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A photographic representation of the variability in the G-banded structure of the chromosomes in the mouse karyotype

A guide to the identification of the individual chromosomes

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Abstract. Analysis of the mouse chromosomes is becoming increasingly important in many fields of genetic research. It is generally considered that the mouse chromosomes are more difficult to analyse than, for example, human chromosomes which has often led to their misidentification. This article presents a guide to the correct identification of trypsin-Giemsa banded chromosomes from the mouse. The variability in the G-banded structure of each chromosome is presented pictorially together with some suggestions for their unequivocal identification. Since many of the mouse chromosomes have similar banding patterns, those chromosomes which are more frequently misidentified have been compared and contrasted. Finally a summary of the main features for the identification of each chromosome is presented.

Introduction

Over the past several years cytogenetic analysis of the laboratory mouse has become increasingly important in many fields of genetical research. Perhaps the most widespread use of the mouse is in cancer research where detailed karyotypic studies have demonstrated the importance of specific chromosome changes in neoplasia (for review and references see Miller and Miller 1983). Gene mapping studies using somatic cell hybrids represent another area requiring detailed chromosome analysis since one of the parental cells is often murine in origin. In many of these studies it is essential to be able to identify the individual mouse chromosomes accurately and sometimes to determine the origin of chromosomal rearrangements which have arisen (see Cowell and Wigley 1982).

It is generally accepted that mouse chromosomes are more difficult to analyse than human or Chinese hamster chromosomes. All of the normal mouse chromosomes are telocentric and represent a continuous variation in size (see later). They cannot therefore be ordered initially into discrete groups on the basis of centromeric position. One of the difficulties associated with accurate identification of mouse chromosomes has been the lack of a standard work that illustrates the mouse karyotype and offers guidance for distinguishing between chromosomes with similar banding patterns. The lack of such a suitable reference work has no doubt also been a contributing factor to the frequent misidentification of mouse chromosomes, which on occasion has led to confusion concerning the relevance of individual specific chromosomes involved, for example, in some forms of murine cancer (see Spira 1980 in response to Dofuku et al. 1979).

The now universally accepted order of the chromosomes in the mouse karyotype was presented in 1972 by a standardisation committee (Committee on Standardised Genetic Nomenclature for Mice 1972). Although these chromosomes were G-banded, the quality of banding in the karyotype presented by the committee was poor and it is generally accepted that it offers little assistance in identification to those less familiar with mouse chromosomes. The main reason for this is that the chromosome banding patterns were somewhat indistinct and bear little resemblance to the banded chromosomes now being obtained by the majority of laboratories. The situation was improved considerably by Nesbitt and Francke (1973) who presented well-banded chromosomes and contrasted the banding obtained for each chromosome using different techniques. Though this was a great improvement over the 1972 standard, the chromosomes of Nesbitt and Francke (1973) were selected to show only the extremes of detail possible and again are not always easily related to more average preparations. The introduction of a nomenclature that identified every band on mouse metaphase chromosomes was invaluable at this point and has stood the test of time.

It is the purpose in this article to present a photographic interpretation of the variability of the banded structure of mouse chromosomes and hopefully to provide assistance in their individual identification.

Some notes on technique

Despite the emergence of many new banding procedures, which often have only highly specialised uses, trypsin-Giemsa banding is still the most commonly used technique. A review of the other banding techniques used for the mouse chromosomes can be found in Miller and Miller (1981). I have chosen to concentrate only on the variability of the trypsin-Giemsa (hereafter simply called G-banding) banded appearance of the mouse chromosomes in this article. This banding method is the most commonly used, does not require expensive equipment or reagents and offers an excellent permanent record of the banded structure of the chromosomes. It is my experience that Q-banding does not

provide the same resolution as G-banding, a view which although shared by others (Buckland et al. 1971; Schnedl 1971; Nesbitt and Francke 1973) is not a universally held opinion (see Miller et al. 1971; Miller and Miller 1981). In the mouse, C-banding offers little additional assistance in the identification of the individual chromosomes although it may be useful in identifying polymorphisms involving centromeric heterochromatin. Although the mouse Y chromosome is C-band negative, since the centromeres of the other chromosomes stain intensely following normal G-band procedures the Y chromosome is easily identifiable without additional C-banding.

The development of banding techniques has also resulted in a variety of different methodological modifications. Each group working with chromosomes have their own favoured methods, which may often be surrounded with idiosyncrasies peculiar to that group. It is not intended here to review, or contribute to, the mythology surrounding banding techniques. However, since the banding method used can, to some extent, modify the final appearance of the chromosome it is perhaps necessary to emphasise at the outset that all of the chromosomes presented in this article were banded using one technique, the details of which have been presented fully elsewhere (Cowell 1980b). However, aware of the variation produced by these different banding techniques, I have tried to include as diverse an appearance of each chromosome as possible to cover all eventualities.

The guidelines offered in this article are intended largely for beginners in the identification of the mouse chromosomes, but as with most visual interpretations the ability of the reader to follow these guidelines depends to some extent on their inherent pattern recognition capabilities.

Nomenclature

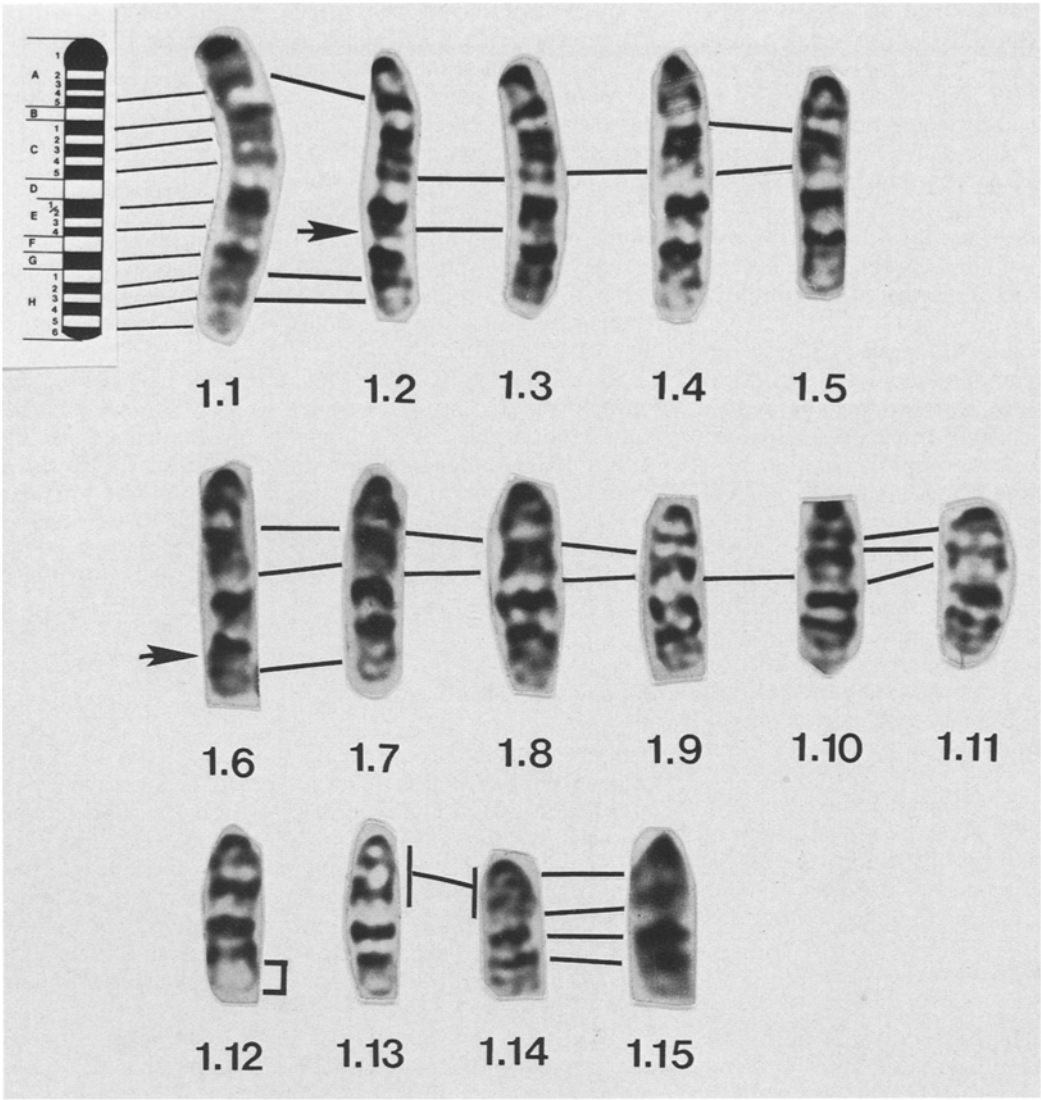
Unlike the majority of mammalian karyotypes, all mouse chromosomes are telocentric so there is no need to distinguish between individual arms. The system proposed by Nesbitt and Francke (1973) discriminates between major and minor bands. A band is a part of the chromosome that is clearly distinguishable from its adjacent segments. The chromosomes are visualised as consisting of a continuous series of light and dark bands with no interbands. The major bands are those readily identifiable in preparations showing only minimal information and each is given a capital letter starting with "A" at the centromeric (proximal) end. Each major band is preceeded by the number of the chromosome thus, 5A and 6B. A region of a chromosome is defined as that part between major bands. In good G-banded preparations some of the major bands can be subdivided into minor bands whose visibility depends on the quality of the banding. Each minor band is given a number within the lettered group, e.g. 5A1, 6B2. In all cases the region consisting of the centromeric heterochromatin is designated A1. Strictly speaking the term "centromere" refers to a highly specific, functional part of the chromosome not visible in mitotic chromosomes. In the following text the liberty has been taken of referring to the darkly staining centromeric heterochromatin as the centromere. I feel that although not strictly accurate this makes description of the chromosomes less tedious and more readable. All regions of the chromosome, the G-positive and the G-negative bands, are given a band designation that allows for more accurate identification of specific break sites involved in chromosome rearrangements. A negative band is an unstained portion of the chromosome and positive bands may be defined as pale, medium or heavy depending on the intensity of the staining. As banding techniques improve it is highly likely that even the minor bands will be resolved into sub-bands, as in the human karyotype (see Yunis 1981), and the proposed system has the facility to accommodate these additions. Nesbitt and Francke (1973) proposed that the sub-bands could be designated by a small letter thus, 5B2a and 5B2b although in keeping with the human nomenclature an equally acceptable system would be 5B1.1, 5B1.2 etc.

The karyotype contains 19 autosomal pairs and 2 sex chromosomes. The chromosome order follows the usual rules; the largest being number 1 and the smallest being 19. In designating a particular band in the karyotype three things are required: (1) the chromosome number, (2) the region letter, and (3) the band number within the region if necessary. These items are given in order without punctuation, e.g., 5D2 indicates chromosome 5, region D, band 2.

Chromosome identification

The chromosomes presented in this article have been obtained from a collection of karyotypes made for the analysis of both normal mouse embryonic cells and various mouse epithelial cell lines. More comprehensive details of the karyotypes of these cells have been reported elsewhere (Cowell 1979, 1980a, 1980b, 1981, 1982a, 1982b; Cowell and Wigley 1982). When the chromosomes were derived from tumor cells, only those chromosomes that appeared structurally normal to the limits of the resolution available have been used.

In essence this analysis is a pictorial representation of the variability of the G-banded appearance of all of the mouse chromosomes. The chromosomes are considered individually and for each, a range of appearances from maximum to minimum detail is presented. In the initial description of banding patterns of individual chromosomes, examples have been selected to illustrate the particular points made in the discussion. However since each chromosome shows more variation than can be conveniently discussed, the description of each one is followed by a block presentation of examples for that particular chromosome showing as much of the variation as possible. These latter sections are designed for comparison purposes and can be referred to for identification of chromosomes without attention to the details of the individual bands. However to be used properly both sections should be referred to. Important in the initial identification of each chromosome is the recognition of invariant features of the banding pattern that are characteristic features for the identification of the chromosome. Throughout the following discussion these bands are referred to as "landmarks". It should be noted that the term "landmark" is used in human nomenclature (ISCN 1978) to describe the first band in each subdivision of a chromosome. Where the word "band" has been used, the reader should interpret this to mean G-positive band. The full description will only be used for special emphasis. Banded regions that fail to take up stain will be called G-negative. The above terms are not intended to replace



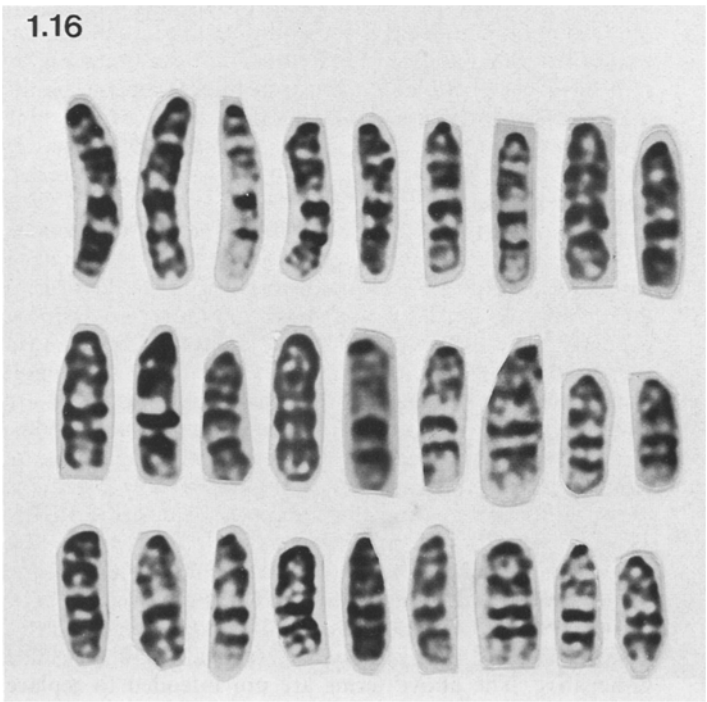
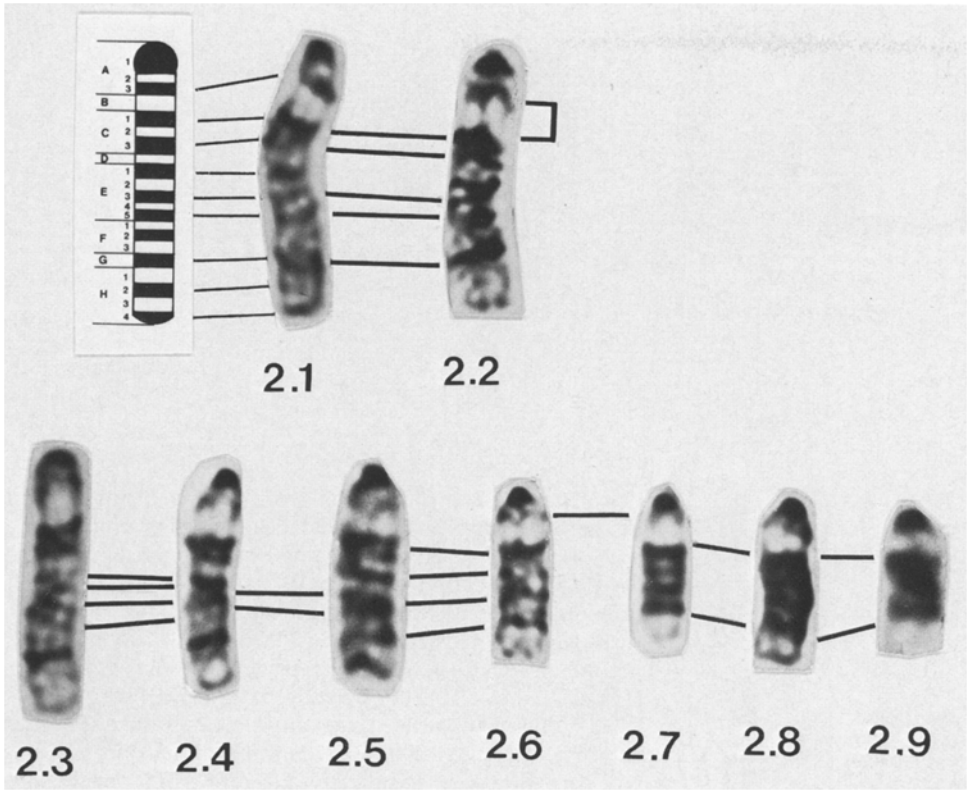


Fig. 1. Chromosome 1



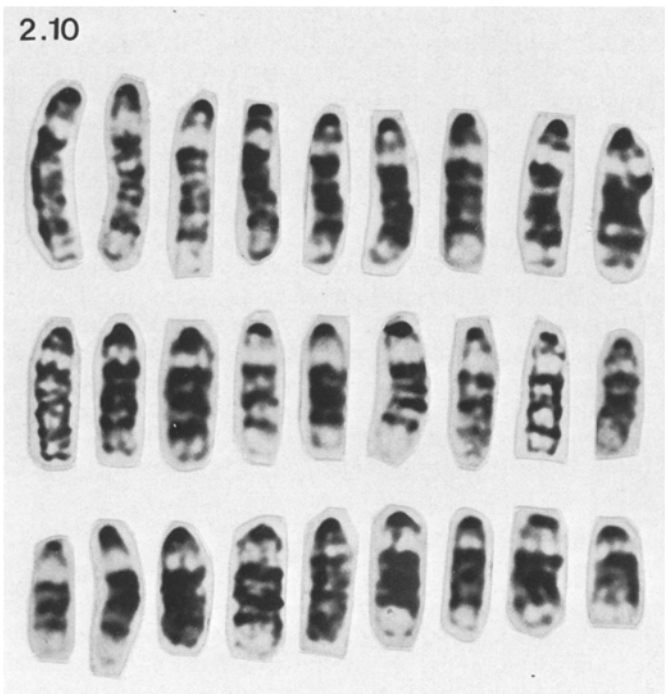


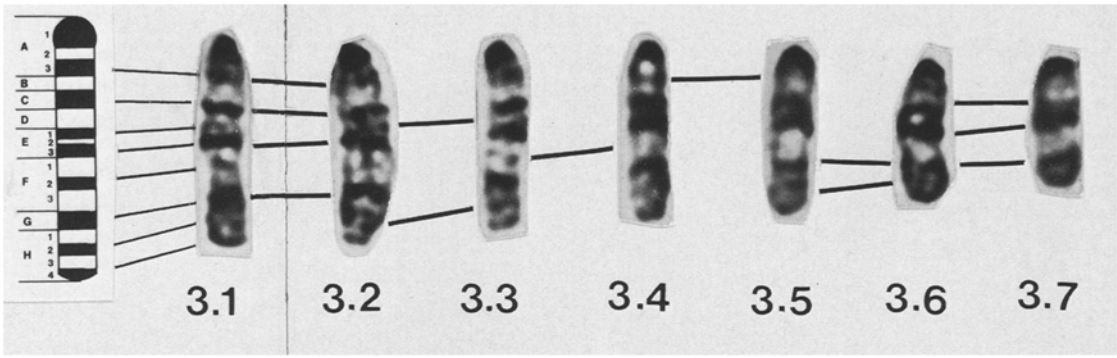
Fig. 2. Chromosome 2

any existing system of nomenclature but are used merely for easier reading.

Chromosome 1

Chromosome 1 is the largest chromosome and contains a high density of G-positive bands. On extended chromosomes each band can be distinguished but the close proximity of the bands relative to each other along the length of the chromosome means that in certain regions some of the bands almost invariably merge together. The major landmarks are the two distally located heavy bands comprising the 1E and 1G groups (Fig. 1). Analysis of Figure 1.16 shows that no matter how distorted or indistinct the chromosome banding pattern these two bands are always recognisable. Three of the bands are rarely seen; 1A3, 1E1 and 1H6. The absence of the 1A3 band (or the fact that it merges with 1A5) means that, in the proximal region of chromosome 1 there is usually only a single heavy band, 1A5 (Fig. 1.1, 1.2). This band often remains distinct, flanked by G-negative regions (e.g. Fig. 1.1–1.5, 1.9) and is also an important band in the identification of chromosome 1. Sometimes in the more contracted chromosomes however, this band merges with the centromere (e.g. Fig. 1.7, see also Fig. 1.16).

In good preparations it is always possible to distinguish three discrete bands in the 1C region (Fig. 1.1–1.3). Bands 1C1 and 1C3 often stain with equal intensity (Fig. 1.3, 1.4); band 1C5 is often less intense (compare Fig. 1.2–1.5). It is not unusual to find that these three bands merge to form a single G-positive region with the sum length of the three constituent bands (e.g. Fig. 1.6, 1.7). Either contraction of the chromosome, or a reduction in the stain intensity of band 1C5, results in a smaller, heavy band in the same position just below band 1A5 (e.g. Fig. 1.9, 1.12). The 1C region may eventually diminish to only a single band (Fig. 1.7–1.12), although occasionally a faint band, which is presumably band 1C5, can be seen at the distal extreme (Fig. 1.10). Whether the 1C region contains a large group of bands or a single band, it is usually distinct because



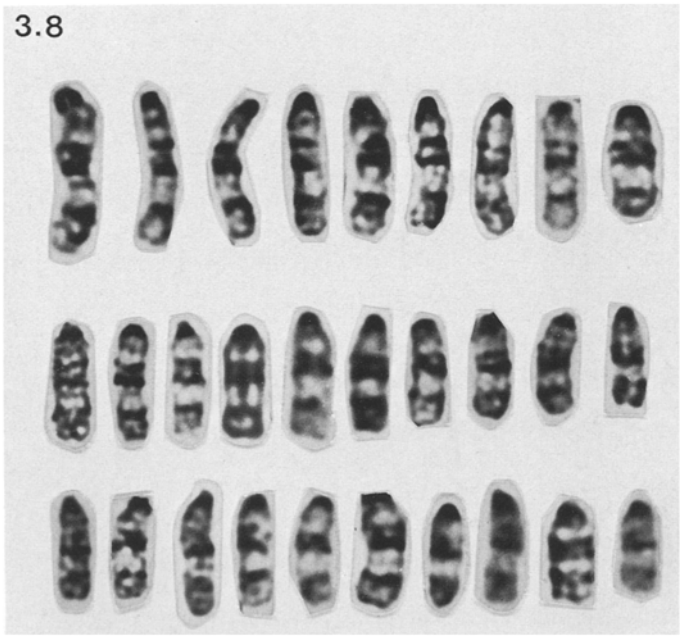


Fig. 3. Chromosome 3

of the G-negative regions on either side (Fig. 1.8, 1.9). These faint regions tend to highlight the dark group of bands in the proximal portion of the chromosome.

Although band 1E1 is rarely seen (presumably it fuses with 1E2), in good preparations band 1E3 is usually visible as a faint band below 1E1 (Fig. 1.1–1.3, and see arrow in Fig. 1.2). More often band 1E3 fuses with 1E1 thus creating a single band representing the entire 1E region (Fig. 1.7–1.15). Band 1G usually remains as a single heavy band (Fig. 1.1–1.5), although it sometimes merges with band 1H2 (e.g. Fig. 1.7, 1.12). Often only a single band can be seen below the 1G region (Fig. 1.9–1.11) and sometimes none at all (Fig. 1.12–1.14).

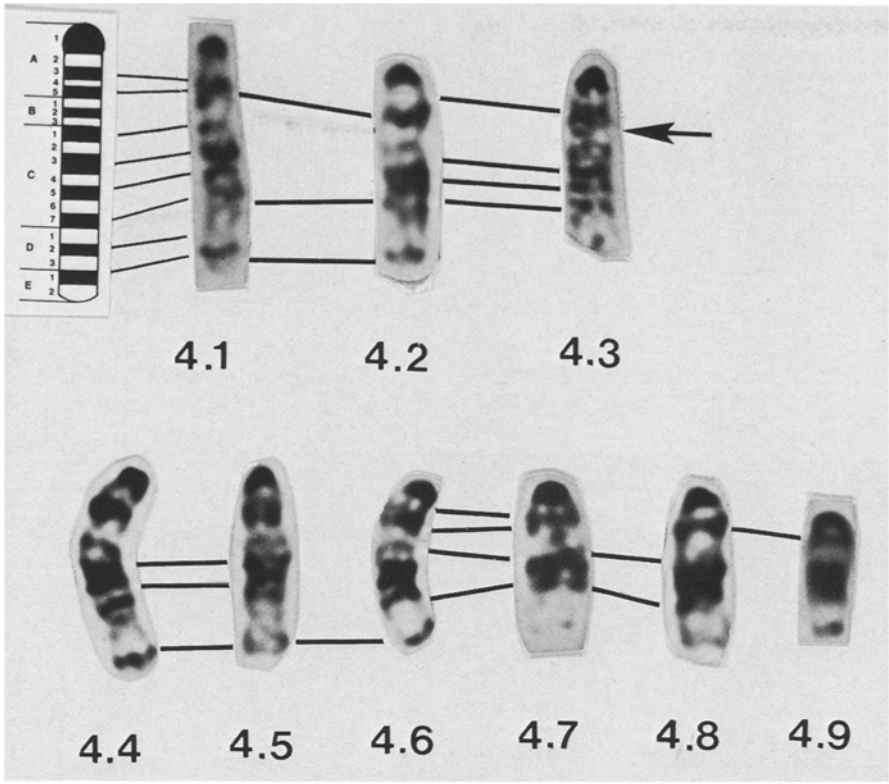
The G-negative bands along chromosome 1 effectively break the chromosome up into discrete regions (see Fig. 1.6–1.8). Thus the 1D region divides the chromosome into two distinctive halves. Below 1D are the two prominent heavy landmark bands, 1E and 1G, which are roughly equidistant from each other and the distal end of the chromosome (see Fig. 1.12, 1.13 for the best illustration). Above the 1D region are two darkly stained groups of bands, the wide 1C region and the narrower 1A region, which usually remains distinct from the centromere.

Chromosome 2

Chromosome 2 is one of the more readily distinguishable of the large chromosomes and bears little resemblance to any of the other chromosomes. Possibly the best feature for its identification is the pale 2B region just below the centromere. In all but the best chromosomes, band 2A3 fuses with the centromere (see Fig. 2.7–2.9) leaving the 2B region as a G-negative space below the centromere (Fig. 2.2). Note the consistency of this feature in Figure 2.10. None of the other large chromosomes have this characteristic with the possible exception of the X chromosome, which is otherwise completely different from chromosome 2. Below the 2B region is a doublet of dark bands, 2C1 and 2C3, whose intense staining tend to enhance the G-negative appearance of the 2B region. Although usually discrete, bands 2C1 and 2C3 may fuse to form a single band in shorter chromosomes (Fig. 2.6, 2.7). Band 2E1 often remains discrete (Fig. 2.1–2.7) and lies midway between the 2C1/3 doublet and another doublet below, comprising bands 2E3/5 and 2F2. In all but the very extended chromosomes, 2E3 and 2E5 fuse to give a single band (Fig. 2.4) which, in shorter chromosomes also includes band 2F2 (Fig. 2.5–2.7). The 2G band is always present and on occasion band 2H2 can be seen immediately below it (Fig. 2.4). The terminal 2H4 band is rarely seen (Fig. 2.5) and thus the distal end of the chromosome generally appears as a G-negative region (see Fig. 2.6–2.9). In its simplest form chromosome 2 consists of four centrally placed dark bands flanked by G-negative regions (see Fig. 2.7). These four bands may merge to a greater (Fig. 2.9) or lesser (Fig. 2.8) extent.

Chromosome 3

Chromosome 3 is one of those chromosomes most frequently misidentified mainly because its major landmarks are similar to those of several other chromosomes (see later). These landmarks consist of a doublet of dark bands approximately one-third the way along the chromosome and another dark band near to the distal end. The two heavy bands, 3C and 3E3, are bisected by a single faint band, 3E1, (Fig. 3.1 and 3.2) which is amongst the first to become indistinct in more contracted chromosomes (Fig. 3.4–3.7). In these cases the doublet of heavy bands may merge to form a single thick band (Fig. 3.4 and 3.7). The most proximal band on chromosome 3, 3A3, is usually separated from the centromeric region even in contracted chromosomes (compare Fig. 3.2 and 3.6) although occa-



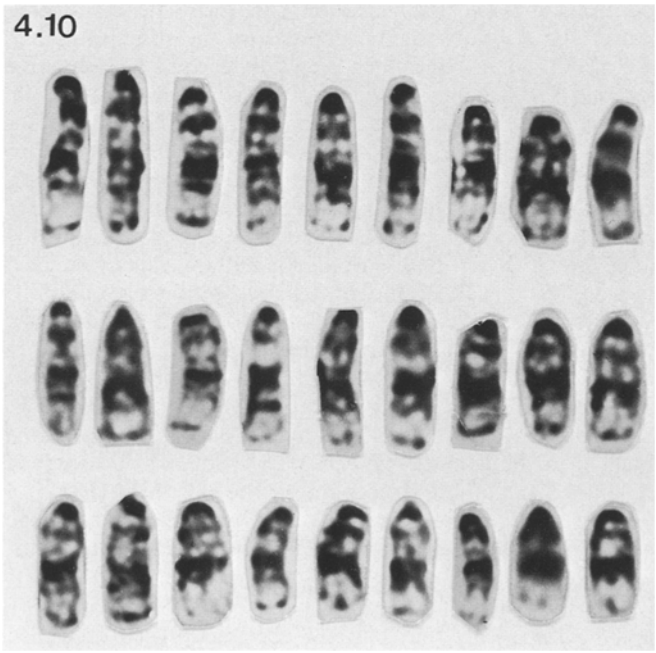
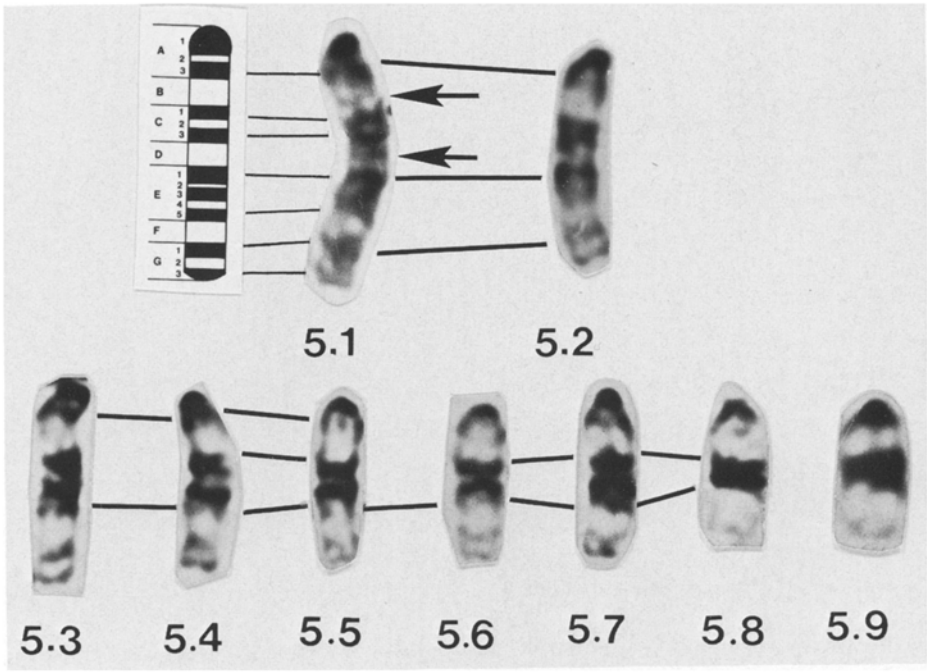


Fig. 4. Chromosome 4

sionally it may merge with the centromere (Fig. 3.5). The least frequently observed band is 3F2, ordinarily the only band between the two landmark regions. Its failure to take up stain produces a pale region just below the midpoint of the chromosome. Band 3G is invariant but may change with respect to its proximity to the distal end of the chromosome (compare Fig. 3.5 and 3.7). The 3H region of chromosome 3 sometimes consists of two bands, 3H4 often becoming terminal (Fig. 3.2, 3.3). Most often only band 3H2 can be seen clearly (Fig. 3.5).

Chromosome 4

Chromosome 4 is one of the chromosomes that can be recognised more easily when there is less detail in the banding. In those cases (see Fig. 4.5, 4.6) the major landmarks are the tightly grouped bands between 4C1–4C7, located slightly below center and the 4A3 band situated just below the centromere. In some cases (Fig. 4.7, 4.8) these may be the only dark bands on the chromosome. In chromosomes showing near maximum detail it is often impossible to resolve bands 4A3 and 4A5 (but see Fig. 4.3), which usually form a single heavy band just below the centromere (Fig. 4.4). The 4B2 band is also rarely seen although it is sometimes associated with the 4A region (Fig. 4.3). In all but the poorest banded chromosomes, band 4C3 is visible and usually distinct from the very heavy 4C1 band (Fig. 4.5, 4.7). Although 4C5 is seen in elongated chromosomes (Fig. 4.1, 4.2) just below 4C3, these two bands often merge to form a single band located just below the midpoint of the chromosome (Fig. 4.4, 4.6). The 4C7 band is usually distinguishable and forms the most distal of what is often a central triplet of bands consisting of 4C1, 4C3/5 and 4C7. When band 4C3 becomes indistinct this often creates a doublet (Fig. 4.7). The coalescence of all of these bands in the 4C region creates a single heavy band just below the midpoint (Fig. 4.8 and 4.9). The 4D region, is a light region subdivided by a single dark band, 4D2, which is sometimes seen (Fig. 4.1) but more often lost (Fig. 4.2–4.9) creating a pale subterminal region. The most distal heavy band, 4E1, may or may not be present but when it is may either be subterminal (Fig. 4.2) or terminal (Fig. 4.4, 4.6). The distal end of chromosome 4 however is most often either pale or G-negative (Fig. 4.3, 4.5, 4.7, 4.8).



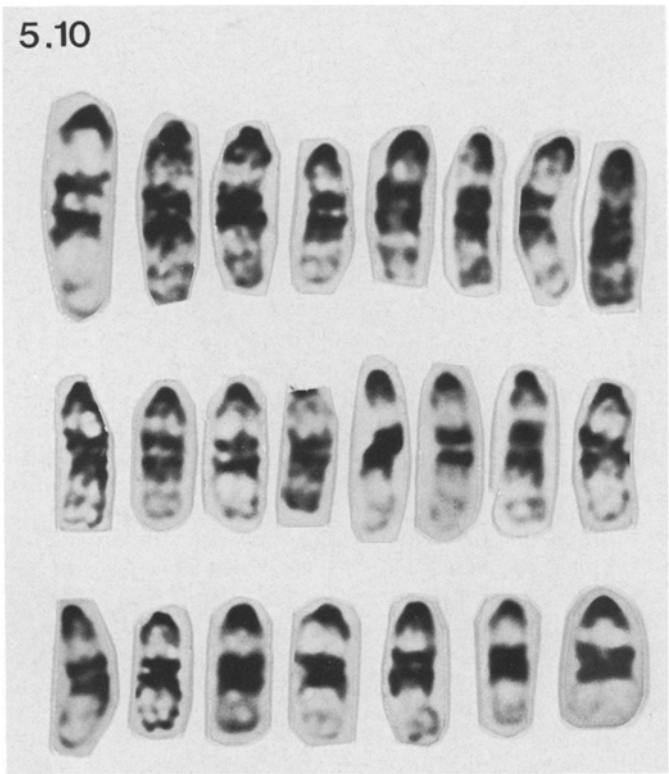


Fig. 5. Chromosome 5

Chromosome 5

Chromosome 5 is generally easy to recognise since all of the major dark bands are located in the center of the chromosome and often the regions above and below are G-negative (see Fig. 5.4–5.9). The other important band in the identification of this chromosome is 5A3; most important is its relative position with respect to the centromere. Even in the most elongated chromosomes, band 5A3 lies just below the centromere (see Fig. 5.1, 5.2). In shorter chromosomes this band may either merge with the centromere (Fig. 5.4) or become completely indistinct (Fig. 5.5, 5.6, 5.9). The 5B region has been described as a G-negative region (Nesbitt and Francke 1973) which is usually the case. In a very few preparations, however, a faint band was detected in the center of the 5C region (indicated by the top arrow in Fig. 5.1). The upper half of chromosome 5, therefore, contains two faint bands at most, which if indistinct give this region its more characteristic G-negative appearance (see Fig. 5.5–5.9). The distal half of chromosome 5 is a mirror image of the proximal region with only two small bands, 5G1 and 5G3, of which only 5G1 is obvious even in the longer chromosomes (Fig. 5.2, 5.3). In more contracted chromosomes even 5G1 becomes indistinct making the distal end of chromosome 5 G-negative (Fig. 5.5–5.9). Consequently all of the major banding structure is located in the central third of chromosome 5. Two bands of roughly equal intensity comprise the 5C region (Fig. 5.1) and often these two merge together to give either a large doublet band (Fig. 5.2–5.4) or in more contracted chromosomes a single band (Fig. 5.5, 5.6). As with region 5B, it was possible to detect a small band in region 5D (bottom arrow in Fig. 5.1) that has not previously been described (see Nesbitt and Francke 1973). Most often, however, this band becomes part of the 5C or 5E subdivisions. Of the three bands in the 5E region usually only two are seen (Fig. 5.3), bands 5E1 and 5E3, which often fuse into a single band. In more contracted chromosomes the 5E5 band is no longer distinctly visible (Fig. 5.6) or appears as a grey spur to the heavy 5E1/3 band. As with the 5C region, the 5E group of bands can be reduced to a single band (Fig. 5.6). In the most contracted chromosomes the 5C and 5E regions fuse to form a single, dark, central band usually flanked by pale G-negative regions (Fig. 5.8, 5.9). On a few occasions the 5C–5E region merges without any great reduction in chromosome size (compare Fig. 5.7 and 5.8).

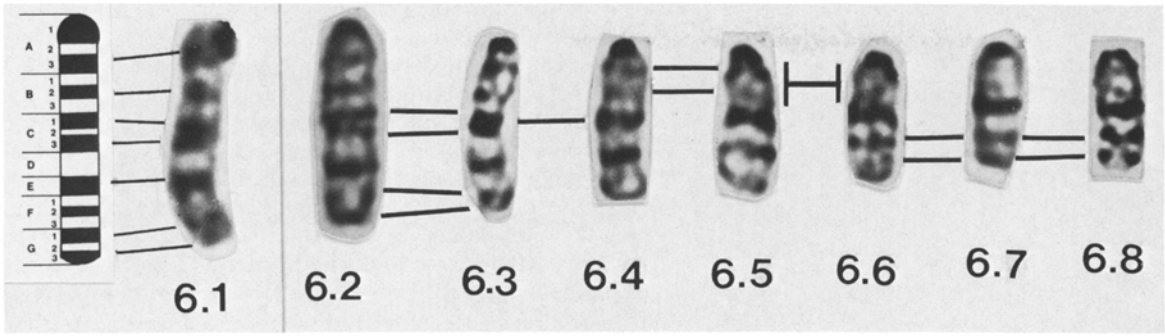


Fig. 6. Chromosome 6

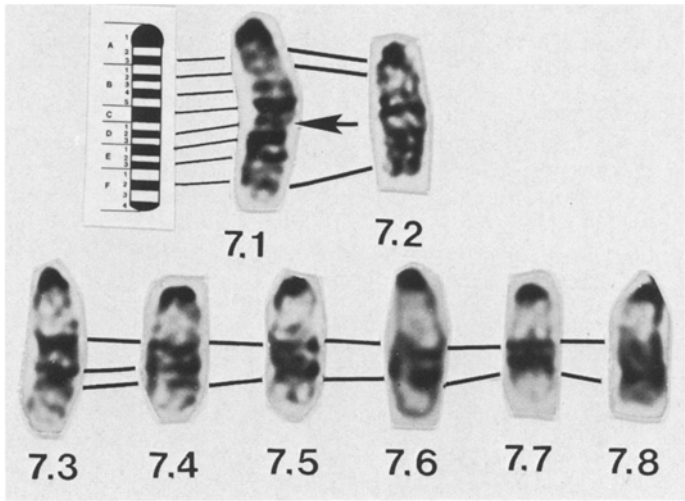


Fig. 7. Chromosome 7

Chromosome 6

An important feature of chromosome 6 is the even distribution of the major bands along its length (see Fig. 6.2, 6.3). There are no obvious landmarks. The best is the centrally located doublet comprising 6C1 and 6C3, which is by no means a unique feature within the karyotype. Chromosome 6 is more easily recognised when there is less detail. In the proximal half of the chromosome there are two major bands, 6A3 and 6B2. Band 6A3 can be heavier than 6A2 although they may also be approximately equal in size (see Fig. 6.4, 6.5). These bands also may no longer be visible (Fig. 6.7, and examples in Fig. 6.9). The 6A3 band sometimes merges with the centromere (Fig. 6.5, 6.6). The terminal region often resolves into only a single band (see Fig. 6.3–6.7). Band 6F2 is rarely visible and probably fuses with 6E. The two bands in 6G also fuse to form a single band (see Fig. 6.3) which may be terminal (Fig. 6.7) or subterminal (Fig. 6.8). The 6E band is the other landmark located just below 6C and creates a doublet of heavy bands just below the midpoint of the chromosome. When the 6G group fuses to form a single band, the lower half of chromosome 6 contains three dark, regularly spaced bands which is the easiest way to identify this chromosome (Fig. 6.7–6.9).

Chromosome 7

Chromosome 7 is another of the more frequently misidentified chromosomes, showing many characteristics of several of the other chromosomes. The major landmarks are the

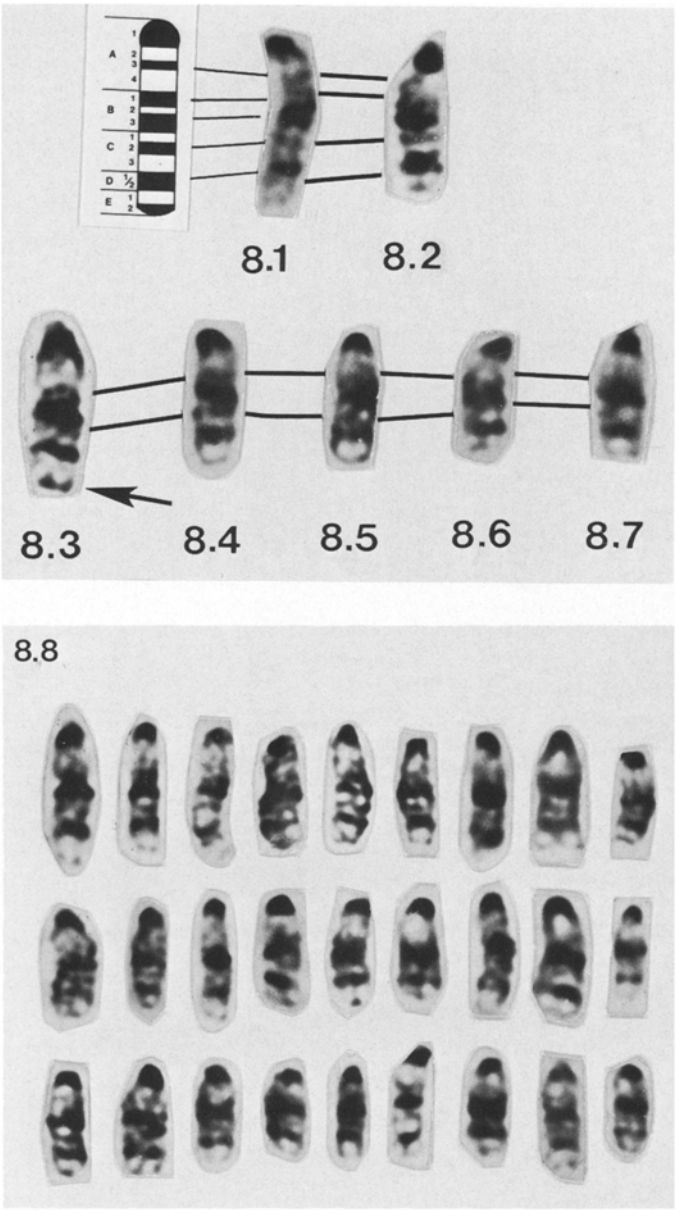


Fig. 8. Chromosome 8

two near centrally located, darkly staining regions, 7C and 7E. Between these dark bands is a smaller band 7D2 (indicated by the arrow in Fig. 7.1); however, this band more often fuses with band 7C (Fig. 7.2–7.8). The 7E region consists of two dark bands 7E1, and 7E3, which usually remain discrete (Fig. 7.1–7.4) but in smaller chromosomes fuse into a single band (Fig. 7.6–7.8). Although many chromosomes show doublets near to the center of the chromosome, it is their relative position on the chromosome that aids in identification. Thus the heavy doublet (7C–7E) is below the midpoint of the chromosome, such that the distance from the centromere to the first band, 7C, is about twice that from the most distal band, 7E3, to the distal end of the chromosome. The proximal region contains three bands, which are all visible in good preparations (see Fig. 7.1) but are frequently no longer visible in poorer preparations. Consequently the proximal region of this chromosome sometimes appears grey (Fig. 7.3, 7.4). More often this region is essentially G-negative (Fig. 7.5–7.8). The same is also true for the distal region containing bands 7F2 and 7F4. Occasionally band 7F2 can be seen (Fig. 7.3), but the distal end is more often pale resulting in the more typical appearance of this chromosome (see Fig. 7.5–7.8). The central, heavy bands may resolve into only two thick bands (Fig. 7.6) which may occasionally be somewhat thinner (Fig. 7.7) depending on the length of the chromosome. In the most extreme cases these bands merge to give a generally dark appearance to the lower half of the chromosome (see Fig. 7.8).

Chromosome 8

Chromosome 8 is also a frequently misidentified chromosome. Its main features are the dark centrally located bands with another smaller band near to the distal end. The 8A3 band is only seen in longer chromosomes (Fig. 8.1) and is not usually visible or merges with the centromere (Fig. 8.4). Band 8B1 can usually be seen immediately above 8B3, the major band on chromosome 8 (Fig. 8.1–8.3). This band may, however, become indistinct and merely provide a less intensely stained continuation of band 8B3 (compare Fig. 8.3 and 8.4). Alternatively 8B1 may become incorporated into 8B3 (Fig. 8.5–8.7). Band 8C2 has a similar fate, often becoming part of 8B3 (Fig. 8.6). The overall effect is that the region 8B1 through 8C2 appears as a central, G-positive region, which is darker in the middle (Fig. 8.5–8.7). Below this central mass of bands lies the dark doublet 8D1/2 which can only be distinguished in well banded preparations (see Fig. 8.1), more usually only a single dark band is observed (Fig. 8.3–8.7). The dark terminal band, 8E2, is usually lost giving the distal end of chromosome 8 a pale appearance although sometimes the terminal band can be detected (see arrow in Fig. 8.3).

Chromosome 9

The single most important landmark on chromosome 9 is the dark subterminal band located approximately three-fourths of the way down the chromosome. Despite the many variations in appearance of this chromosome, this band from the 9E region remains a constant feature. Unfortunately the presence of such a dark subterminal band is also a feature of many other chromosomes and thus makes chromosome 9 another of the more frequently misidentified chromosomes. According to Nesbitt and Francke (1973) the 9E subdivision consists of three bands. In their description the distal G-positive staining band in 9E was divided into two bands, 9E3 and 9E4. No G-negative band was present between them but band 9E4 was considered less intensely staining. I found no justification for dividing this single darkly staining region into two bands and in Figure 9 the distal G-positive band in 9E is referred to simply as 9E3. Band 9E1 is seldom seen other than as a faint spur to 9E3, the dark band below (see arrow in Fig. 9.2). The terminal region of chromosome 9 is more often G-negative (Fig. 9.3), although occasionally the terminal 9F4 band can be seen (Fig. 9.5). The length of this pale region relative to the rest of the chromosome is another useful means of distinguishing chromosome 9 from other similarly banded chromosomes (see later). The proximal three-fourths of chromosome 9 contains three equidistantly

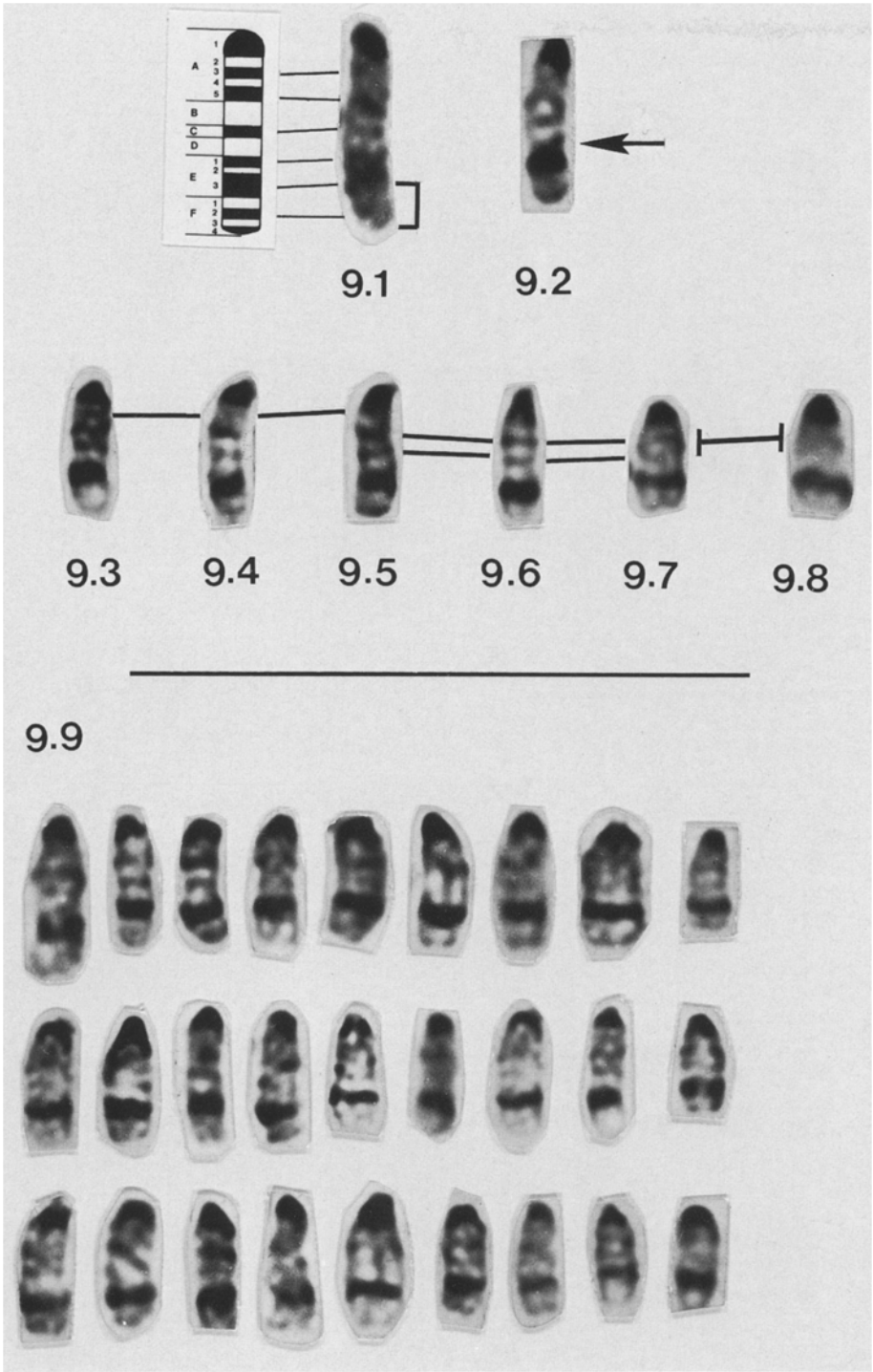


Fig. 9. Chromosome 9

spaced bands. Of these the 9A3 band stains most weakly and as a consequence most frequently becomes indistinct (compare Fig. 9.3 with 9.4) due to its merging with the centromere (Fig. 9.5). The failure of 9A3 to be seen distinctly results in the more usual appearance of chromosome 9 (Fig. 9.6) with a dark subterminal band below two other bands that are darkly stained and evenly spaced along the chromosome. When chromosome 9 shows the least detail, the two bands 9A5 and 9C may be very faint (Fig. 9.7) or merged to give a generally grey appearance to the proximal half of the chromosome (Fig. 9.8).

Chromosome 10

The most distinctive features of chromosome 10 are the three closely apposed bands in the upper half of the chromosome. These bands constitute the 10B group. Between these bands and the centromere is a faint band, 10A3, which can be seen in most average-sized chromosomes (Fig. 10.1–10.4) but not in more condensed ones (Fig. 10.6–10.9). Of the three bands in the 10B region, 10B5 is the weakest and sometimes becomes indistinct (compare Fig. 10.6 and 10.7), leaving only two dark bands in the top half of the

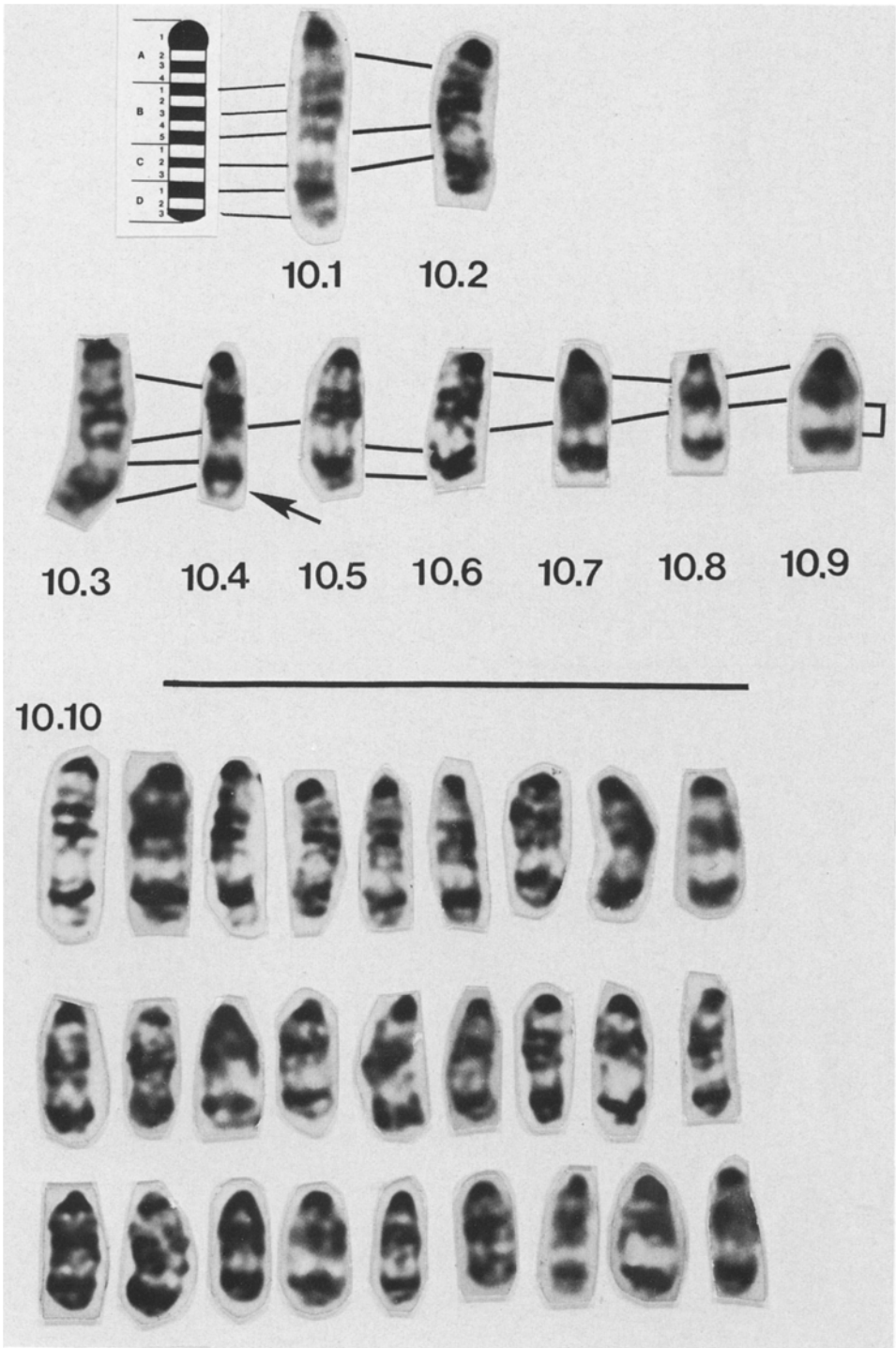


Fig. 10. Chromosome 10

chromosome. In some cases the 10A and the 10B group may merge together (Fig. 10.7), which may also be extended to include the centromere. In other preparations the composite 10A/10B band is still separated from the centromere, presumably by band 10A2. In the shorter chromosomes the top one-third of the chromosome stains darkly (Fig. 10.9). The unbanded 10C1 region is also an important landmark (bracketed in Fig. 10.9) and separates the 10B region from the 10C2/D region. Band 10C2 is only seen in the best preparations (Fig. 10.1, 10.2) and more usually merges with band 10D1 (Fig. 10.4) providing a subterminal band. The terminal 10D3 band is rarely seen and thus the distal end of the chromosome remains clear (Fig. 10.4, 10.5). In the shorter chromosomes (Fig. 10.6–10.9) the 10D1 band becomes almost terminal giving the most characteristic appearance of chromosome 10 with three dark proximal bands separated from a dark, almost terminal band by a clear G-negative region.

Chromosome 11

The major landmarks of this chromosome are the twin dark bands just below the centromere, the rest of the chromosome being relatively unstained. In some preparations the

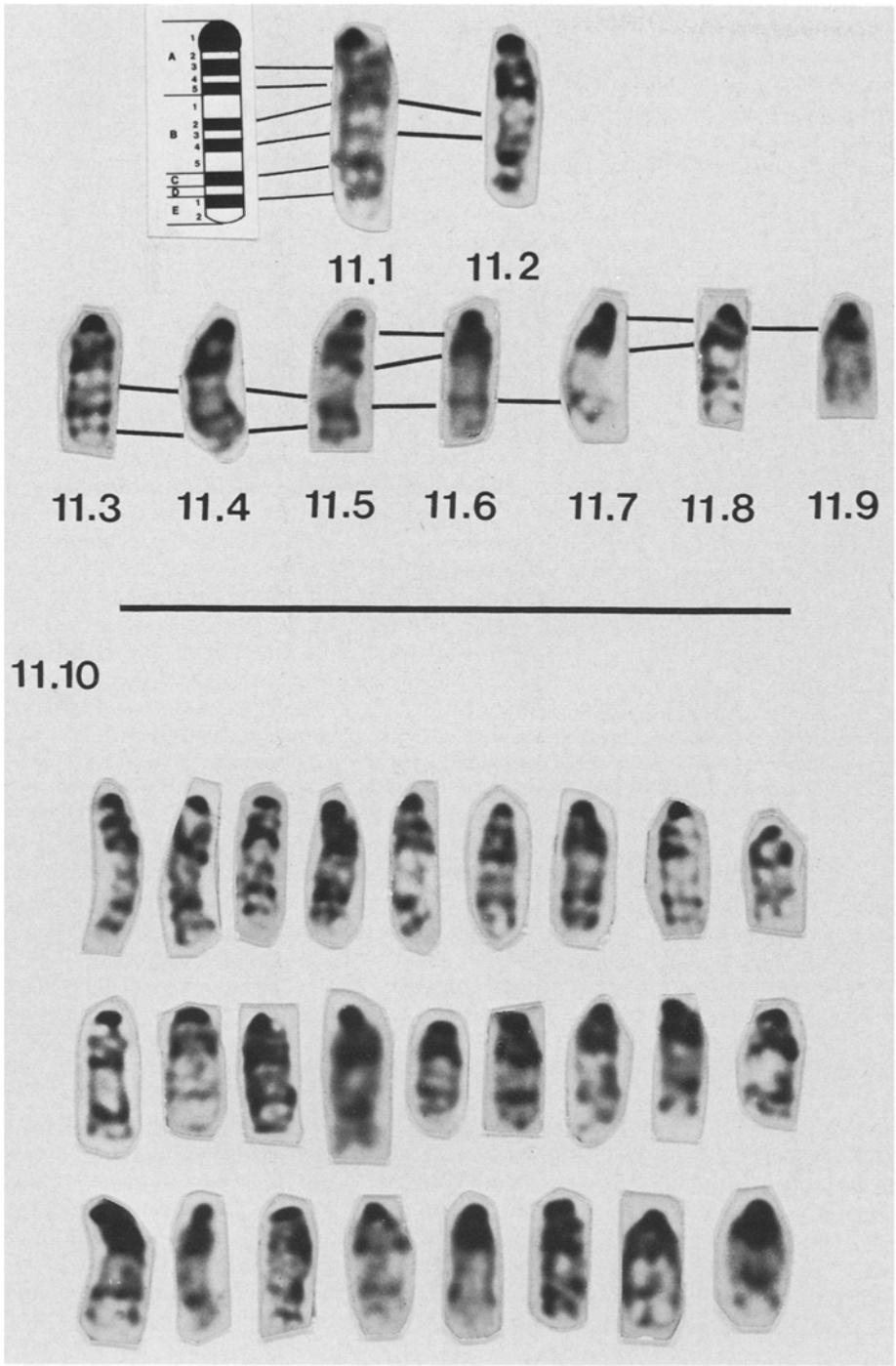


Fig. 11. Chromosome 11

two bands, 11A3 and 11A5, may be lighter but usually they are very dark (compare Fig. 11.1 and 11.2). These two bands may fuse (Fig. 11.3, 11.4) whilst remaining distinct from the centromere by virtue of the clear G-negative band, 11A2. Very often however when 11A3 and 11A5 fuse, they also merge with the centromere (Fig. 11.6–11.9), creating a darkly stained region occupying the proximal one-fourth of the chromosome. The size of the fused 11A region may vary from the sum size of the constituent bands (Fig. 11.7) to that of only a single band (see Fig. 11.8, 11.9). The two bands in the 11B group, 11B2 and 11B4, are amongst the first to disappear. It is difficult to determine exactly what happens to them both; 11B2 is no longer distinct possibly fusing with 11B4 which itself fuses with 11C. The net result is a single band in the center of the chromosome (Fig. 11.3, 11.4, 11.8). Both of these bands may be no longer visible making the central region of the chromosome unbanded (Fig. 11.5–11.7). Below the 11B group is the only other major band on chromosome 11, band 11C, which always remains subterminal but in some cases may be lost along with the 11B group (see Fig. 11.7, 11.9). The most distal of the bands, 11E1, is also frequently unstained. When present, 11E1 forms the third member of the distally located group (Fig. 11.3), however, it may be faint (Fig. 11.4), ter-

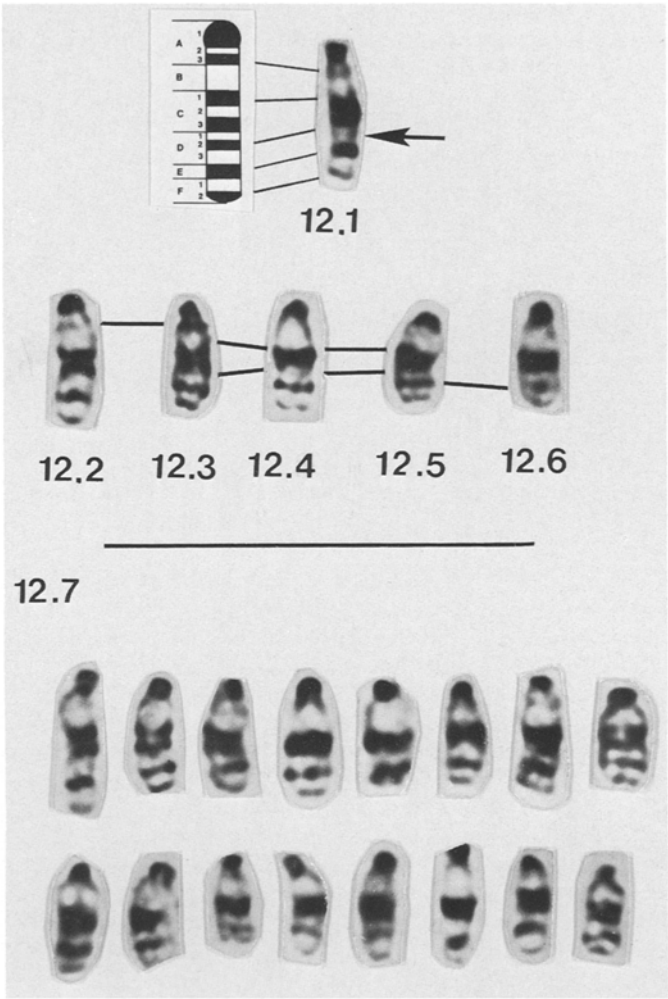


Fig. 12. Chromosome 12

minal (Fig. 11.5) or unstained (Fig. 11.6). When all of the distal bands, 11B3, 11C and 11E1, are no longer visible, chromosome 11 has a dark proximal region and the rest of the chromosome is G-negative (Fig. 11.7) or has an indistinct grey appearance (Fig. 11.9).

Chromosome 12

Chromosome 12 probably shows the least banding variability of the intermediate-sized chromosomes. The most proximal band, 12A3, is visible in the longer chromosomes (Fig. 12.1, 12.2) and may fuse with the centromere (Fig. 12.3), but in many chromosomes it is indistinct (Fig. 12.4–12.7). The heavy central doublet of bands 12C1 and 12C3 can sometimes be separated (Fig. 12.2, and see Fig. 12.7) but more often they merge to form a thick central doublet (Fig. 12.3), which varies in size (compare Fig. 12.3, 12.4 and 12.5). Band 12D2 (indicated by the arrow in Fig. 12.1) is rarely seen (Fig. 12.3–12.6) and the only other prominent band is 12E, which is always subterminal. On the distal end of chromosome 12, band 12F2 is usually present although on occasion may be less distinct (see Fig. 12.3).

Chromosome 13

Chromosome 13 is one of the more difficult to identify. In my experience the one definitive feature of chromosome 13 is the G-negative region that separates the two main groups of bands. In Figure 13.9 this region is indicated by the arrow and all of the other chromosomes (Fig. 13.2–13.10) are lined up to demonstrated the consistent appearance of band 13B. It was possible to detect three bands in the 13A region as opposed to the two reported by Nesbitt and Francke (1973). The extra band is indicated by the arrow in Figure 13.1. It was also possible to distinguish another additional band in the distal region of the chromosome (indicated by the arrow in Fig. 13.2). In the majority of chromosomes, however, only two bands could be detected in region 13A. Band 13A3 can be thicker than band 13A5 and it is reasonable to assume that the additional proximal band identified is derived from the splitting of 13A3. In other preparations 13A3 can be the same size as 13A5 (compare Fig. 13.3 and 13.4). These bands may merge with each other and also with the centromere to give the proximal region of the chromosome a darkly stained appearance (Fig. 13.6, 13.8). The G-negative 13A2 band may also separate these bands from the centromere (Fig. 13.7). Of the three bands in the distal portion of the chromosome, 13C3 is the strongest staining (Fig. 13.3–13.9) and although 13C1 often remains distinct from 13C3 (e.g. Fig. 13.4) it may sometimes merge with it (Fig. 13.5, 13.7). The terminal 13D2 band may (Fig. 13.5) or may not (Fig. 13.6) be obvious. In the most extreme cases the proximal and distal groups of bands just described may be reduced to a single band associated with the centromere and located subterminally (Fig. 13.9). The 13C group bands regardless of their appearance hardly, if ever, become terminally located.

Chromosome 14

Chromosome 14 is characterised by the dark central group of bands and a dark terminal group of bands. The most proximal band, 14A3, is hardly ever seen and when present is very faint (upper arrow in Fig. 14.3). This band either fails to stain easily or fuses with the centromere. In longer chromosomes such as the one shown in Figure 14.1, the three central bands can be resolved but more often bands 14C1 and 14C3 fuse into a single dark band (Fig. 14.2, 14.3). Band 14D2 lies immediately below 14C1/3 and is less intensely stained (Fig. 14.2, 14.3). In the shorter chromosomes 14D2 is lost completely leaving the 14C group as the only G-positive band in the center of the chromosome. Nesbitt and Francke (1973) chose to split the first band in the 14E group into two closely apposed bands. No evidence for such a distinction was found in this study, and although 14E4 was sometimes seen (Fig. 14.1, 14.3), more often it merges with the 14E1/2 band (Fig. 14.4–14.6). This band is not terminal, and in elongated chromosomes (Fig. 14.1–14.6) the distal end of the chromosome has a G-negative band. In shorter chromosomes, however, the 14E group of bands becomes terminal and may either occupy up to one-fourth of the chromosome (Fig. 14.4) or be reduced in size almost to that of the 14C midgroup of bands (Fig. 14.5, 14.6).

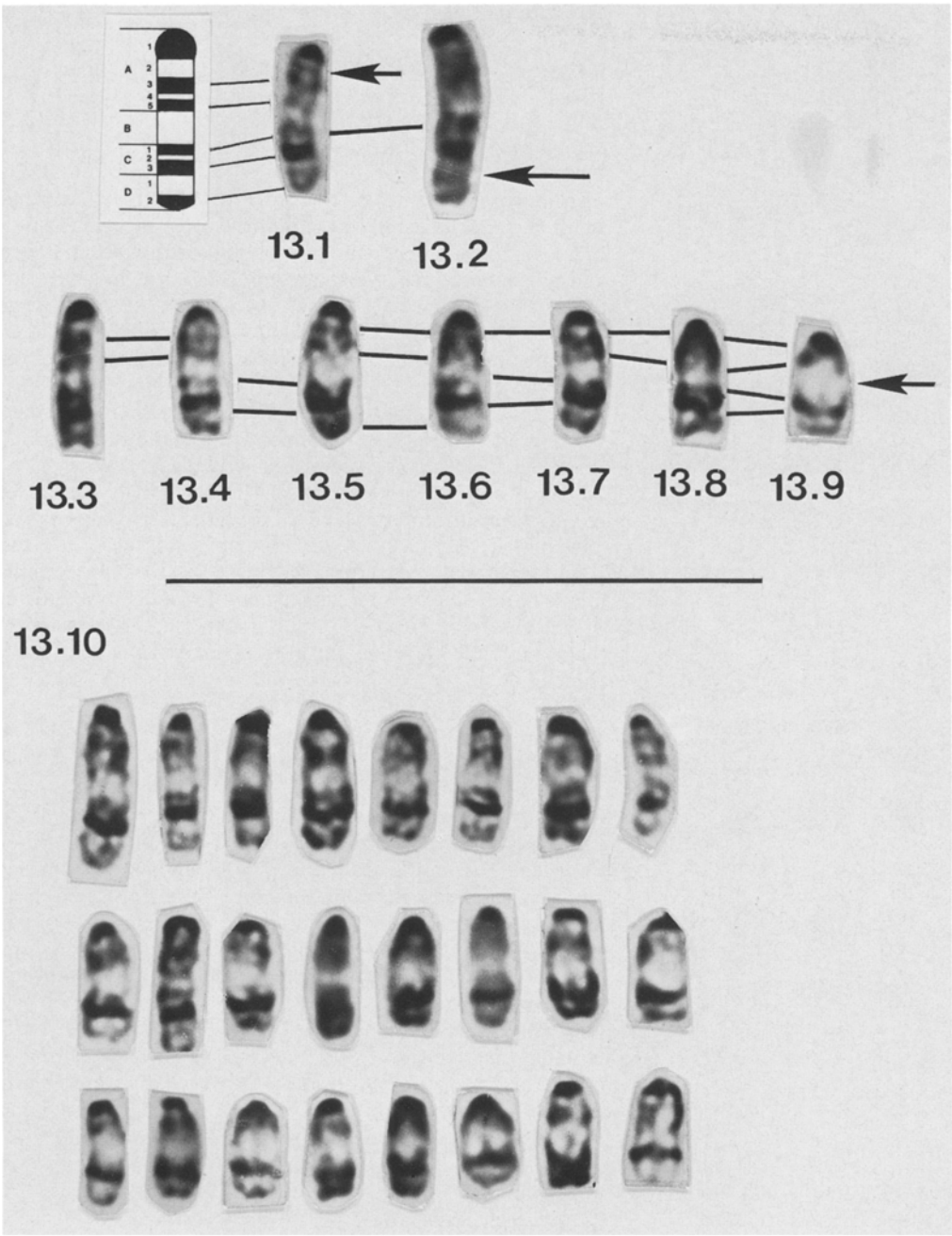


Fig. 13. Chromosome 13

Chromosome 15

The most important feature for the identification of chromosome 15 is the pale distal region occupying approximately one-third of the length of the chromosome. In contrast the proximal region of the chromosome stains darkly. None of the other small chromosomes (8–19) have this pale staining distal end. In my experience the distal 15F3 band is usually absent but it can be seen in some cells, usually in overstained preparations. The smaller bands, 15B1 and 15F1 are rarely seen and even when present are very faint. Thus the most common appearance of chromosome 15 is shown in Figures 15.3 and 15.4, with a dark band just distal to the centromere followed by the a heavy doublet of 15D1 and 15D3. The remainder of the chromosome is mostly unstained. Region 15F may be quite prominent (Fig. 15.8) but is more often very faint (Fig. 15.3, 15.6). Often the sometimes distinct 15D1/15D3 doublet merges to form a heavy central band twice the thickness of 15B3 (Fig. 15.5). In more contracted chromosomes (Fig. 15.5, 15.6) the middle doublet is smaller. In those chromosomes showing the least detail the entire proximal region of the chromosome is darkly stained and the distal region is pale (Fig. 15.8, 15.9).

Chromosome 16

This chromosome has virtually the reverse banding pattern of that of chromosome 15, with a pale proximal region and a very dark distal end. The main landmark is the distal

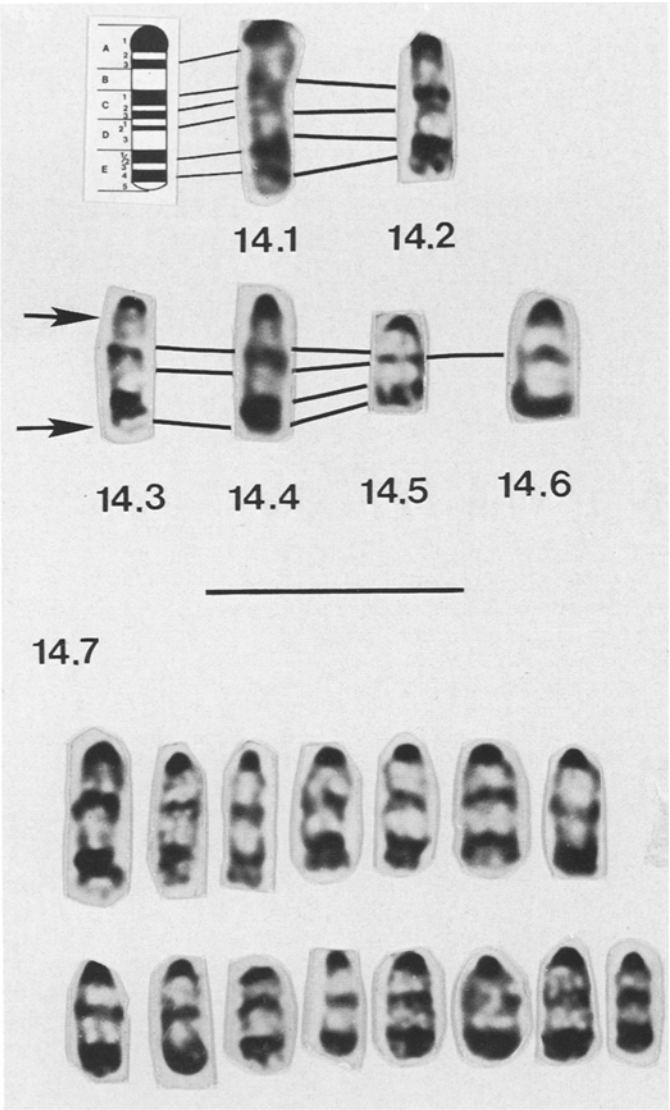


Fig. 14. Chromosome 14

dark region, which comprises one-third to one-half of chromosome 16. This is a unique feature because, none of the other smaller chromosomes share it although some other chromosomes have a distally located dark band. In extended chromosomes the distal region can be resolved into two bands, 16C1 and 16C3 (Nesbitt and Francke 1973). In one prometaphase chromosome (Fig. 16.1) it was possible to resolve band 16C1 into two bands (arrowed in Fig. 16.1). Often the entire 16C subdivision merges together to form a dark composite band (Fig. 16.2). The only other two bands on the chromosome are located in the proximal region (see arrows in Fig. 16.2) and are usually faint (Fig. 16.1). The weaker band 16B2, is often indistinct possibly merging with 16B4. This results in the typical appearance of chromosome 16, with a dark distal end and a single dark band, 16B2/4, slightly above the chromosomal midpoint (Fig. 16.4). Sometimes 16B4 merges with the 16C group (Fig. 16.5) resulting in a G-negative proximal region (Fig. 16.7, 16.8). On occasion the 16C group is smaller than usual (compare Fig. 16.5 and 16.6). In those preparations showing the least information chromosome 16 consists of a darkly stained centromere and distal region separated by a clear G-negative region (Fig. 16.9).

Chromosome 17

Chromosome 17 is not often confused with any of the other small chromosomes provided that the most proximal band, 17A3, is visible. This band can be regarded as a landmark and always occupies the space immediately below the centromere (see Fig. 17.1–17.5). On occasion 17A3 may merge with the centromere (Fig. 17.6). All of the other bands on chromosome 17 are at, or below the midpoint of the chromosome, the major ones being the two dark bands 17C and 17E1. Below these bands are 17E3 and 17E5. Band 17E5 is not usually visible and although often terminal (Fig. 17.2) may also be subterminal (Fig. 17.1). When band 17E5 cannot be seen and only 17E3 is visible, the lower half of the chromosome contains three regularly spaced dark bands (Fig. 17.3). More often, however, the 17E3 band is no longer distinctly visible leaving only two dark, subterminal bands (Fig. 17.4), which may be fused to a greater or lesser extent (Fig. 17.5–17.7). In the most extreme form the two bands fuse to form a single subterminal band (Fig. 17.8).

Chromosome 18

Chromosome 18 has two dark central bands (Fig. 18.1) located one-third (18B3) and two-thirds (18D) the chromosome length from the distal end. These bands can be considered as landmarks although they are also a feature of chromosome 19 (see below). In addition to the two central bands a smaller band can be seen above 18B3 and another, below 18D. These smaller bands are 18B1 and 18E2, respectively. In many preparations the 18B1 band merges with 18B3 to give a single band (Fig. 18.2). Generally however, 18E2 remains distinct from 18D (see Fig. 18.3, 18.4) although it may become faint and in more contracted chromosomes fuse with 18D (Fig. 18.6, 18.7). The terminal 18E4 band is almost always present (but see Fig. 18.8).

Chromosome 19

Chromosome 19 is the smallest chromosome and has only three bands (Fig. 19.1). A terminal band, 19D2, is sometimes evident (Fig. 19.2) but more often cannot be seen clearly (Fig. 19.3). The other two bands are located centrally and in contacted chromosomes may merge (Fig. 19.4) and be reduced in size to that of a single band (Fig. 19.5). Although chromosome 19 is fairly distinct within the mouse karyotype, in some cancer cells it can often be confused with small chromosome fragments, which have been generated as a result of chromosome deletions and rearrangements (see Cowell 1981).

The X chromosome

The most important landmarks on the X chromosome are the two dark bands located in the lower half of the chromo-

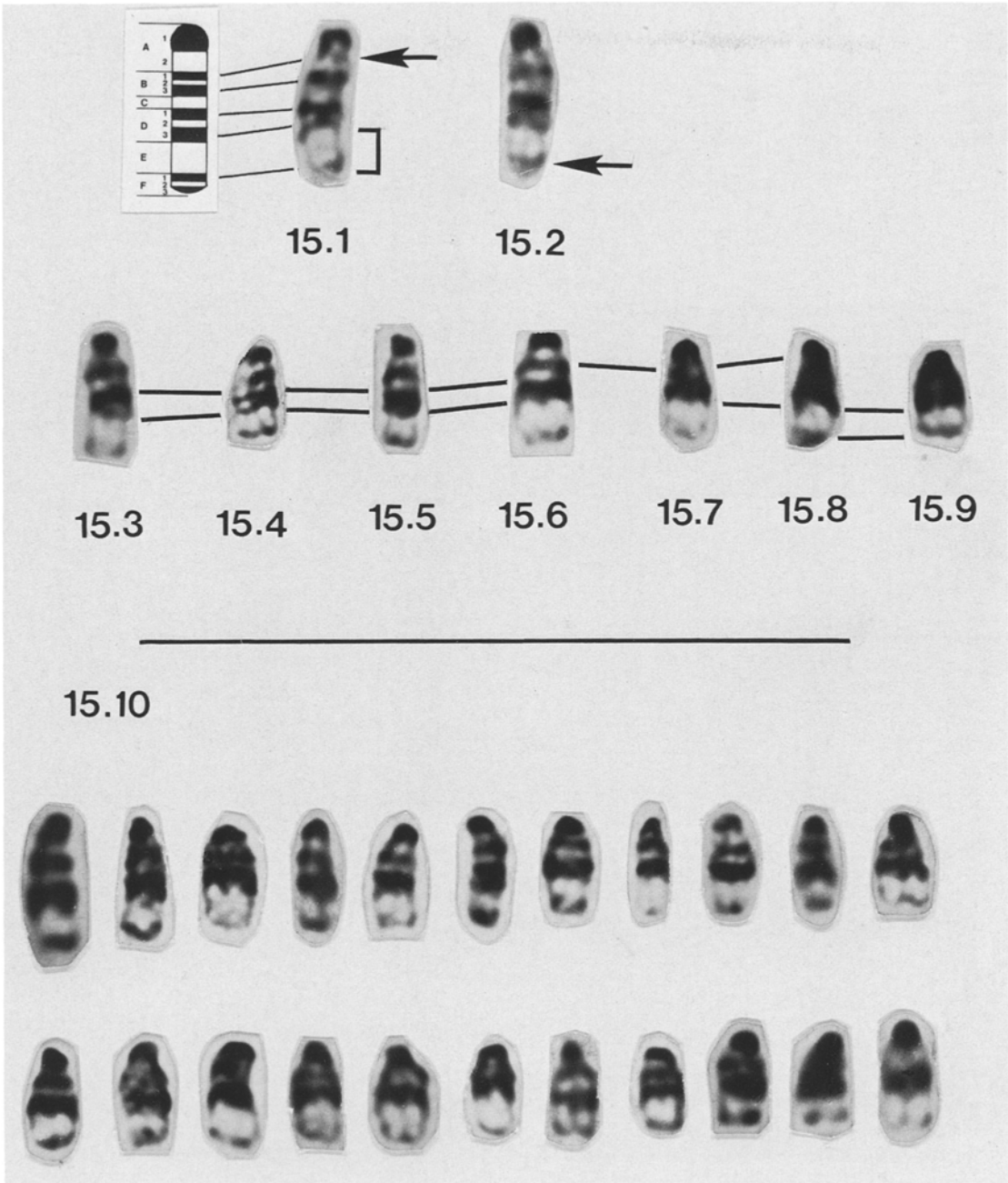


Fig. 15. Chromosome 15

some. These two bands, C and E, are almost always visible and are separated by the G-negative D region (see Fig. 20.3–20.7). Although in the original description of the X chromosome by Nesbitt and Francke (1973) the C region was considered to be a single band, in certain elongated chromosomes it was possible to detect smaller bands above and below C (indicated by the arrows in Fig. 20.2). The same was true for band E. The distal tip of the chromosome contains two bands, F2 and F4, which are only visible in good preparations (Fig. 20.1, 20.2). More usually the tip of the X chromosome is a pale or G-negative region (Fig. 20.3). The proximal half of the chromosome contains three dark bands A3, A5 and A7. Of these bands A3 is the weakest (Fig. 20.4) sometimes merging with A5 (compare Fig. 20.5 with Fig. 20.6) and sometimes absent (Fig. 20.7). In more contracted chromosomes the entire A region merges, giving a general grey appearance to the upper half of the chromosome. In still other cases the A and C regions merge into a grey mass of bands (Fig. 20.9) leaving only the E band prominent.

The Y chromosome

The main feature of the Y chromosome is its lack of a darkly staining centromere. In Fig. 21 this is easily seen if compared with the other chromosomes presented above. Several bands can be discerned on the Y chromosome, but they are usually indistinct giving it an overall grey appear-

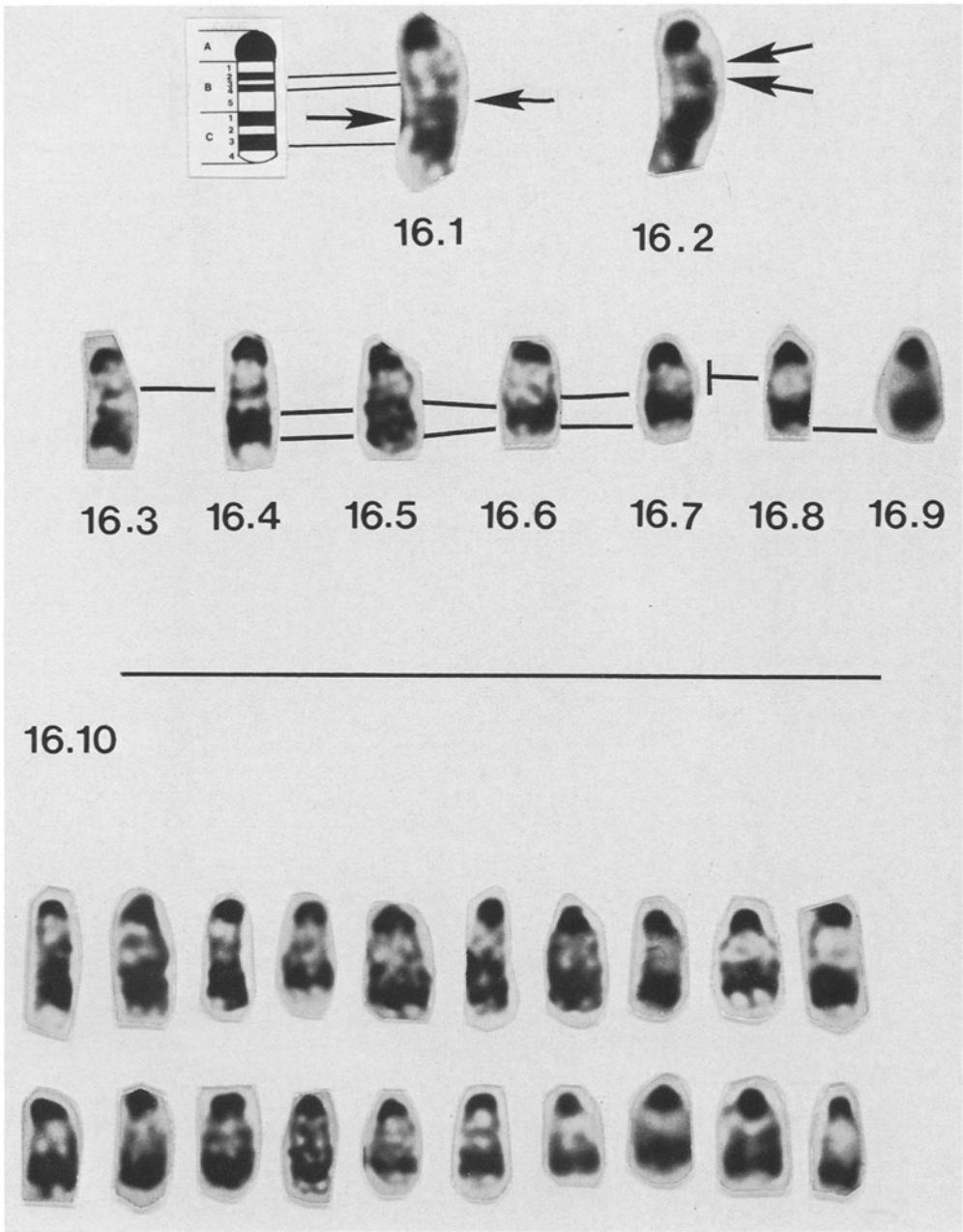


Fig. 16. Chromosome 16

ance (Fig. 21.1). Of the four most prominent bands two, C1 and C3, are located roughly centrally but may occupy a more proximal position (Fig. 21.4, 21.8). The most proximal band, A1, can appear terminally (Fig. 21.3). This is also true for the E band, which is the weakest and is sometimes lost (Fig. 21.5). In short chromosomes (Fig. 21.7) the entire band complement may merge or be indistinct (Fig. 21.9). In the smaller chromosomes (Fig. 21.8) the A region above the other three bands may be constricted.

Distinguishing between chromosomes with a similar banding pattern

The telomeric nature of all of the mouse chromosomes makes karyotypic analysis difficult enough, but the fact that certain chromosomes also have similar banding patterns and landmarks makes identification of individual chromosomes even more difficult. It is not uncommon therefore to find that a few of the mouse chromosomes are misidentified. Misidentification may lead to confusion concerning the specific relevance of particular chromosome abnormalities in certain cells. In some cases individual chromosomes may be confused with more than one other in the karyotype. In the discussion below I have compared and contrasted those chromosomes that in my experience are most frequently confused and have offered some hints on how they may be distinguished.

As in the previous section the usefulness of this guide will depend on whether the individual using it perceives the chromosomes and their landmarks in a manner similar to that outlined.

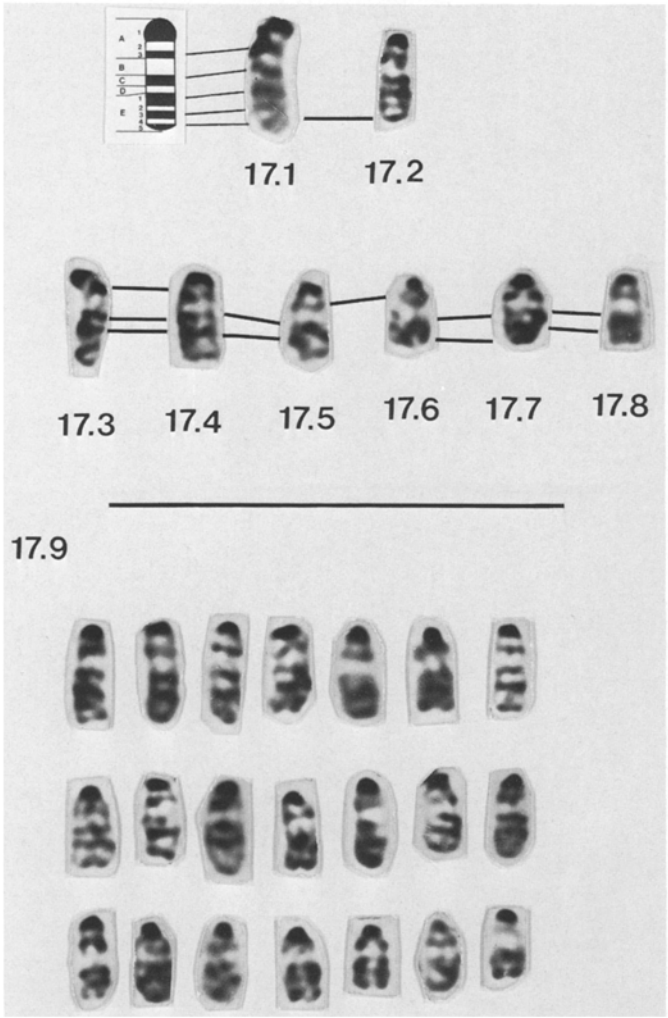


Fig. 17. Chromosome 17

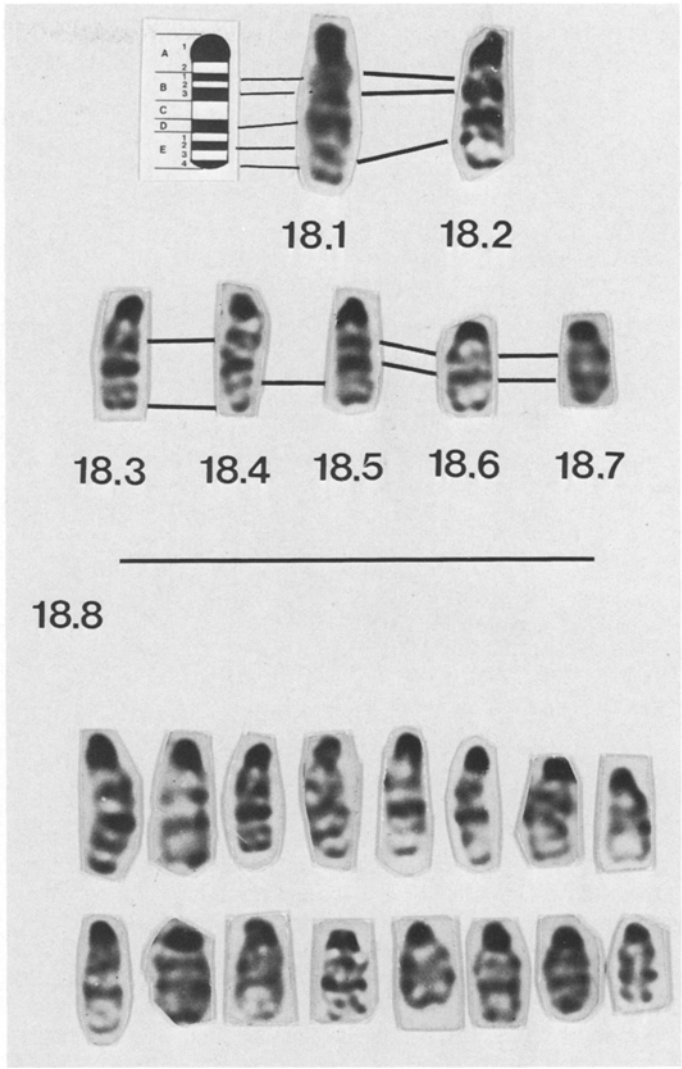


Fig. 18. Chromosome 18

Chromosome 1

Chromosome 1 bears some resemblance to two other chromosomes, the details of which are summarised in Figure 22. Always the first consideration in these cases should be the size of the chromosomes. Any presumed member of the chromosome 1 group that is smaller than the rest should be carefully scrutinised for potential misidentification.

Chromosome 1 vs X

In the upper half of Figure 22 (22.1, 22.2) the X chromosome is compared with chromosome 1. The main reason for the confusion between these two chromosomes is that they share similar landmarks, namely two dark bands in the distal half of the chromosome (indicated by the arrows in Fig. 22.1). However, considering these two bands alone, the top band on chromosome 1 is usually the heavier of the two, whereas on the X chromosome the bottom band is heavier. When the proximal half of both chromosomes is indistinct, it is quite easy to confuse them. The proximal half of the X chromosome contains three bands in the 20A group that are closely apposed; this is also a feature of the 1C group on chromosome 1. These groups of bands have been aligned in Figure 22.2 to emphasise this point. It can be seen that the bands of the 1C group are usually closer together than those of the 20A group. The presence of any band above this triplet of bands is definitive for chromosome 1. The critical band is the 1A3/5 doublet on chromosome 1, which lies immediately below the centromere (arrowed in Fig. 22.2, 22.3). In the X chromosome there are no bands above the triplet, leaving a G-negative space between the most proximal band and the centromere. This distinction is shown in Figure 22.3 where the clear 20A region on the X chromosome has been bracketed and on either side an example of chromosome 1 has been included for comparison. Note the dark 1A3/5 band (arrows) immediately below the centromere.

Chromosome 1 vs 6

Chromosome 6 is another chromosome that resembles chromosome 1. The similarities are illustrated in Figure

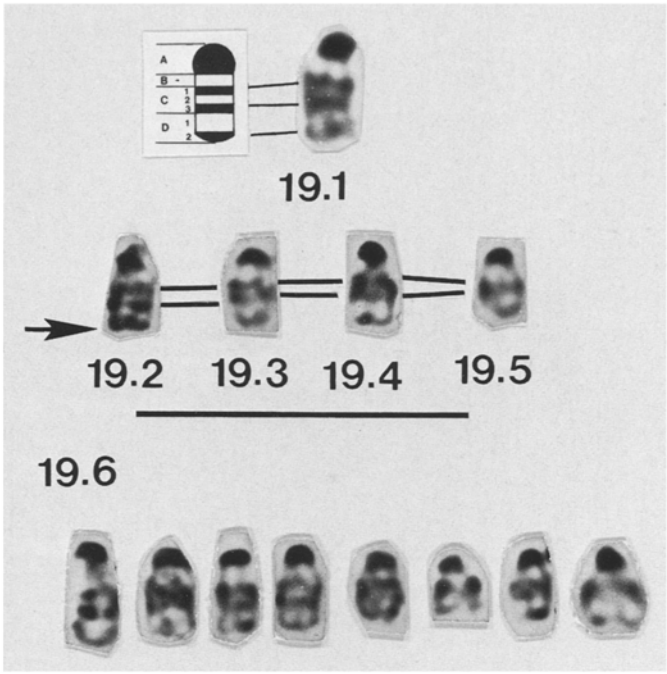
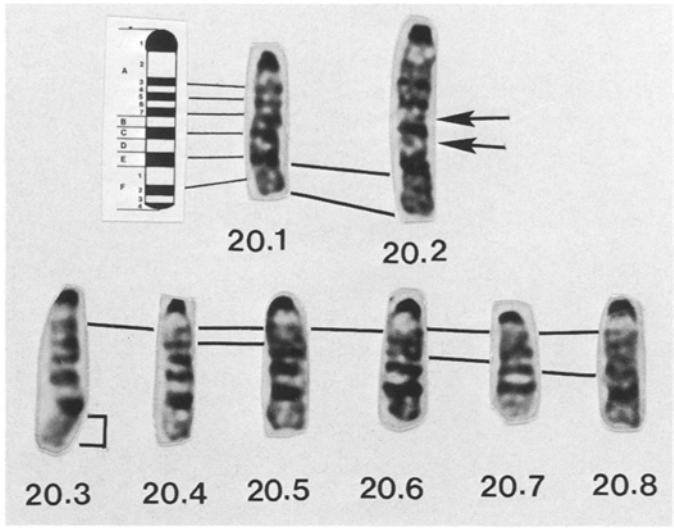


Fig. 19. Chromosome 19



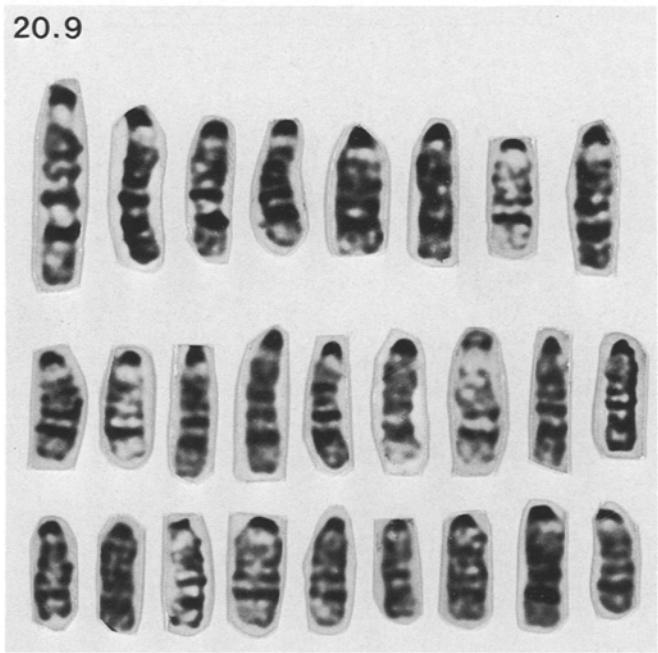


Fig. 20. X chromosome

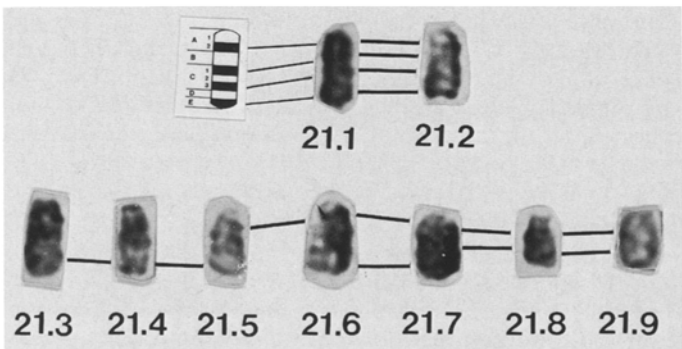


Fig. 21. Y chromosome

22.4–22.6. As with the X chromosome, both chromosomes 1 and 6 have two dark bands in the distal region. Unlike the X chromosome, chromosome 6 has a band immediately below the centromere so in this instance the 1A3 band cannot be used as a distinctive feature. The triplet of G-positive bands immediately below 1A3 on chromosome 1 is now the important feature. In chromosome 6 the second most proximal band, 6B2, is much smaller than the 1C triplet even when this region has fused into a single band as illustrated in Figure 22.5. Another distinguishing feature is the relative position of the band immediately below the most distal of the dark landmark bands (see arrows in Fig. 22.4). On chromosome 1 this band, 1H2, is close to the heavy 1G band whereas band 6G1 is relatively lower on chromosome 6. Finally the banding morphology above the landmark bands on both chromosomes 1 and 6 are often indistinct. It may then be useful to determine the relative position of the first heavy landmark band on each chromosome with respect to the centromere. In Figure 22.6 both chromosomes 1 and 6 have been aligned by the centromeres, and it can be seen that the heavy 1G band is situated below the midpoint of chromosome 1 whereas band 6C1 is above the midpoint on chromosome 6. Thus the position of these landmarks relative to chromosome length is also an important means of distinguishing between these two chromosomes.

Chromosome 3 vs 10

Chromosome 3 is most frequently confused with chromosome 10 (see Fig. 23.1–23.4). Both these chromosomes have two dark bands below the centromere (indicated by the arrows in Fig. 23.1) and a dark subterminal band. Chromosome 10 is smaller than chromosome 3. Whereas chromosome 3 usually has only two dark bands, 3C and 3E1/3, in the proximal half of the chromosome, chromosome 10 often shows three closely apposed bands (see Fig. 23.2). In shortened chromosomes, however, the most distal of these bands is often faint and resembles band 3F2 on chro-

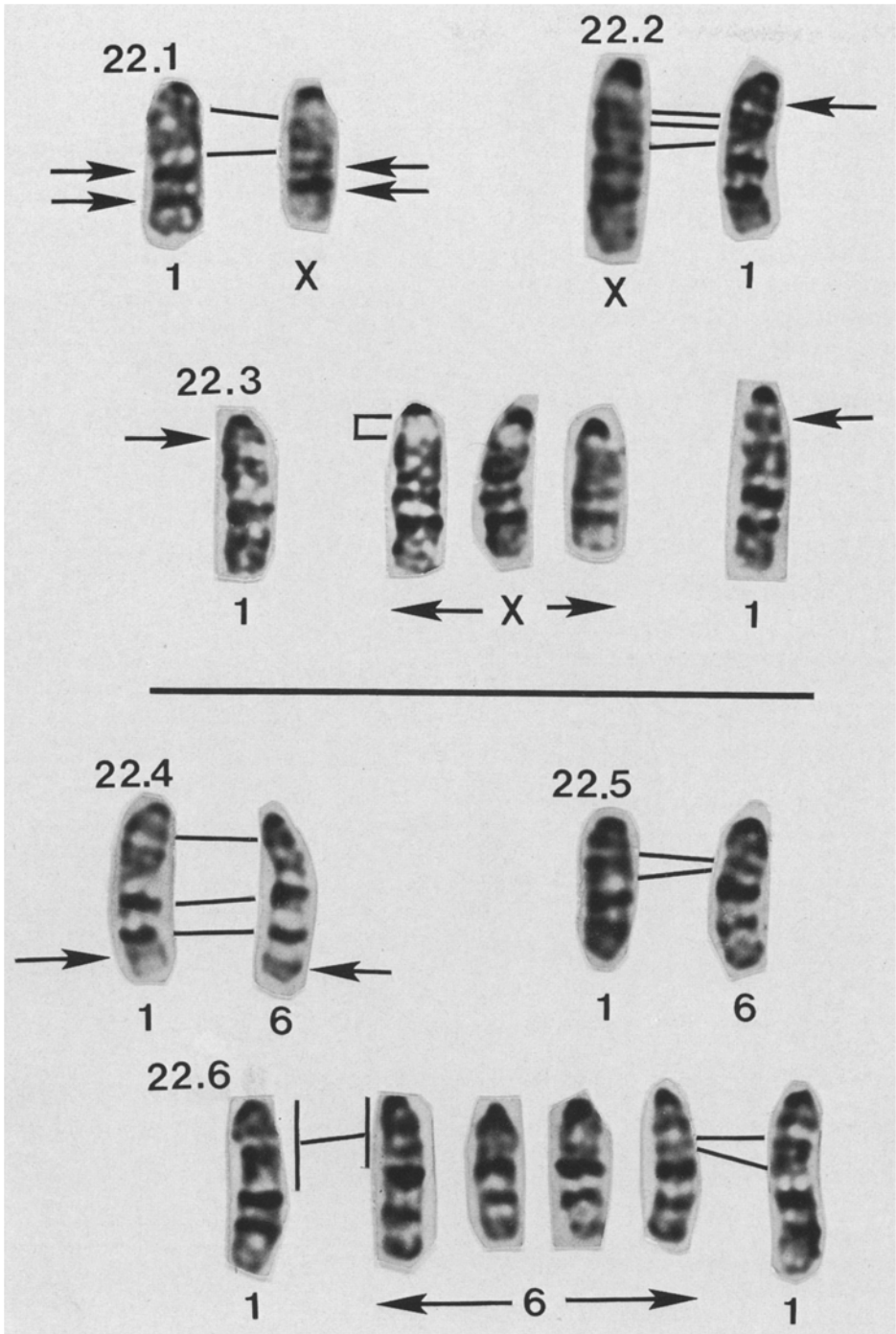


Fig. 22. Comparison of chromosome 1 with the X chromosome (*above*) and chromosome 6 (*below*)

mosome 3 (Fig. 23.1). In these cases it is easier to distinguish the two chromosomes by the position of the dark subterminal band relative to the distal end of the chromosome. As shown in Figure 23.1, band 3G is relatively further from the end of chromosome 3 than band 10D1 from the end of chromosome 10. Sometimes the distal end of both chromosomes 3 and 10 may stain darkly and the proximity of the subterminal band is difficult to assess (Fig. 23.2). In these cases it may be possible to distinguish the two chromosomes by the size of the weakly banded region between the centromere and the first dark band. This region is larger in chromosome 3 (see Fig. 23.2, 23.3). If both of the above criteria are insufficient, a distinction made be possible based on the relative proximity of the two dark proximal bands to each other. These bands usually remain discrete on chromosome 3, but on chromosome 10 they often merge into a single band (Fig. 23.4 and see also Fig. 3.8 and 10.10).

Chromosome 3 vs 6

The similarity between chromosomes 3 and 6 lies in the first three prominent bands. Thus, as indicated in Figure

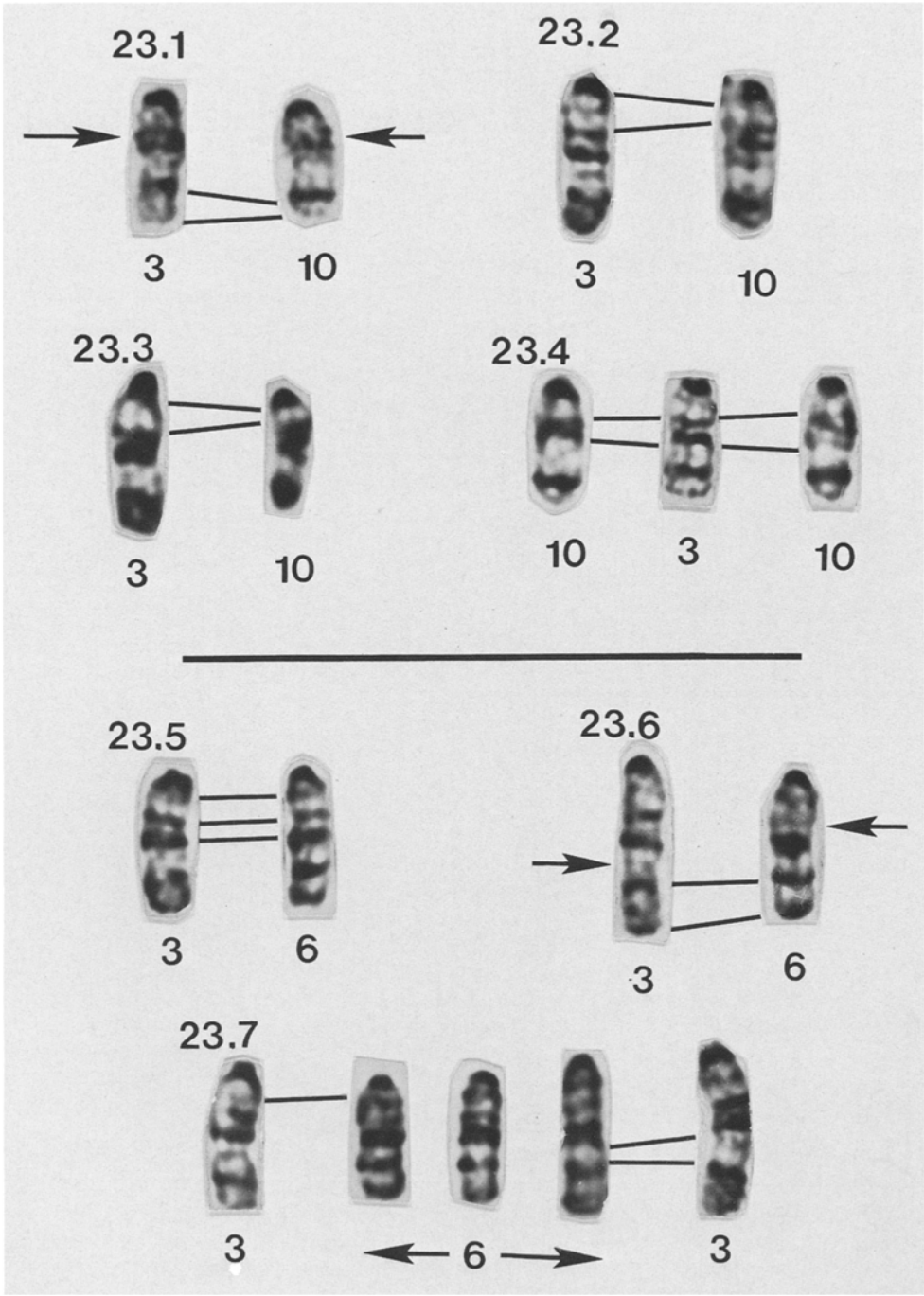


Fig. 23. Comparison of chromosome 3 with chromosome 10 (*above*) and chromosome 6 (*below*)

23.5, when band 3A3 is darkly stained, the upper halves of the two chromosomes are virtually identical. It is the lower half of the chromosomes that provides the means for distinguishing between these two chromosomes. Often band 3G is the only prominent band on the distal half of chromosome 3 and is situated further from the chromosomal midpoint than is band 6E, the most prominent band in the distal half of chromosome 6 (see Fig. 23.6, 23.7). Sometimes a faint band, 3F2, is seen above band 3G and below 3E1/3 (indicated by the arrow in Fig. 23.6). This is rarely the case in chromosome 6. The space between bands 6C1/3 and 6E is almost always G-negative. Sometimes the distal third of chromosome 3 contains three bands whereas chromosome 6 always shows only two bands (Fig. 23.6). Chromosomes 3 and 6 are further compared in Figure 23.7, which demonstrates that the most proximal band on chromosome 3, 3A3, is frequently faint (shown on the left). In chromosome 6 band 6A3 usually stains darkly (see also Fig. 6.9).

Chromosome 4 vs 5

Chromosomes 4 and 5 resemble each other by virtue of their dark centrally located group of bands (see Fig. 24.1). The main distinction between these two chromosomes de-

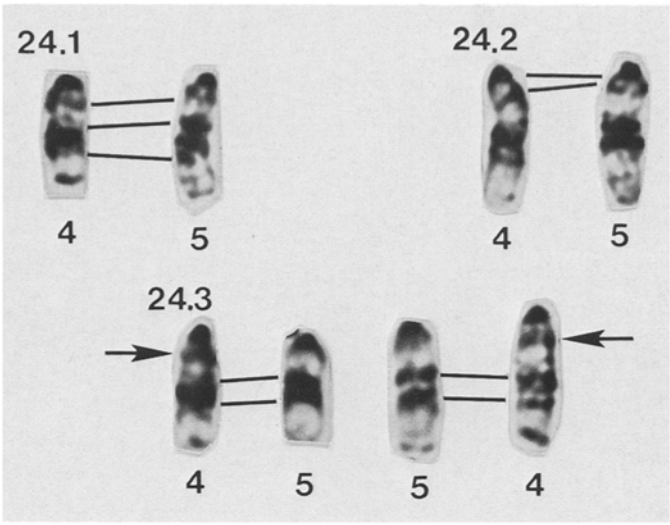


Fig. 24. Comparison of chromosome 4 with chromosome 5

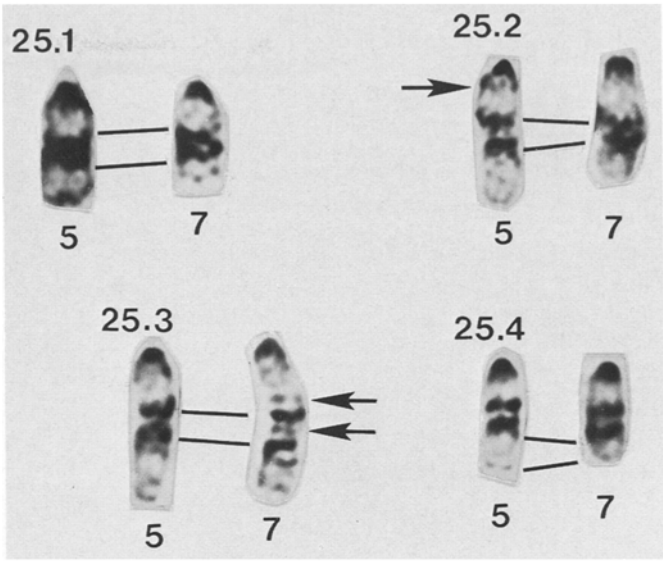


Fig. 25. Comparison of chromosome 5 with chromosome 7

pends on the position of a band located immediately below the centromere. In chromosome 5 this band, 5A3, is closer to the centromere (Fig. 24.2) than is its counterpart 4A3/5 on chromosome 4. In the most extreme cases the 5A3 band is no longer distinctly visible (Fig. 24.3), but band 4A3/5 on chromosome 4 is always present (see arrows on Fig. 24.3). The terminal region of chromosomes 5 is often G-negative (see Fig. 5.10), whereas in many cases the subterminally located 4E1 band can be seen at the distal end of chromosome 4 (Fig. 24.3). In Figure 24.3 the two chromosomes are compared and it can be seen that the two central bands may either remain distinct (right) or fuse (left), in which case chromosome 4 shows faint bands above and below the fused doublet. When the major proximal band in both chromosomes merges with the centromere, the relative position of the central band mass along the chromosome is an important feature for identification. In chromosome 5 the two bands straddle the midpoint of the chromosome but in chromosome 4 they are located below the central point.

Chromosome 5 vs 7

Chromosomes 5 and 7 are the most difficult to distinguish when they show minimal information. In these cases the only detail on both chromosomes is a pair of dark, roughly centrally located bands, which may fuse (Fig. 25.1) or remain discrete (Fig. 25.4). The relative position of the dark bands then affords the best way to distinguish between the two chromosomes. In chromosome 5 they are exactly around the midpoint of the chromosome, i.e., the distance between the centromere and the first band equals the distance from the second band to the distal end of the chromosome. In chromosome 7 the former distance is roughly twice that of the latter (see Fig. 25.4). In some cases, the first dark band on chromosome 7 is flanked by smaller, fainter bands (arrows in Fig. 25.3) as opposed to the single thick band characteristic of chromosome 5, and it is easy to distinguish between the two chromosomes.

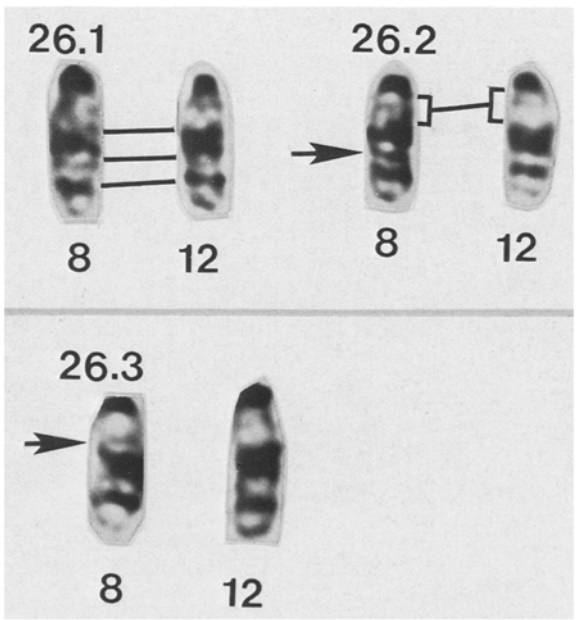


Fig. 26. Comparison of chromosome 8 with chromosome 12

Chromosome 8 vs 12

These two chromosomes are often hard to distinguish since both contain dark central bands and a single dark subterminal band (Fig. 26.1). The most typical appearance of chromosome 12, however, retains only these bands (see Fig. 26.2), whereas in chromosome 8 there is often evidence of bands above and below the dark central ones (indicated by the arrows in Fig. 26.2 and 26.3). Even when these bands are not specifically visible there is always a general greyness around the central dark band of chromosome 8 (see Fig. 8.9), whereas in chromosome 12 these areas are clear (Fig. 26.2). The distal ends of chromosomes 8 and 12 are virtually identical, with a single subterminal band and a small G-positive terminal end (Fig. 26.1–26.3). The telo-

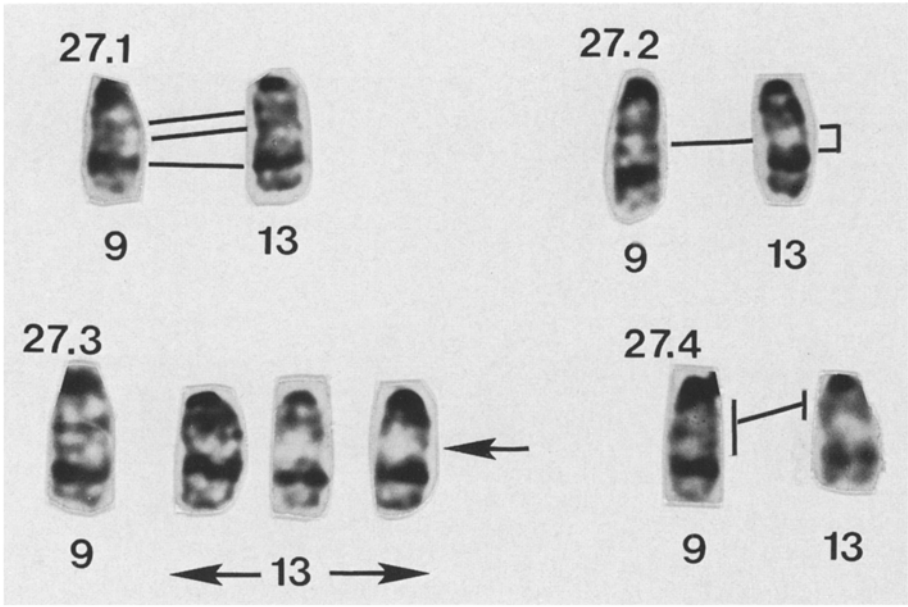


Fig. 27. Comparison of chromosome 9 with chromosome 13

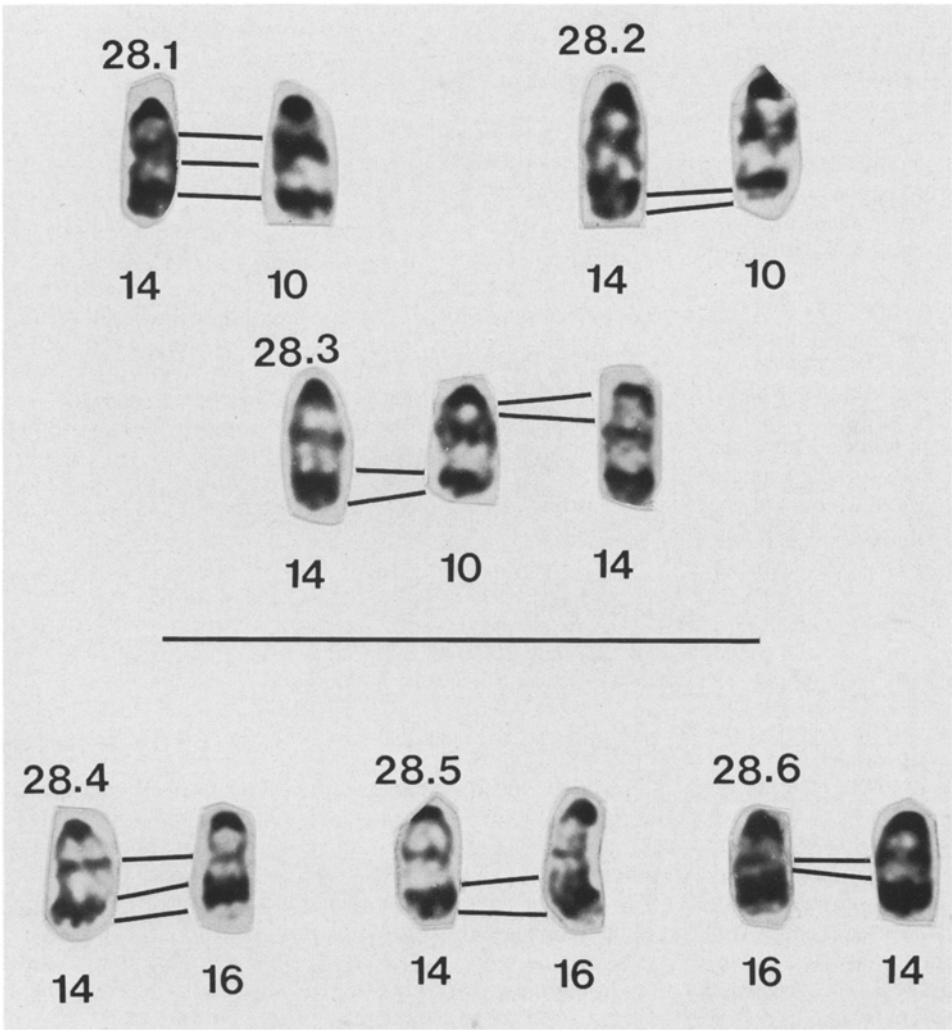


Fig. 28. Comparison of chromosome 14 with chromosome 10 (*above*) and chromosome 16 (*below*)

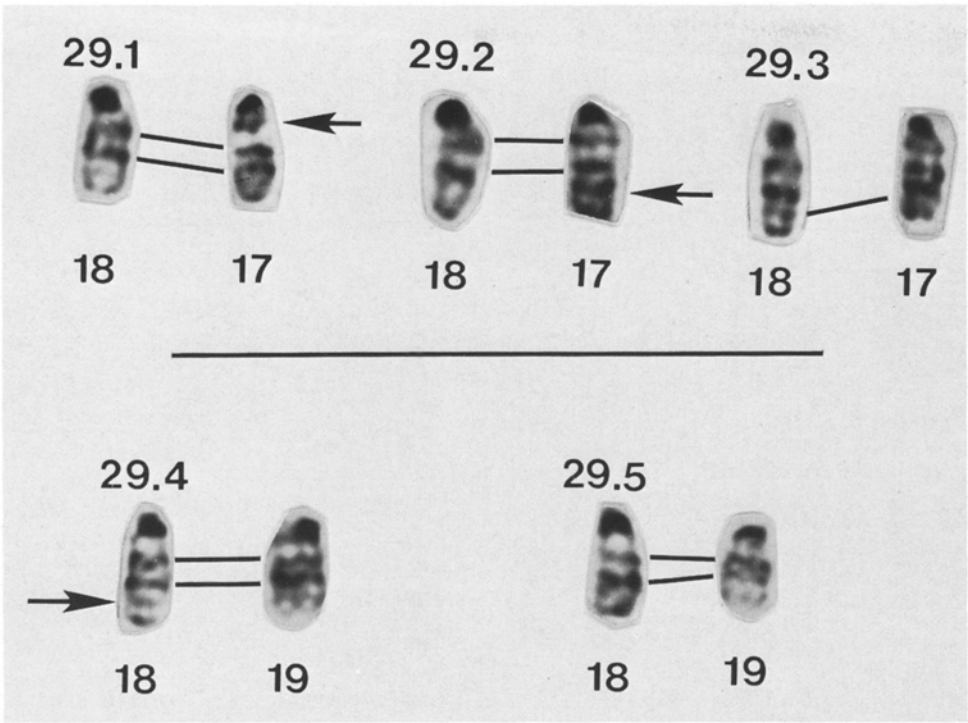


Fig. 29. Comparison of chromosome 18 with chromosome 17 (*above*) and chromosome 19 (*below*)

meric band is more often clearly visible in chromosome 12 (compare Figs. 8.8 and 12.7).

Chromosome 9 vs 13

Chromosomes 9 and 13 are the most frequently confused chromosomes in the mouse karyotype and share a very similar banding pattern. In particular both have a dark subterminal landmark band (Fig. 27.1) and two other less prominent bands above the subterminal landmark (Fig. 27.1). A subtle distinction between these two fainter bands lies in their position relative to the centromere. The two central bands on chromosome 9 are equidistant along the chromosome whereas in chromosome 13 they tend to be closer to the centromere. The result of this bias is to create a G-negative region just below the midpoint of chromosome 13 (indicated by the brackets in Fig. 27.2). This clear area is the decisive feature for distinguishing between these two chromosomes, in addition to being an important landmark in identifying chromosome 13. In Figure 27.3 several examples of variations in the appearance of chromosome 13 have been lined up with a single copy of chromosome 9. The light 13B band is indicated by an arrow and looking across the chromosomes the consistency of this feature, which is not present on chromosome 9, can be seen. Even when the banding is indistinct on both chromosomes (Fig. 27.4), the 13B region can be seen below a grey area that is smaller than the completely grey proximal two-thirds of chromosome 9.

Chromosome 14 vs 10

Chromosomes 14 and 10 are only misidentified in preparations showing relatively poor banding. The two chromosomes are similar when the 10B triplet of bands on chromosome 10 is reduced to a single band, which then resembles the two centrally located bands on chromosome 14 (Fig. 28.1). Close analysis reveals that the subterminal band on chromosome 10 is in fact nearer the distal end of the chromosome than is its counterpart on chromosome 14 (Fig. 28.2). When the entire subterminal regions of both these chromosomes are stained darkly, the terminal band is much larger on chromosome 14 than on chromosome 10 (Fig. 28.3). The other way of distinguishing between these two chromosomes depends on the position of the darkly stained central bands relative to the centromere. In chromosome 14 these bands are closer to the midpoint of the chromosome whereas in chromosome 10 they are closer to the centromere (Fig. 28.3).

Chromosome 14 vs 16

Sometimes chromosome 14 can also be mistaken for chromosome 16 (Fig. 28.4) although chromosome 16 is generally smaller than chromosome 14 in any given metaphase. Examples from different spreads have been matched up in Figure 28.4 to demonstrate the similarity between them. Both contain darkly staining distal ends and a weak central band. The distance from the centromere to this central band is roughly equal in both chromosomes (Fig. 28.4). The main distinction between them depends on the size of the dark terminal group of bands, which is larger in chromosome 16 and can occupy roughly one-third of the chromosome length (Fig. 28.5). Also the relative proximity of the central band to the dark terminal region is important. In chromosome 14 the centromeres, central band and terminal group are spaced equidistantly. In contrast, the central band on

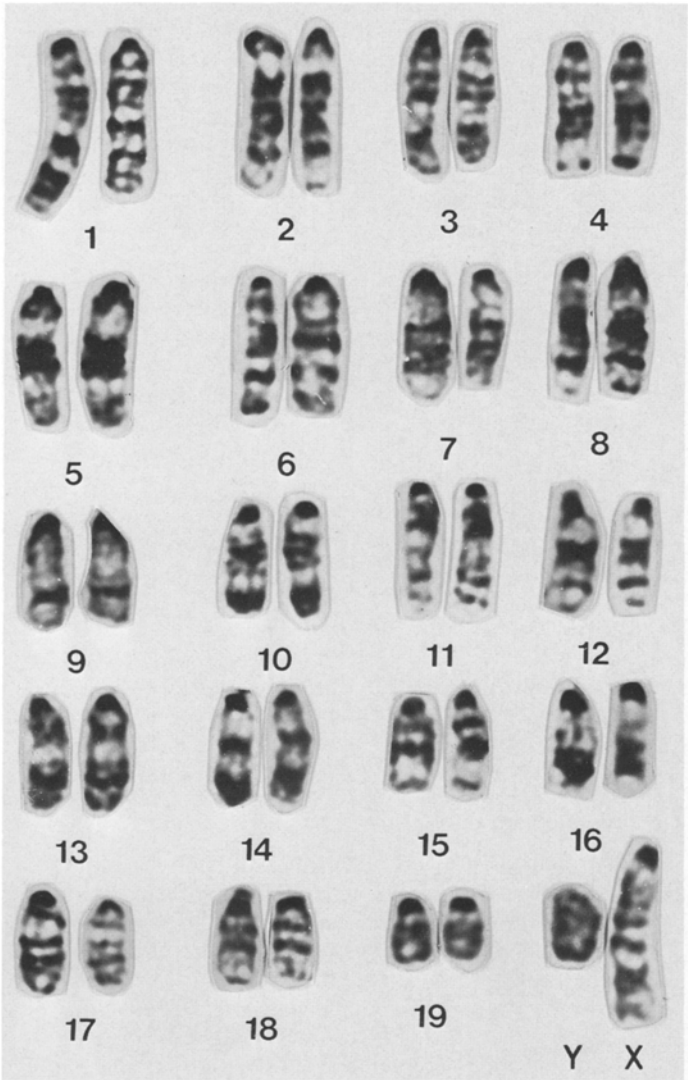


Fig. 30. Complete mouse karyotype showing normal banding detail

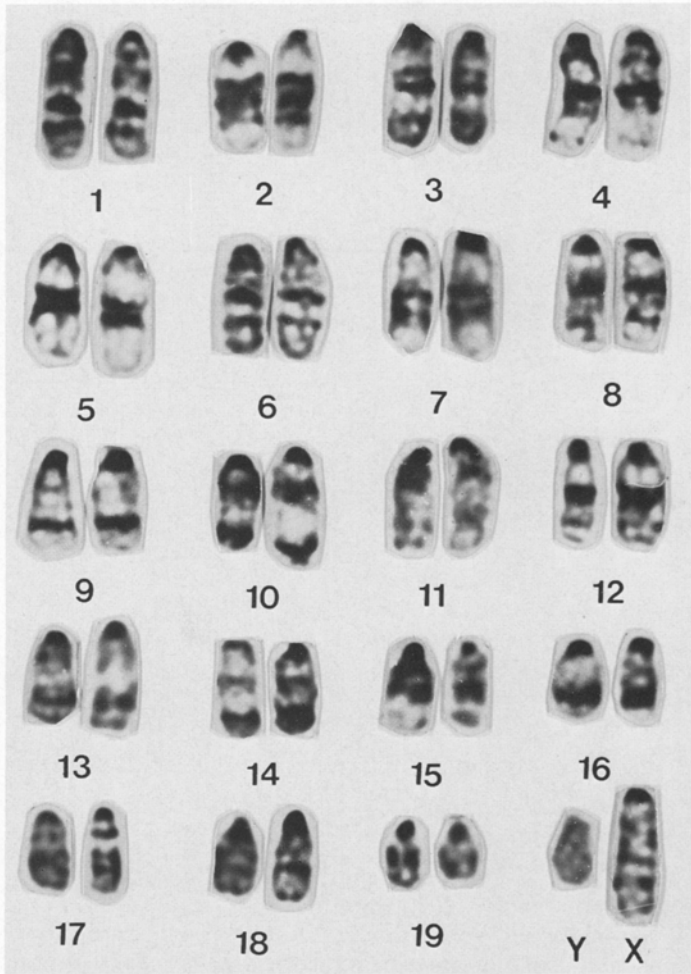


Fig. 31. Complete mouse karyotype showing normal banding detail

chromosome 16 is much closer to the terminal group than to the centromere (Fig. 28.6).

Chromosome 18 vs 17

Chromosome 18 can occasionally be confused with chromosome 17 but only when the banding on chromosome 17 is poor. As shown in Figure 29.1, when the proximal 17A3 band (arrow) merges with the centromere, this may leave only two other dark G-positive bands on chromosome 17. However, these are usually situated below the midpoint of the chromosome, whereas on chromosome 18 they are more central. When band 17A3 is very dark (Fig. 29.2), this can sometimes be confused with the proximal 18B3 band on chromosome 18. In this case the presence of a third heavy band, 17D1/2 (indicated by the arrow in Fig. 29.2), is definitive for chromosome 17. Chromosome 18 may show three heavy bands when the 18E3 band is particularly obvious (Fig. 29.3). This band however is usually much smaller than 17D1/2 and is situated relatively lower down the chromosome. Finally the distal end of chromosome 18 is usually clearly banded (Fig. 29.3) or G-negative (Fig. 29.2), whereas the distal end of chromosome 17 is usually grey (Fig. 29.3 and see also Fig. 17.9).

Chromosome 18 vs 19

These two chromosomes are confused by virtue of the two dark centrally located G-positive bands that are often the only features of both chromosomes. Chromosome 18 is usually longer than chromosome 19 although this cannot always be used as a means of identification. In longer chromosomes a faint band, 18E3, below the two dark central bands on chromosome 18 is a feature not present on chromosome 19 (Fig. 29.4). When both chromosomes show only two dark G-positive bands, their relative proximity to each other is the best way to distinguish between them (see Fig. 29.5). Thus the two central bands are always much closer together on chromosome 19 than on chromosome 18. As a result, there is often an obvious G-negative region (18C) between the two central bands on chromosome 18, whereas on chromosome 19 the 19C2 region is less obvious (see also Fig. 19.6).

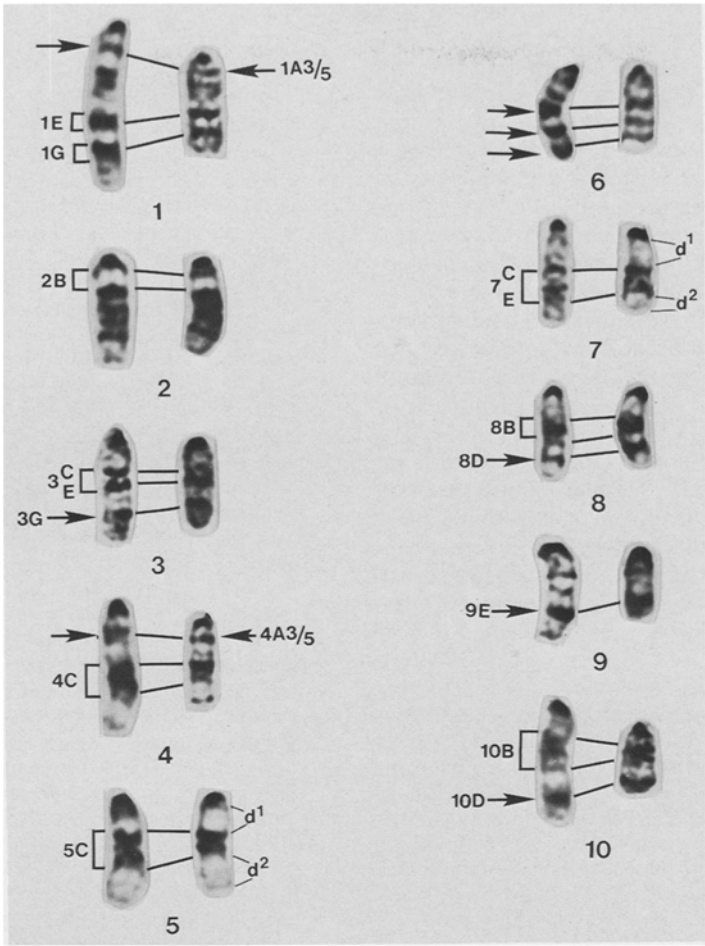
Chromosome 1
Primary: Two heavy G+ bands (1E, 1G) in lower half of chromosome
Secondary: Single thin band (1A3/5) immediately below centromere
Similar to: X, 6

Chromosome 2
Primary: G− region (2B) below centromere
Secondary: High density of G+ bands below the G− region
Similar to: None

Chromosome 3
Primary: Two heavy G+ bands (3C, 3E) closely apposed in upper half of chromosome
Secondary: Distal heavy G+ band
Similar to: 6, 10

Chromosome 4
Primary: Subcentral mass of G+ bands (4C)
Secondary: Single dark band 4A3/5 immediately below centromere
Similar to: 5, 7

Chromosome 5
Primary: Dark central mass of G− bands (5C)
Secondary: d1 = d2
Similar to: 4, 7



Chromosome 6
Primary: Three G+ bands, equidistantly spaced in lower half of chromosome
Secondary: None
Similar to: 1, 3

Chromosome 7
Primary: Dark group of G+ bands (7C–7E) in lower half of chromosome
Secondary: d1 > d2
Similar to: 4, 5

Chromosome 8
Primary: Dark central G+ group of bands (8B)
Secondary: Subterminal G+ band (8D)
Similar to: 12

Chromosome 9
Primary: Subterminal heavy G+ band (9E)
Secondary: None
Similar to: 13

Chromosome 10
Primary: Subterminal heavy G+ band (10D)
Secondary: Triplet of closely apposed G+ bands immediately below centromere
Similar to: 3, 14

Chromosome 11
Primary: Dark group of G+ bands (11A3/5) immediately below centromere
Secondary: Generally pale or grey (not G−) distal two-thirds of chromosome
Similar to: None

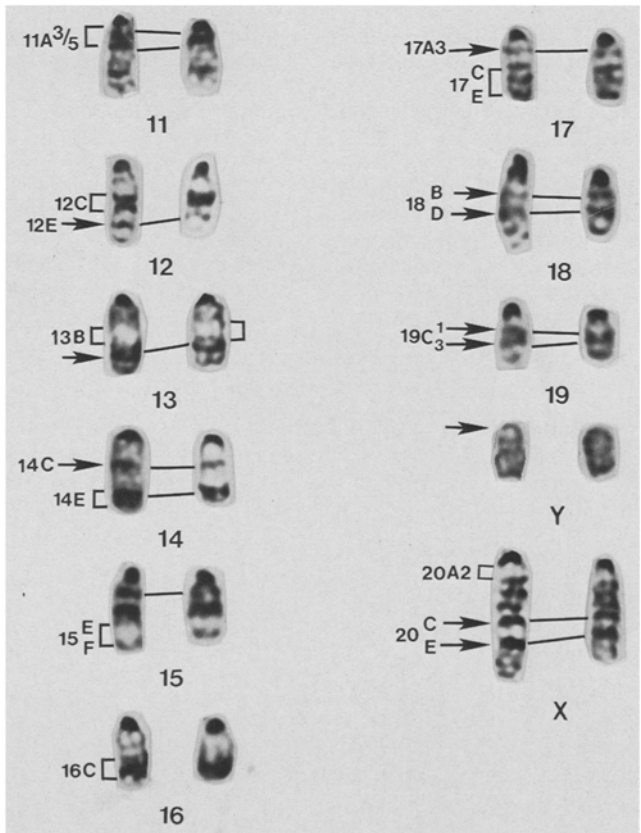
Chromosome 12
Primary: Dark central group of G+ bands (12C)
Secondary: Thin subterminal G+ band (12E)
Similar to: 8

Chromosome 13
Primary: Central G− region (13B)
Secondary: Thin subterminal G+ band (13C3)
Similar to: 9

Chromosome 14
Primary: Central G+ band (14C)
Secondary: Terminal, heavy G+ region (14E)
Similar to: 10, 16

Chromosome 15
Primary: G− distal one-third of chromosome (15E)
Secondary: None
Similar to: None

Chromosome 16
Primary: Dark terminal group of G+ bands (16C)
Secondary: None
Similar to: 14



Chromosome 17
Primary: Closely apposed triplet of G+ bands (17C–E) in lower half of chromosome
Secondary: Single G+ band (17A3) immediately below centromere
Similar to: None

Chromosome 18
Primary: Two central G+ bands (18B, 18D)
Secondary: None
Similar to: 19

Chromosome 19
Primary: Two central G+ bands (19C1, 19C3)
Secondary: None
Similar to: 18

Y Chromosome
Primary: Absence of a G+ centromere
Secondary: None
Similar to: None

X Chromosome
Primary: Two dark G+ bands (20C, 20E) in lower half of chromosome
Secondary: G− region (20A2) immediately below centromere
Similar to: 1

Fig. 32. Major landmarks of the chromosomes in the mouse karyotype. Abbreviations used are *G−* Giemsa-negative, *G+* Giemsa-positive, *d* distance between marked points

Landmarks at a glance

For general karyotyping and initial screening of cells whose karyotype is unknown it is usually sufficient in the first instance to order the chromosomes on the basis of location or presence of particular landmark bands. Some of the chromosomes can be identified on the basis of these "primary" landmarks alone. However, as discussed in the section on chromosome identification, some of the chromosomes have similar primary landmarks. In these cases it is usually sufficient to refer to "secondary" landmark regions. Using these major bands the chromosomes can be ordered rapidly in the karyotype and then special attention given to those chromosomes that are either of interest or that appear abnormal.

Figure 32 illustrates those primary and secondary landmarks that I have found useful for the identification of each chromosome and lists the chromosomes that have a similar set of landmarks and that may be consequently confused. It is hoped that this section will provide a quick reference source for identification of the individual chromosomes. The complete mouse karyotype is presented in Figures 30, 31.

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