satellite relative to the earth.

Each satellite can photograph an area once every 18 days. The Thames River at Dorchester is visible in either of two photos taken on consecutive days during each 18-day cycle.

The photographic resolution of the satellites is good enough to allow objects larger than about 100m to be detected. Smaller objects, if they have very high contrast or are long, can also be seen.

Photographic Interpretation

A list of the 19 satellite photos which show the Dorchester area is given in Figure 6. Of the photos taken in 1975, only the one taken on July 29 and the companion photo on July 30 have a small amount of cloud cover. In fact, these are the only clear photos of the test site which have been taken in the summer.

The EROS Data Center furnished these two photos as 9.5 inch positive transparencies. One set of these was enlarged by a factor of about 15.5 and negatives were made of the area of the test site around Dorchester.

```
                                      EROS DATA CENTER DATA INQUIRY SYSTEM                          DATE 11/06/75   REPORT DIJ02
                                          GENERAL LIST (TERMINAL)                                   TIME     16:09  PAGE          1
GEOP 8 // N513800 W011200
 19 ACCESSIONS
LIST FOR SMM 5110C159 DORCHESTER

 TYPE COVERAGE       FILM SOURCE  PHOTO/SCENE ID  QUAL CLD  DATE   CENTER/1ST FRAME CTR  SCALE   ALT OLAP  1ST LAST NOF MICROFILM CCT

ERTS-1 (MSS)             B&W-02.2" 81066102825A000  8888 50% 720927 N51 38 46 E000 09 26 3369000 9130 10%                  200041698
 SCENE        (N52 10 43,E001 49 37)(N52 35 27,W000 44 13)(N50 41 40,E001 00 47)(N51 05 28,W001 28 26) S11 3806 M5 113     55  53

ERTS-1 (MSS)             B&W-02.2" 81C94102855A000  8888 60% 721015 N51 34 59 E000 04 19 3369000 9182 10%                  200051361
 SCENE        (N52 07 07,E001 44 55)(N52 31 59,W000 49 37)(N50 37 34,E000 55 55)(N51 01 28,W001 33 57) S11 3806 M5 113     55  53

ERTS-2 (MSS)             B&W-02.2" 821881016550000  5558 10% 750729 N51 45 59 E000 02 59 3369000 9094 10%                          0
 SCENE        (N52 17 45,E001 43 07)(N52 42 30,W000 50 30)(N50 49 05,E000 54 12)(N51 12 53,W001 34 48) S11 3806 M5 113     55  53

ERTS-2 (MSS)             B&W-02.2" 822061016250000  8888 60% 750816 N51 42 59 E000 03 59 3369000 9087 10%                  200121355
 SCENE        (N52 15 08,E001 43 35)(N52 39 13,W000 50 01)(N50 46 21,E000 55 42)(N51 09 31,W001 33 16) S11 3806 M5 113     55  53

ERTS-1 (MSS)             B&W-02.2" 81228102935G000  8888 10% 730308 N51 40 08 W000 06 10 3369000 9221 10%                  200161557
 SCENE        (N52 12 33,E001 34 56)(N52 37 18,W001 00 40)(N50 42 33,E000 45 58)(N51 06 21,W001 44 54) S11 3806 M5 113     55  53

ERTS-2 (MSS)             B&W-02.2" 82152101735000C  0000 90% 750623 N51 26 59 W000 08 59 3369000 9239 10%                          0
 SCENE        (N51 59 31,E001 31 47)(N52 24 14,W001 03 22)(N50 29 19,E000 43 02)(N50 53 06,W001 47 26) S11 3806 M5 113     55  53

ERTS-1 (MSS)             B&W-02.2" 81031103415A000  5555 30% 720823 N51 48 07 W001 19 56 3369000 9141 10%                  200020600
 SCENE        (N52 20 18,E000 20 31)(N52 44 45,W002 14 12)(N50 51 03,W000 28 00)(N51 14 33,W002 58 03) S11 3806 M5 113     55  53

ERTS-1 (MSS)             FCC-07.3" 81031103415A200 6BG R 30% 720823 N51 48 06 W001 19 56 1000000 9141 00%                 200020600
 SCENE        (N52 20 18,E000 20 31)(N52 44 45,W002 14 12)(N50 51 03,W000 28 00)(N51 14 33,W002 58 03) S11 3808 M5 500   185 178

ERTS-1 (MSS)             B&W-02.2" 81121103505A000  2888 40% 721121 N51 32 54 W001 23 51 3369000 9250 10%                  200150417
 SCENE        (N52 04 58,E000 17 40)(N52 30 29,W002 17 41)(N50 34 54,W000 32 22)(N50 59 27,W003 03 03) S11 3806 M5 113     55  53

ERTS-1 (MSS)             B&W-02.2" 81229103525A000  8888 20% 730309 N51 41 49 W001 31 08 3369000 9224 10%                  200161653 Y
 SCENE        (N52 14 12,E000 10 05)(N52 39 01,W002 25 37)(N50 44 11,W000 39 01)(N51 08 04,W003 10 00) S11 3806 M5 113     55  53

ERTS-1 (MSS)             FCC-07.3" 81229103525A200 3BG R 20% 730309 N51 41 49 W001 31 08 1000000 9224 00%                 200161653
 SCENE        (N52 14 12,E000 10 05)(N52 39 01,W002 25 37)(N50 44 11,W000 39 01)(N51 08 04,W003 10 00) S11 3808 M5 500   185 178

ERTS-1 (MSS)             B&W-02.2" 81247103525G000  8888 10% 730327 N51 37 36 W001 36 23 3369000 9252 10%                  200190313
 SCENE        (N52 10 11,E000 04 55)(N52 34 56,W002 31 05)(N50 39 51,W000 44 03)(N51 03 39,W003 15 18) S11 3806 M5 113     55  53

ERTS-1 (MSS)             B&W-02.2" 81319103455A000  8888 10% 730607 N51 46 19 W001 37 41 3369000 9112 10%                  200221815
 SCENE        (N52 18 46,E000 02 06)(N52 42 34,W002 32 16)(N50 49 38,W000 45 26)(N51 12 32,W003 15 07) S11 3806 M5 113     55  53

ERTS-1 (MSS)             FCC-07.3" 81319103455A200 6BG R 10% 730607 N51 46 19 W001 37 41 1000000 9112 00%                 200221815
 SCENE        (N52 18 46,E000 02 06)(N52 42 34,W002 32 16)(N50 49 38,W000 45 26)(N51 12 32,W003 15 07) S11 3808 M5 500   185 178

ERTS-2 (MSS)             B&W-02.2" 82027102325N000  5885 90% 750218 N51 27 59 W001 20 59 3369000 9214 10%                  200020142
 SCENE        (N52 00 05,E000 15 46)(N52 25 19,W002 14 47)(N50 30 16,W000 29 32)(N50 54 32,W002 59 26) S11 3806 M5 113     55  53

ERTS-2 (MSS)             B&W-02.2" 82045102325N000  5555 90% 750308 N51 35 59 W001 15 59 3369000 9132 10%                  200021264
 SCENE        (N52 07 44,E000 24 08)(N52 32 52,W002 09 25)(N50 38 42,W000 24 52)(N51 02 54,W002 53 51) S11 3806 M5 113     55  53

ERTS-2 (MSS)             B&W-02.2" 82091102315G000  5885 60% 750413 N51 27 59 W001 30 59 3369000 9104 10%                  200031446
 SCENE        (N51 59 59,E000 08 42)(N52 24 21,W002 24 13)(N50 31 13,W000 40 01)(N50 54 40,W003 08 25) S11 3806 M5 113     55  53

ERTS-2 (MSS)             B&W-02.2" 821711023050000  8888 90% 750712 N51 39 59 W001 27 59 3369000 9155 10%                  200110864
 SCENE        (N52 12 03,E000 12 29)(N52 36 50,W002 21 53)(N50 42 44,W000 36 25)(N51 06 34,W003 06 09) S11 3806 M5 113     55  53

ERTS-2 (MSS)             B&W-02.2" 821891022450000  8588 20% 750730 N51 45 00 W001 22 59 3369000 9093 10%                          0
 SCENE        (N52 16 53,E000 16 57)(N52 41 24,W002 16 40)(N50 48 10,W000 31 37)(N51 11 46,W003 00 39) S11 3806 M5 113     55  53
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Figure 6. Landsat photos of the Dorchester area.

Contact (positive) prints of the red and infrared imagees are shown in Figure 7. The scale of these photos is about 1:64,300; if the entire satellite photos were enlarged to the same scale, they would be 2.9m wide. The ground area shown in these photos is 6.8km by 5.2km, somewhat larger than the area shown in the map of Figure 3. Band 6 was quite similar to Band 7, but had a lower contrast. Band 4 was very low contrast because of thin haze and atmospheric scattering.

Photographic subtraction of the Band 7 image from the Band 5 image was of no help in interpreting these photos. Instead, it was found that a color composite constructed with diazo film was excellent for comparing Bands 5 and 7 (5). A qualitative map of the ratio of red to infrared brightness as determined from the false color image is given in Figure 8. The key to the symbols shown in that figure is listed in Figure 9, along with the estimated cause for each spectral ratio.

This map and the original photos show no trace of the crop marks due to the river meanders. During 1975, the archaeological crop marks, and the associated geological ones, had their highest visibility during the first week in July and had disappeared by mid-July. On July 29 when the satellite photo was taken, most of the crops were golden or were harvested.

The July 29 photo does show that one field within the bend of the river was still quite green then. This photo also shows that the ponds of water which indicate gravel pits cover a larger area than is shown on the base map of Figure 3.

Two satellite photographs taken in 1973 were also examined to see if there was any trace of the geological crop marks on them. However, it was found that the Band 5 image, by far the most useful for this task, was obscured on both dates. On March 8, a heavy haze was responsible. One June 7, thin cloud cover, at an altitude of about 9km, seriously reduced visibility in Band 5. However, on both dates there was fair visibility of the ground in Band 7 (6). These satellite photos are shown in Figures 10 and 11; the scale is the same as those in Figure 7.

The resolution of these three photos is indicated by the field boundaries which are visible in them (see Figure 12). The crops growing in 1970 in some of these fields are mapped in Figure 13. The broken lines in the figure indicate boundaries which are not shown in Figure 3. Since some of the detectable fields are smaller than the size of the geological

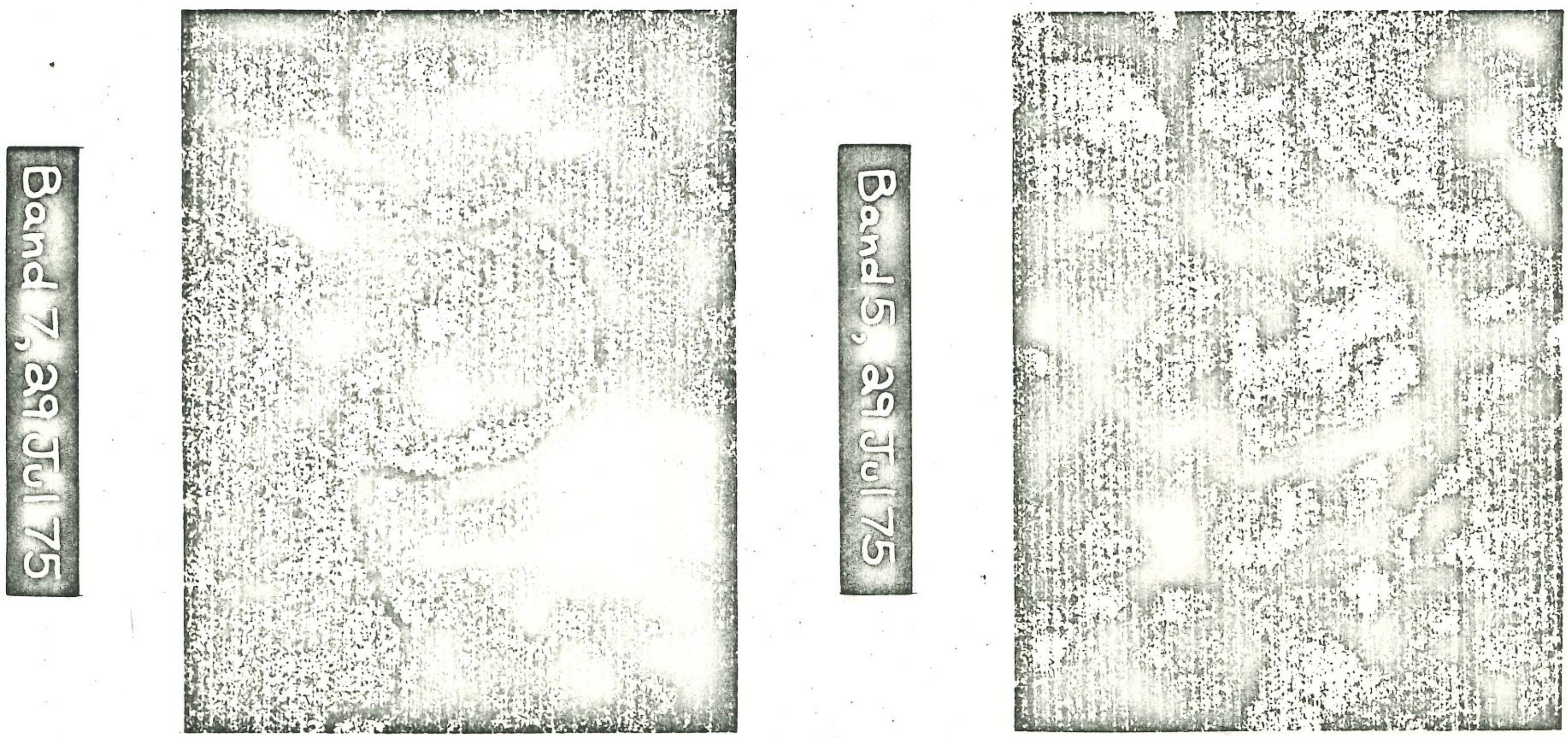

Figure 7. Landsat-2 photograph; red (Band 5) and infrared (Band 7) images are at a scale 1:64,300.

E-2188-10165

Figure 8. Red and infrared brightness of the photos in Figure 7.

SYMBOL	MEANING	POSSIBLE CAUSE
ri	red and infrared low brightness	water
r>i	both low, but red brighter	bare soil?
r<I	very low red brightness, high infrared	lush green vegetation
rI	low red and high infrared brightness	moderately green vegetation
Ri	high red and low infrared brightness	stubble?
R>I	both high, but red brighter	matured field crops

Figure 9. Interpretation key for Figure 8.

Band 7, 8 Mar73

Band 5, 8 Mar73

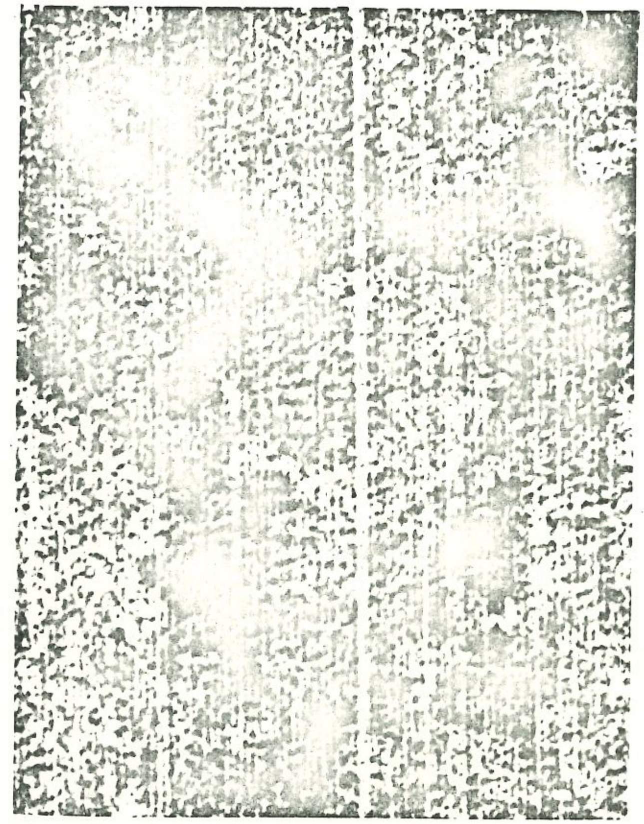

Figure 10. Landsat-1 photograph; same scale as Figure 7.

E-1228-10293

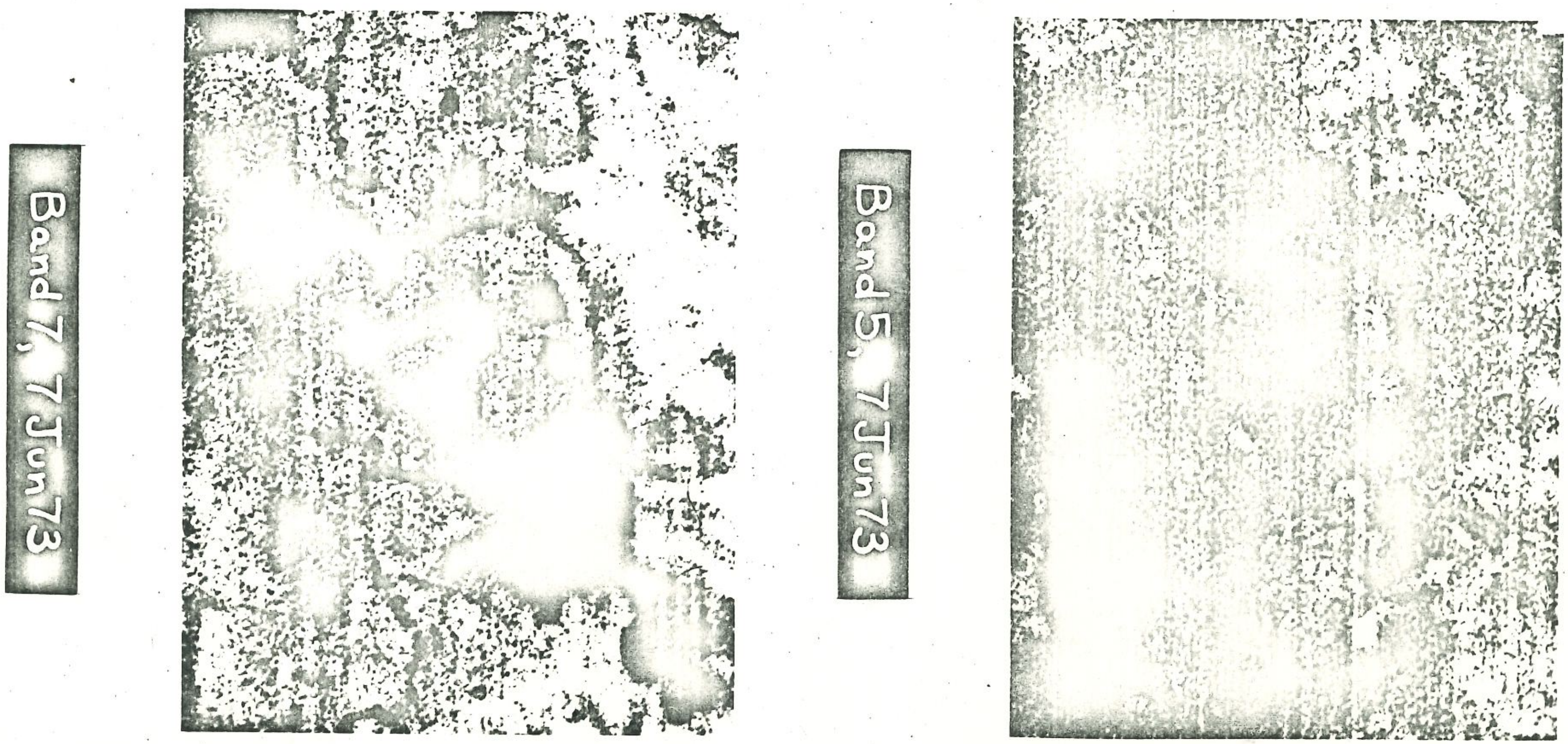

Figure 11. Landsat-1 photograph; same scale as Figure 7.

Figure 12. Field boundaries detected on Landsat photographs.

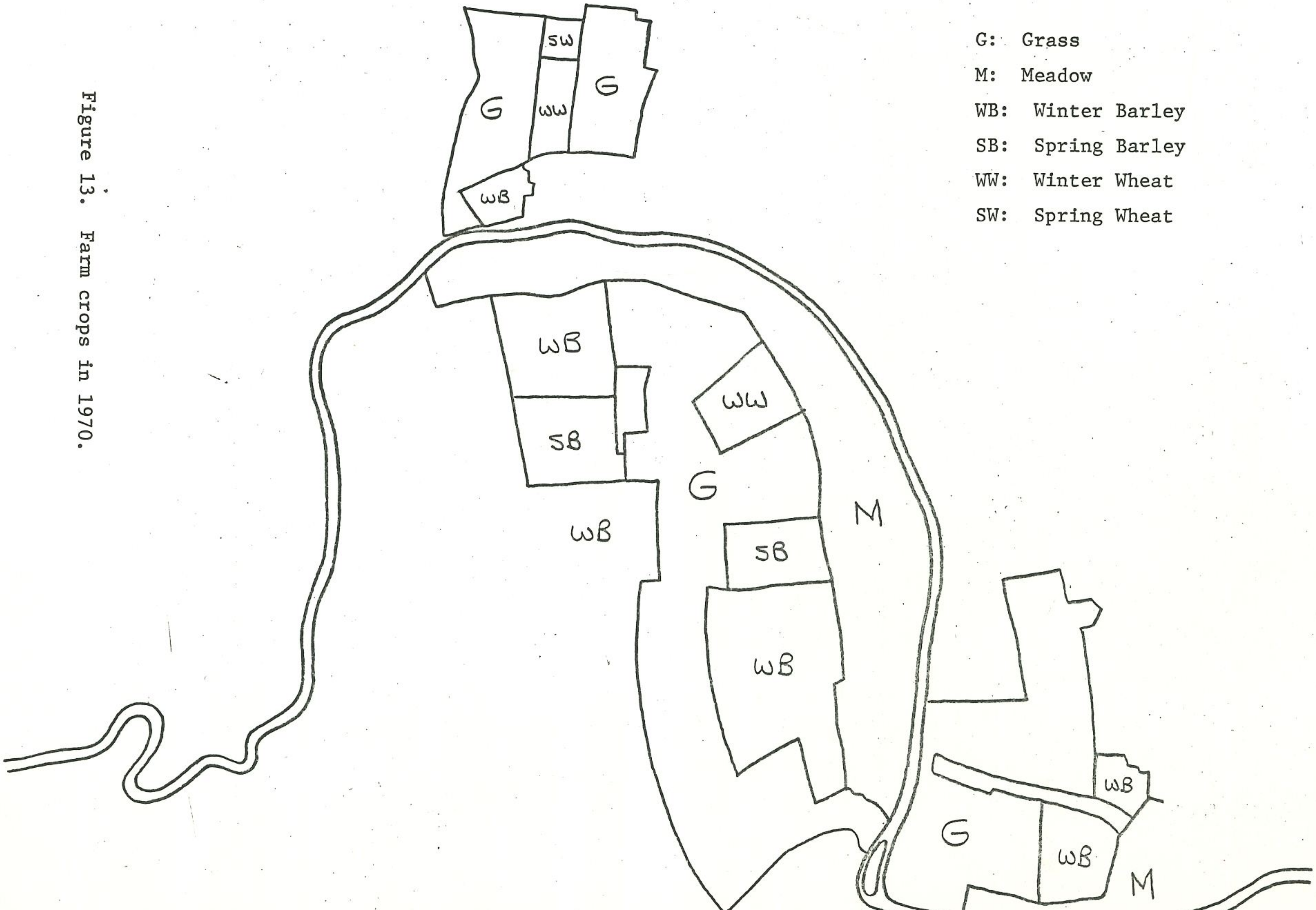

Figure 13. Farm crops in 1970.

crop marks, it is surmised that these geological marks will be visible on photos taken at the right time.

The cloud cover probability for southern England in summer is about 60%. Therefore, it is poor luck that no photos are available from the June 24 or July 12 overflights of Landsat-2, or from the six other times during the period from April through August for which pictures would have been valuable.

Future Work

It is hoped to be able to continue this experiment in the 1976 growing season. If a photo taken at about the right time becomes available, it might be important to get the highest possible resolution from it. As a start, photographic combination of the two pictures taken on consecutive days may decrease the loss of resolution due to film grain and the raster pattern (stereoscopic parallax should be no problem). Also, it might be possible to make a digital contour map of the brightness ratio of Bands 5 and 7; since only about 1000 pixels are necessary, the processing of the Computer Compatible Tapes might not be too difficult.

It might also be possible to examine other areas along the Thames River if a greater selection of June and July photos becomes available. If an anomalous pattern within a known field becomes visible during the growing season, it might indicate the partial maturity of that field's crop; this would mark the best time for aerial photography.

Hopefully, it will also be possible to investigate other river valleys which have a known appearance of archaeological crop marks; the Mississippi-Missouri would be the prime example.

Conclusion

Since the 18-day periodicity of Landsat imagery has a unique capability of aiding archaeological reconnaissance, it is hoped that cloud and haze cover are more favorable in the future. The 9.5 inch positive transparencies of the red and infrared images have been excellent for detecting patterns in the growth of crops.

Acknowledgment

This project was made possible with the help of the National Aeronautics and Space Administration, both for getting the satellite photos taken and in furnishing them for this investigation. A grant from the National Science Foundation, SOC-75-04203, funded the interpretation of these photos and the publication of this report.

References

1. L. Deuel, Flights into Yesterday (St. Martin's Press, New York, 1969).
2. J. N. Hampton, "An Experiment in Multispectral Air Photography for Archaeological Research", Photogrammetric Record 8(43):37-64 (April 1974).
3. Royal Commission on Historical Monuments (England), A Matter of Time (Her Majesty's Stationery Office, London, 1960).
4. T. H. Maugh II, "ERTS: Surveying Earth's Resources from Space", Science 180(4081):49-51 (6 April 1973).
5. O. G. Malan, "Diazo Color Composites of ERTS and Multispectral Photography", South African Journal of Science 70(6):185,186 (June 1974).
6. A. P. Colvocoresses, "Unique Characteristics of ERTS", Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1, NASA SP-327 (U.S. Government Printing Office, Washington, 1973).