OPHTHALMOSCOPIC STUDIES ON THE EYES OF MAMMALS

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INTRODUCTORY NOTE

In 1901, in volume 194 of these *Philosophical Transactions*, there was published a paper by Dr George Lindsay Johnson under the title 'Contribution to the Comparative Anatomy of the Mammalian Eye, chiefly based on Ophthalmoscopic Examination'. It attracted considerable attention mainly on account of the fifty coloured fundus pictures which accompanied it, representing nearly all the orders and many families.

After the publication of his paper Johnson continued his researches, first in England and later in South Africa, where he lived after 1911. Most of the animals were examined in zoological gardens, but to complete his material, he undertook several journeys to Europe and Australia, and participated in two arctic expeditions.

He published an account of the fundus in Amphibia and reptiles (Johnson 1927) and made a few observations on birds, whose fundi have been fully described by Casey Wood (1917). The definitive work on the fundi of mammals which he had planned, however, was never published, and it is doubtful if it was ever written; in the later part of his life he became preoccupied with other problems. In any case, among the papers he left behind after his death in 1943, no manuscript of this kind was found. But the plates, 160 in number, were there, together with the explanatory text, and were acquired by Dr A. Jokl of

Johannesburg. Through his efforts, and those of Professor Raymond Dart and Professor P. V. Tobias of Johannesburg, 50 selected plates can now be presented.

All eyes were examined by direct ophthalmoscopy with an ordinary (reflecting) ophthalmoscope and a uniform source of light. For very small animals, a smaller mirror was used with a working distance of 1 in. or less. With patience and kindness, most animals could be induced to tolerate examination without resistance. Smaller animals were placed on the lap of the keeper during the examination. Other animals were examined while restrained with a net, but larger animals, including bears and wolves which could not be quietened down, were placed in a sack and gagged. Some animals were hypnotized by the ophthalmoscope light and remained motionless. A large African lion immediately fell asleep when the light fell on its eye, so that it was difficult to keep the eye open. A general anaesthetic was used only rarely, on one occasion with a fatal result.

Although several of the pictures of the fundus were executed by Lindsay Johnson himself, he was greatly helped by Mr A. W. Head, an excellent draughtsman and well known artist. Lindsay Johnson taught Head to use the ophthalmoscope and most of the pictures were painted by him, under the constant supervision of Lindsay Johnson.

The magnification of all the drawings, with one exception (that of the common mole, *Talpa europaea*, which is magnified 120 diameters) lies between 16 and 18 diameters. For the mole, Lindsay Johnson devised an illuminated micro-ophthalmoscope, using a mirror and low-power microscope.

The publication of a selection of 50 of Lindsay Johnson's drawings has necessitated some revision of his text; in addition his nomenclature has been amended to bring it into line with common modern practice.

D. WHITTERIDGE

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DESCRIPTION OF THE PLATES

Order PRIMATES

Sub-order ANTHROPOIDEA

Figure 1. *Homo sapiens.* European albino. The fundus shows an almost entire absence of pigment. Both the choroidal and retinal vessels show up prominently, and the white sclerotic can be seen shining through, especially over the inner and lower parts of the field. There is always a considerable amount of red colouring matter over the greater part of the temporal side of the fundus.

Figure 2. *Pongo pygmaeus.* Orang-utan. This fundus is very similar to those of the chimpanzee (Johnson 1901, plate 2) and the gorilla, but there is less pigmentation, the background being of a somewhat lighter brown.

Figure 3. *Macaca mulatta.* Rhesus macaque. The type is rapidly becoming divergent and differs from all the true apes in many of its details. This monkey has a violet-pink fundus,

with a few choroidal vessels scattered over it, especially on the nasal side. The disk is long, oval, and uniformly pinkish-scarlet. The macula is circular, well defined, and pinkish-brown. It is surrounded by a whitish reflex.

Figure 4. *Mandrillus sphinx*. Mandrill. This has a characteristic fundus, covered all over with a dense fine network of anastomosing choroidal vessels which give the otherwise greyish background a pinkish colour. The arteries and veins are almost indistinguishable from each other. The disk is a uniform vermilion.

Figure 5. *Cercopithecus albigularis*. Sykes's monkey. It has no characteristic features.

Figure 6. *Cercopithecus aethiops*. Green monkey. A striking fundus. The dichotomously dividing choroidal vessels are very conspicuous, and the translucent nerve fibres spread far and wide. The most striking object is the huge circular macula, which is quite twice as large as the disk; it forms a uniform light brown patch perfectly circular and having a much darker central disk (the fovea) which has a brilliant central reflex. It forms a very beautiful object when examined by the direct view with the ophthalmoscope. The macula is entirely uniform in colour and is devoid of vessels.

Figure 7. *Cercocebus torquatus*. Sooty mangabey. The macula is surrounded by a narrow bright ring, which makes it a very conspicuous object when seen with the ophthalmoscope. The choroidal vessels are very conspicuous and closely resemble those of the gibbon (Johnson 1901, plate 2).

Figure 8. *Saimiri sciureus*. Common squirrel monkey. Although all the Cebidae are New World or American monkeys, their fundi closely resemble those of the Cercopithecidae. Thus the fundus of Ateles ater and that of the mangabey are almost identical with those of the Cercopithecidae, the main difference being found in the macula. In the squirrel monkey the macula is a deep slate-grey colour like the rest of the fundus, but the peculiarity lies in the border of the macula which consists of a ring made up of a great number of fine striae, green on the inside, yellow in the middle, and red at the margin of the ring. They are prismatic colours and resemble those in the marmoset ring, which is made up of yellow and green colours.

Figure 9. *Ateles paniscus*. Black spider monkey. This fundus closely resembles those of most of the Cercopithecidae. It has no features that are peculiar or worth mentioning.

Figure 10. *Alouatta seniculus*. Red howler. This fundus is a dark slate colour covered with fine choroidal mottling. The disk is uniformly pink over which the retinal vessels spread. These arteries are indistinguishable from the veins. They are bright vermilion over the disk, and chocolate coloured over the fundus which is almost universally the case among the Simiae. The macula is very small, only about a third of the diameter of the disk, and is surrounded by a large ill defined whitish halo.

Sub-order Prosimii

Figure 11. *Nycticebus coucang*. Slow loris. This drawing shows a precisely similar fundus to that of the Galagos (Johnson 1901, plate 5), except for a large number of green spots scattered all over the background and covering the golden tapetum wherever they are present. Moreover, the tapetum nigrum does not form a dense brownish-black layer as in the other cases, but I think the reason is that the tapetum nigrum does not extend so far inwards

towards the centre of the field; moreover, the pigment is by no means so dense. When these Galagos and Loris are continually exposed to full daylight, they go blind, as I have demonstrated by direct experiments. All the Galagos as well as the Loris and Tarsius are night animals.

Order INSECTIVORA

Figure 12. *Talpa europaea.* Common Eurasian mole (× 120 diameters). This fundus bears a striking resemblance to that of the hedgehog (Johnson 1901, plate 6), the only difference being that instead of a light grey, it is a decided buff colour. The disk is round and covered with a dense network of blood vessels forming a sort of thalamus which covers its entire surface; this is probably a primitive form of the pecten as in the disk of the hedgehog. The drawing is magnified about 120 diameters. The fundus was examined through a compound microscope. I used a 4 mm objective and a 2 magnification ocular, which together gave a magnification of 2 × 60 or 120 diameters approximately. I had to use concentric illumination, which was provided by a mirror fixed at an angle of 45° and centrally perforated. The beautiful fundus and the perfection of the eye, which is furnished with an active pupil and a beautifully clear crystalline lens, at once disposes of the popular idea that the mole is blind. The thick fur which entirely covers up the eye when it lies inside the orbit, effectually screens the animal's eye from the glare of daylight, and the animal makes use of a special set of muscles which no other animal possesses to project the eye outside the orbit whenever it requires to use its eyes. The mole has the smallest eye of any mammal in existence, being approximately 1 mm in diameter.

Order CARNIVORA

This immense group contains nearly all the flesh-eating mammals. The fundi are usually characterized by having three distinct zones. 1. A highly reflecting and usually intensely bright central zone in which vision is most acute; this is known as the tapetum lucidum. 2. A narrow intermediate zone, which may consist of two bands of different colours but more frequently of only one colour, which is always quite different from the central zone. 3. A broad dark-coloured peripheral zone which extends right up to the ora serrata where the retina ends. On the other hand many fundi consist of only two colours. Most of the Carnivora seek their prey at dusk, and their fundi are modified accordingly to suit the altered conditions of light.

Family Felidae

Figure 13. *Panthera leo.* Lion. This drawing was made from a full grown African lion, recently captured, which happened to be temporarily deposited at Jamrach's Menagerie in Whitechapel, London. It was made by the direct view with the ophthalmoscope. Although the animal was quite wild I found no difficulty in making the drawing, as I discovered that as soon as the light from an incandescent bulb was projected into the animal's eye, it became hypnotized and entirely passive, so much so that I found it exceedingly difficult to keep its eyes open while the drawing was made. But it never moved or gave the slightest trouble. I have repeatedly observed this hypnotic effect in various animals, especially among the bears, marsupials and rodents. Many members of the cat tribe are unaffected by artificial light. The wombat I found especially susceptible to its effects; the moment the light was focused on its eye, the animal went into a deep slumber,

and it was necessary to wake it up at frequent intervals in order to obtain the drawing. I may add that in all cases in which the animal possessed a tapetum lucidum, it was found impossible to draw this after death, even immediately after, as the colours of the central zone of the fundus changed the moment the circulation ceased in the vessels, and in addition the media lost their transparency. The fundus of Panthera leo is a vivid emerald green over the whole of the tapetum lucidum, or central area. This green background is covered with innumerable buff-white patches, either oval, round, or irregular, in the centre of which is a brown dot or nucleus. Outside this central area a peripheral zone is to be seen, which consists of large flame-shaped violet-red pigmented masses, becoming very dark violet (nearly black) towards the periphery. The disk is very large, perfectly circular, of an Indian-red colour, and round its margin about a dozen vessels curl over exactly as one sees in a case of long-standing glaucoma in a human being. Of these dozen vessels three are very large trunks, each containing a central white reflecting line or streak. This 'glaucomatous' cupping is only apparent, and is due not to recession of the disk, but to a thickening of the circumferential layers.

Figure 14. *Felis catus*. Siamese cat. The central area is bright canary-yellow, mottled all over with faint greenish patches which become much more vividly green below the disk, so much so as almost to constitute an intermediate zone. About three disk breadths below the disk the outer zone begins. This is a brilliant vermilion colour, not uniform, but it looks as if it is made up of an immense number of broad, flame-shaped lines which, as they approach the green area, blend together into a confused mass, ending in red dots. This appearance resembles that in the lion. I have not observed it in any other member of the cat tribe, although it reappears in the Genetta and Paradoxurus. The disk is circular, white, with a faint pink border. The usual three great branches (which are obviously veins), enter the disk by curling over the margin. The arteries are very small and about a dozen in number. They spread out in all directions.

Figure 15. *Acinonyx jubatus*. Cheetah. This animal has a fundus which is made up of three distinct zones. A central vivid canary-yellow area; and intermediate brilliant emerald green area which appears to consist entirely of closely packed emerald green dots, being sparsely distributed over the central area; a peripheral zone of a reddish-purple-brown colour. This zone is likewise covered all over with dark brown dots similar in size to those in the intermediate area. The disk is brownish-red of an irregular oval shape, and bordered by a purple-brown line. The arteries and veins are distinct and both emerge and enter the eye in three groups. One set ascend vertically upwards and then branch out horizontally on either side, while the two lower sets of vessels curl over the disk to pass obliquely downwards and outwards or inwards to vanish for the most part in the cells of the central and intermediate zones. A few branches descend vertically downwards to become lost in the purple-brown peripheral layer.

Family Viverridae

Figure 16. *Paradoxurus hermaphroditus*. Common palm civet. The three zones are very pronounced and distinct. The usual central golden yellow zone contains numerous dots, which however are not green, as in the other types, but are of a deeper shade of yellow. The intermediate zone consists of patches of green pigment cells, and the outer zone

consists of dull red or reddish-brown flame-shaped processes. The disk is much smaller than in figure 15; it is pinkish-white, and three large veins curl over the edge. The arteries are thin and very numerous.

Figure 17. *Herpestes nepalensis.* Spotted ichneumon. This animal has a very remarkable fundus. There are only two zones; a large central zone which consists of a bright emerald green background, but filled in with an immense number of light brown irregular patches, in each of which one or two or more dark brown dots are to be seen; the peripheral zone is entirely made up of these brown patches which become more fused together towards the periphery. The disk is very large, red in colour, and dark red at the margin. The usual three large veins enter the disk, but do not curl over the edge, as is the case in all the previous examples of the Family we have described (see also Johnson 1901, plate 8). Moreover, the vessels proceed towards the centre of the disk, but do not fuse into a common trunk. The periphery of the disk is surrounded by orange coloured patches. The two great descending veins run a parallel and vertical course, into which a few branches join the main trunks at nearly right angles.

Figure 18. *Herpestes pulverulentus.* Grey ichneumon. This fundus is most remarkable. It consists of two zones: a central zone of intensely vivid emerald green, almost blue-green in shade, which is strewn all over with darker green dots; the peripheral zone is unique in being made up of vivid prussian-blue flame-shaped processes. This is almost the only fundus I have ever seen showing blue in any large quantity, although I have met with small patches of intense blue in some of the domestic cats' fundi. These flame-shaped processes are very interesting, and seem to be confined to the Felidae and Viverridae, although we find them only in certain members of each genus. (To study this figure the page should be turned 90° clockwise.)

Figure 19. *Suricata suricatta.* Common suricate. This animal has a uniform fundus which is of a dark chocolate colour, mottled all over with small dark brown patches or dots. There is no trace of any differentiated zones, which distinguishes the Cynictis and the Suricate from all the other Carnivora. The disk is circular and buff coloured, with a very white well defined border. The vessels are large, the arteries being clearly different in colour from the veins. The vessels curl slightly over the edge of the disk. The optic nerve fibres can be seen radiating in every direction all over the fundus for a considerable distance from the disk border.

Family Hyaenidae

Figure 20. *Crocuta crocuta.* Spotted hyaena. This fundus closely resembles the Hyaena hyaena (Johnson 1901, plate 9), but the disk is a much deeper red which assumes a brownish tinge. The three big veins are in evidence, and the veins are just distinguishable from the arteries, which are more vermilion in colour, and much finer and thinner. The intermediate zone is a deeper green and the outer zone a more pronounced reddish-purple. Moreover, the dots which are sprinkled all over the surface are much coarser and larger. The Hyaena brunnea has an exactly similar fundus and is therefore not described or depicted.

Family Canidae

The Canidae all have a fundus with three zones, and in a few instances we find four zones with distinctive colours. In none of the fundi do the vessels curl over the disk as is

the case in the Felidae. The optic disks assume various shapes among the wolves, jackals and foxes.

Figure 21. *Nyctereutes procyonoides*. Raccoon dog. This animal has the three characteristic zones. The light yellow one above the disk, the emerald green one around and just below it, and the peripheral zone of a greyish-brown colour. The vessels all seem to enter or leave the disk all round it, and a little away from its margin. There are no large vessels. The outer layer or zone is of a warm brownish-red colour and is made up of clumps of cells.

Figure 22. *Canis familiaris*. Collie dog. The fundus has a yellow central zone mottled all over with small spots of green and brown. This layer ceases at the disk, and extends upwards as far as can be seen. The central zone is broken up by invasion from the black stroma of the peripheral zone; it consists of orange-red clumps of cells and some yellow ones. The peripheral zone is intensely brown, nearly black, and the vessels stand out very prominently over its surface. The disk is grey and the vessels meet on it to form a half-circle near the centre. There is no distinction between arteries and veins.

Figure 23. *Canis dingo*. Australian dingo. This is probably the oldest variety of dog in existence. The three zones of the fundus are very distinct. The central one has a golden, very brilliant tapetum, covered all over with small brown dots. The medial zone is narrow and is made up of brilliant emerald green clumps of cells. The outer zone is reddish-brown and covered with brown patches. The disk is pure white, large and horizontally oval in shape with fringed edges. The main vessels, six in number, become lost in the white fibres of the nerve.

Figure 24. *Canis latrans*. Coyote. This animal has an intensely brilliant canary-yellow tapetum which extends as far down as the disk. The central zone is very broad, and is also separated from the outer zone by a narrow strip or zone of purple dots. The disk is triangular, and the three main vessels, which we usually find, enter at the corners of the triangle. There are no other large vessels, only a few capillaries.

Figure 25. *Canis lupus*. Wolf. There is practically no difference between this drawing and the preceding.

Figure 26. *Vulpes vulpes*. Red fox. The fundi of the foxes are almost identical with those of the wolves (figures 24 and 25) and the jackal (Johnson 1901, plate 9), the variations being merely in detail. We have the same three zones, yellow, emerald green, and reddish-brown, the same irregular shaped disks, the same greenish dots over the central area, the same arrangement of vessels, namely: one ascending artery and vein, and two vessels directed obliquely downwards. For the most part the vessels all collect together to form a common trunk at the middle of the disk.

Figure 27. *Alopex lagopus*. Arctic fox. The Arctic fox has a pale lavender and very thin zone between the middle and peripheral zones, in contrast to the violet zone of the red fox.

Family Mustelidae

In this group of fundi we find a distinct departure from the previous types. These are the three distinct zones as in the previous cases, but instead of fine dots we get for the most part small patches of pigment of various colours.

Figure 28. *Mustela putorius*. European polecat. This has the usual three zones: yellow,

green and reddish-brown, but instead of fine dots, we get large clusters of greenish dots in the two inner layers, and large patches of brown pigment in the peripheral zone. The disk is dark pink with a red border, and touches the peripheral brown layer, while lying wholly in the green middle layer. The vessels all meet towards the centre where they become lost to view.

Figure 29. *Martes martes*. Pine marten. The central zone is yellow mixed with emerald green, but so covered with light brown dots and minute patches that the yellow colour is largely lost to view. The whole of this zone lies above the disk and the middle zone extends from the top of the disk to three or four disk breadths below it. It is a brilliant emerald green overlying a yellow background, and the whole is strewn with large irregular brown patches. The peripheral zone is a brilliant scarlet mottled all over with brownish cells. Between this zone and the green one is a broad border of reddish-brown, which has a fringe of reddish-brown cells. The disk is circular, large, and pink with a reddish border. The main vessels, six in number, enter the disk at the periphery where they become lost to view.

Figure 30. *Ictonyx striatus*. Zorilla. This fundus has three zones. The central one is very large and consists of a brilliant light golden tapetum strewn all over with greyish and rather large dots or patches of pigment. The peripheral zone is a rich brown covered with profuse mottling of dark brown patches. This zone is separated from the central one by a very narrow zone of emerald green dots. The disk is circular, brownish-red, and twelve or more large vessels, veins and arteries appear to meet together to form a nearly complete circle or vascular ring about its middle. Inside this horseshoe circle the disk is a pale pink colour.

Figure 31. *Lutra lutra*. Eurasian otter. This animal has three very distinct zones: a central brilliant gold or canary-coloured tapetum covered all over with orange dots; a middle zone of brilliant emerald green covered all over with orange-gold irregular patches with brownish borders, precisely as in the Tayra (Johnson 1901, plate 10) and a brown peripheral zone. The disk is round, intensely red, and covered with the branches of vessels which meet at a common centre to form the main trunk.

Family Procyonidae

Figure 32. *Nasua nasua*. Coati. This fundus has only two zones. A large emerald green tapetum, mottled all over with buff-coloured rice-shaped bodies, and a brownish-purple zone. The disk is circular and pale pinkish-white. Three large vessels pass directly across the edge of the disk, and vanish halfway towards the centre. These vessels possess the central bright streak. A large number of small vessels enter (or proceed from) near the centre of the disk. They do not, any of them, join up to form a single trunk.

Figure 33. *Potos flavus*. Kinkajou. This fundus also has only two zones: a large central zone golden yellow on a white background, mottled everywhere with yellow and green spots, and an outer zone of yellowish-red mottled over with dark orange or orange-brown spots. These spots invade the lower part of the central area. They seem to be made up of clusters of reddish cells. The disk is pale brownish-pink, circular, with a faint green ring around the disk. Four main vessels reach the disk, but do not curl over it. Apparently they enter the sheath of the nerve behind the eye. A great number of smaller vessels reach the disk in the same way, but in no instance do any vessels enter or cross over the disk.

Family Ursidae

Figure 34. *Melursus ursinus.* Sloth bear. This animal has a bluish-green inner layer, which is mottled all over with vivid green splashes and minute green dots. The outer zone is a dull reddish-brown colour, with detached clusters of cells which spread some distance into the inner green layer. The disk is large, red in colour, with a deeper red border.

Order CETACEA

Sub-order ODONTOCETI

Figure 35. *Physeter catodon.* Sperm whale. This drawing was made from a full grown specimen over 40 ft. in length. There is no peripheral zone, but the fundus is mottled with patches of darker grey. The disk is horizontally oval and very large, its centre is chalky white and surrounded by a broad zone of bright red which is again surrounded by a black pigment zone. The vessels are very numerous, about a dozen in number, but have none of the ladder-like short lateral contributories, except at the periphery where they divide dichotomously. All the main vessels curl over the edge of the disk as we notice in nearly all the Carnivora.

Order ARTIODACTYLA

Family Bovidae

Figure 36. *Bos taurus.* British wild bull. This fundus consists of four distinct zones. The central zone has a canary-yellow tapetum profusely covered with green and brown spots so as to give the whole a light brownish-green colour. Below this the canary-yellow zone is almost free from these spots so that it keeps its golden colour; it is about half a disk in breadth. Immediately below this is the sensitive zone or streak, which is orange-pink. As in the Indian ox (Johnson 1901, plate 12), this streak corresponds to the macular area in monkeys and in my opinion represents a specialized area of more acute vision. Outside this streak is the circumferential zone which starts from the top of the disk and extends to the circumference of the retina. The disk lies buried in this zone, which is brown covered with black dots.

Figure 37. *Ovis musimon.* Mouflon. The central zone or tapetum is a brilliant greenish-yellow, and covered all over with peculiar stellate dots of dark grey. Each dot has three hair-like processes which arise from three sides of the dot. I have been unable to assign any reason for these peculiar bodies. They only exist over the central and most sensitive zone, being replaced by dull brown patches in the peripheral zone and by clumps of dots in the intermediate zone. The intermediate zone begins about five or six disk breadths above the disk, and is of varying width, being very wide far above and very narrow immediately above the peripheral zone which begins at the top of the disk. This intermediate zone is a pale emerald green and is covered over with patches or clumps of purple-brown clusters of dots. The peripheral zone extends from the top of the disk to the extreme periphery of the retina. It is purplish-brown and mottled all over with brown patches of pigment cells. The disk is very large, triangular with rounded angles, and reddish-orange. The vessels are exceedingly large and numerous. They form three groups. An ascending pair of vessels, artery and vein, which are very large, run close together vertically up as far as the green

intermediate zone, and give off horizontal branches all the way up. The horizontal group of vessels run more or less horizontally outwards from the disk. The descending group of branches are large and ramify all over the peripheral zone. All the three groups of vessels cross the disk without any sign of cupping: they form a convoluted whorl of big trunks which disappear into the main retinal trunks, arterial and veinous, and run through the centre of the optic nerve.

Figure 38. *Capra hircus*. Domestic goat. This animal has a beautiful violet-pink fundus mottled all over with a network of creamy-white, having a darkish rod-shaped mass of pigment in the centre of each mesh. The outer zone is so narrow as to be entirely outside the field of view. The disk is round and pink, and dark red at the margin, with a narrow white zone round it. The main veins are very large and two in number, one descending vertically from the periphery of the retina to the disk, and the other vein ascending from the periphery to the disk; they meet in the middle of the disk, where they disappear. The main arteries are much smaller and thinner than the veins, and are more numerous, but their distribution is much the same.

Figure 39. *Gazella dorcas*. Dorcas gazelle. The fundus has the characteristic pair of vessels, artery and vein, which ascend vertically upwards from the centre of the disk to branch horizontally outwards in both directions. Both artery and vein run close together. The central zone is golden yellow, with a greenish sensitive area which extends for a considerable distance horizontally across the field immediately above the disk in the central zone. Numerous experiments have convinced me that this streak is the site of a specially sensitive area. I am convinced that the animal sees with greater definition over a larger area than we do, but by no means with such critical definition over a small central area. The peripheral zone is purplish-red and mottled all over with dark purple patches. The disk is continuous and forms a long horizontal oval with a whitish border. The surface of the disk is pink, covered with greyish pigment.

Family Cervidae

Figure 40. *Rangifer tarandus*. Reindeer. This fundus bears a striking likeness to that of the hogdeer (Johnson 1901, plate 12), the only difference being that the disk is very broad horizontally, and also gives the impression of being made up of three disks fused together. The vessels run precisely the same way as in the hogdeer. A few bundles of opaque nerve fibres radiate outwards at each end of the disk.

Sub-order Tylopoda

Family Camelidae

Figure 41. *Lama glama*. Llama. This fundus is very similar to that of the Bactrian camel (Johnson 1901, plate 13), except that the entire fundus is a brilliant vermilion covered over with still darker red mottling. All the background below the disk is covered with brownish spots which are exceedingly numerous. The disk is pure white and horizontally oval. The vessels, arteries and veins are quite distinct, the arteries being bright scarlet and the veins a dark crimson. They form a circle round the middle of the disk. There is only one zone, as described.

Figure 42. (See after figure 43.)

Sub-order Suiformes

Family Suidae

Figure 43. *Sus scrofa.* Domestic pig. The fundus has only one zone, which is of purple-brown, mottled over with brownish dots. The disk is horizontally oval and creamy pink. The immense number of semi-opaque nerve fibres radiate outwards from the disk for a considerable distance. Three huge main venous trunks pass straight over the edge of the disk to anastomose around the centre; they run downwards, outwards and obliquely inwards. The arteries are very numerous, but very small compared with the veins. None of the Suidae possesses a tapetum lucidum.

Order PERISSODACTYLA

The fundi of the perissodactyla are entirely different from those of the Artiodactyla. They have no retinal blood vessels, and the fundus is of a more primitive character.

Sub-order Hippomorpha

Figure 42. *Equus caballus.* Domestic horse. This drawing was taken from a brown riding horse. The fundus consists of three zones. A central brilliant golden yellow zone starts immediately above the disk and covers a very large semi-circular area about nine or ten disk breadths across and five or six disk breadths at the top of the arch. This area is not homogeneous but is made up of an immense number of tiny areas or cells, 2 or 3 mm in diameter, when measured by the appearance as seen through the ophthalmoscope which magnifies about 16 times. Each of these tiny circular or hexagonal areas is separated from its adjacent neighbours by a fine greyish line, and in the centre of each is a grey dot or nucleus. As one follows this central zone towards the periphery, the area becomes gradually covered with a network of black pigment which to some extent obscures the definition of the cells. Further away from the disk the pigment layer becomes more and more dense. About half a disk breadth above the disk this zone loses its golden yellow colour and assumes a dark brown colour which is densest around the disk and laterally on each side of it, and gradually fades to a lighter colour as one approaches the periphery. It consists of similar areas to those seen in the central zone, only they are densely covered with brown pigment. It is highly probable that this dark brown colour is necessary to shade the animal's eyes from the glare of the sky so that this reflex may not disturb the vision for lower objects, for it is obvious that the regard of the animal is for the most part confined to the ground, and then to objects only a little above the ground, or at any rate not above the horizon. If we examine the eyes of many mammals we shall notice the same thing. Round about the disk and usually immediately above it we find the sensitive area, which as we have previously remarked is a sort of extension of our maculae area. The disk is horizontally oval and more convex above. It is rosy-red or pinkish-red with a white margin below. The centre is white and contains in most horses a minute red spot, which can be resolved into minute capillaries. It may be the remains of a vestigial pecten. The blood vessels are confined to the disk where they arise a little distance from the margin and run a very short distance on to the brown area. They consist of fine capillaries.

Order RODENTIA

Sub-order MYOMORPHA

Figure 44. *Eliomys dryas*. Garden dormouse. This is a remarkable fundus. The background is dark grey, but covered all over with an immense network of vermilion interlacing and anastomizing choroidal vessels, which give to the fundus an intense fiery red appearance. The disk is very small, but much larger than in other examples of the Myomorpha. It is pink and surrounded by a ring of black pigment. The vessels radiate starfish-wise. The opaque nerve fibres form a very conspicuous aster. The tiny disk has a small white centre body, but what its nature is I could not determine.

Sub-order SCIUROMORPHA

Figure 45. *Citellus citellus*. Ground squirrel. The upper part of the field is much darker in colour than the lower. The entire fundus is a rich brown. The disk is long and slightly concave along its lower border. The surface is covered with a close network of pigment, except along the borders where it forms a white margin. The blood vessels are numerous, and all curl over the edge to disappear between the marginal border and the central pigmented part. A section of the optic nerve behind the eye shows the nerve as a thin narrow ribbon, which can be traced in that form right along the undersurface of the brain. The outer zone is similar to the central one, except that the choroidal vessels are very prominent. Careful tests as to the vision of these squirrels (Johnson 1901, plates 18 and 19), show that they have a long narrow area of acute vision, which I have termed the sensitive area. This runs right along the fundus immediately below the disk, and extends along its whole length and even a little beyond it. There a bright light dazzles the animal and it blinks and turns its head away the moment the light is concentrated on it. But it shows no signs of inconvenience if the light is directed on to any other part of the retina.

Figure 46. *Cynomys ludovicianus*. Prairie marmot. This animal and the alpine marmot have the longest and narrowest disks of any animals I have ever examined. The fundus is uniformly brownish-red. Everywhere over the fundus the choroidal vessels are visible forming a very fine network over the central area around the disk on both sides, but these vessels become very much larger and more prominent further down below the disk. Here they divide dichotomously, the prongs facing downwards towards the periphery. The disk is uniformly white. The retinal vessels are remarkably scanty and anastomose in the form of a thin chain of vessels right along the surface of the disk.

Sub-order HYSTRICOMORPHA

Figure 47. *Myocastor coypus*. Coypu.This animal has a rose-pink fundus slightly mottled all over, and covered with discreet patches of crimson; these do not contribute much to the colour of the fundus, being so few and far apart. The disk is white, circular, and in the centre is a protusion like a wickerwork basket made up entirely of fine capillary vessels. This is undoubtedly a vestigial relic of a pecten. The same thing can be observed in some of the marsupials (Johnson 1901, plates 23, 24, 25 and 26). Numerous semi-opaque nerve fibres spread out from the disk.

Order LAGOMORPHA

Figure 48. *Oryctolagus cuniculus*. Albino rabbit. The disk is a pale greyish-white, and horizontally oval. Two main branches of retinal vessels emerge from the edge of the disk, and curving over run a horizontal course in pairs along the middle of the opaque optic nerve fibres as far as the eye can reach with the ophthalmoscope. The optic nerve spreads out from the disk in two long feathery plumes, one on each side in a horizontal direction. The appearance is very striking and entirely confined to this family. In the Albino, all the vermilion stroma of the background is wanting, and is replaced by the brilliant white of the naked sclerotic behind. The choroidal vessels are very prominent and form an irregular skein all over the fundus.

Order MARSUPIALIA

The Marsupials have characteristic fundi, and although the fundi of the various families are very different, they all differ from those of all the other orders.

Figure 49. *Dendrolagus bennettianus*. Bennett's tree kangaroo. This fundus has a light brown, profusely mottled background which is sparsely covered with broad broken-up masses of bright red and numerous choroidal vessels. The disk is round, and its central two-thirds are covered with a dense network of fine capillaries which forms a kind of thalamus or cushion without any pigment. The periphery of the disk is cream coloured; here the natural colour of the disk shows up, since the basketwork of vessels does not reach the margin. A number of capillaries cross over and extend a short distance along the retina.

Figure 50. *Petaurus norfolcensis*. Flying opossum. This fundus shows what is evidently a primitive formation. The background is dark grey, and covered with a number of very large irregularly distributed choroid vessels. About five disk breadths to the outside of, and a little below the disk, is another of these remarkable dark gaps in the distribution of the choroidal vessels; this dark patch has a still darker spot in the centre. It bears a striking likeness to the patch seen in the American agouti and the brush-tailed wallaby. Perhaps this patch is the analogue of the second macula we find in the birds.

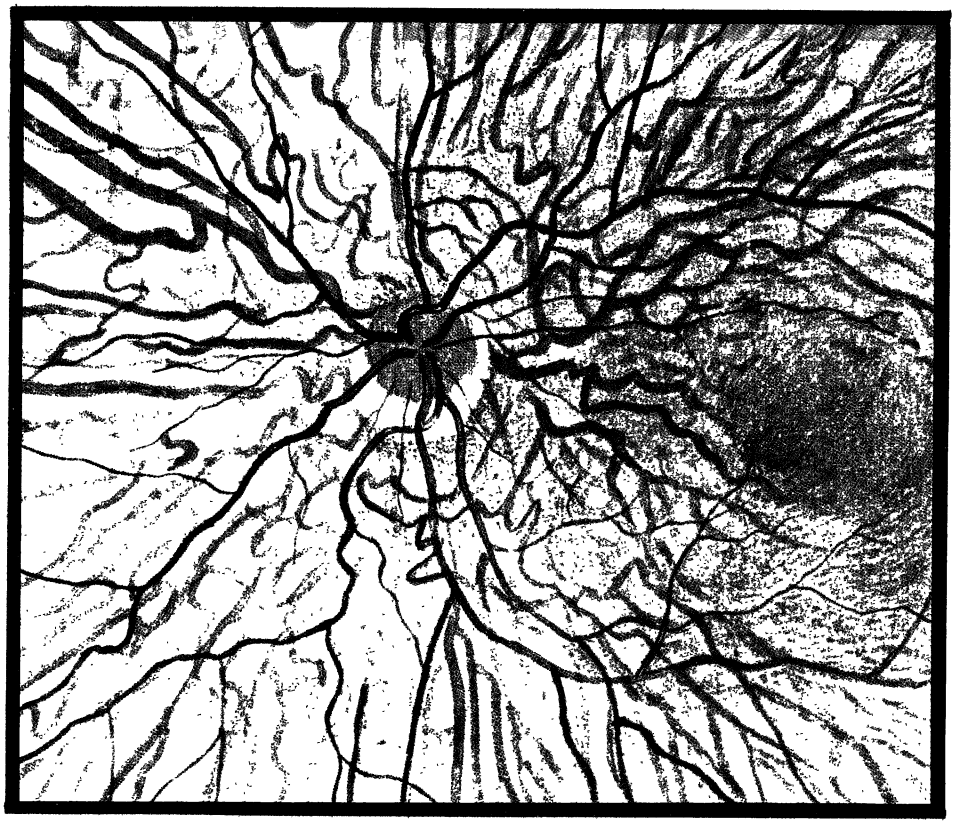

FIGURE 1. *Homo sapiens.* European albino.

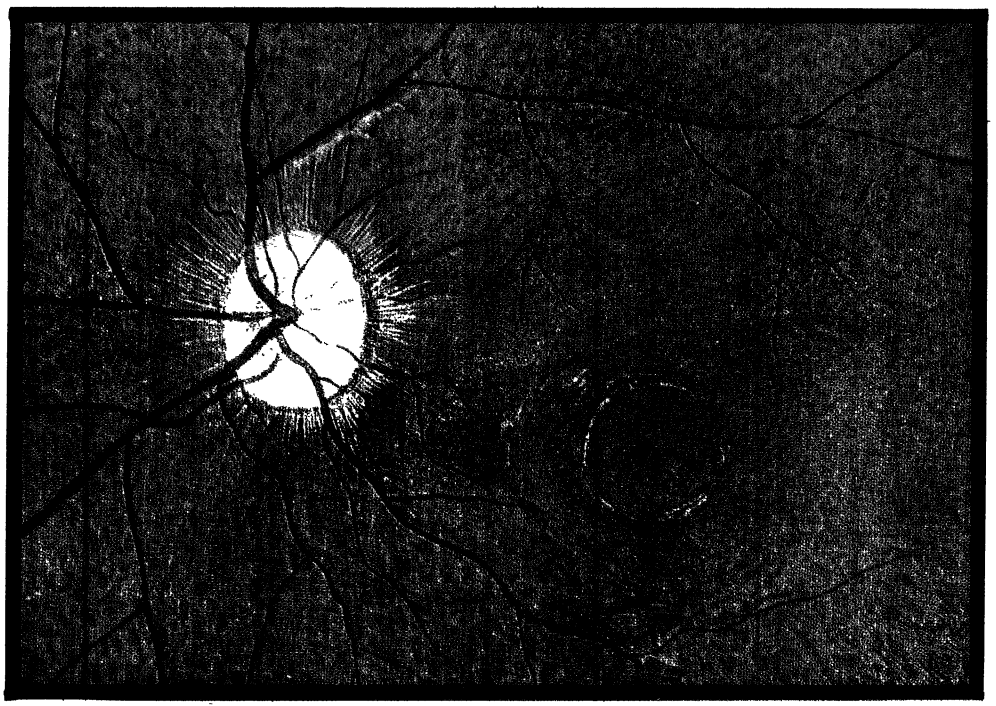

FIGURE 2. *Pongo pygmaeus.* Orang-utan.

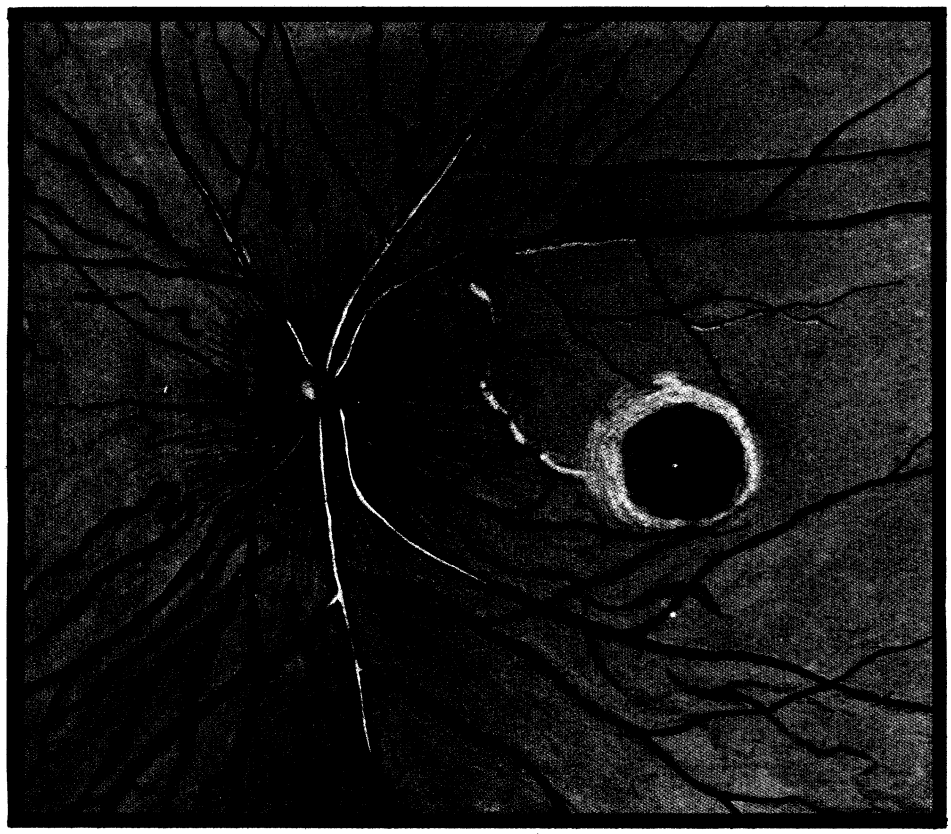

FIGURE 3. *Macaca mulatta.* Rhesus macaque.

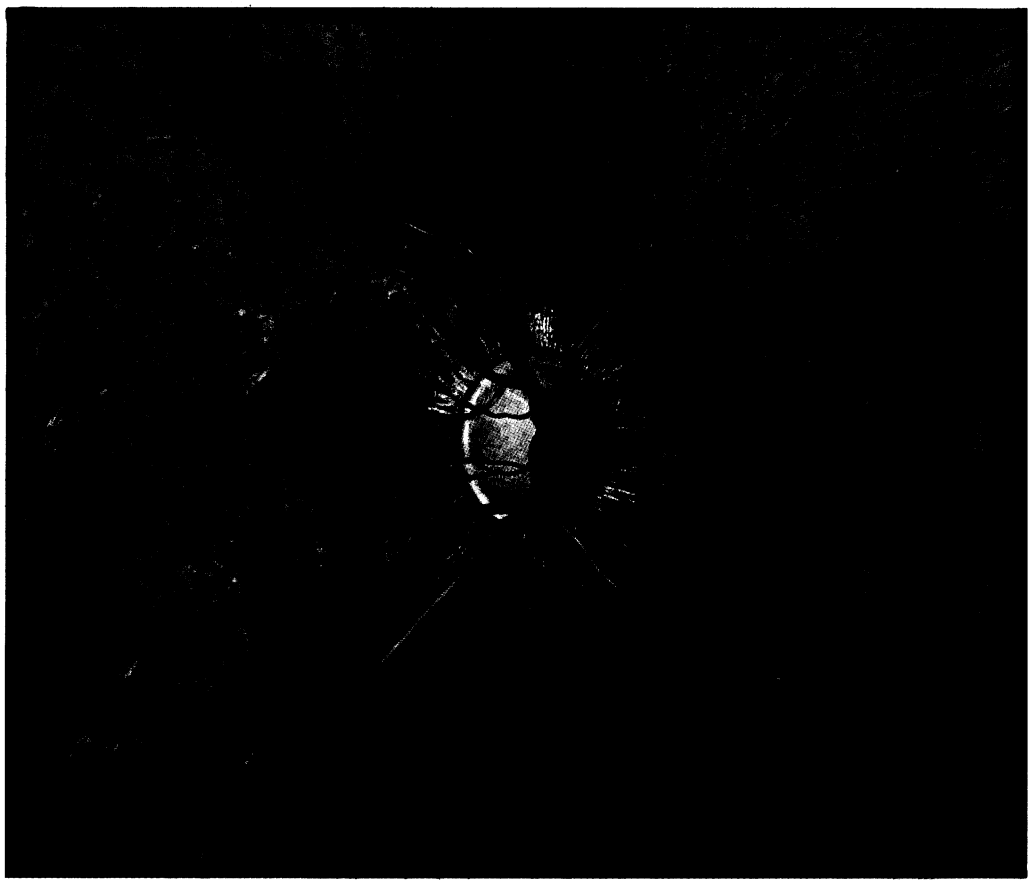

FIGURE 4. *Mandrillus sphinx.* Mandrill.

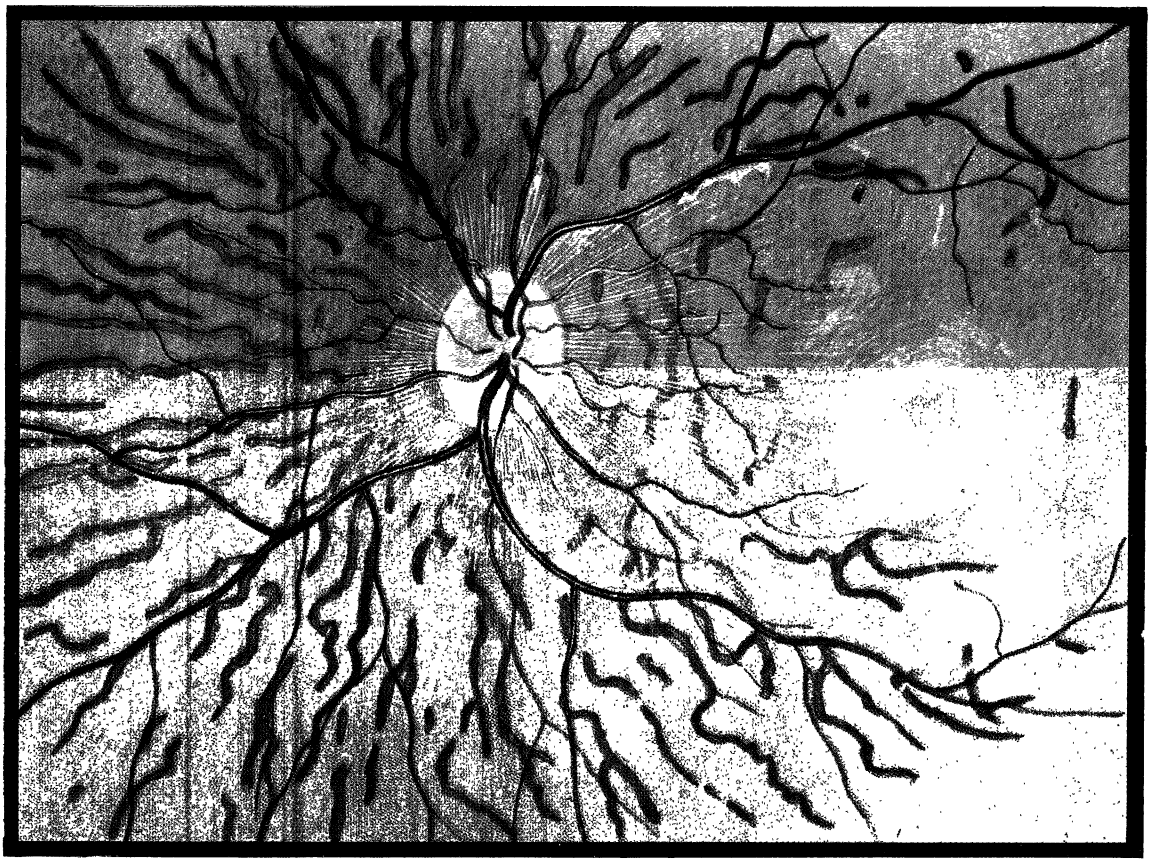

FIGURE 5. *Cercopithecus albigularis*. Sykes's monkey.

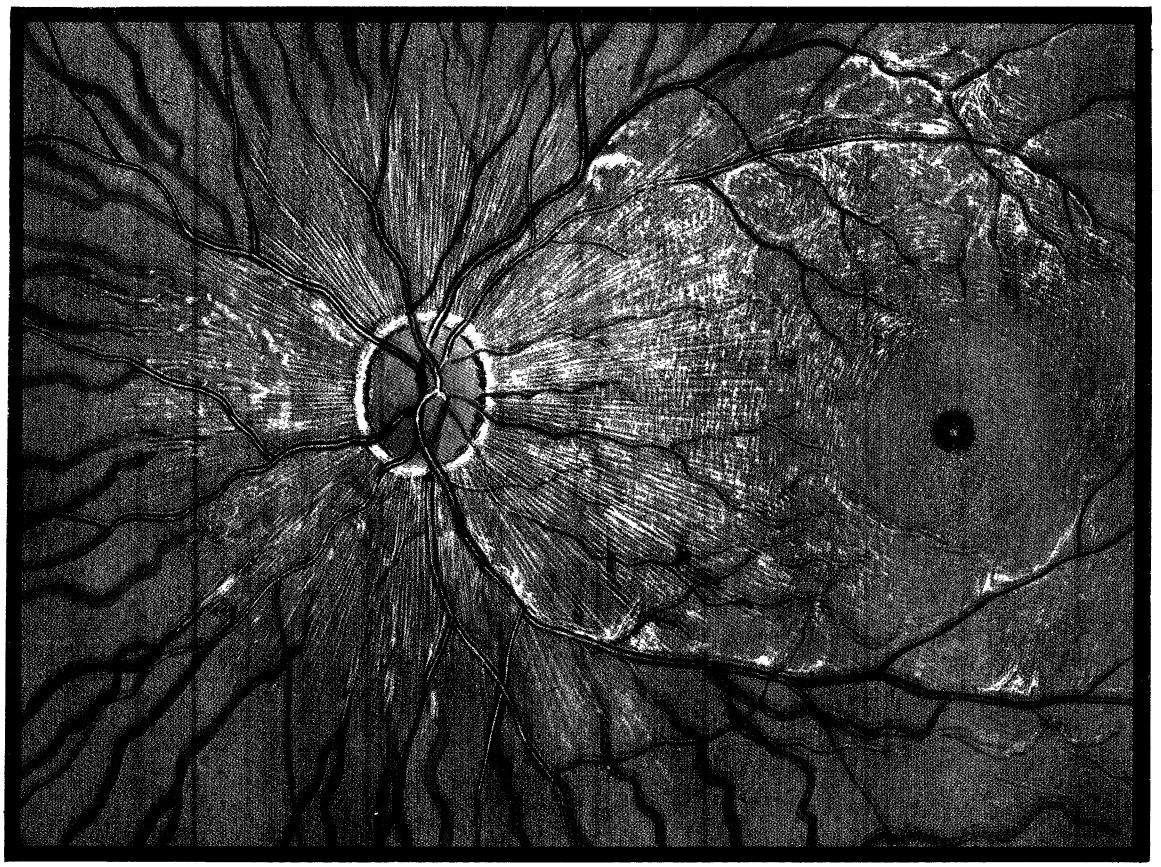

FIGURE 6. *Cercopithecus aethiops*. Green monkey.

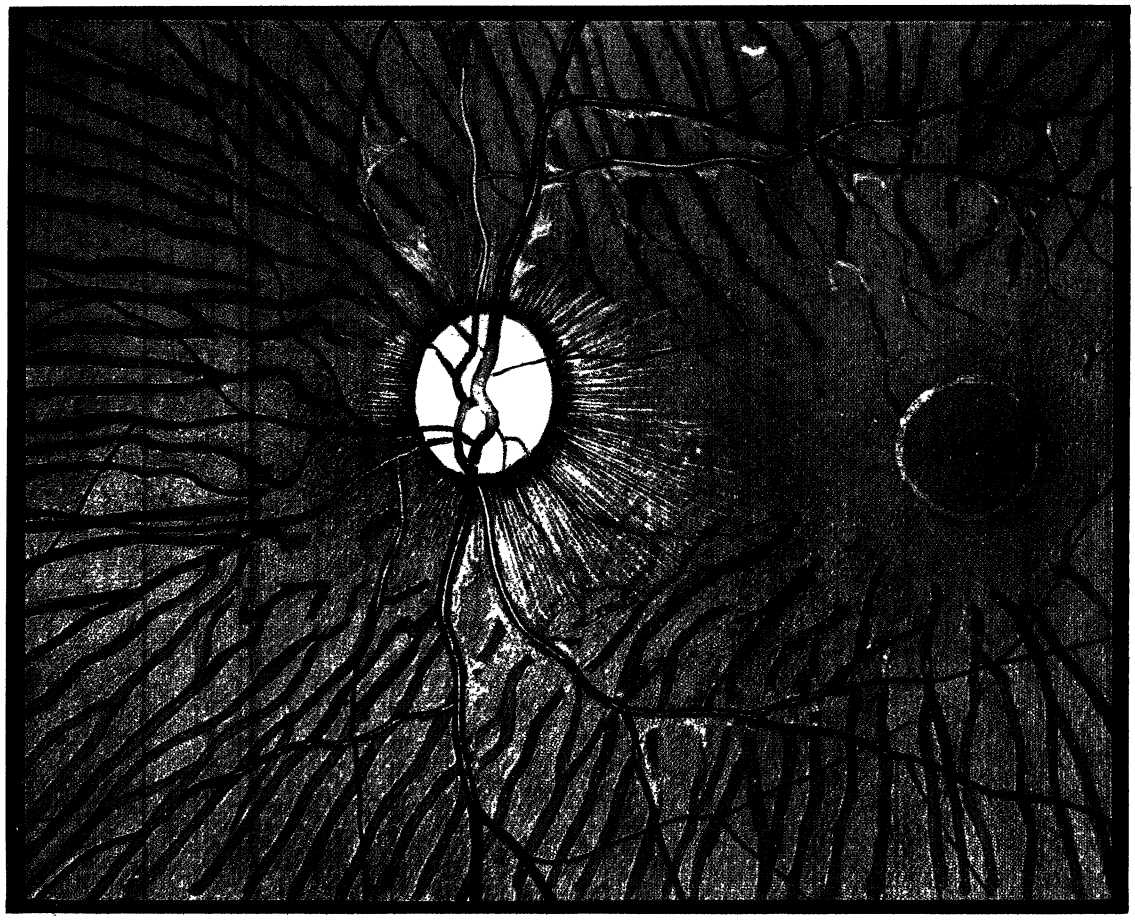

FIGURE 7. *Cercocebus torquatus*. Sooty mangabey.

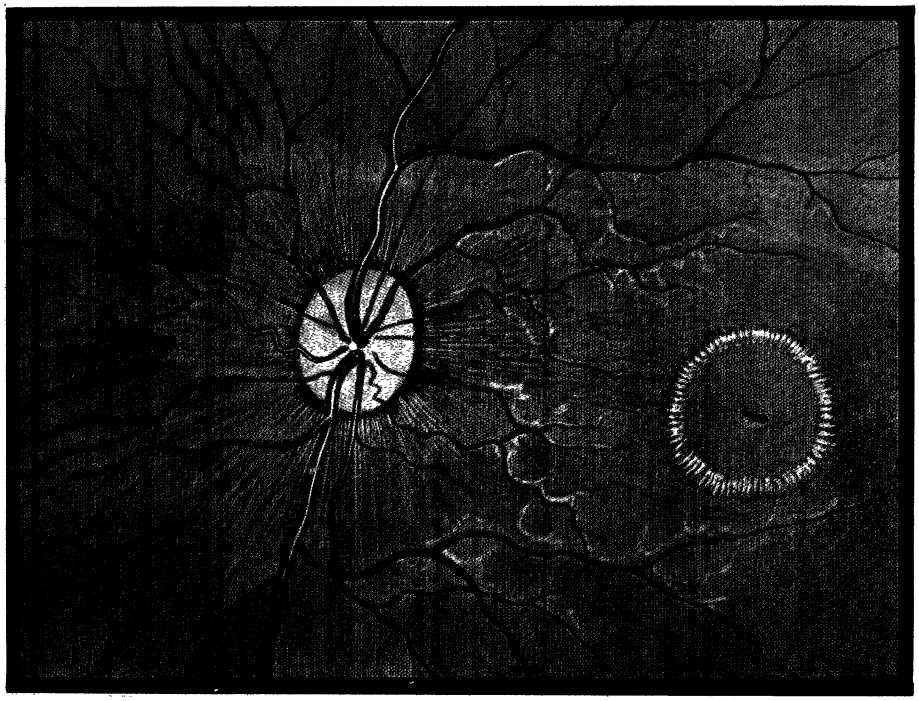

FIGURE 8. *Saimiri sciureus*. Common squirrel monkey.

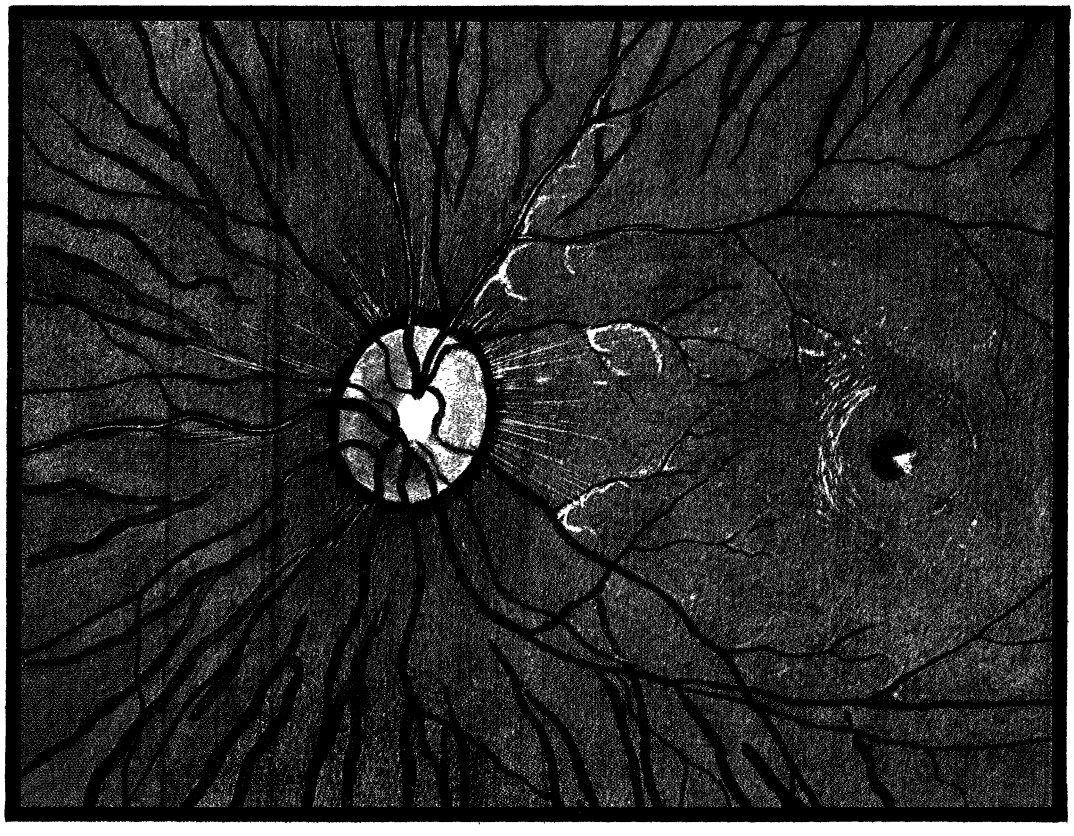

FIGURE 9. *Ateles paniscus*. Black spider monkey.

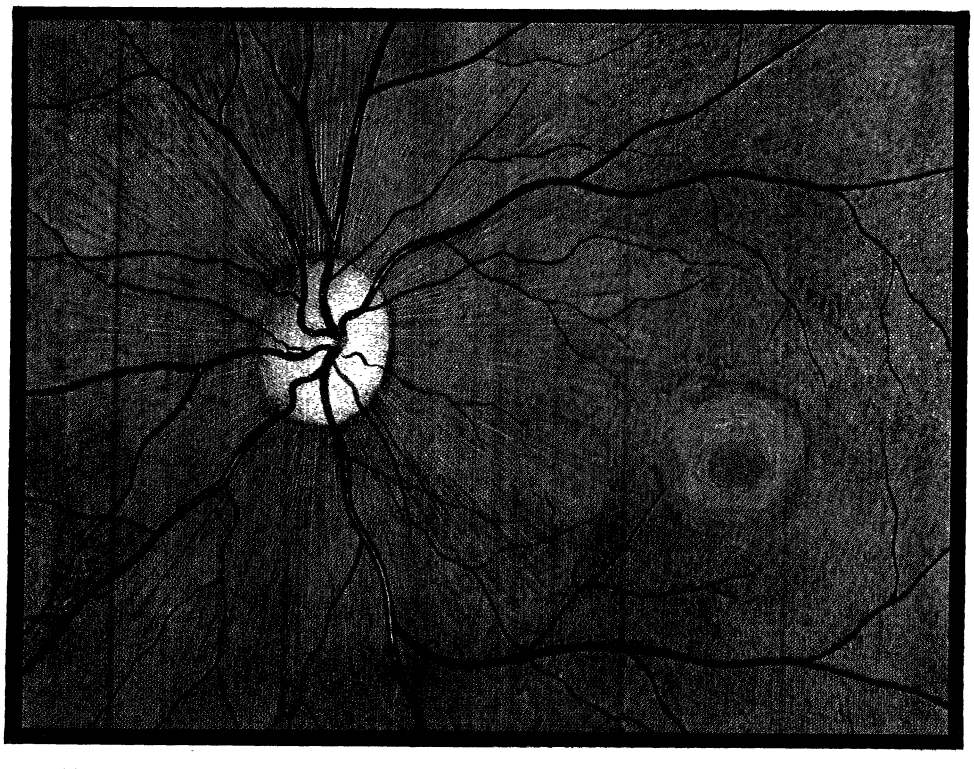

FIGURE 10. *Alouatta seniculus*. Red howler.

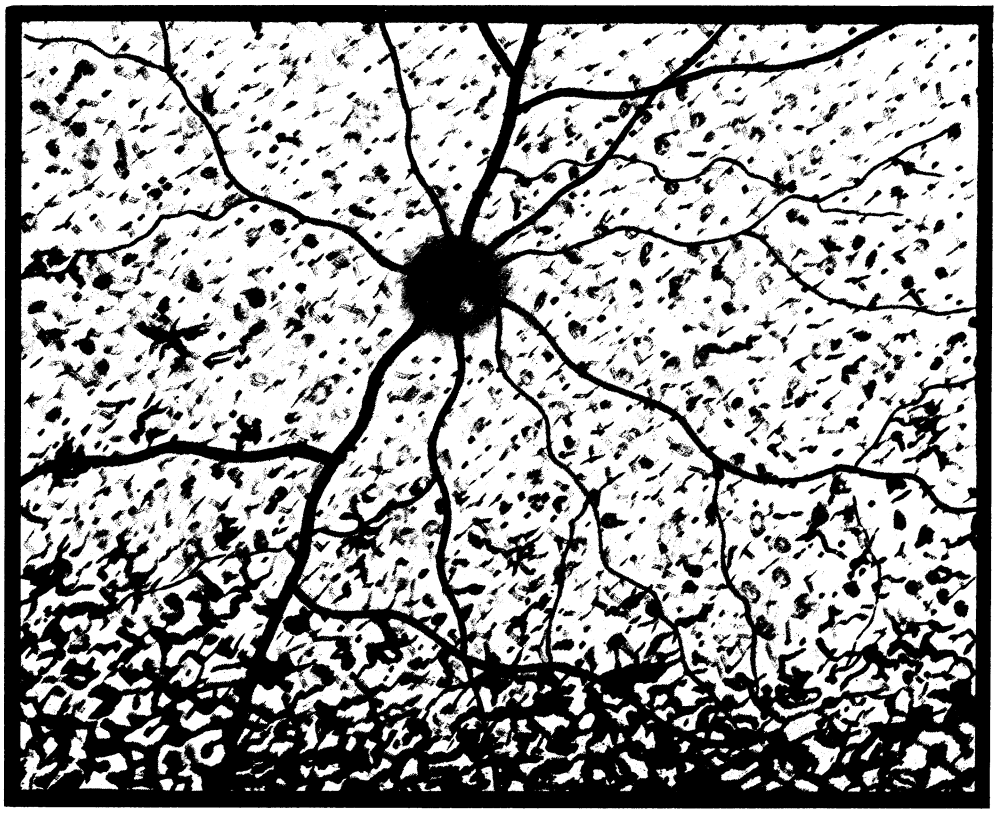

FIGURE 11. *Nycticebus coucang*. Slow loris.

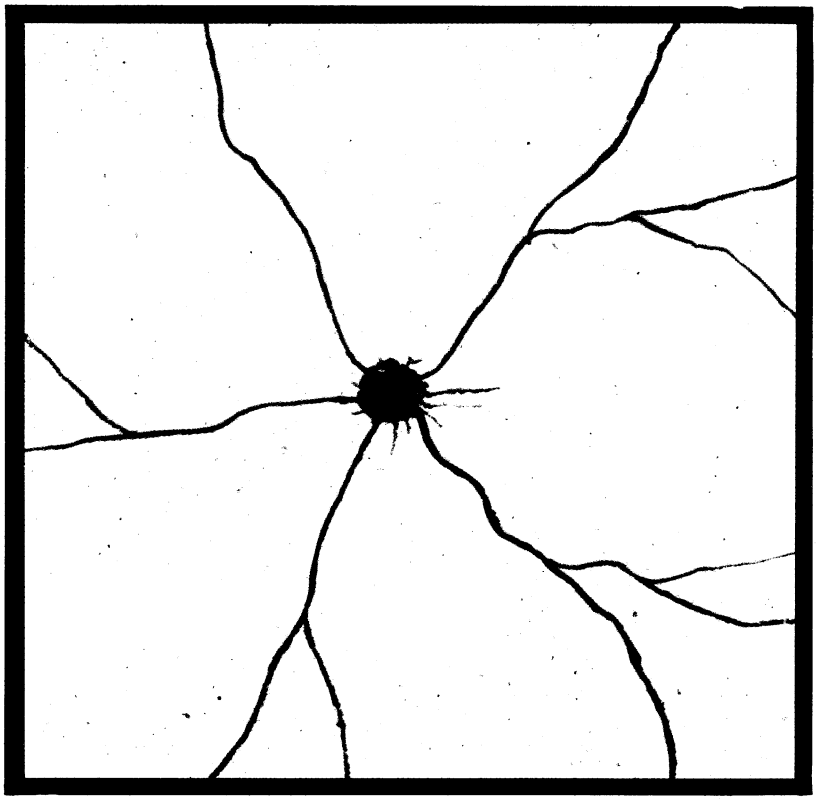

FIGURE 12. *Talpa europaea*. Common Eurasian mole (× 120 diameters).

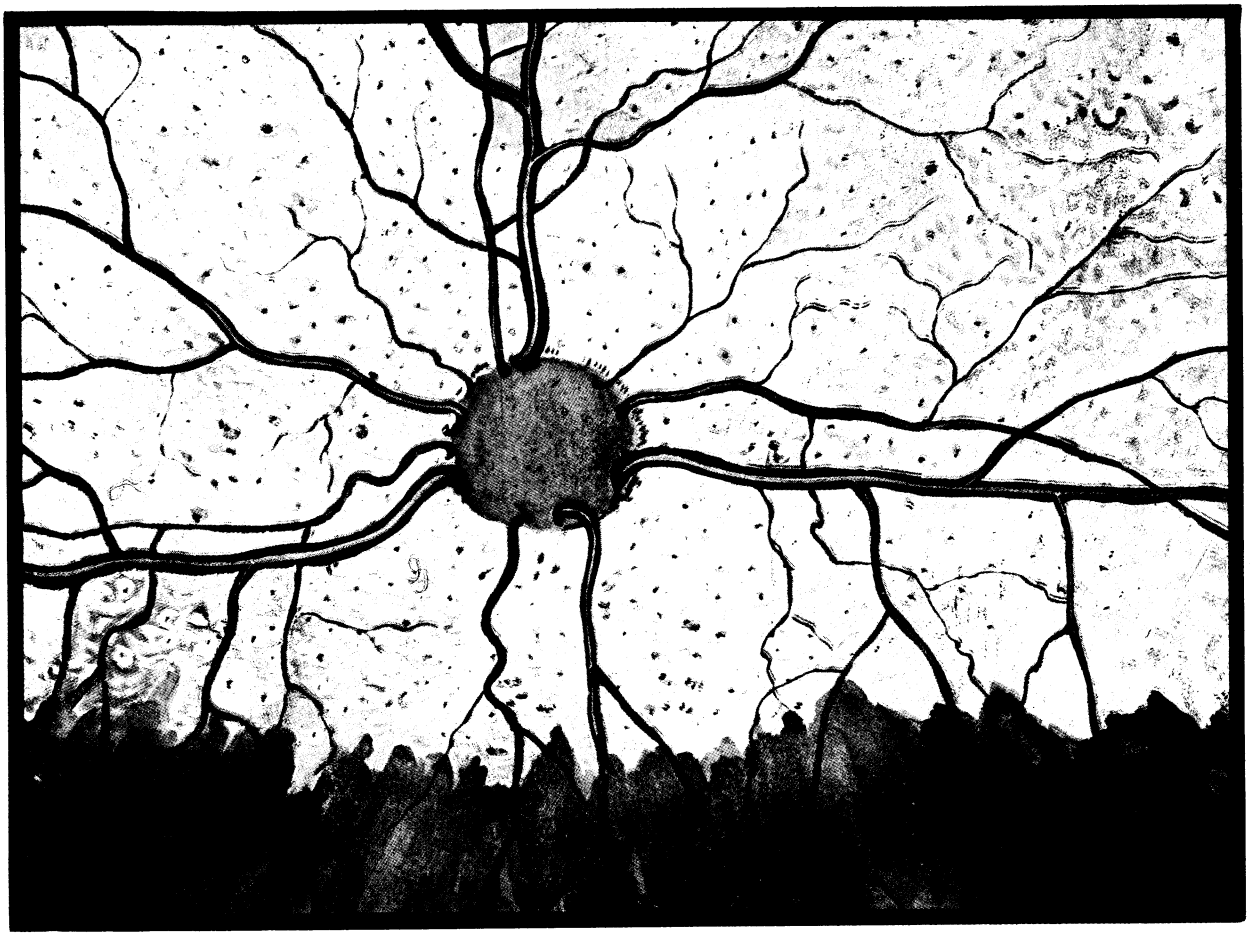

FIGURE 13. *Panthera leo*. Lion.

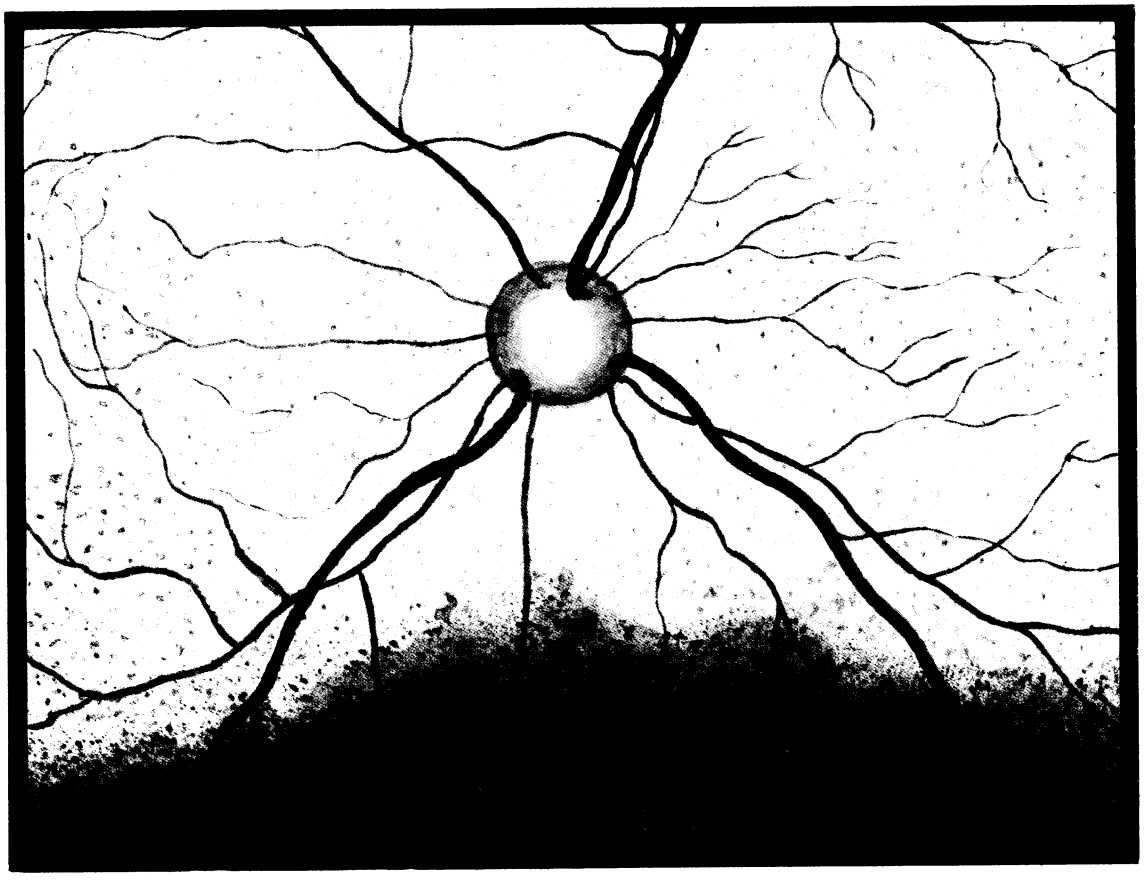

FIGURE 14. *Felis catus*. Siamese cat.

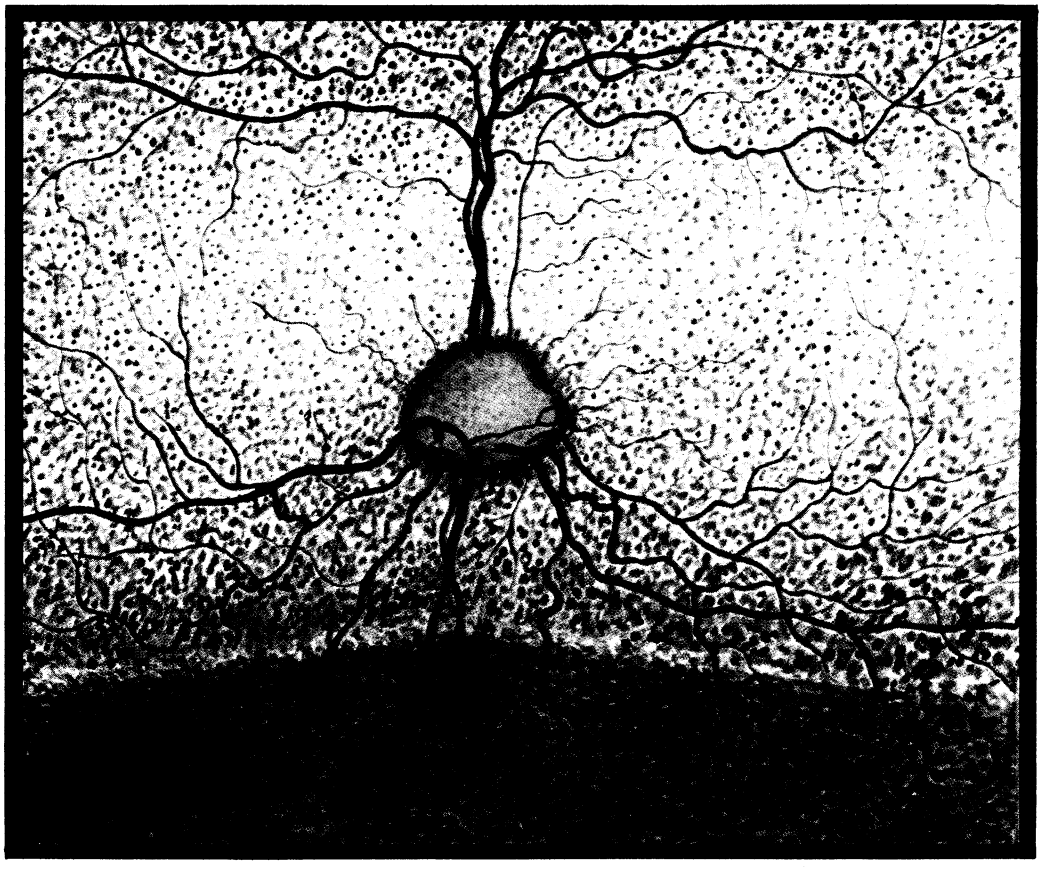

FIGURE 15. *Acinonyx jubatus*. Cheetah.

FIGURE 16. *Paradoxurus hermaphroditus*. Common palm civet.

FIGURE 17. *Herpestes nepalensis*. Spotted ichneumon.

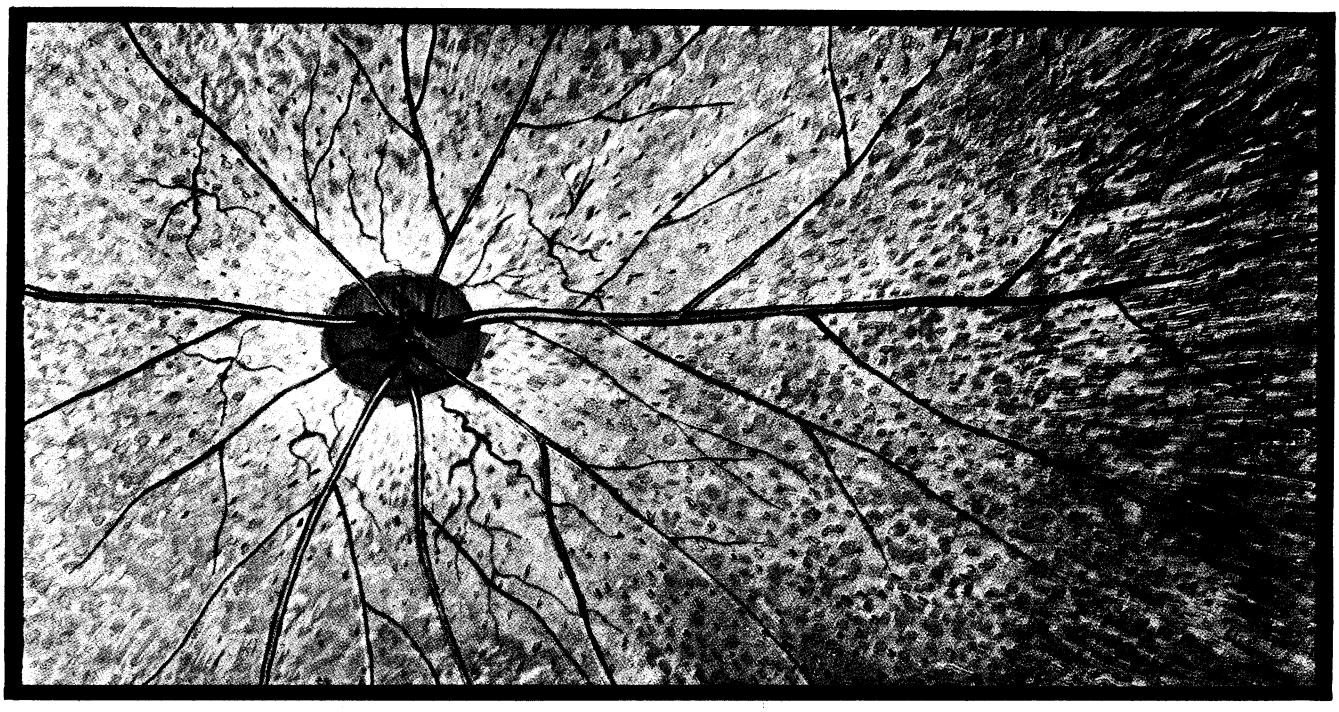

FIGURE 18. *Herpestes pulverulentus*. Grey ichneumon.

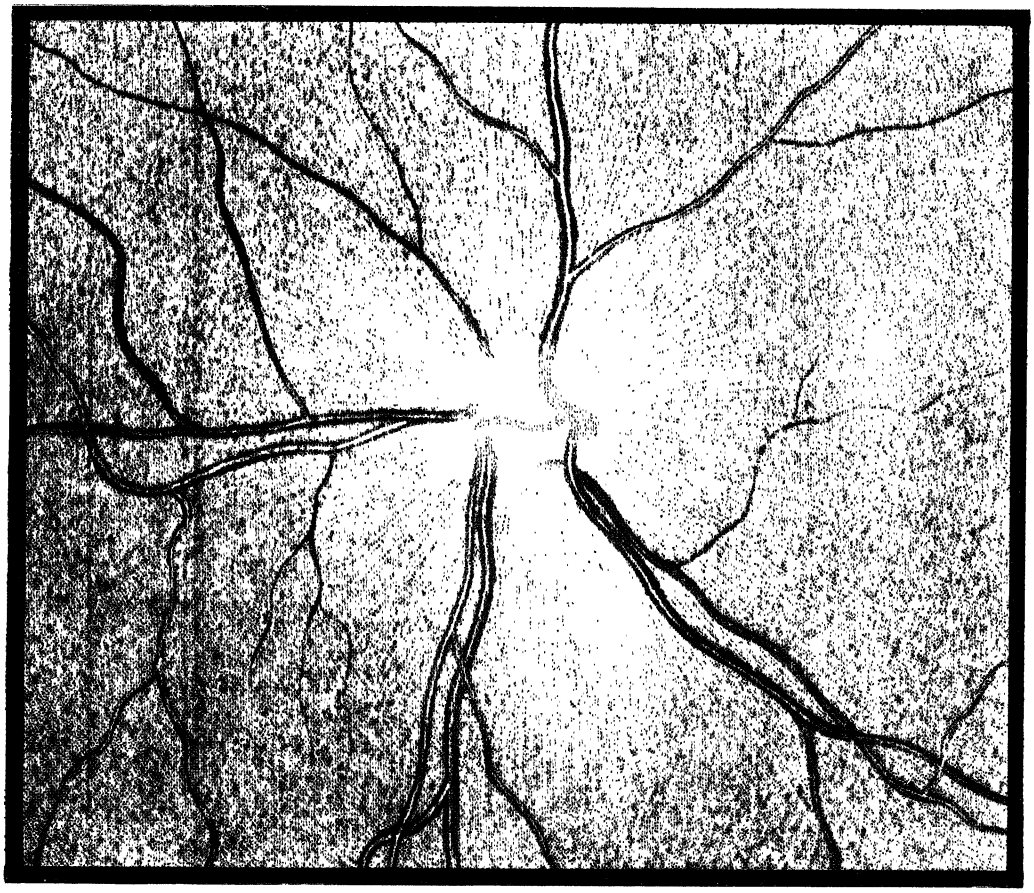

FIGURE 19. *Suricata suricatta*. Common suricate.

FIGURE 20. *Crocuta crocuta*. Spotted hyaena.

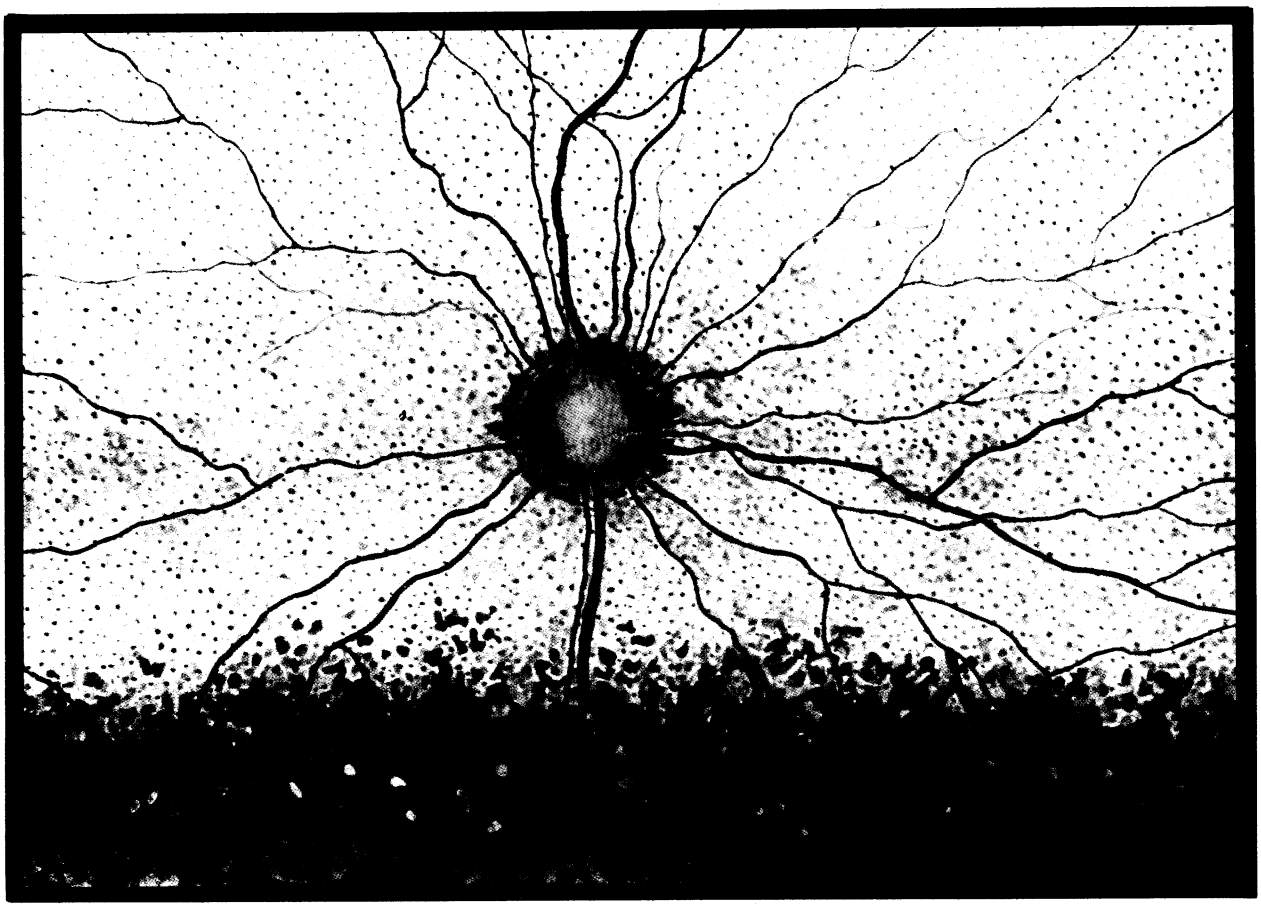

FIGURE 21. *Nyctereutes procyonoides*. Raccoon dog.

FIGURE 22. *Canis familiaris*. Collie dog.

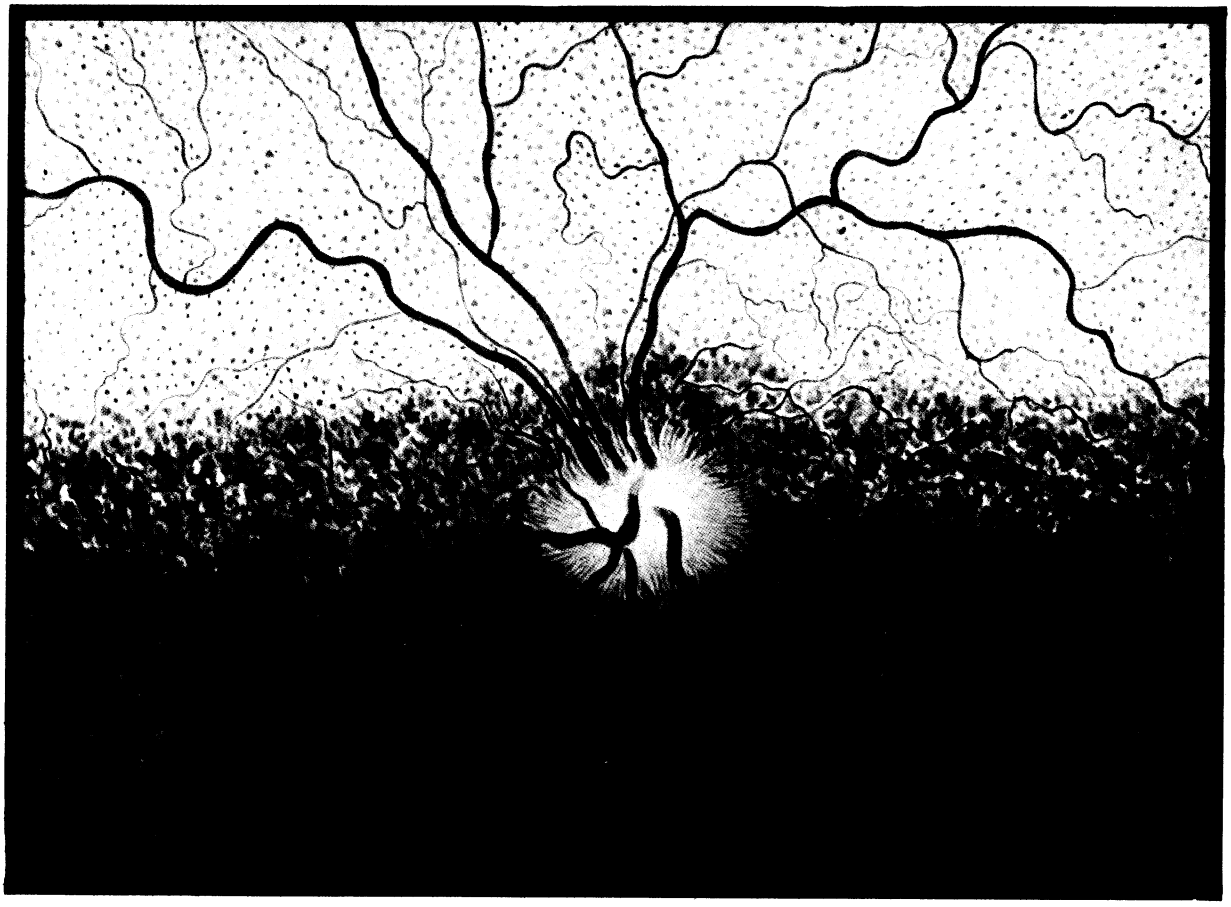

FIGURE 23. *Canis dingo*. Australian dingo.

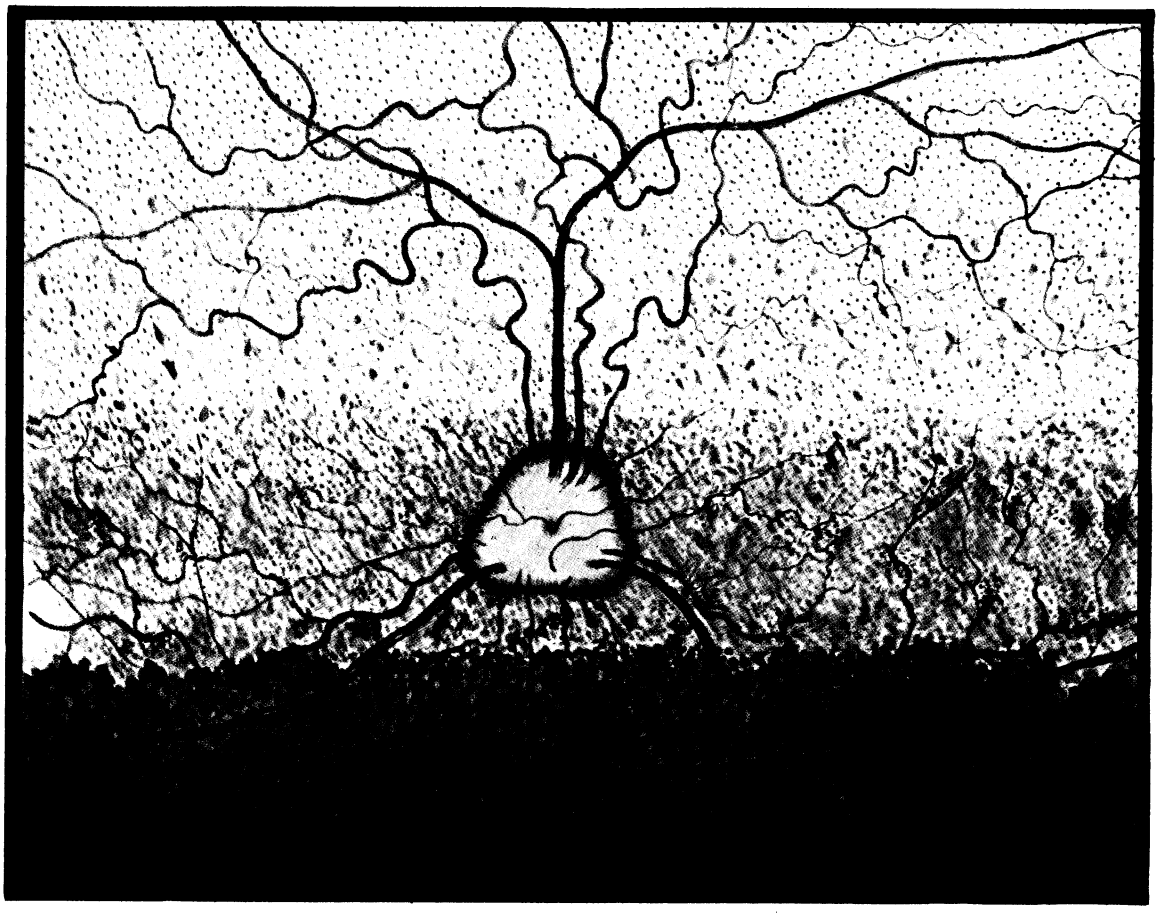

FIGURE 24. *Canis latrans*. Coyote.

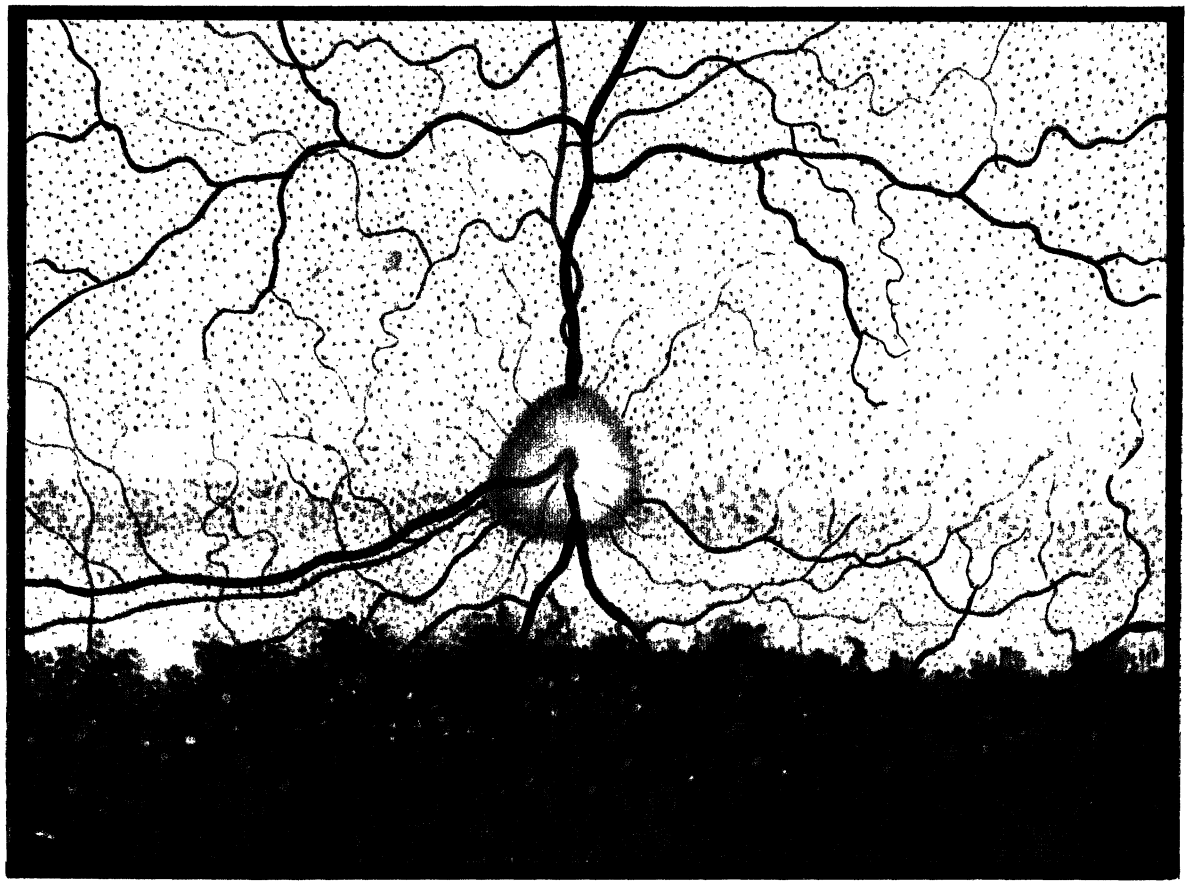

FIGURE 25. *Canis lupus*. Wolf.

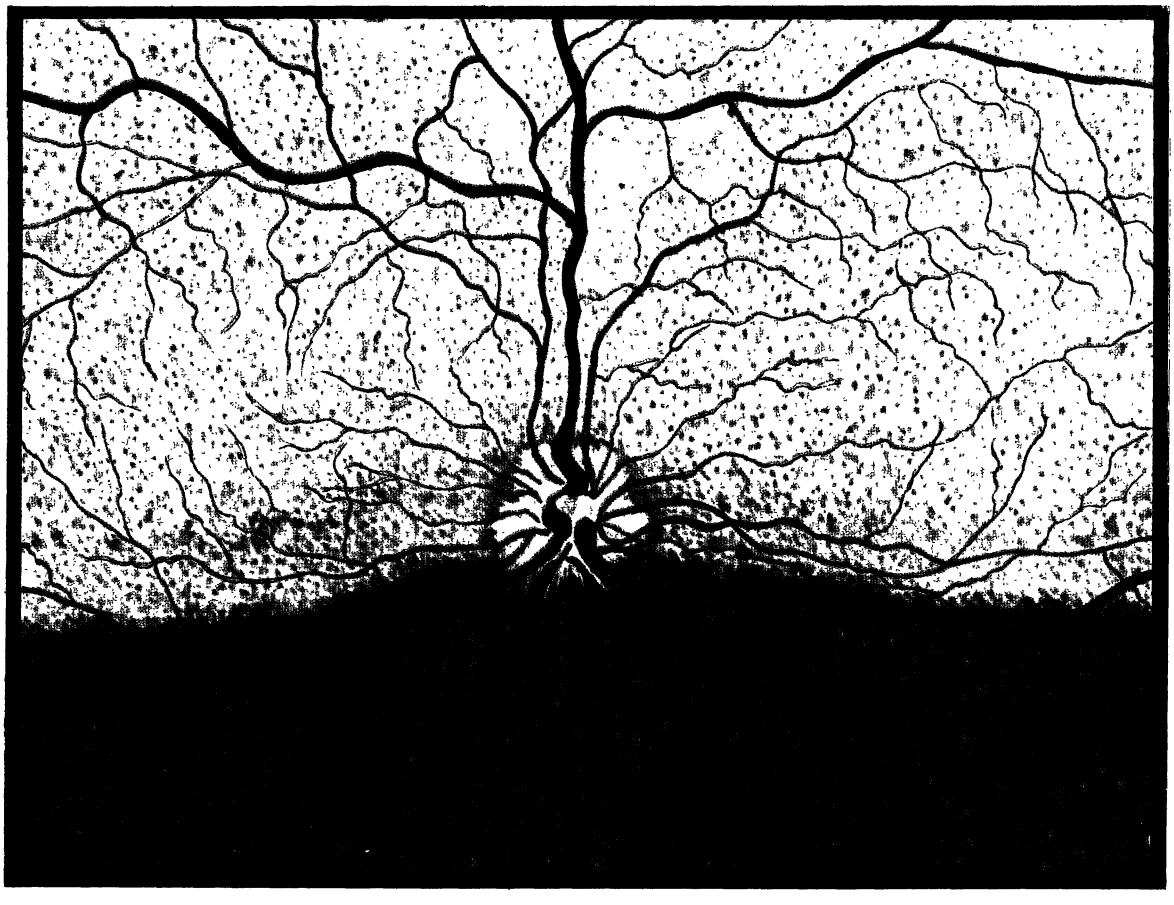

FIGURE 26. *Vulpes vulpes*. Red fox.

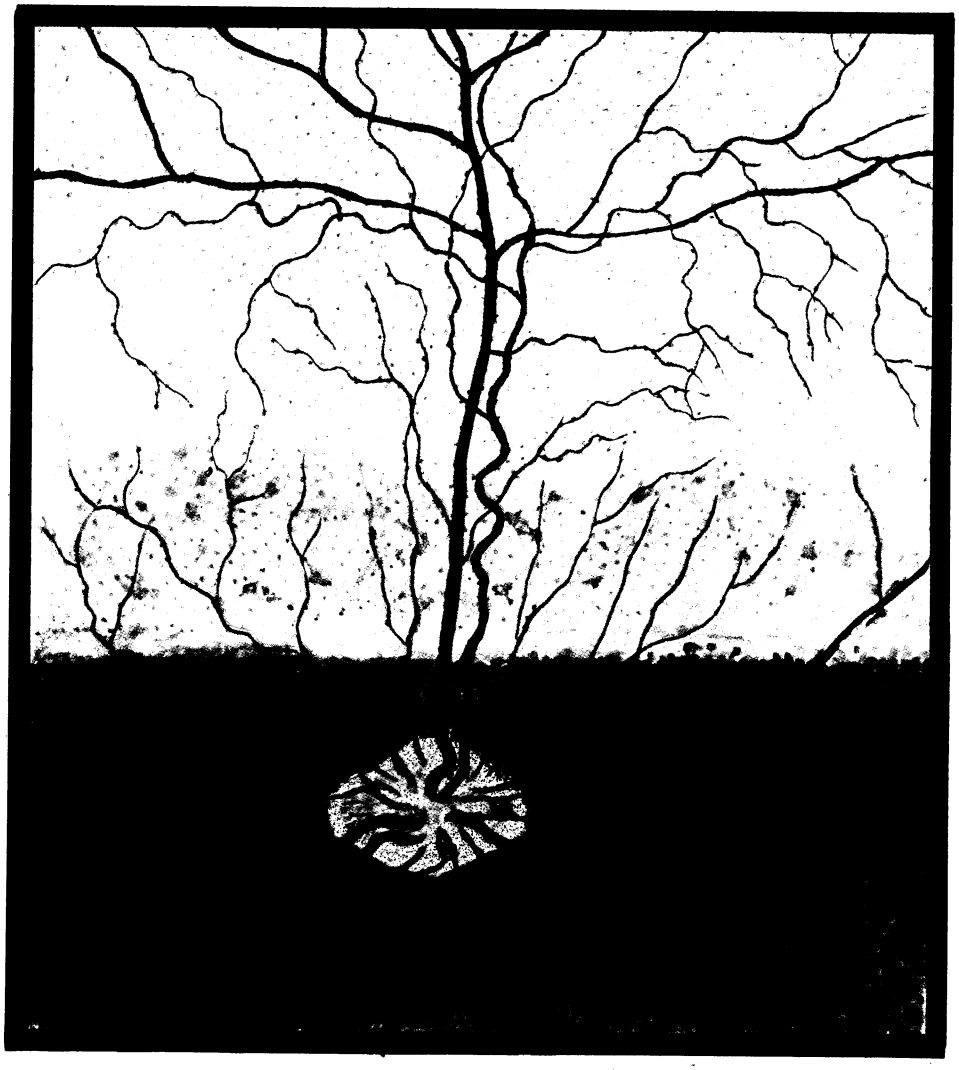

FIGURE 27. *Alopex lagopus*. Arctic fox.

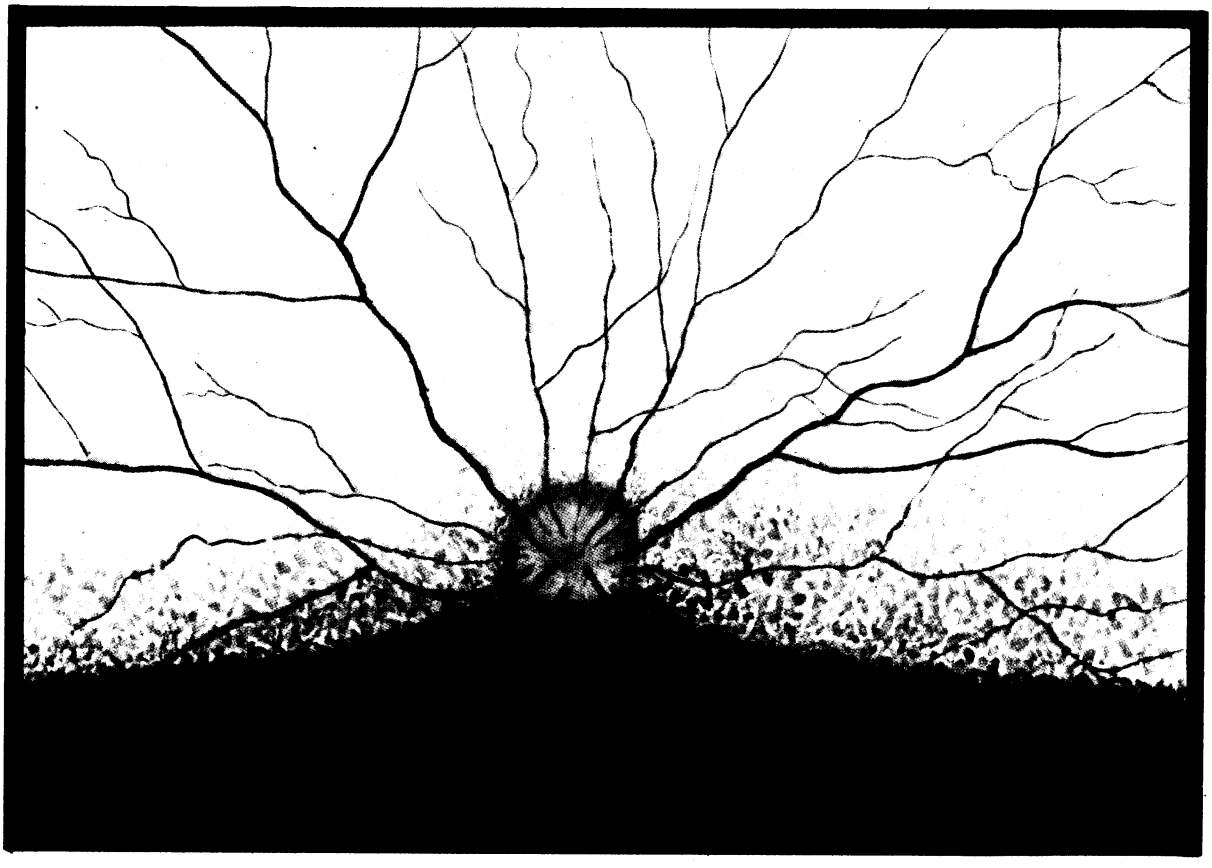

FIGURE 28. *Mustela putorius*. European polecat.

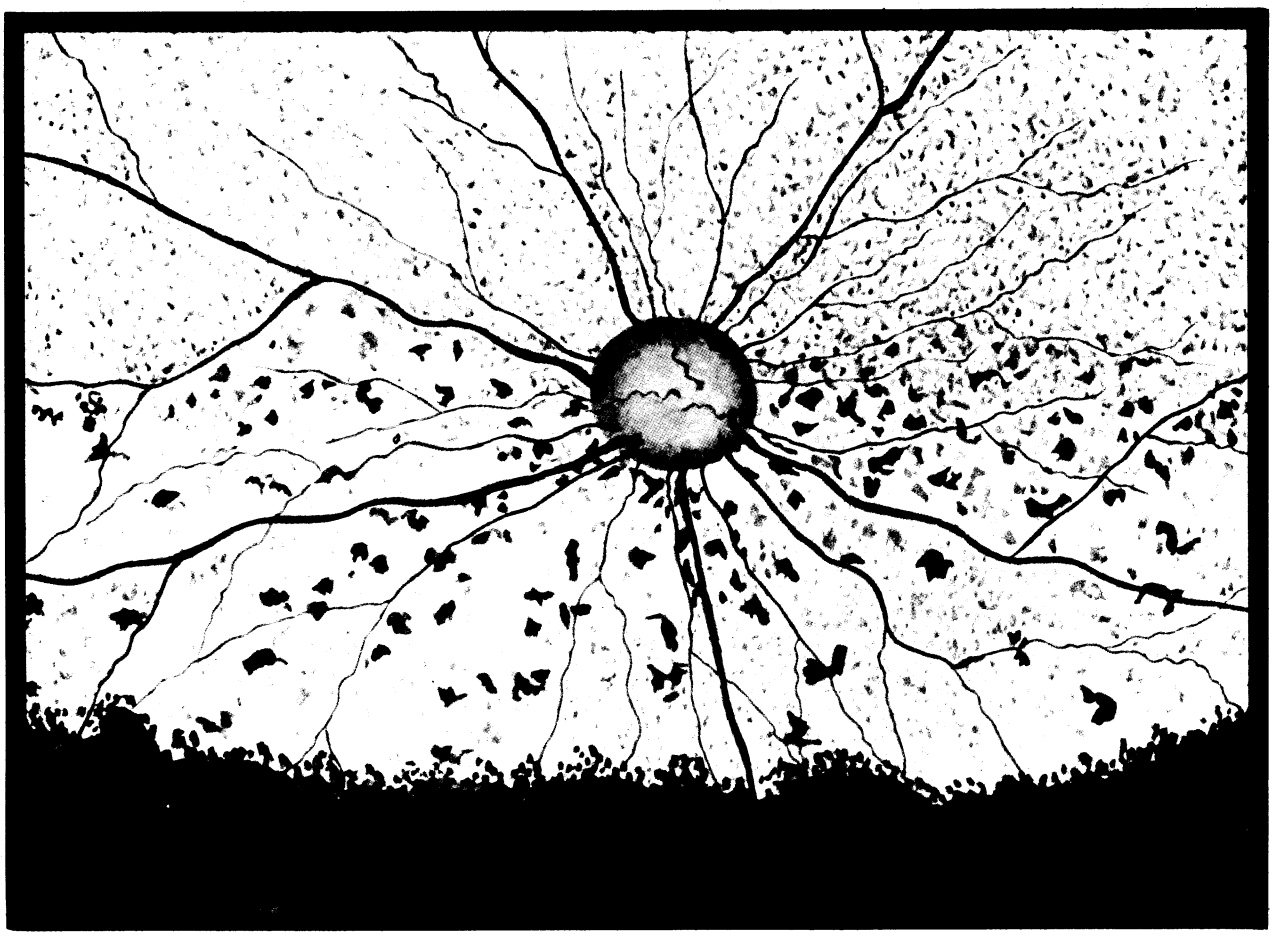

FIGURE 29. *Martes martes*. Pine marten.

FIGURE 30. *Ictonyx striatus*. Zorilla.

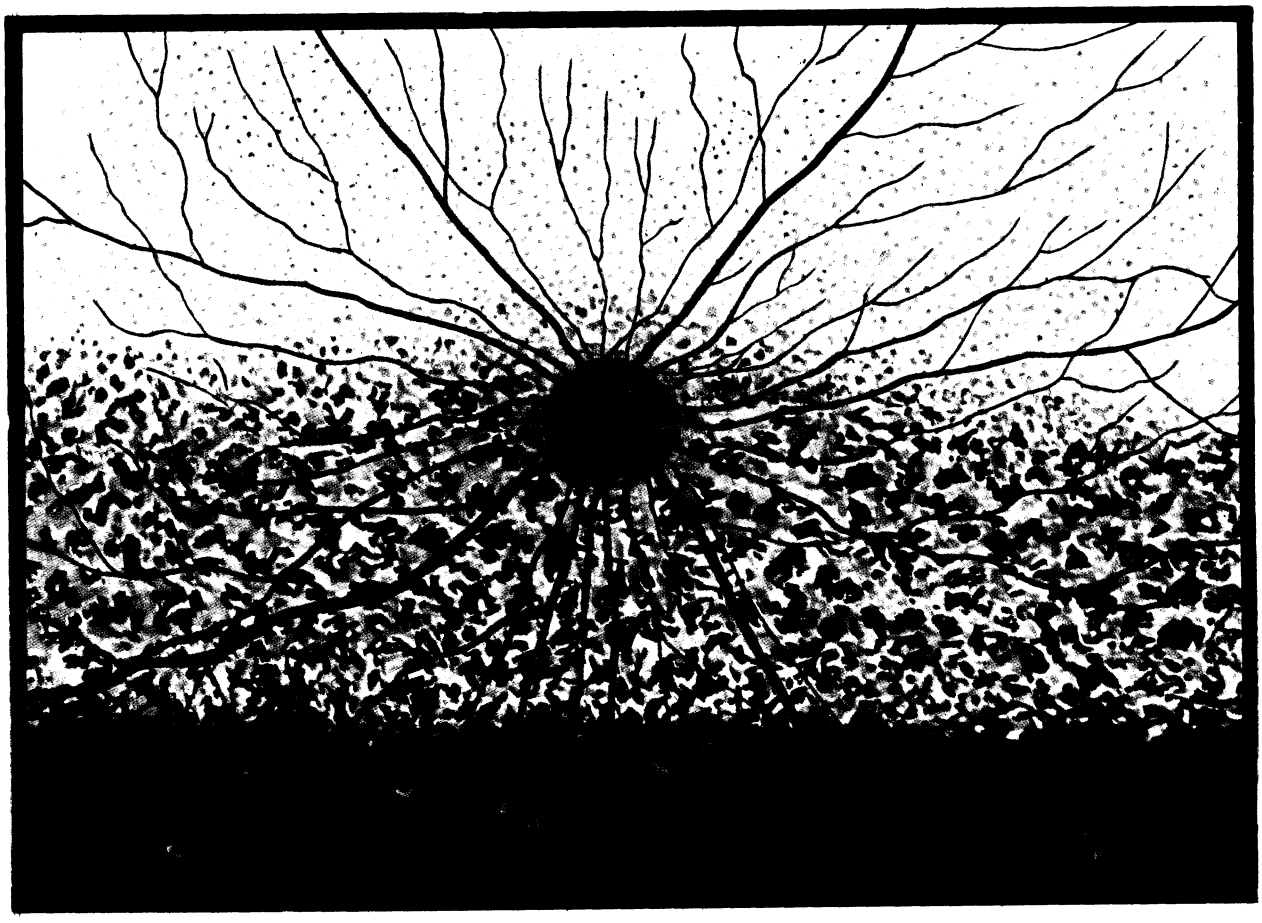

FIGURE 31. *Lutra lutra.* Eurasian otter.

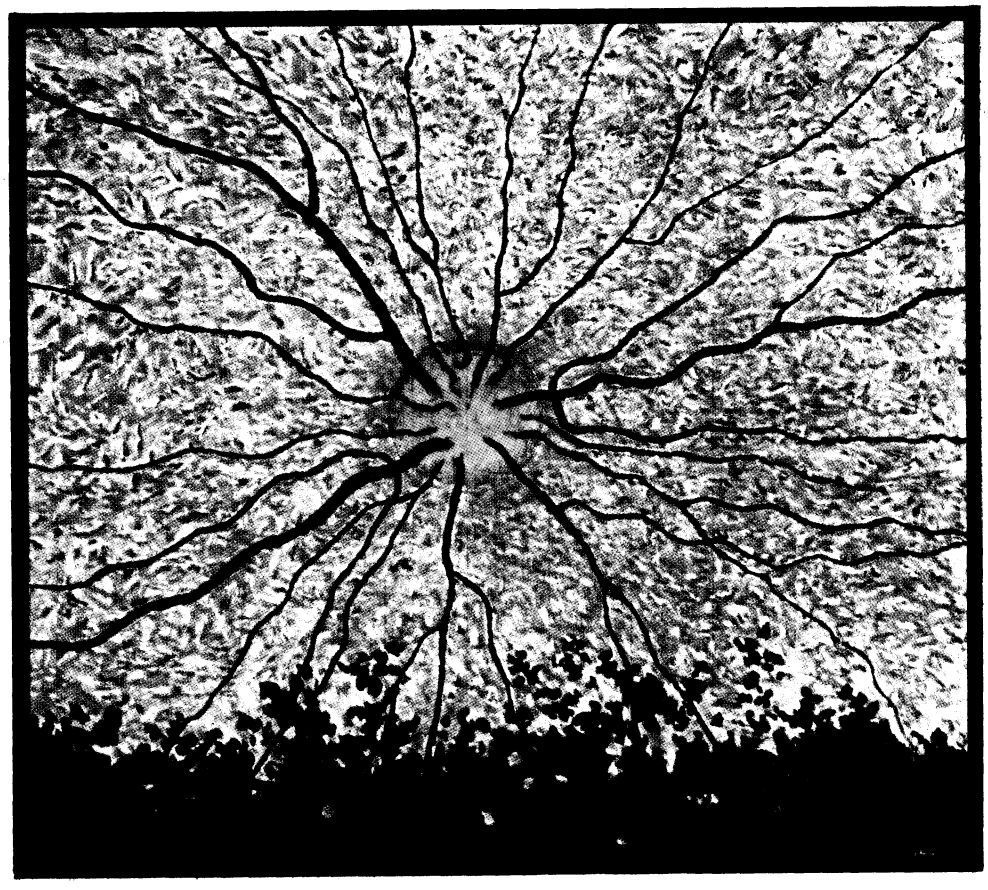

FIGURE 32. *Nasua nasua.* Coati.

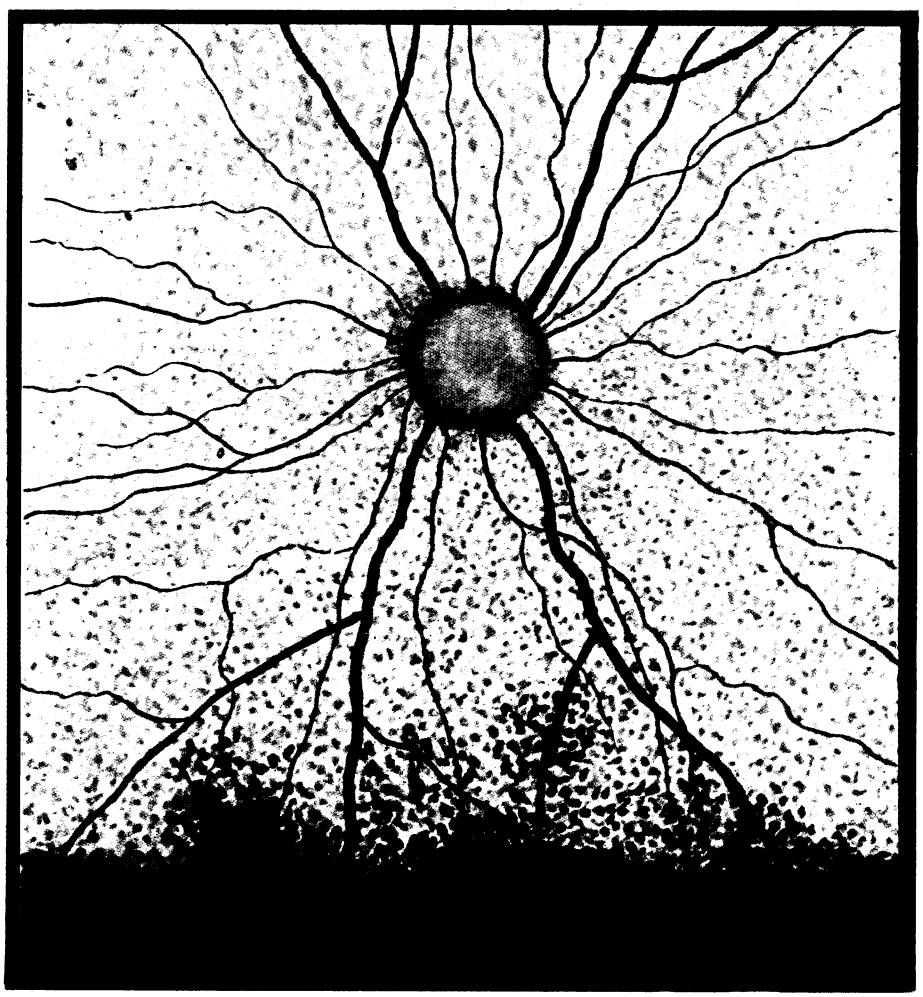

FIGURE 33. *Potos flavus*. Kinkajou.

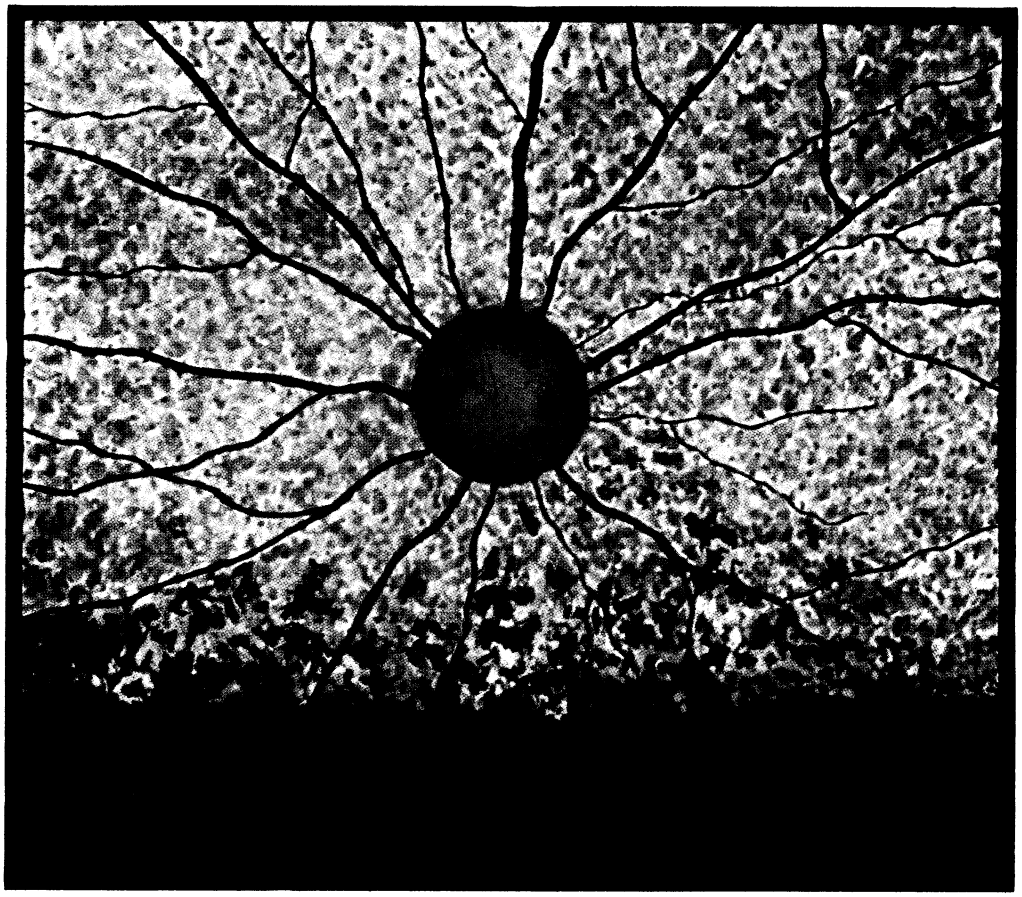

FIGURE 34. *Melursus ursinus*. Sloth bear.

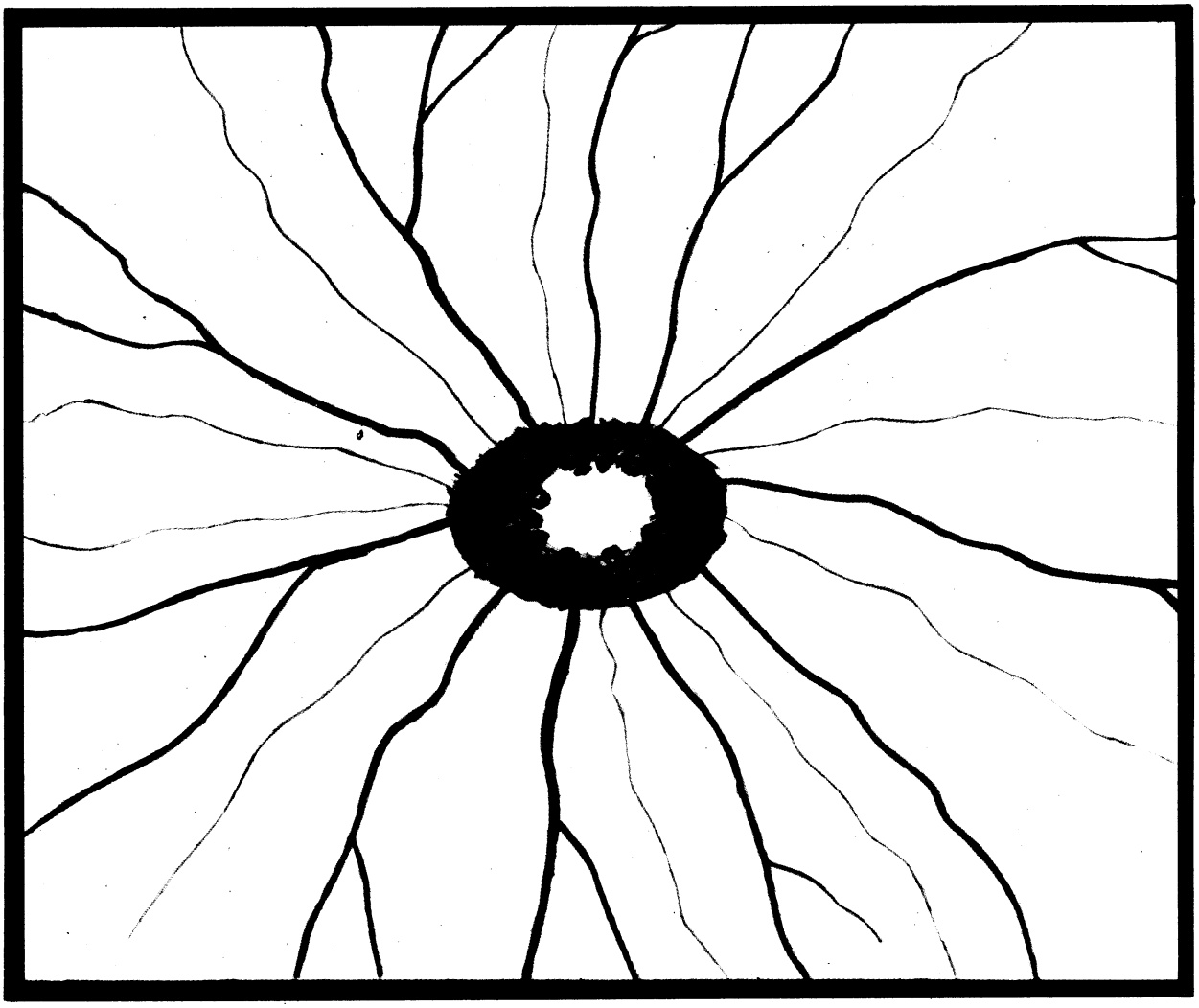

FIGURE 35. *Physeter catodon.* Sperm whale.

FIGURE 36. *Bos taurus.* British wild bull.

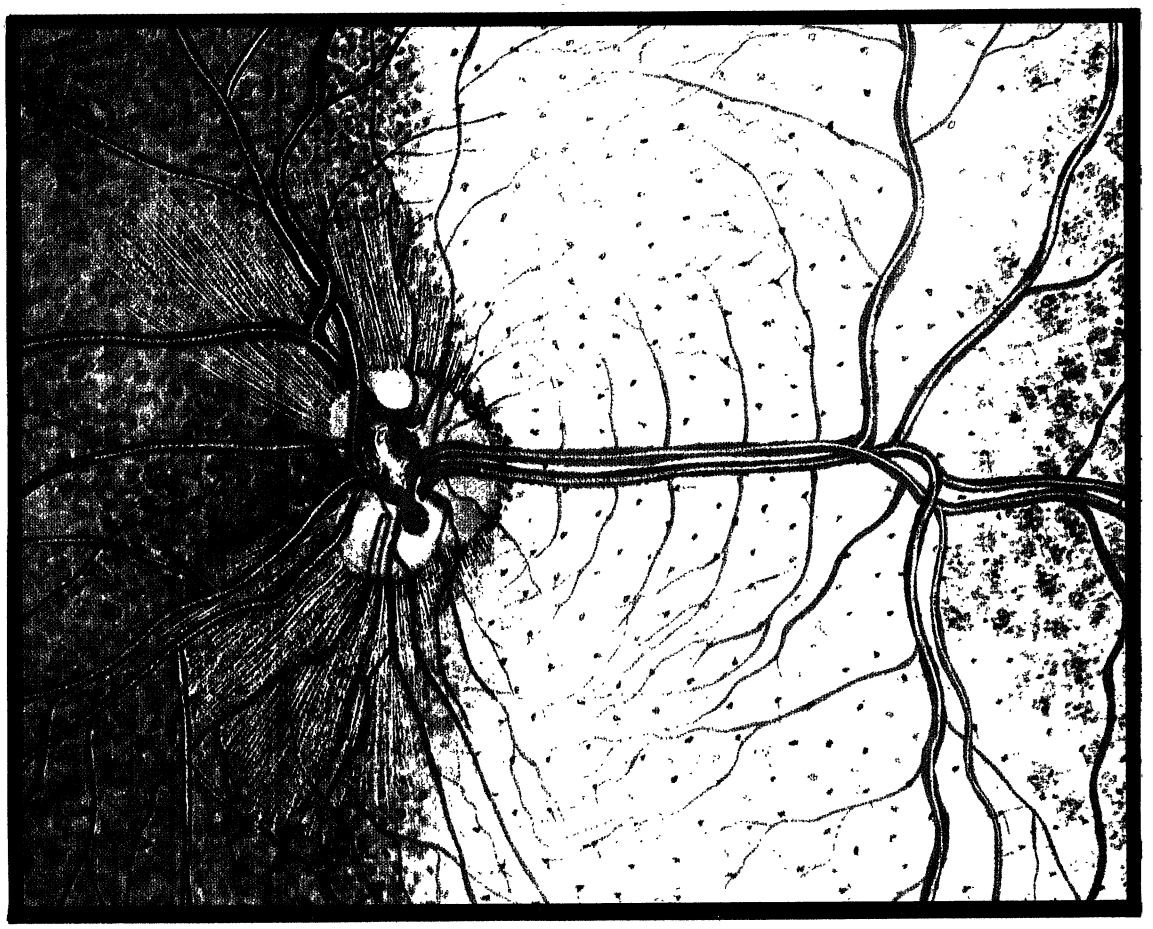

FIGURE 37. *Ovis musimon*. Mouflon.

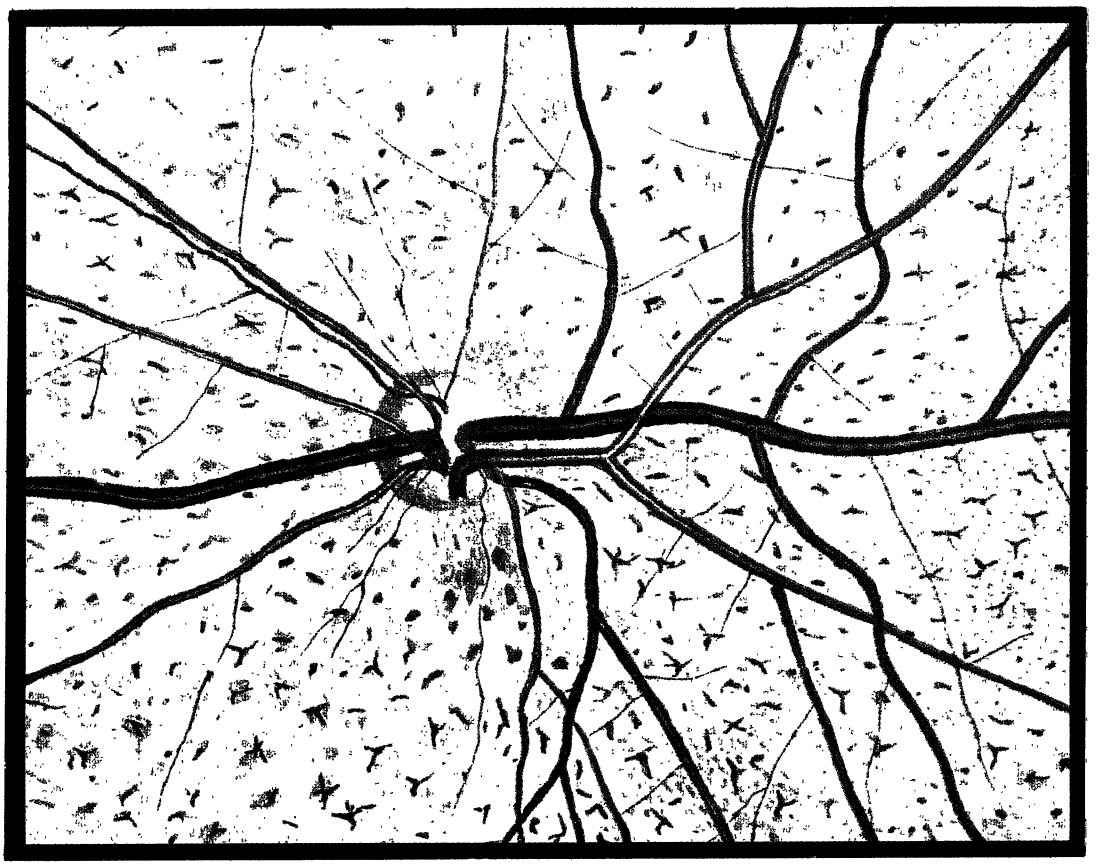

FIGURE 38. *Capra hircus*. Domestic goat.

FIGURE 39. *Gazella dorcas*. Dorcas gazelle.

FIGURE 40. *Rangifer tarandus*. Reindeer.

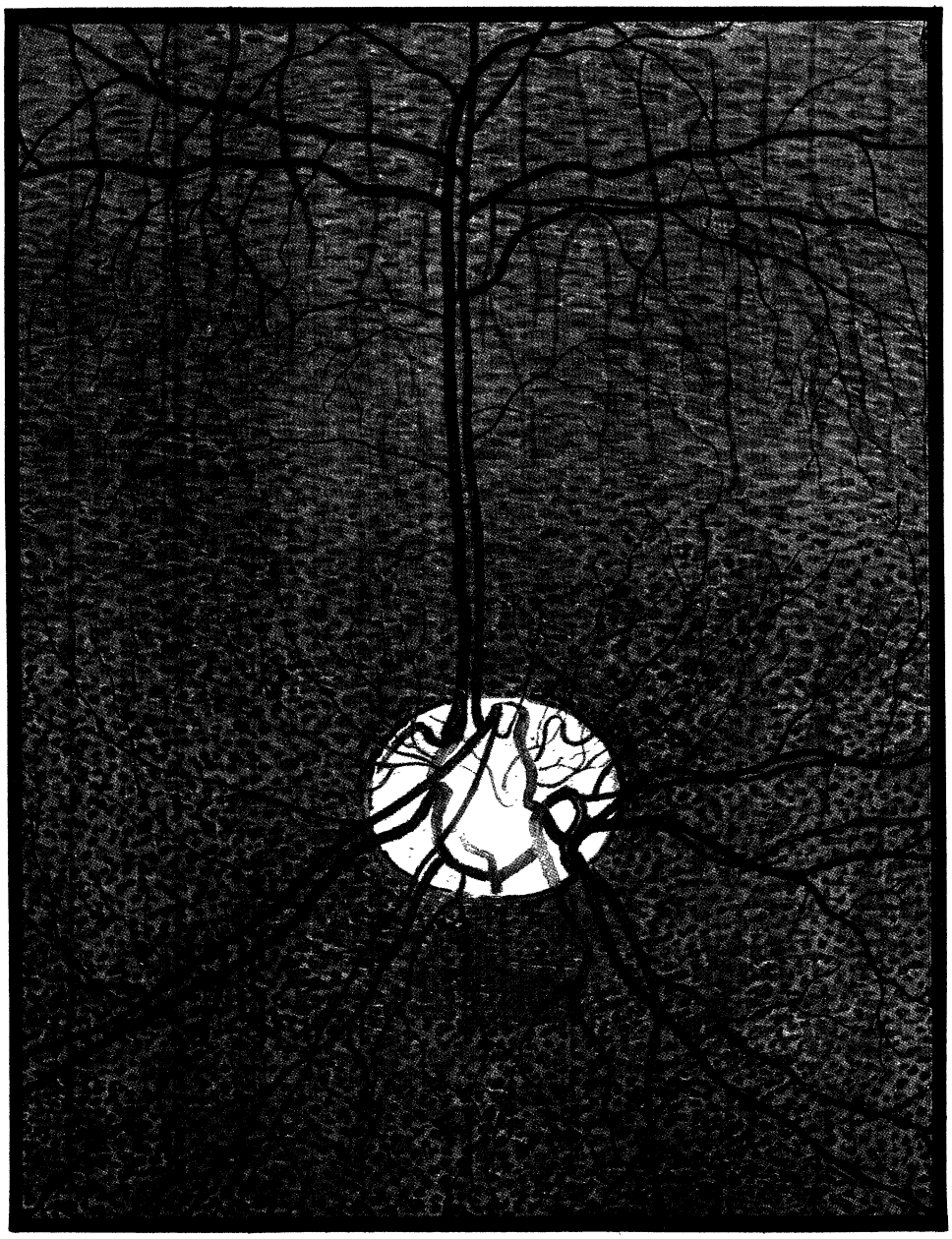

FIGURE 41. *Lama glama*. Llama.

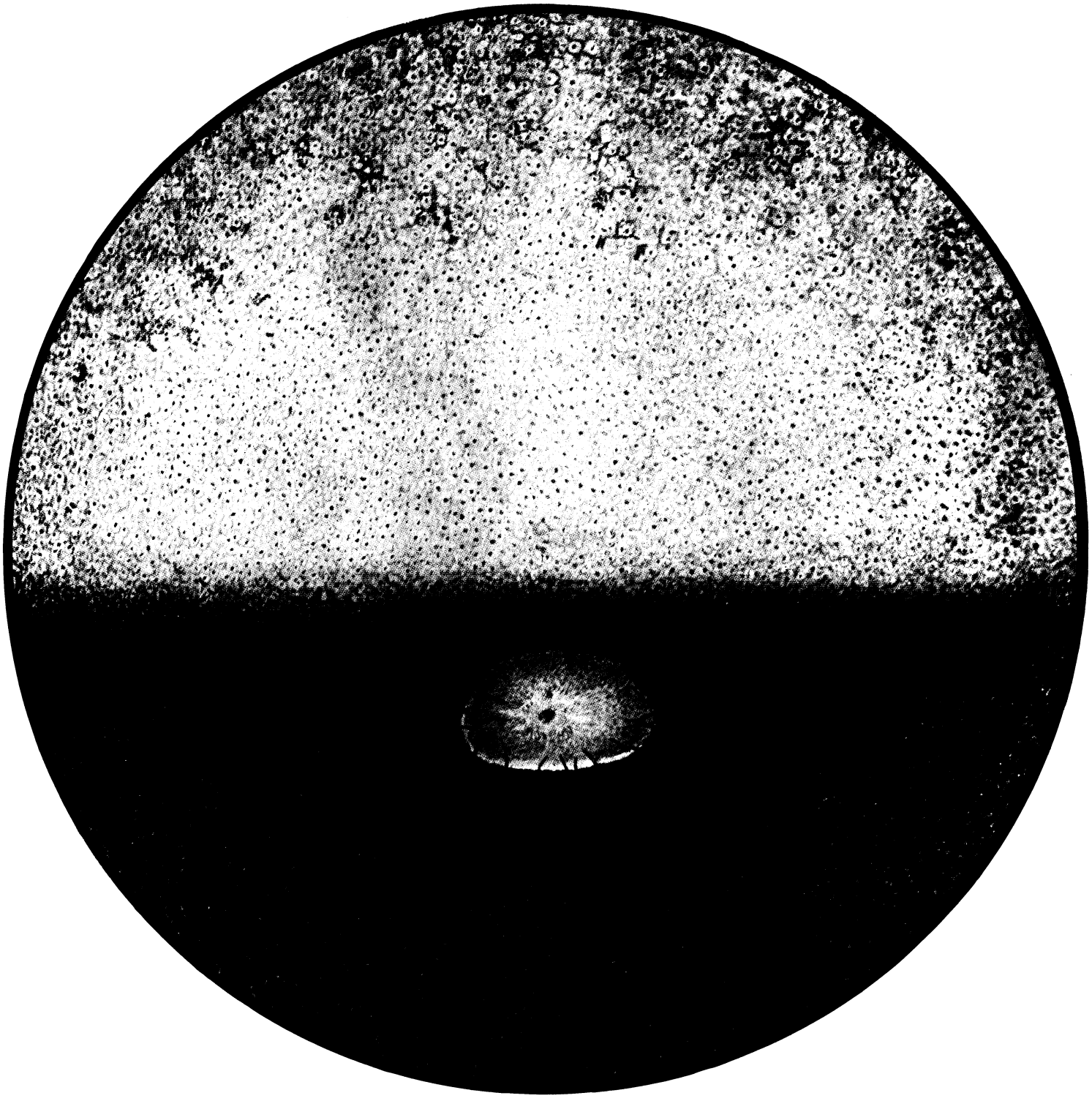

FIGURE 42. *Equus caballus*. Domestic horse.

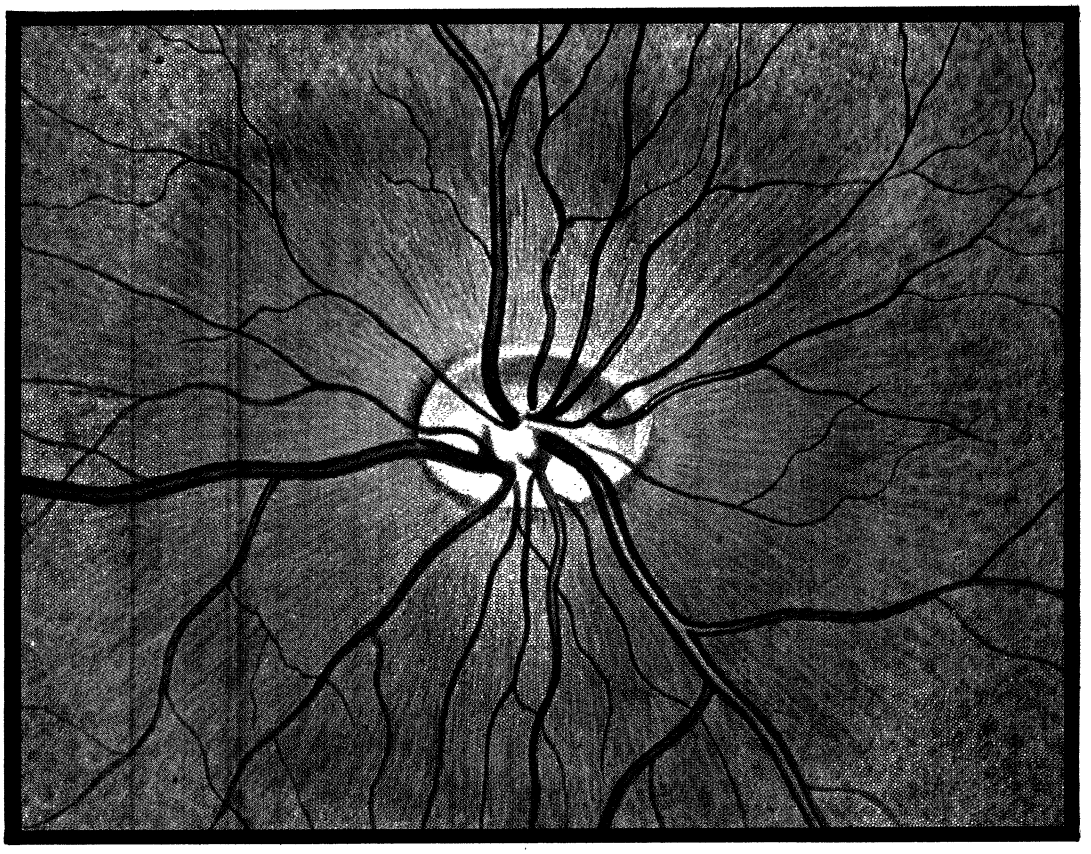

FIGURE 43. *Sus scrofa*. Domestic pig.

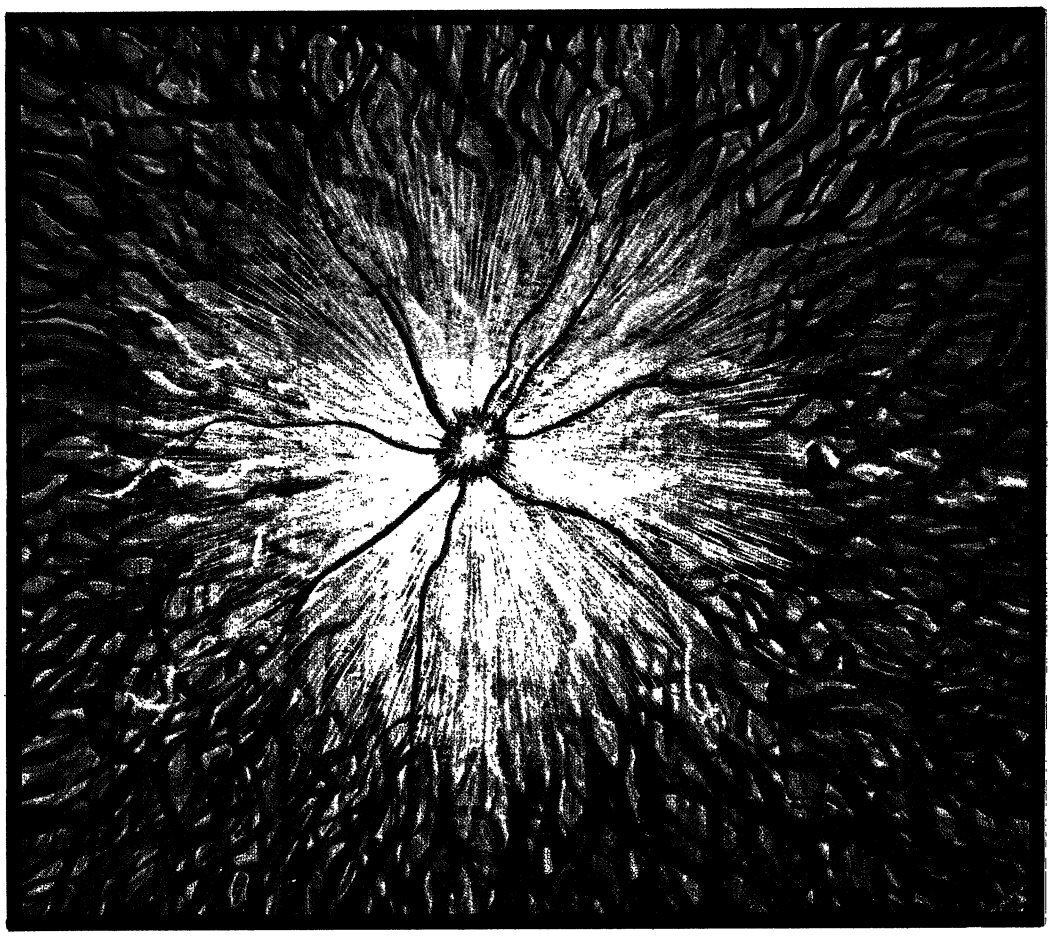

FIGURE 44. *Eliomys dryas*. Garden dormouse.

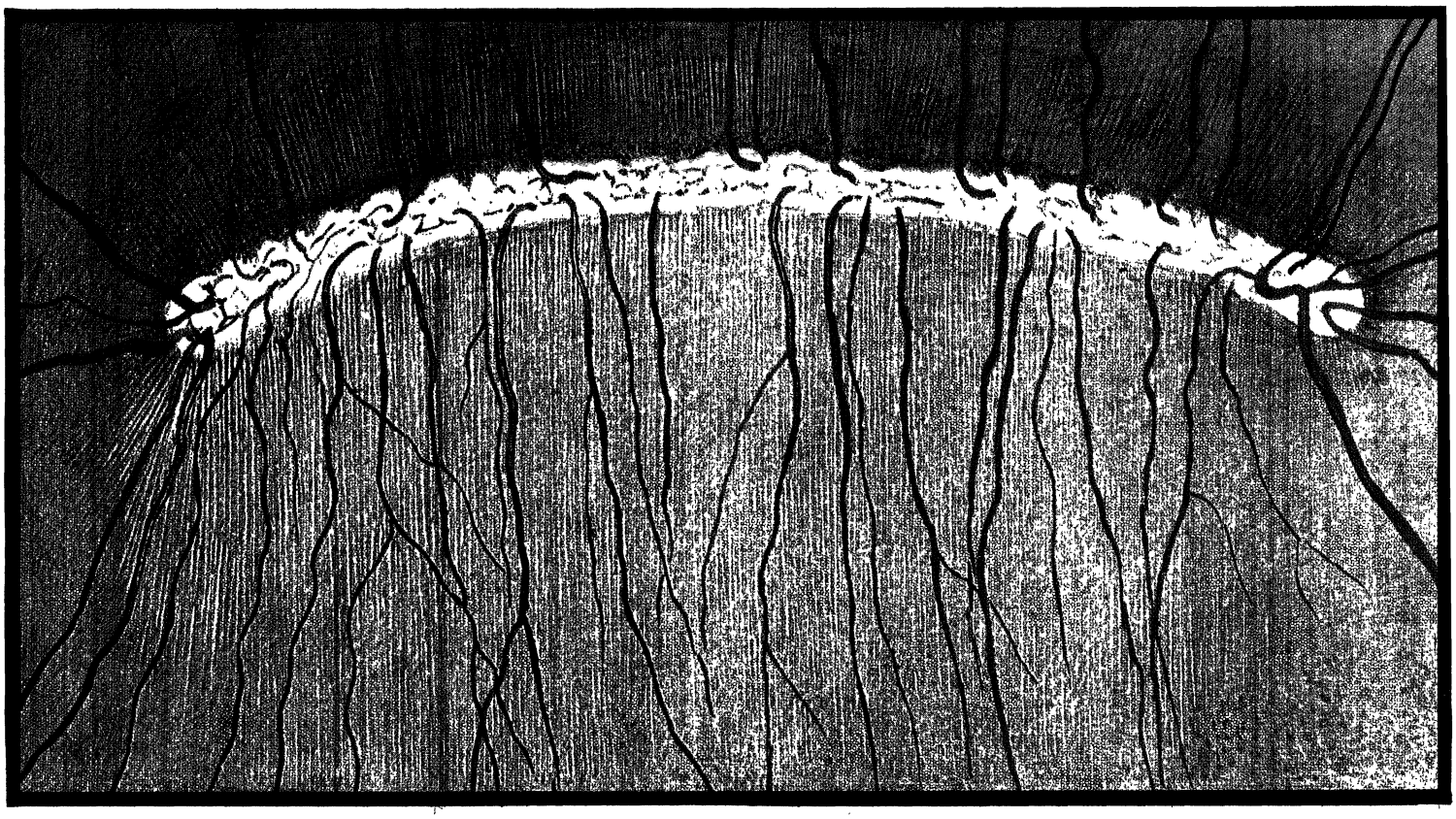

FIGURE 45. *Citellus citellus*. Ground squirrel.

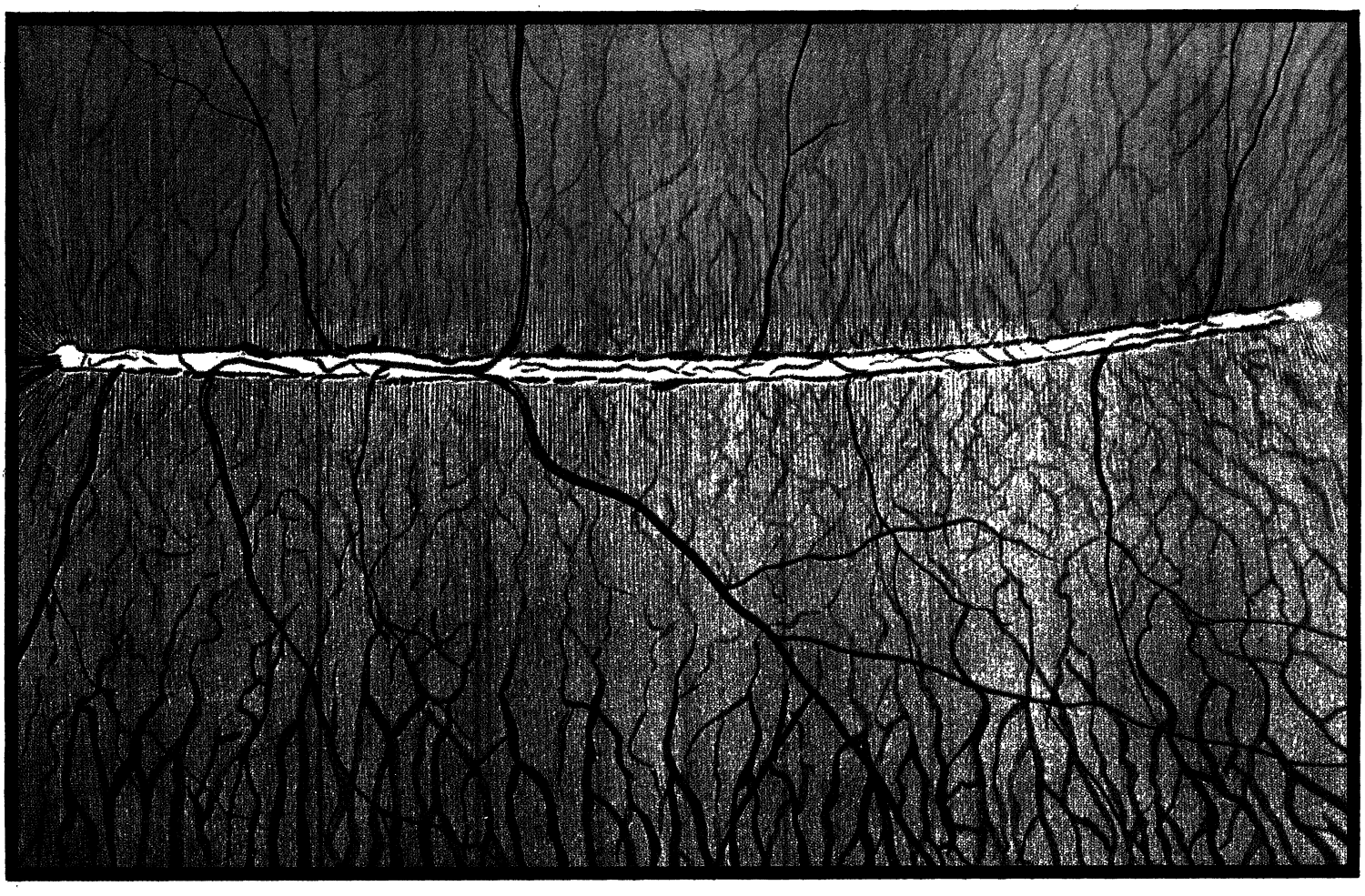

FIGURE 46. *Cynomys ludovicianus*. Prairie marmot.

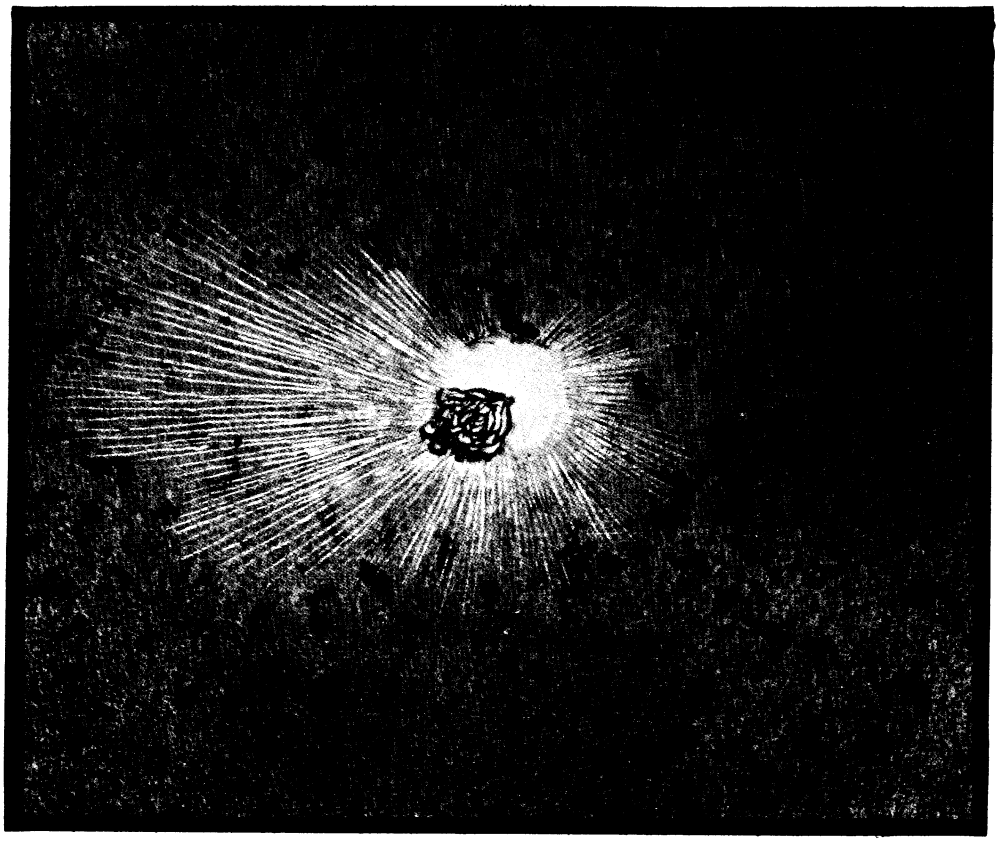

FIGURE 47. *Myocastor coypus*. Coypu.

FIGURE 48. *Oryctolagus cuniculus*. Albino rabbit.

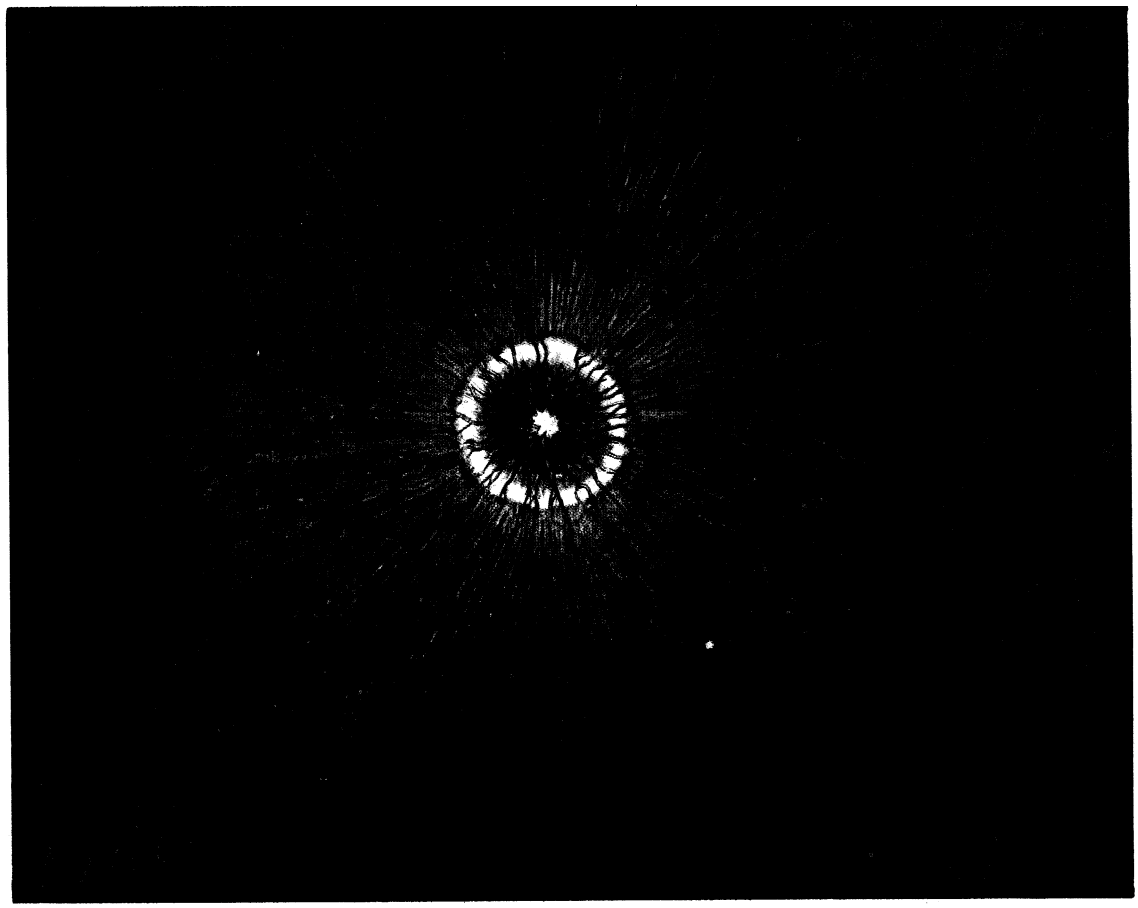

FIGURE 49. *Dendrolagus bennettianus*. Bennett's tree kangaroo.

FIGURE 50. *Petaurus norfolcensis*. Flying opossum.

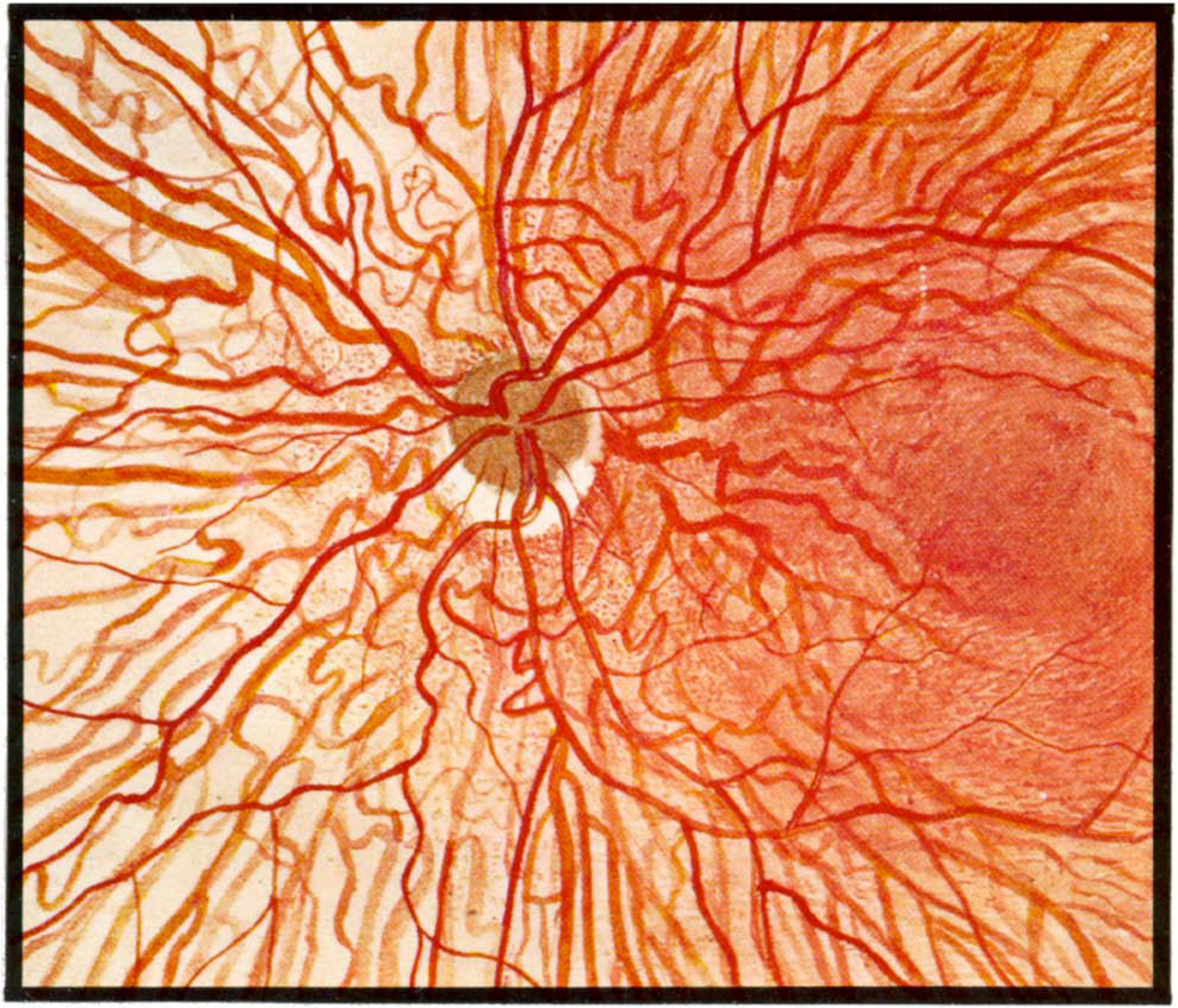

FIGURE 1. *Homo sapiens*. European albino.

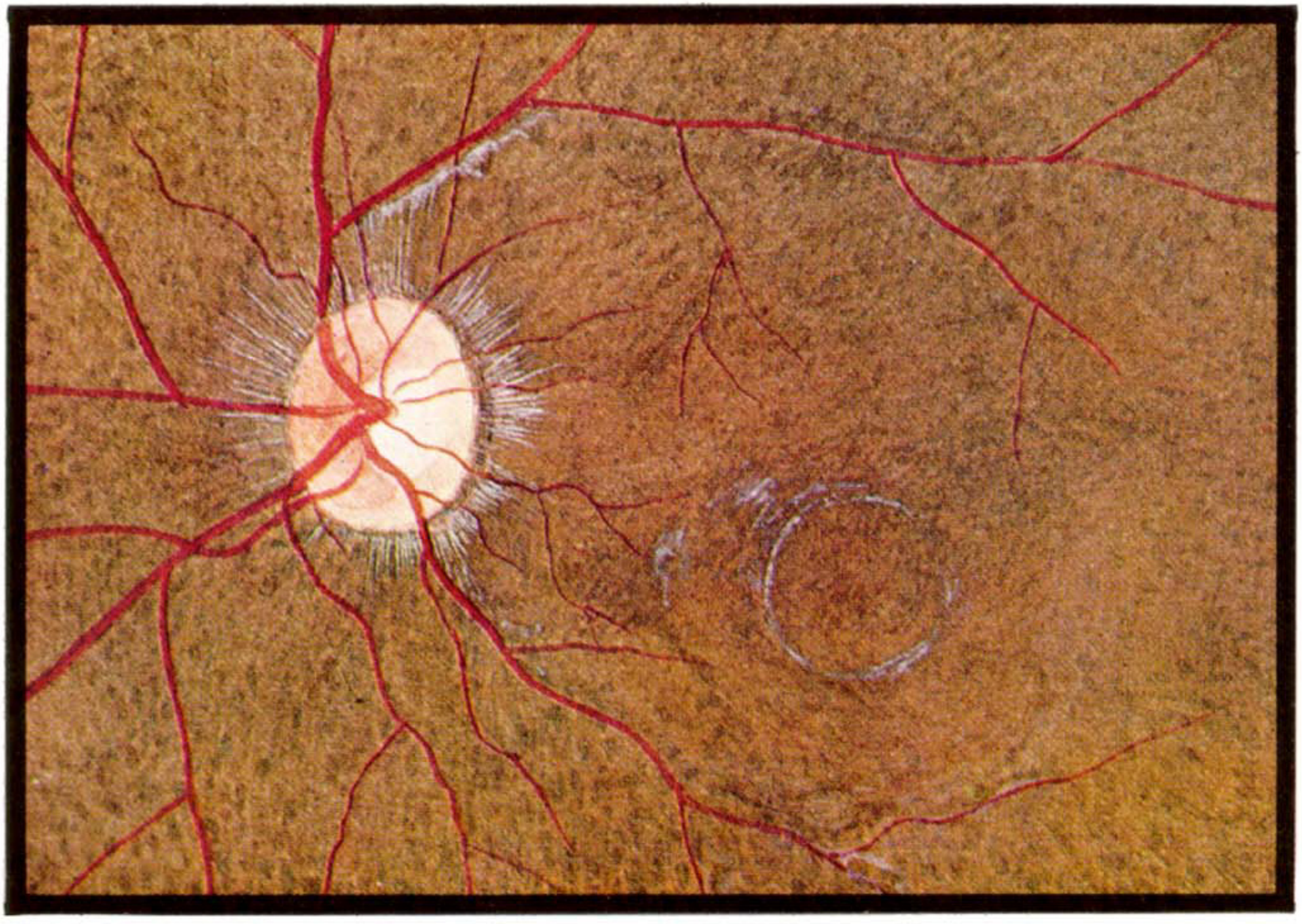

FIGURE 2. *Pongo pygmaeus*. Orang-utan.

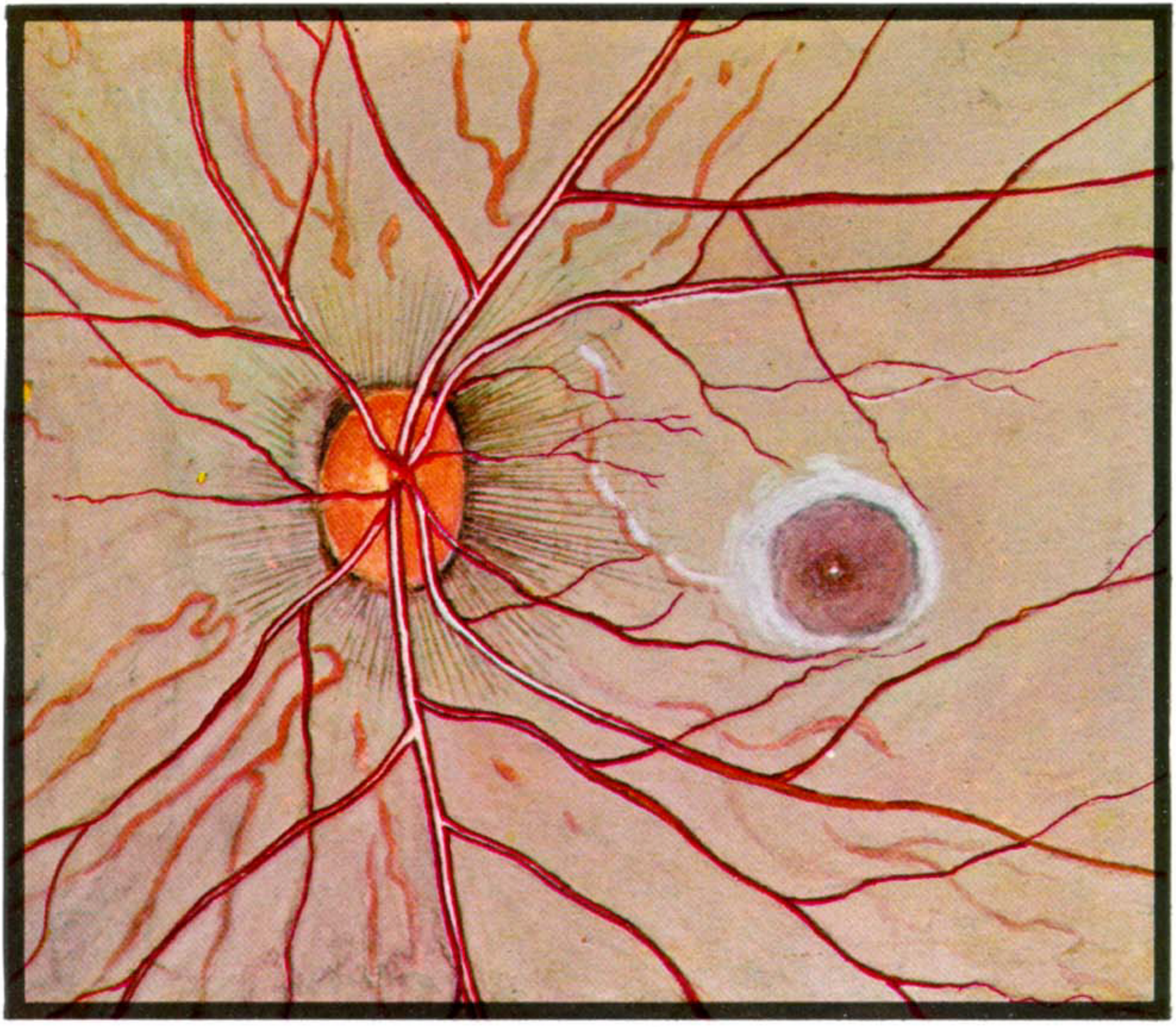

FIGURE 3. *Macaca mulatta*. Rhesus macaque.

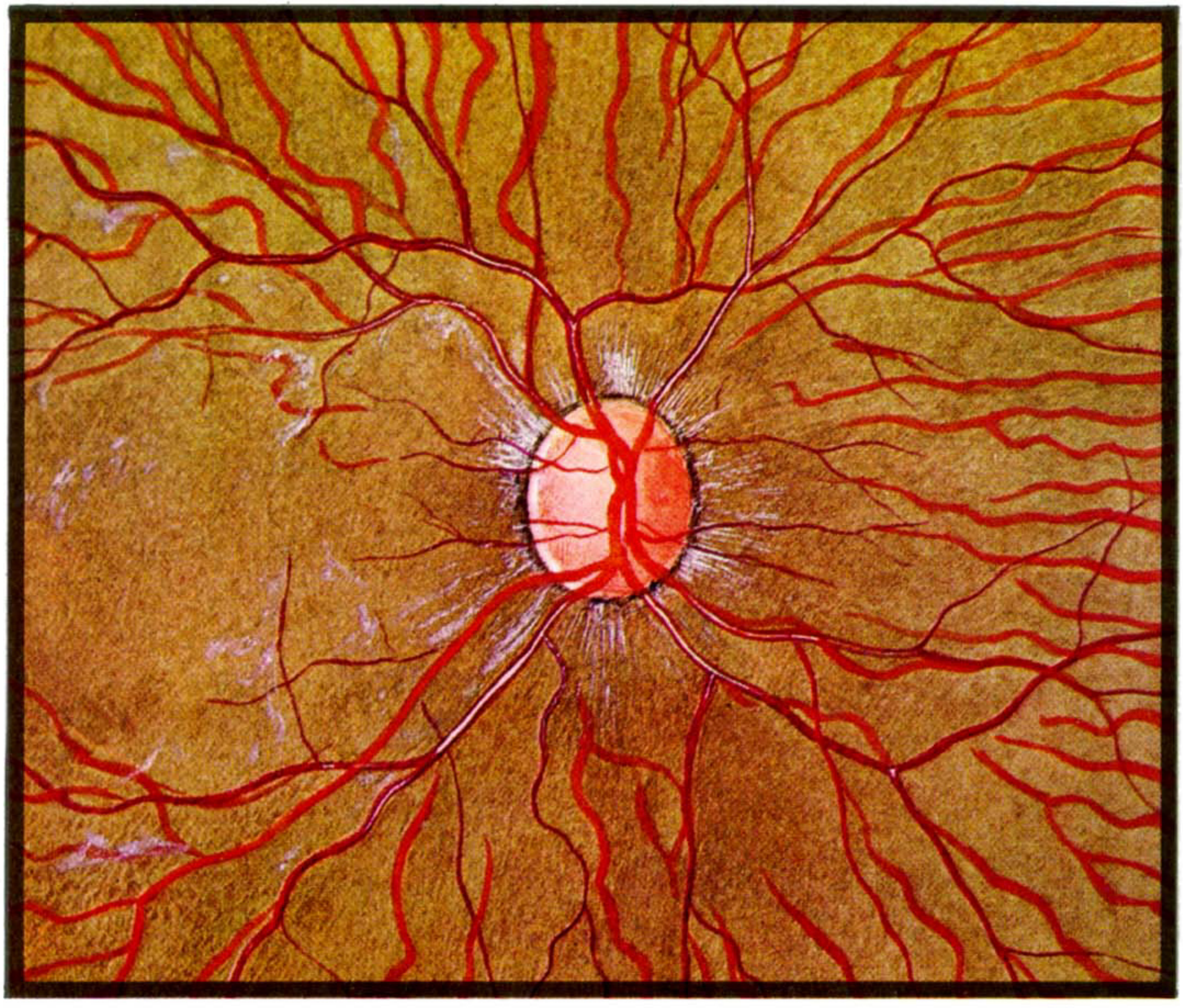

FIGURE 4. *Mandrillus sphinx*. Mandrill.

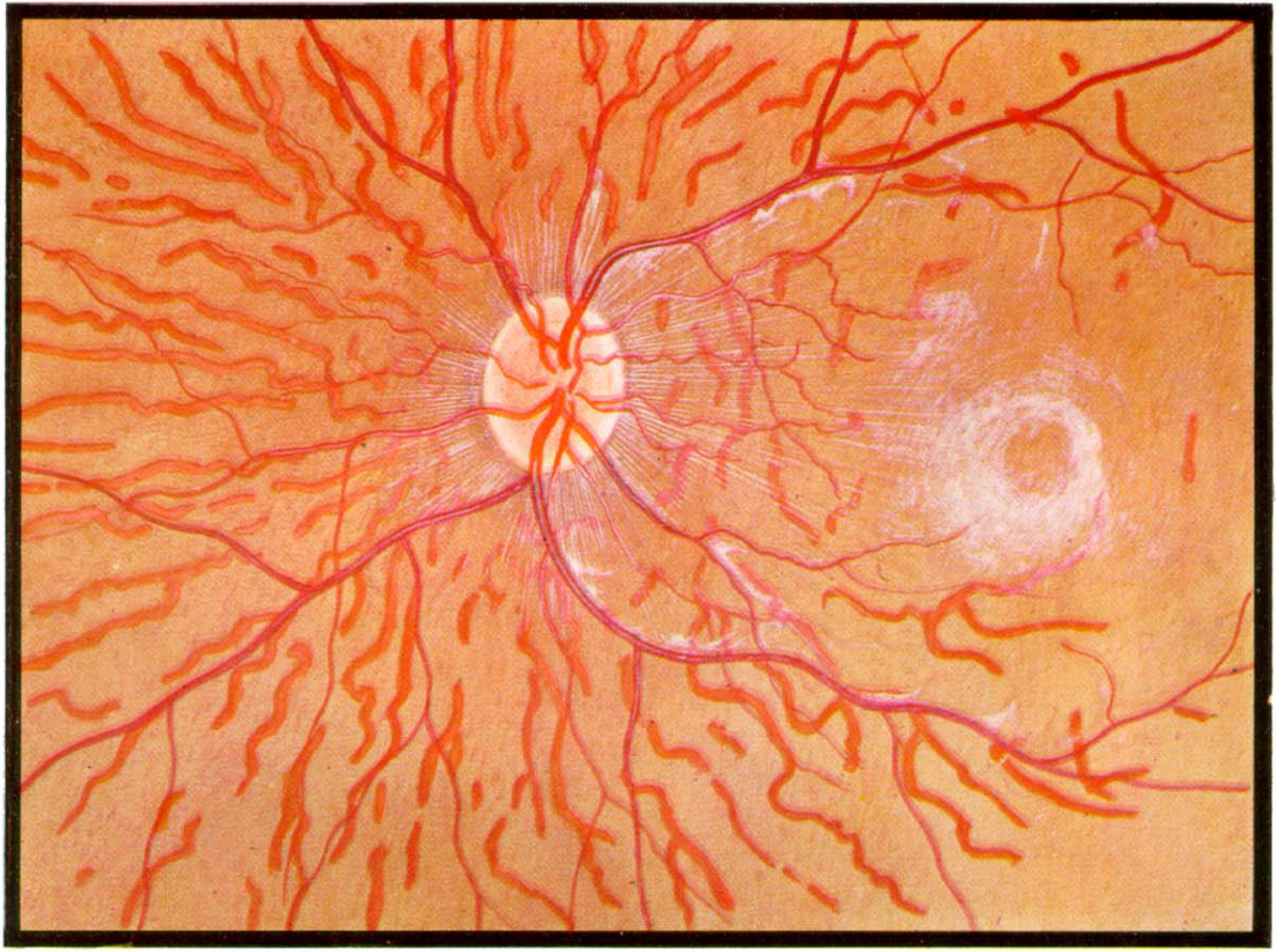

FIGURE 5. *Cercopithecus albigularis*. Sykes's monkey.

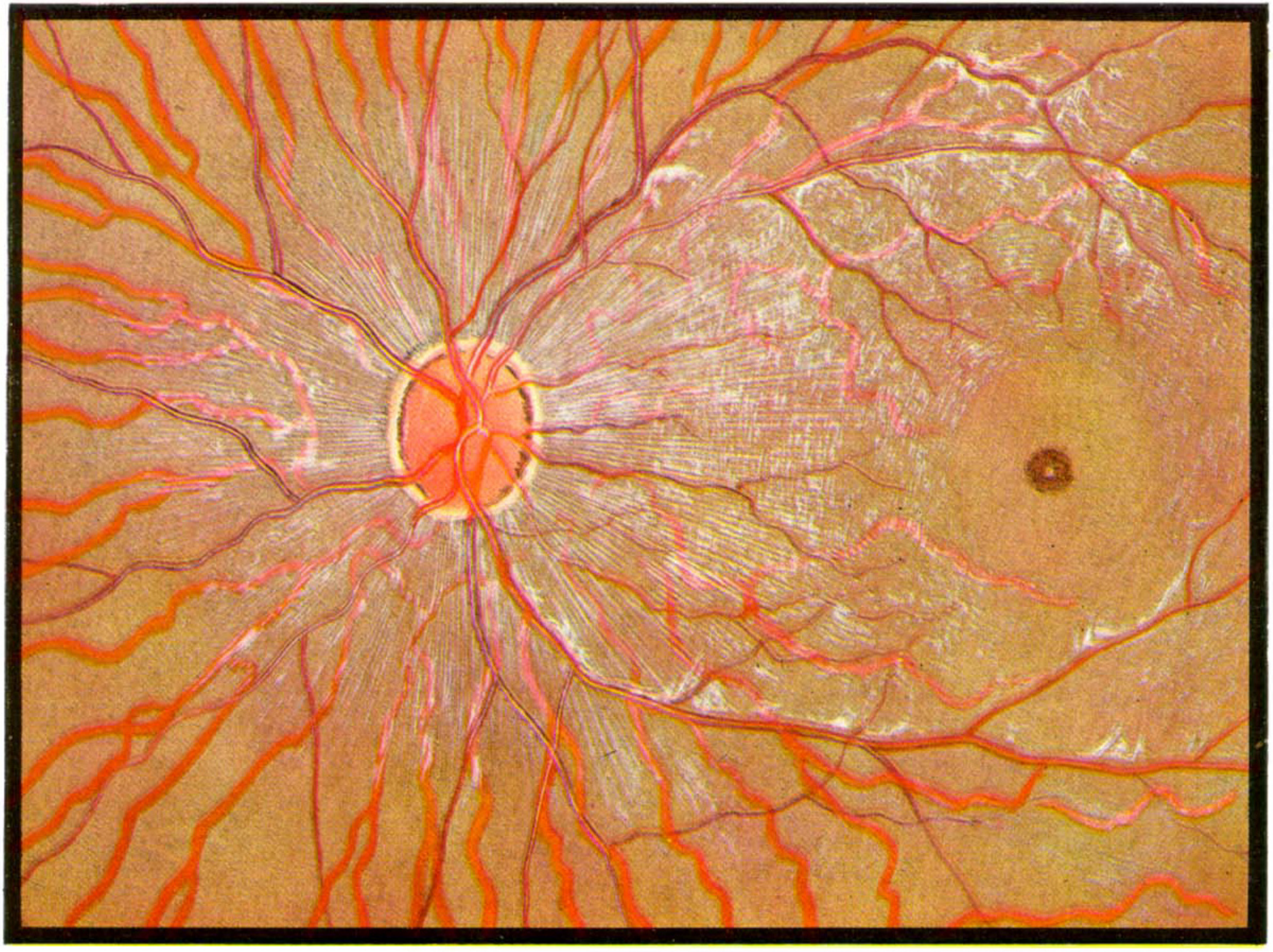

FIGURE 6. *Cercopithecus aethiops*. Green monkey.

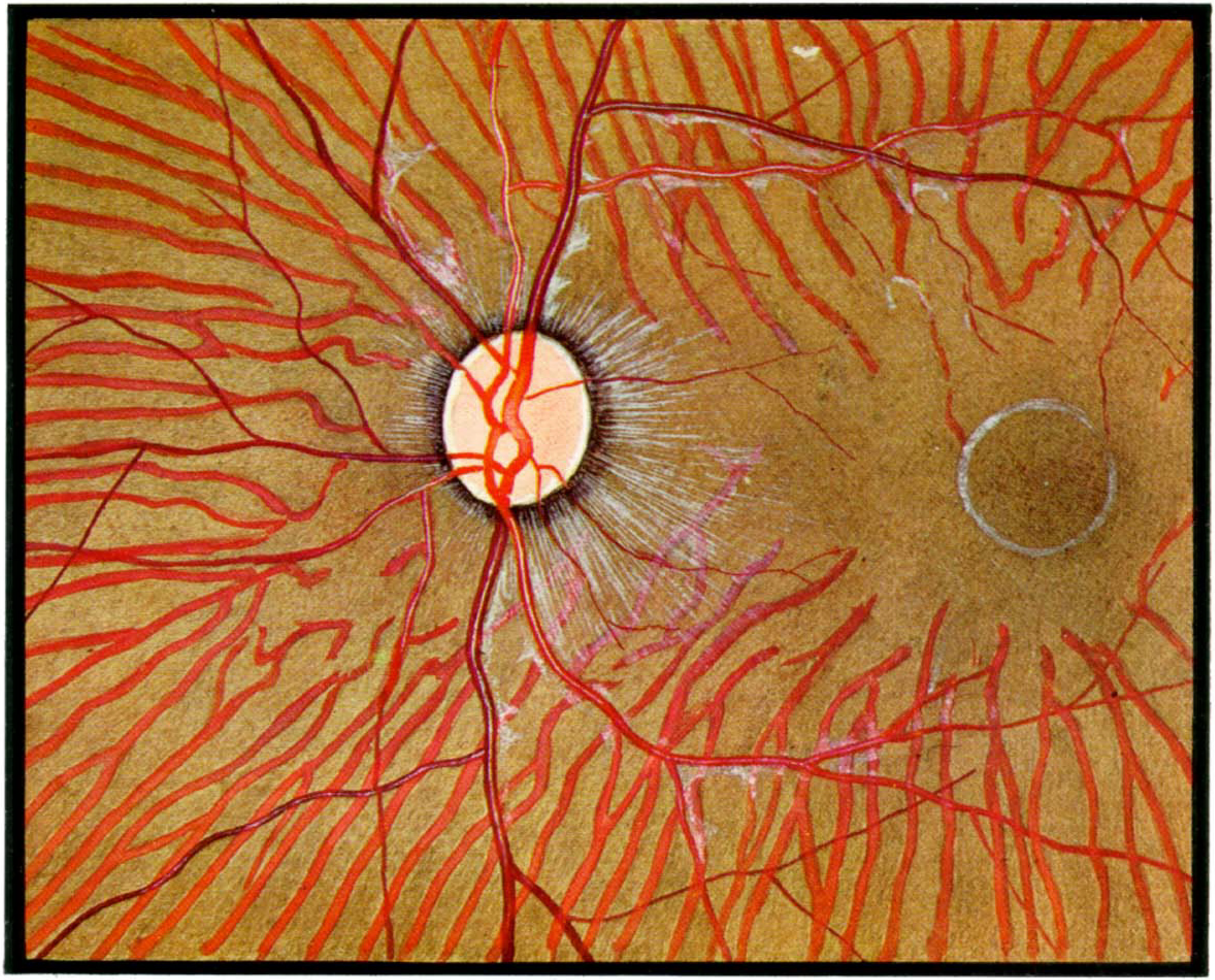

FIGURE 7. *Cercocebus torquatus*. Sooty mangabey.

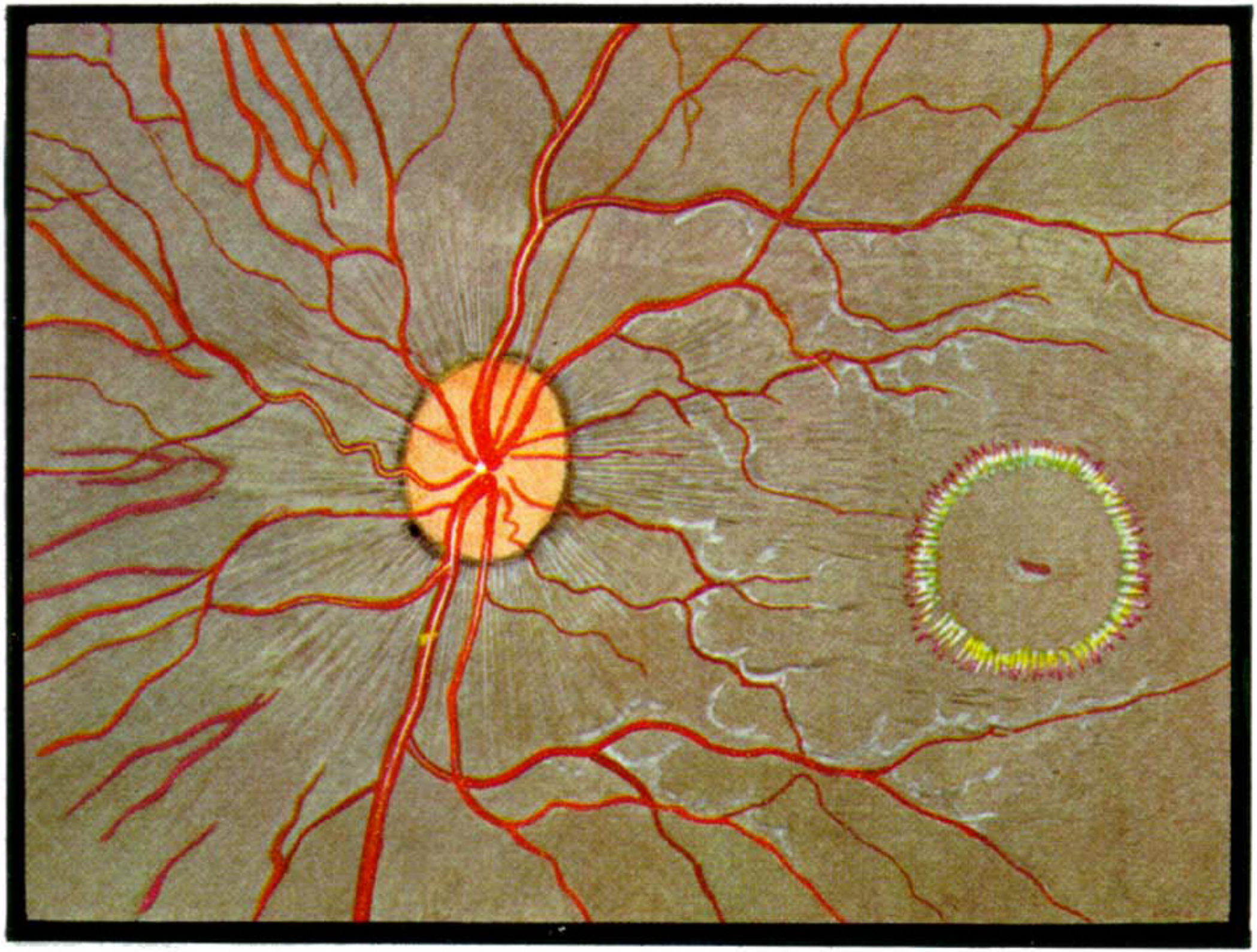

FIGURE 8. *Saimiri sciureus*. Common squirrel monkey.

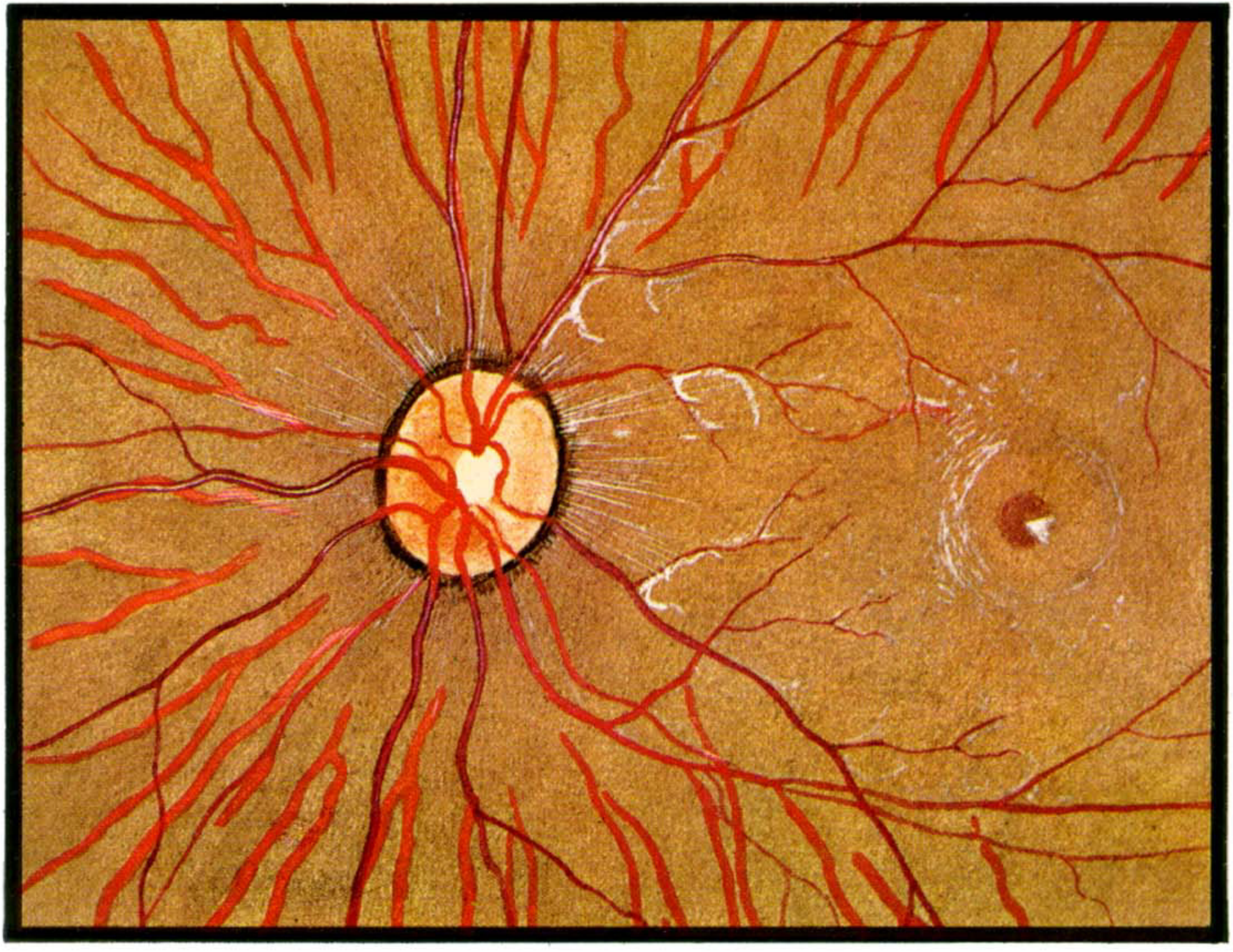

FIGURE 9. *Ateles paniscus*. Black spider monkey.

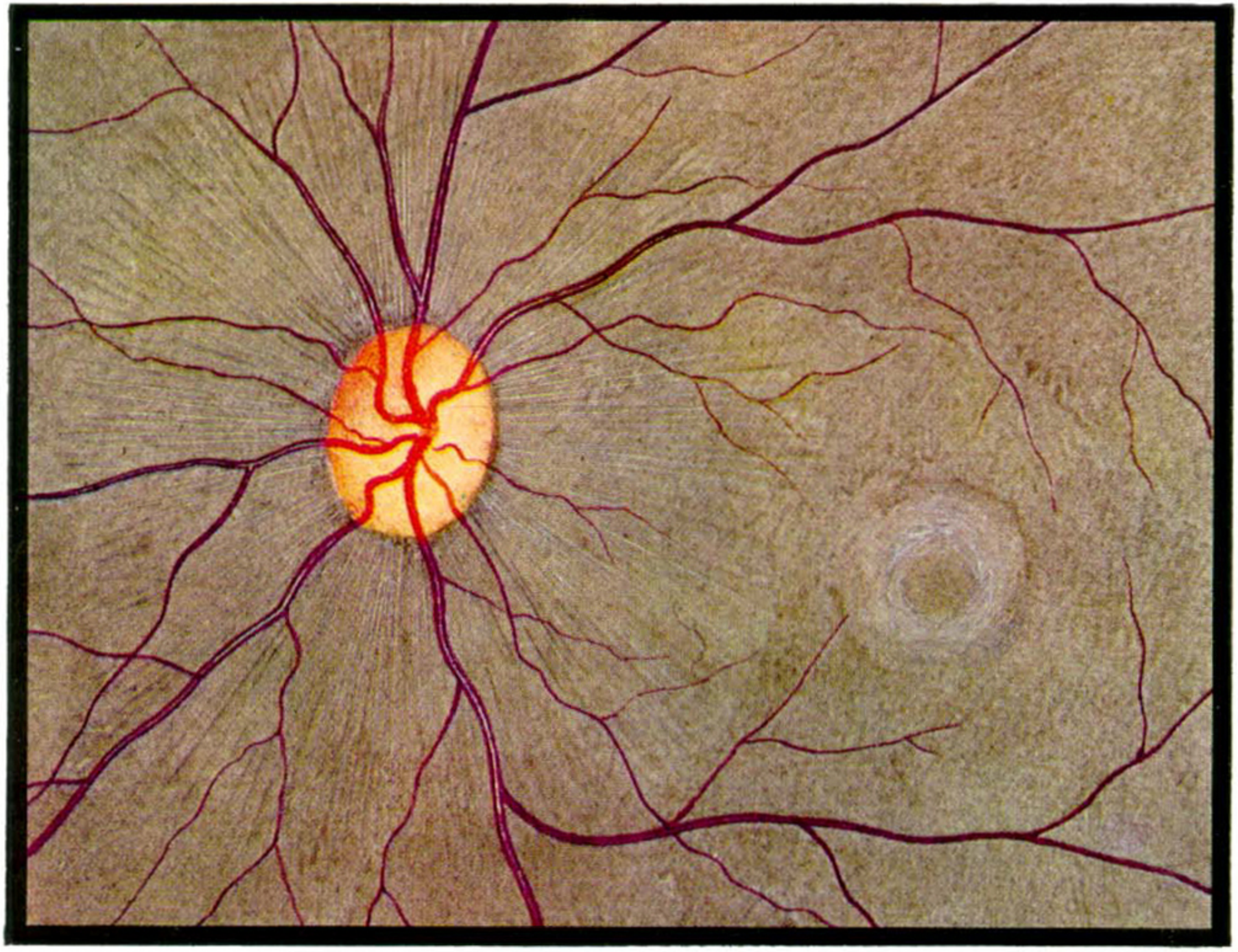

FIGURE 10. *Alouatta seniculus*. Red howler.

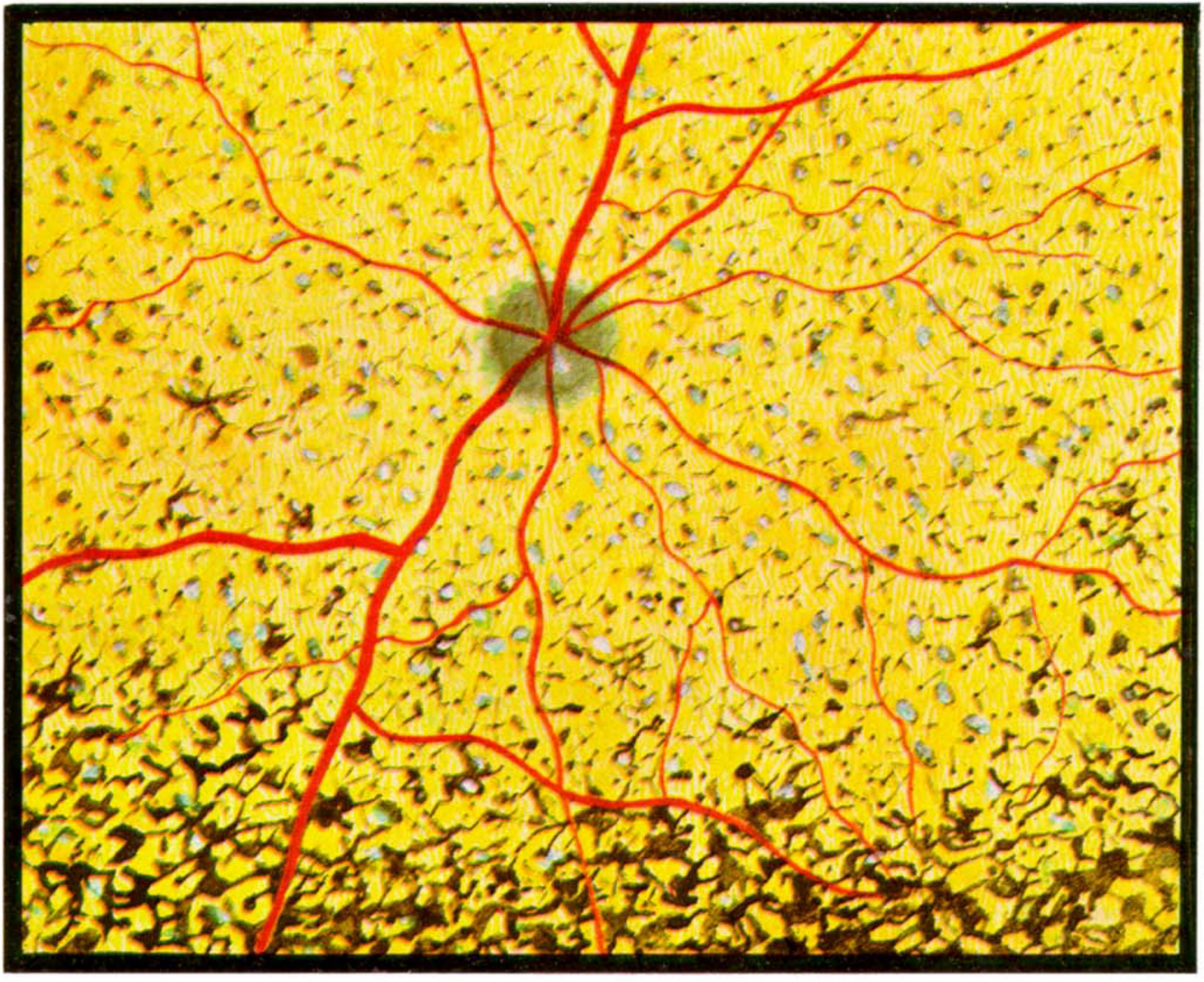

FIGURE 11. *Nycticebus coucang*. Slow loris.

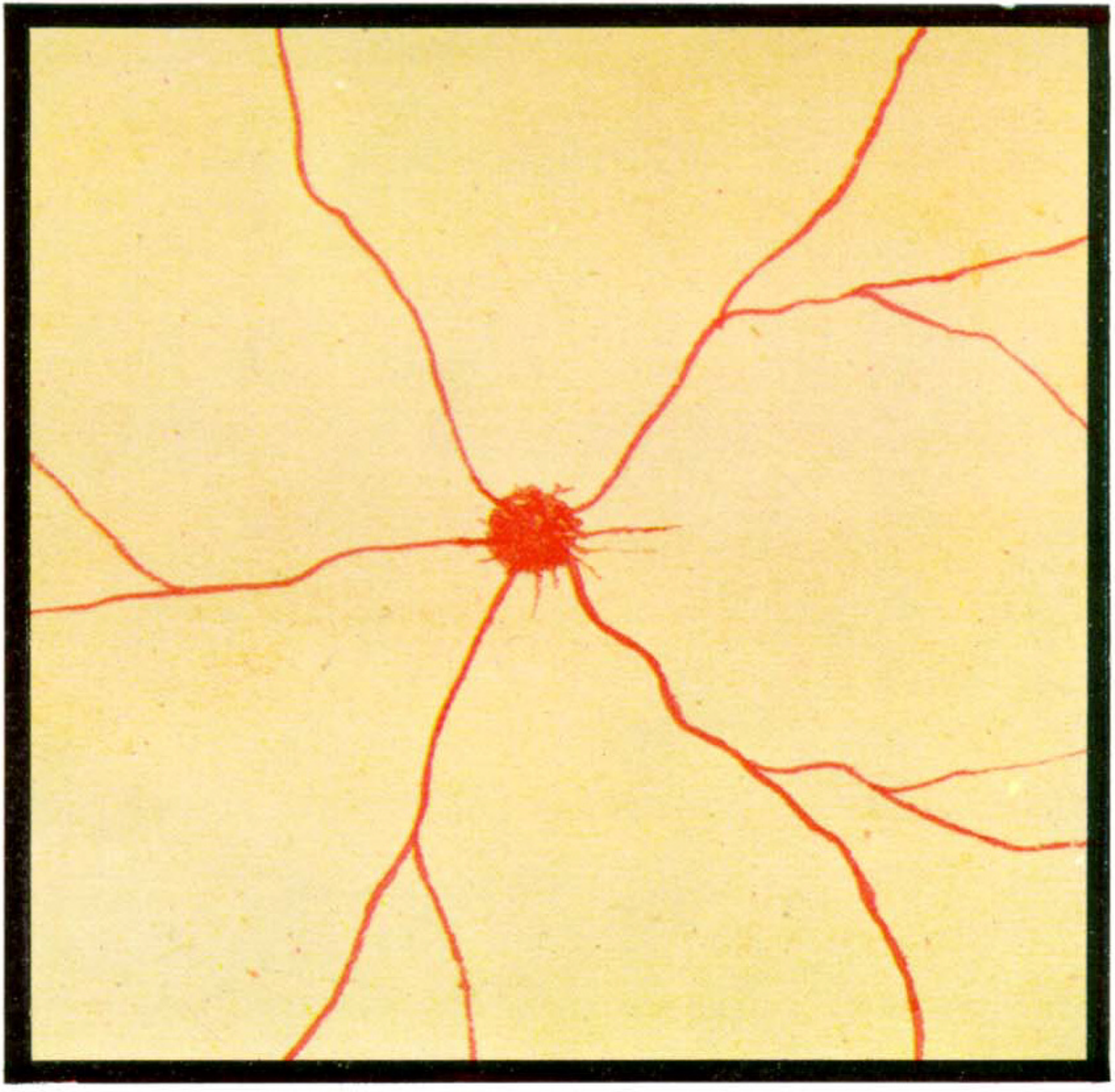

FIGURE 12. *Talpa europaea*. Common Eurasian mole (× 120 diameters).

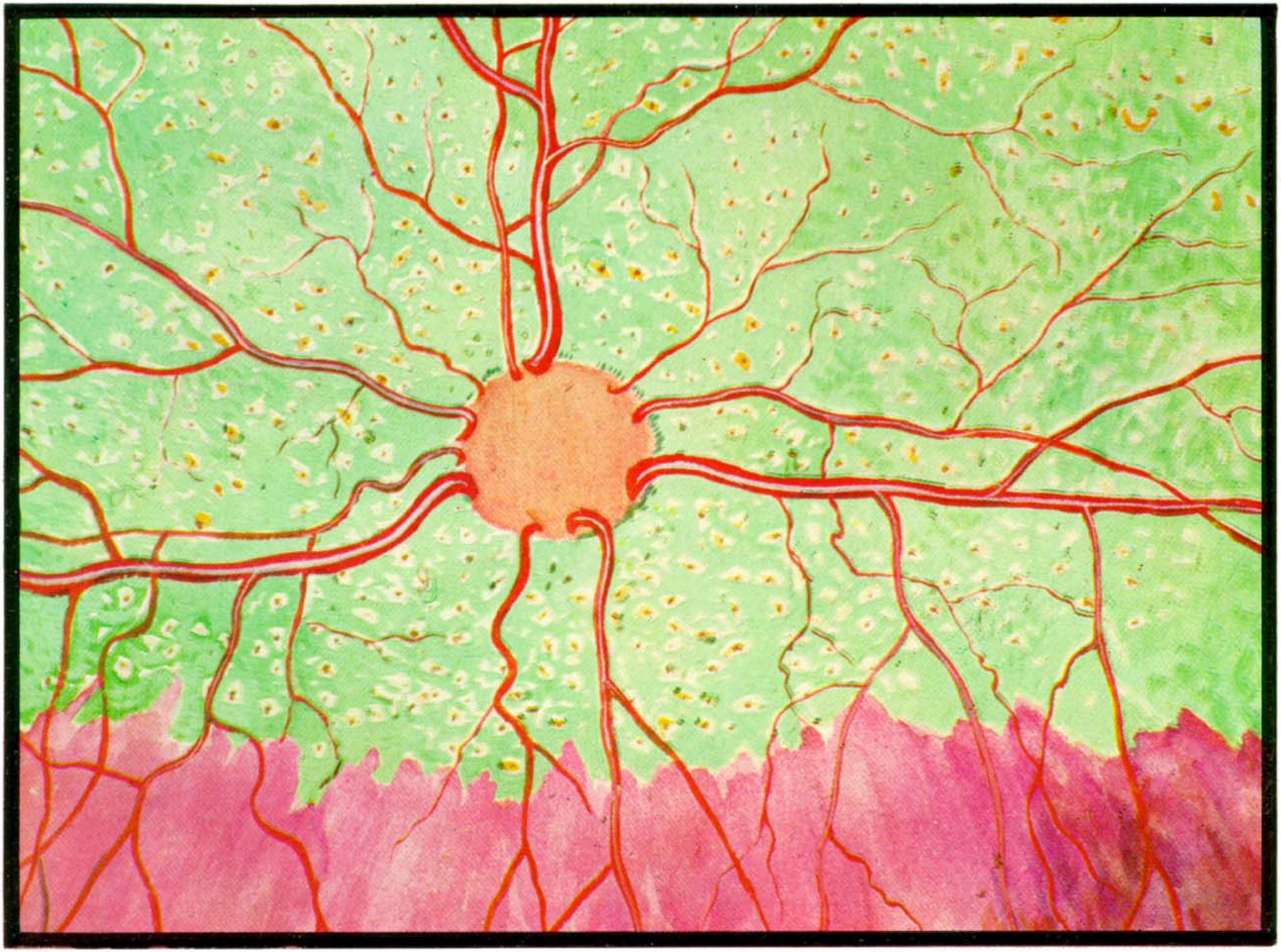

FIGURE 13. *Panthera leo*. Lion.

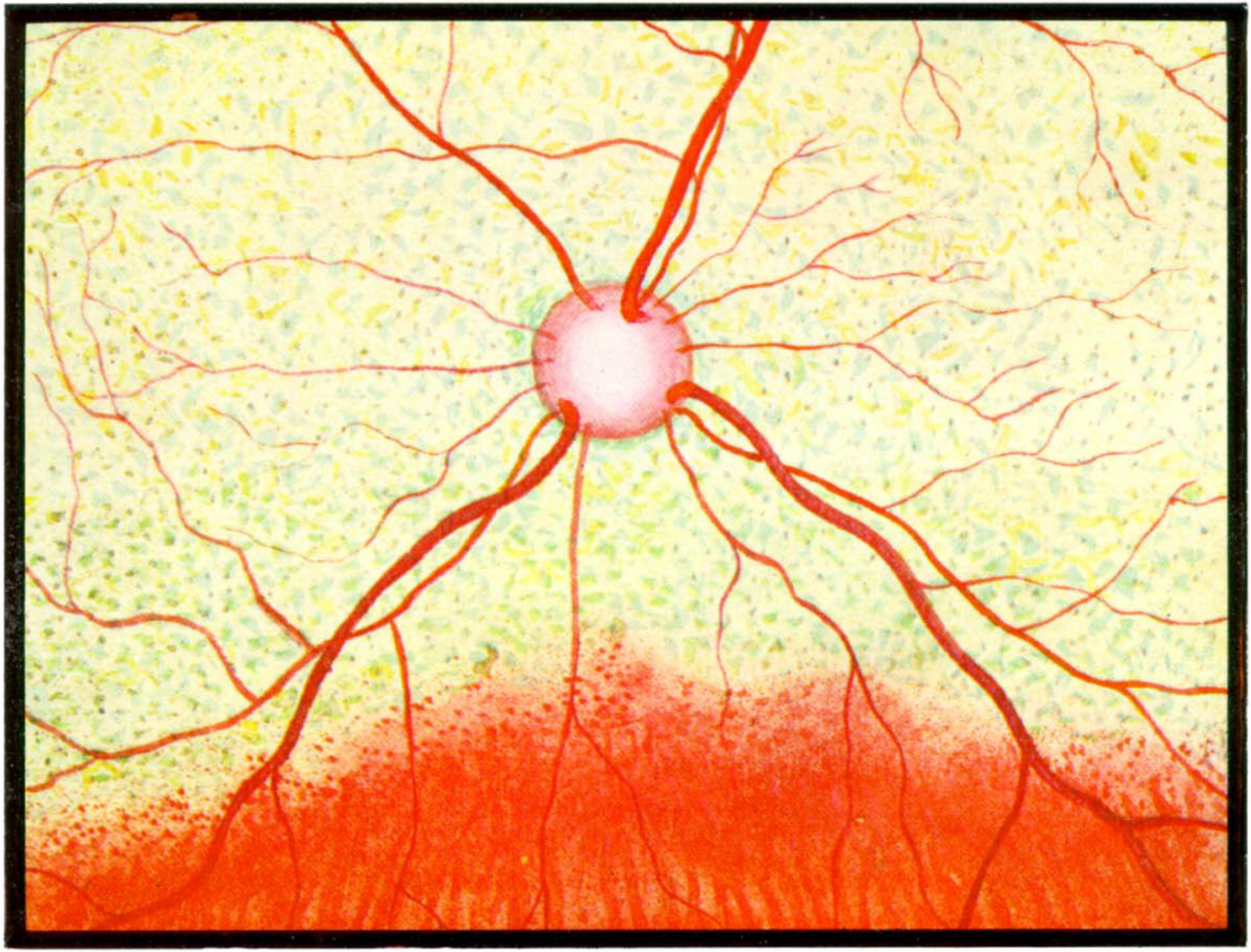

FIGURE 14. *Felis catus*. Siamese cat.

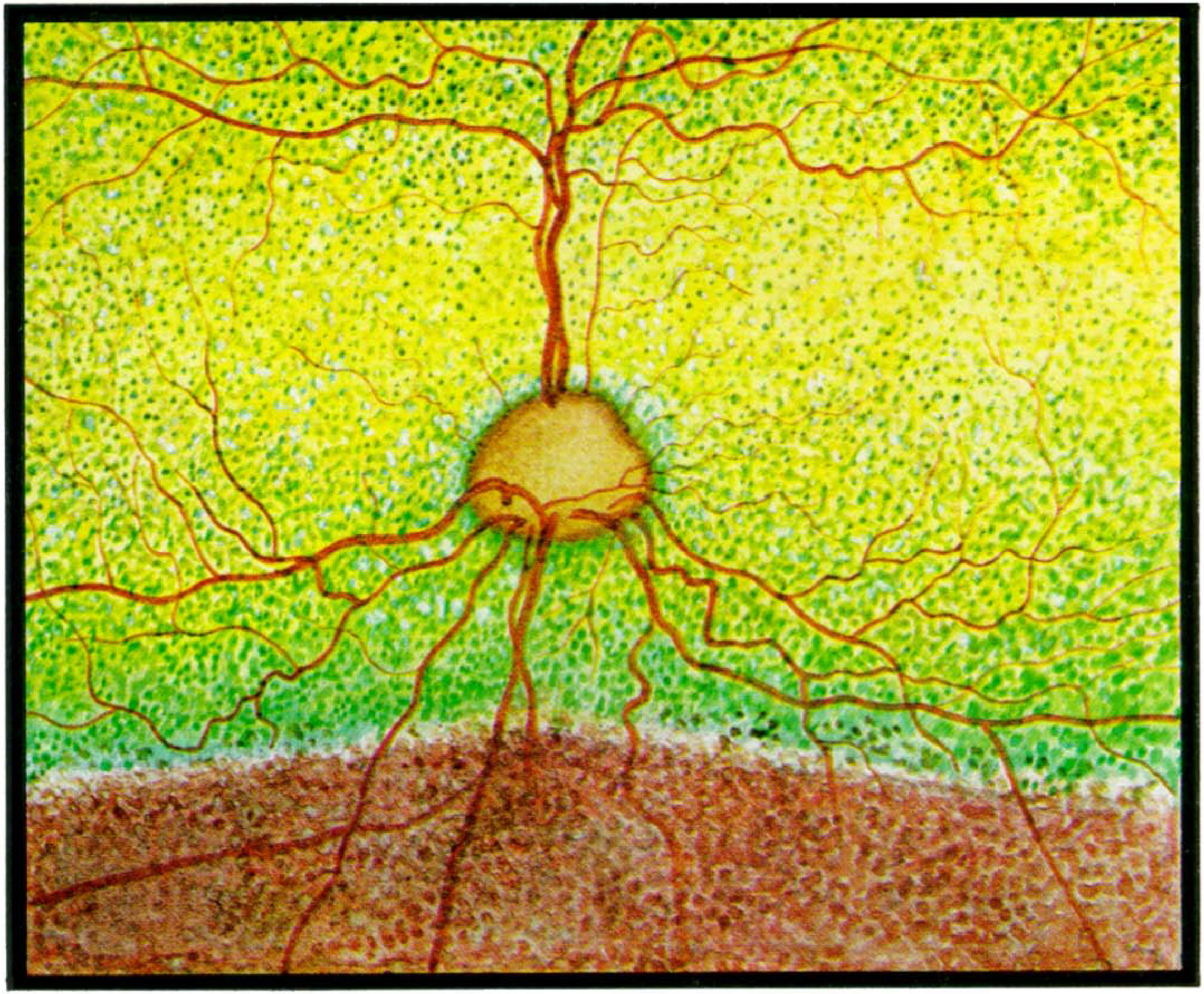

FIGURE 15. *Acinonyx jubatus*. Cheetah.

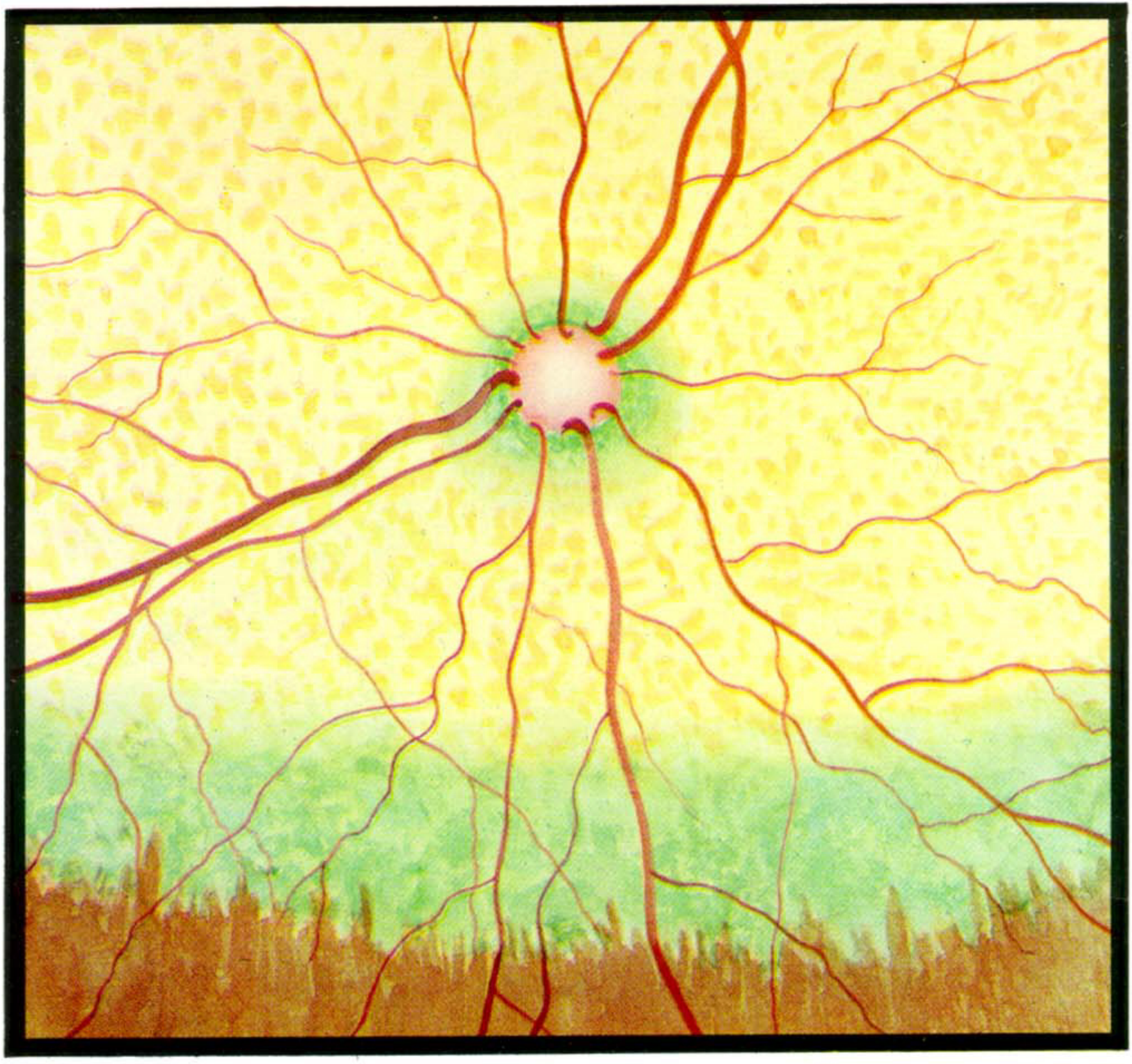

FIGURE 16. *Paradoxurus hermaphroditus*. Common palm civet.

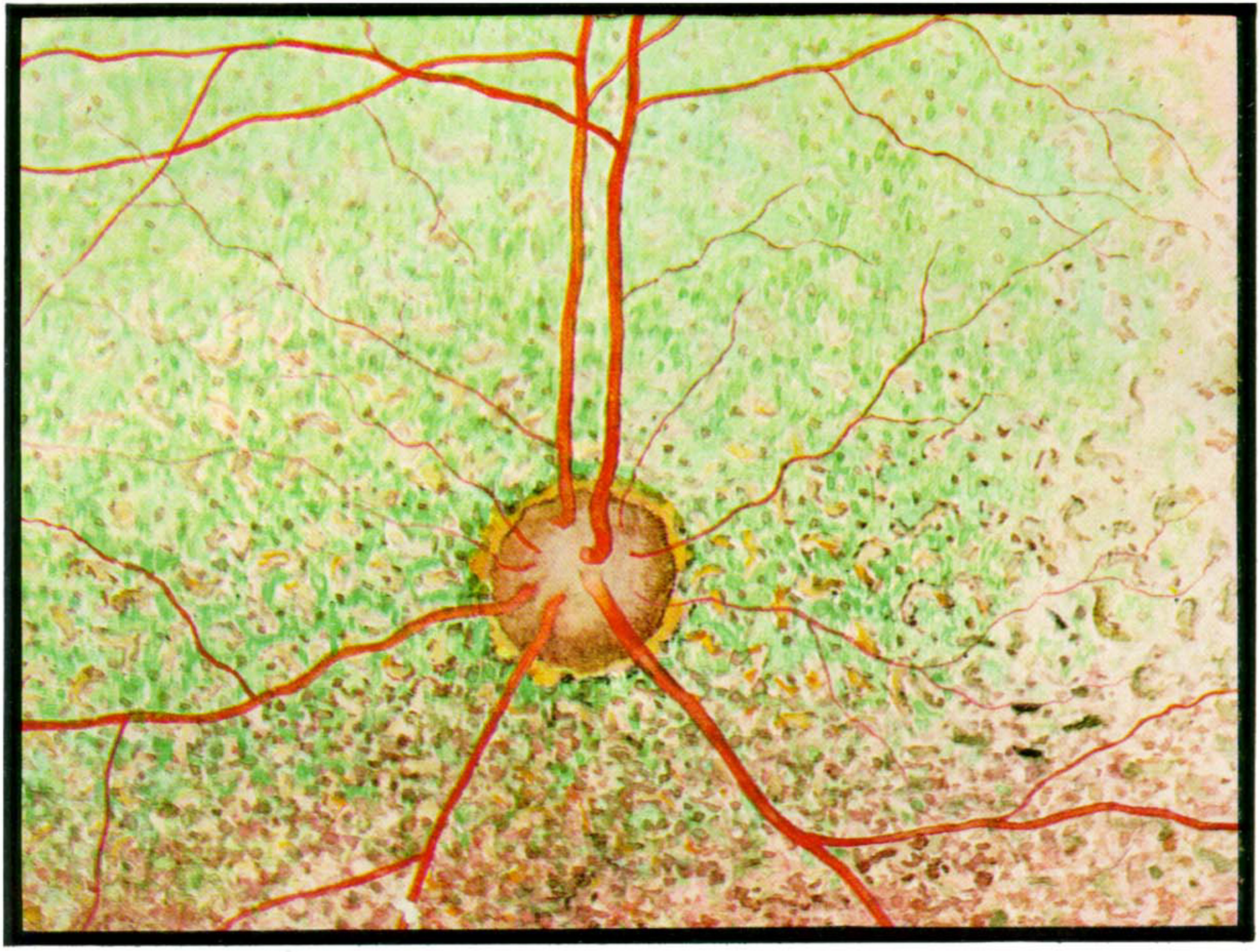

FIGURE 17. *Herpestes nepalensis*. Spotted ichneumon.

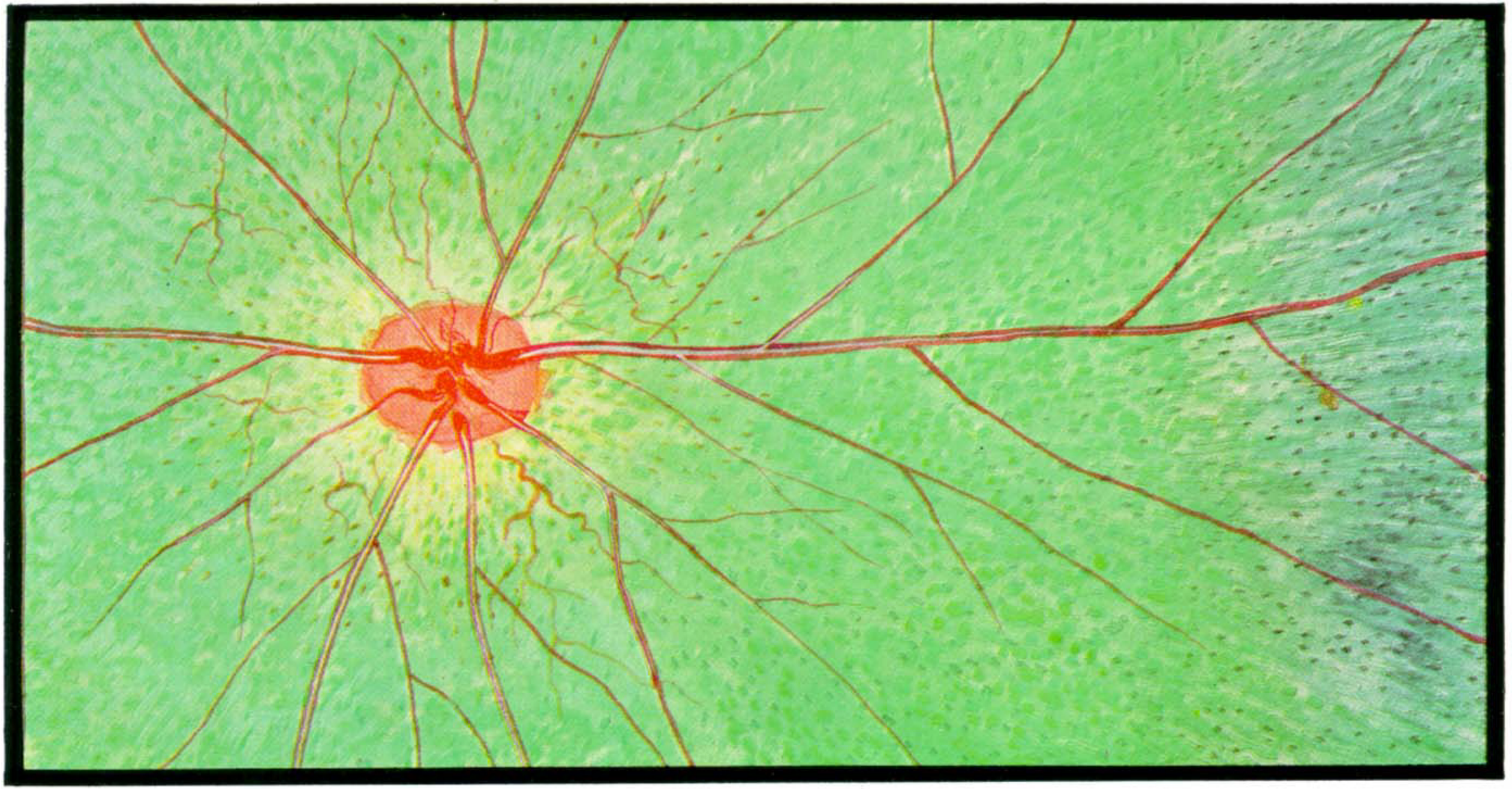

FIGURE 18. *Herpestes pulverulentus*. Grey ichneumon.

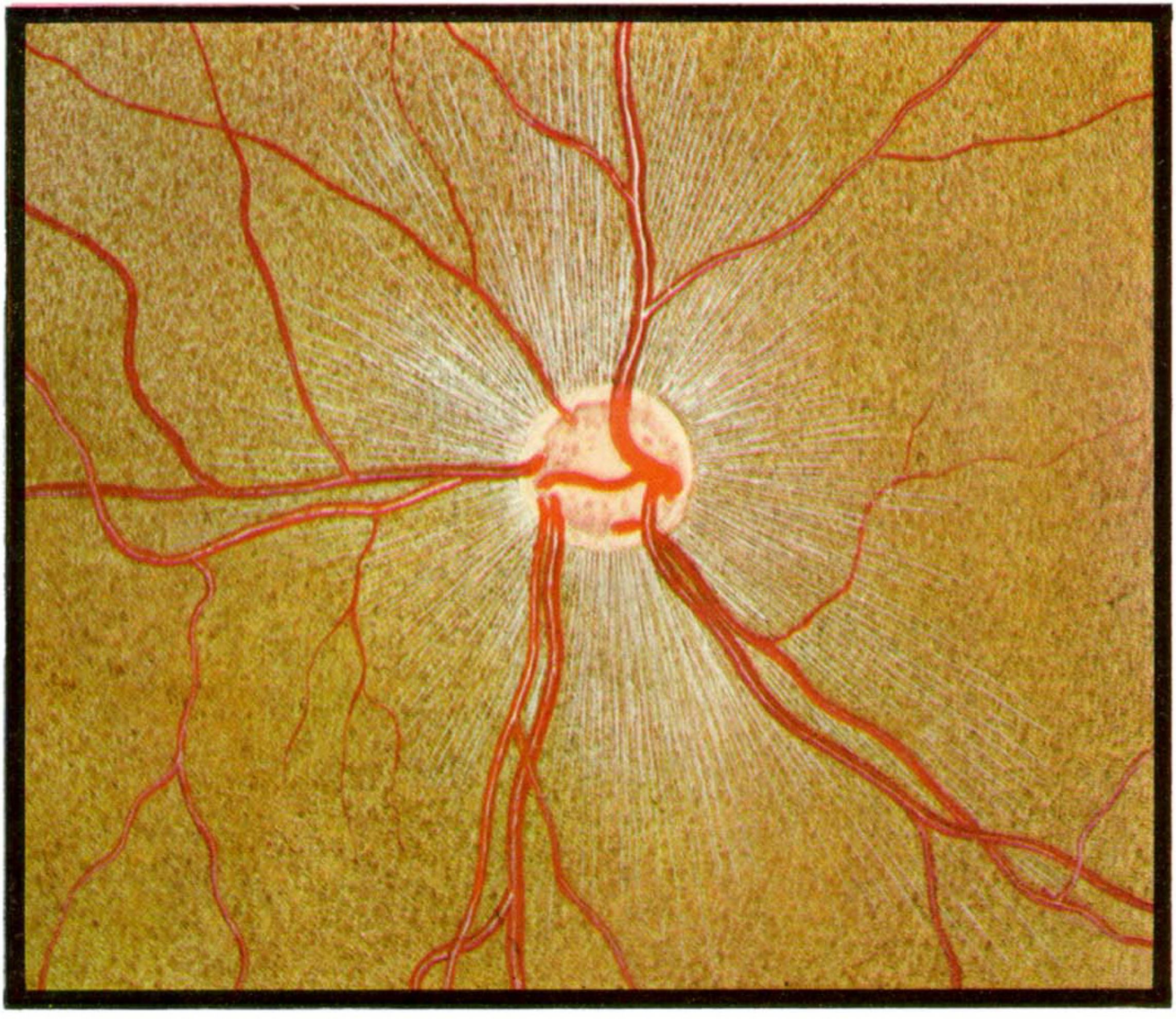

FIGURE 19. *Suricata suricatta*. Common suricate.

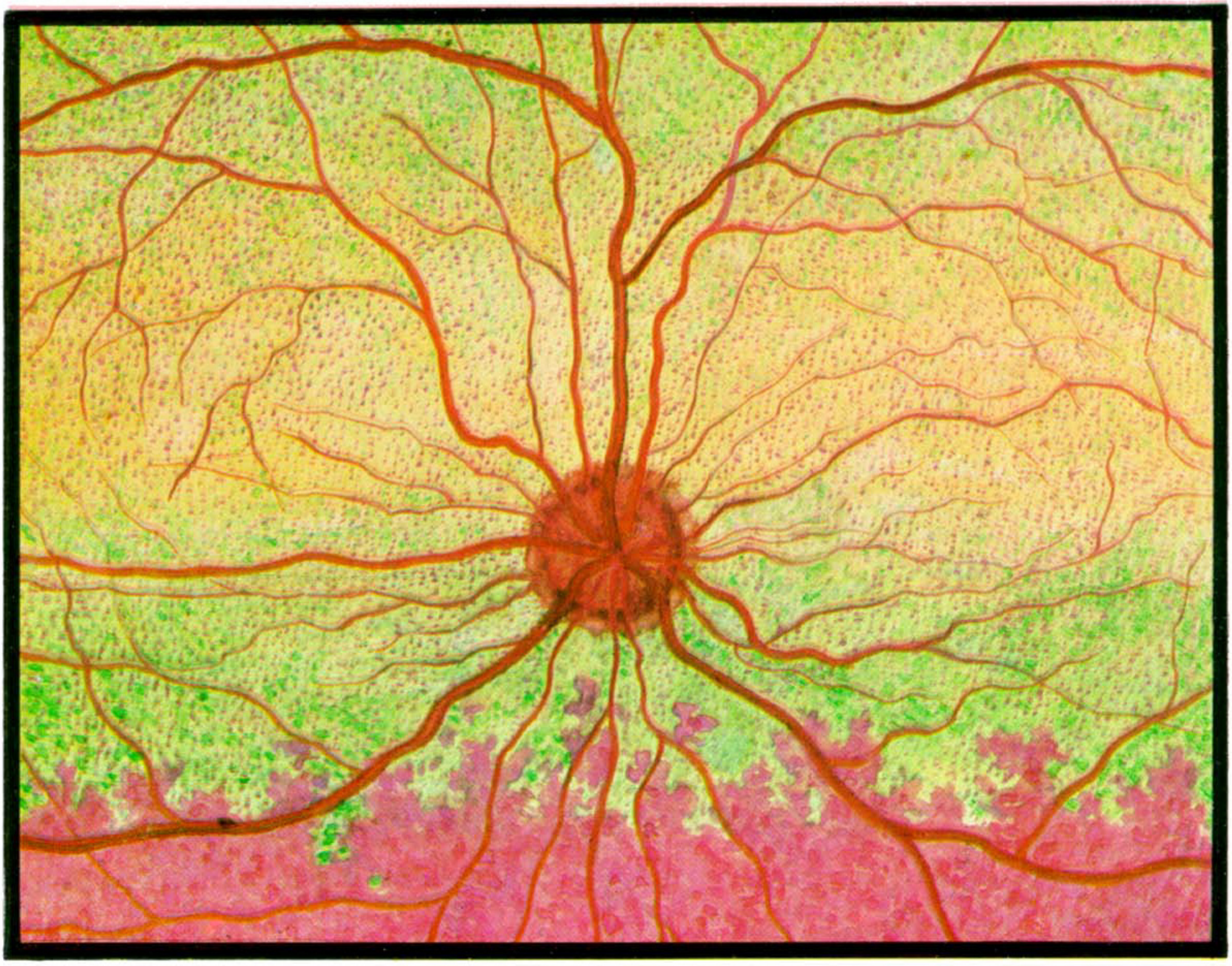

FIGURE 20. *Crocuta crocuta*. Spotted hyaena.

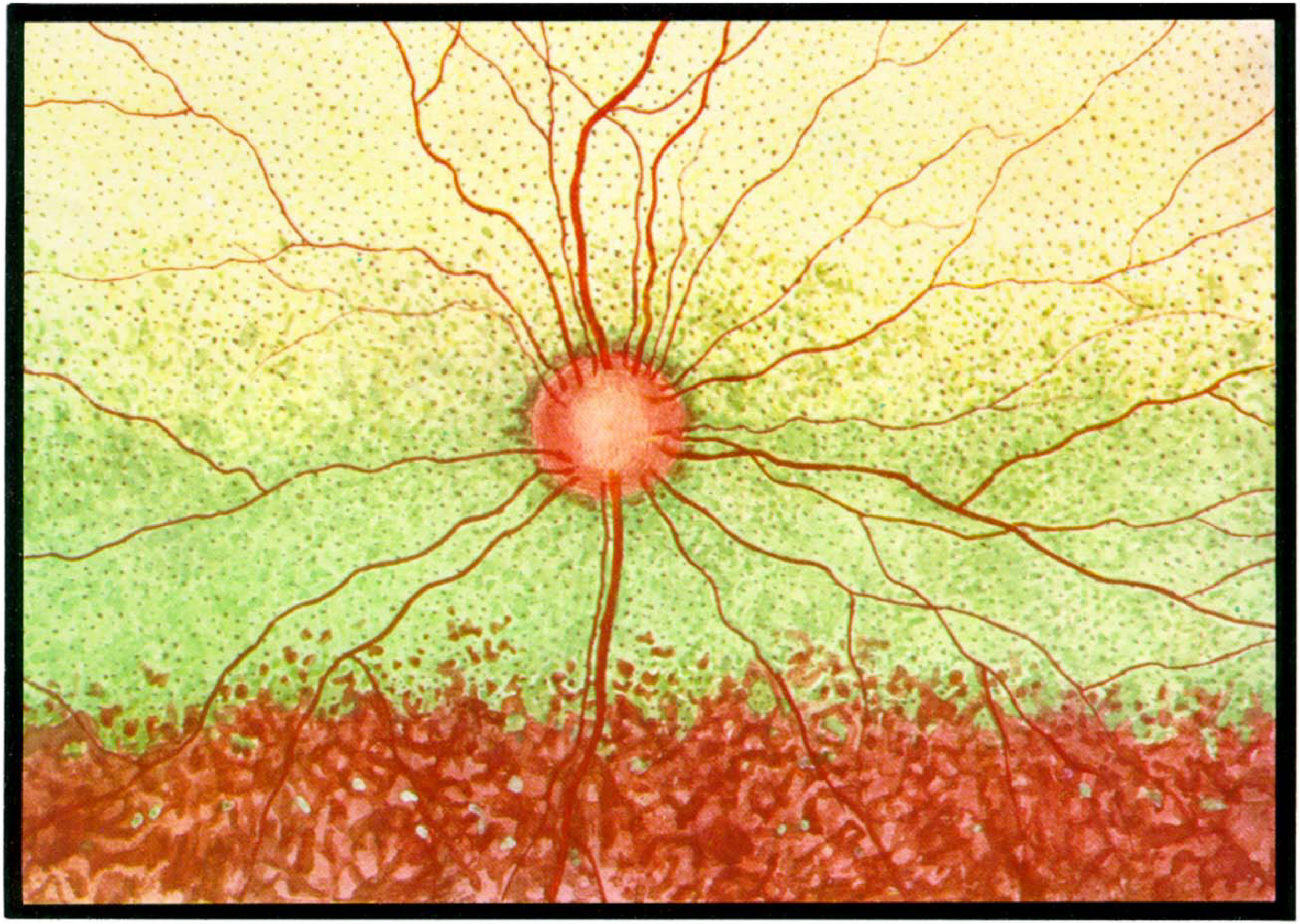

FIGURE 21. *Nyctereutes procyonoides*. Raccoon dog.

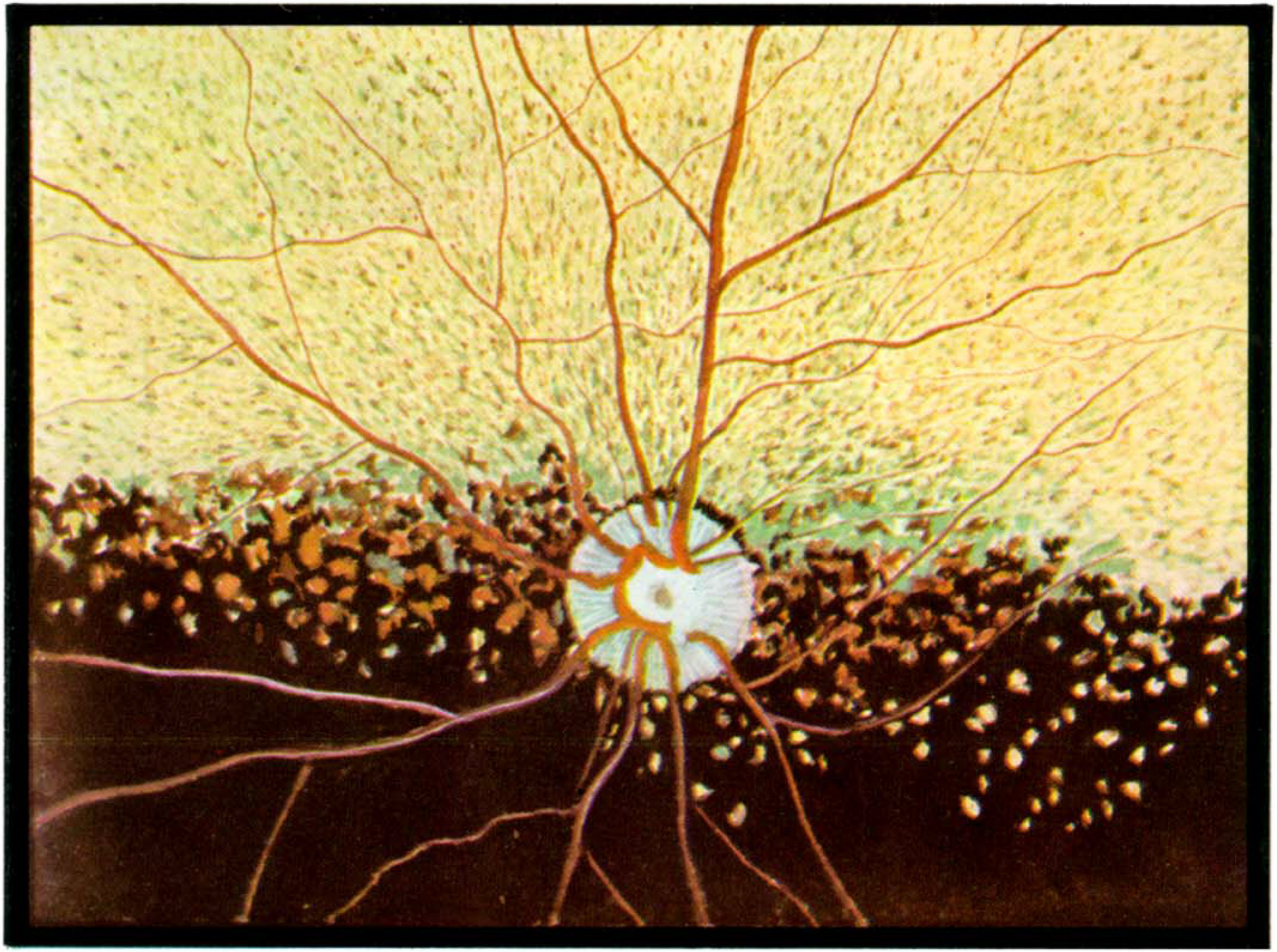

FIGURE 22. *Canis familiaris*. Collie dog.

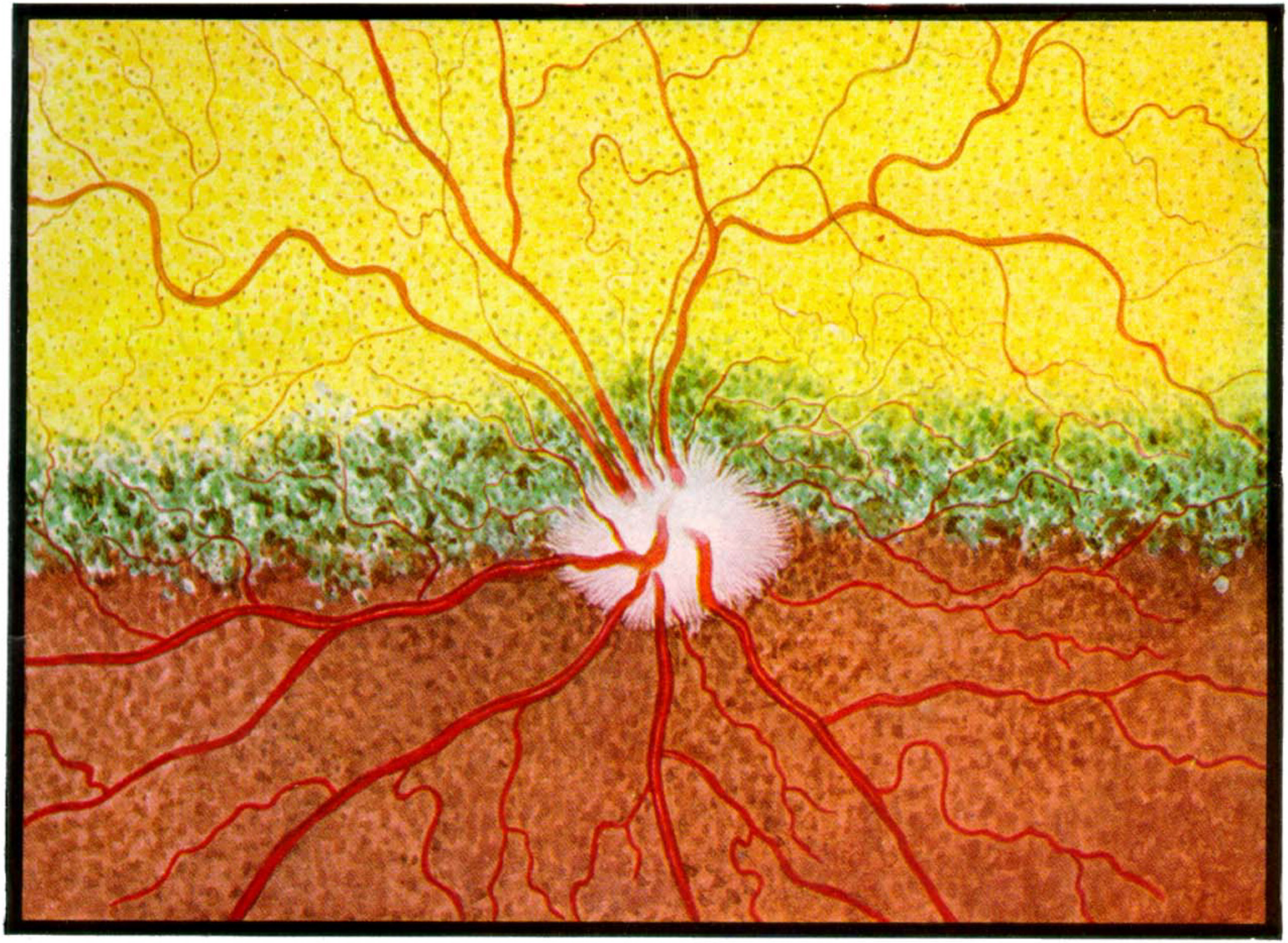

FIGURE 23. *Canis dingo*. Australian dingo.

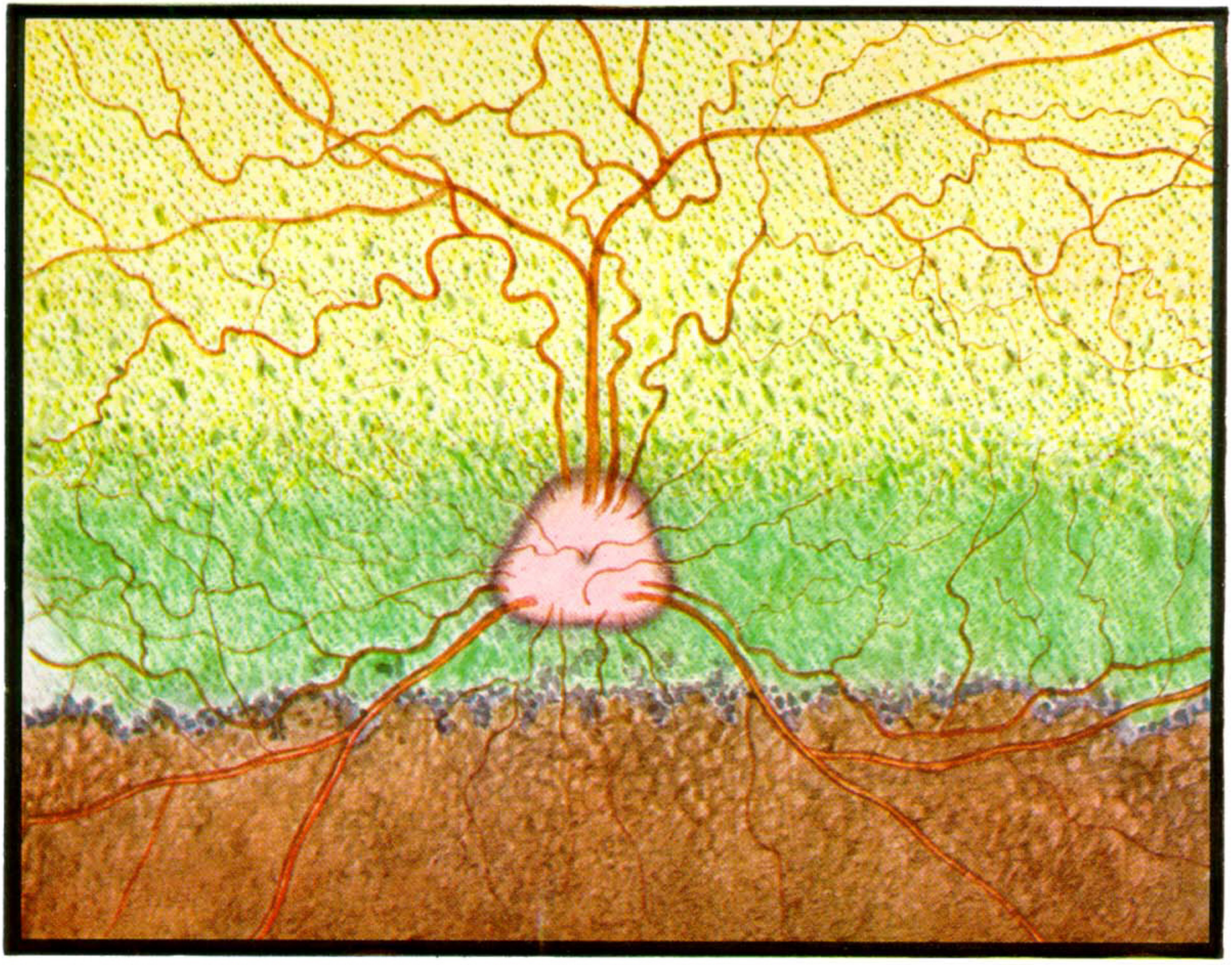

FIGURE 24. *Canis latrans*. Coyote.

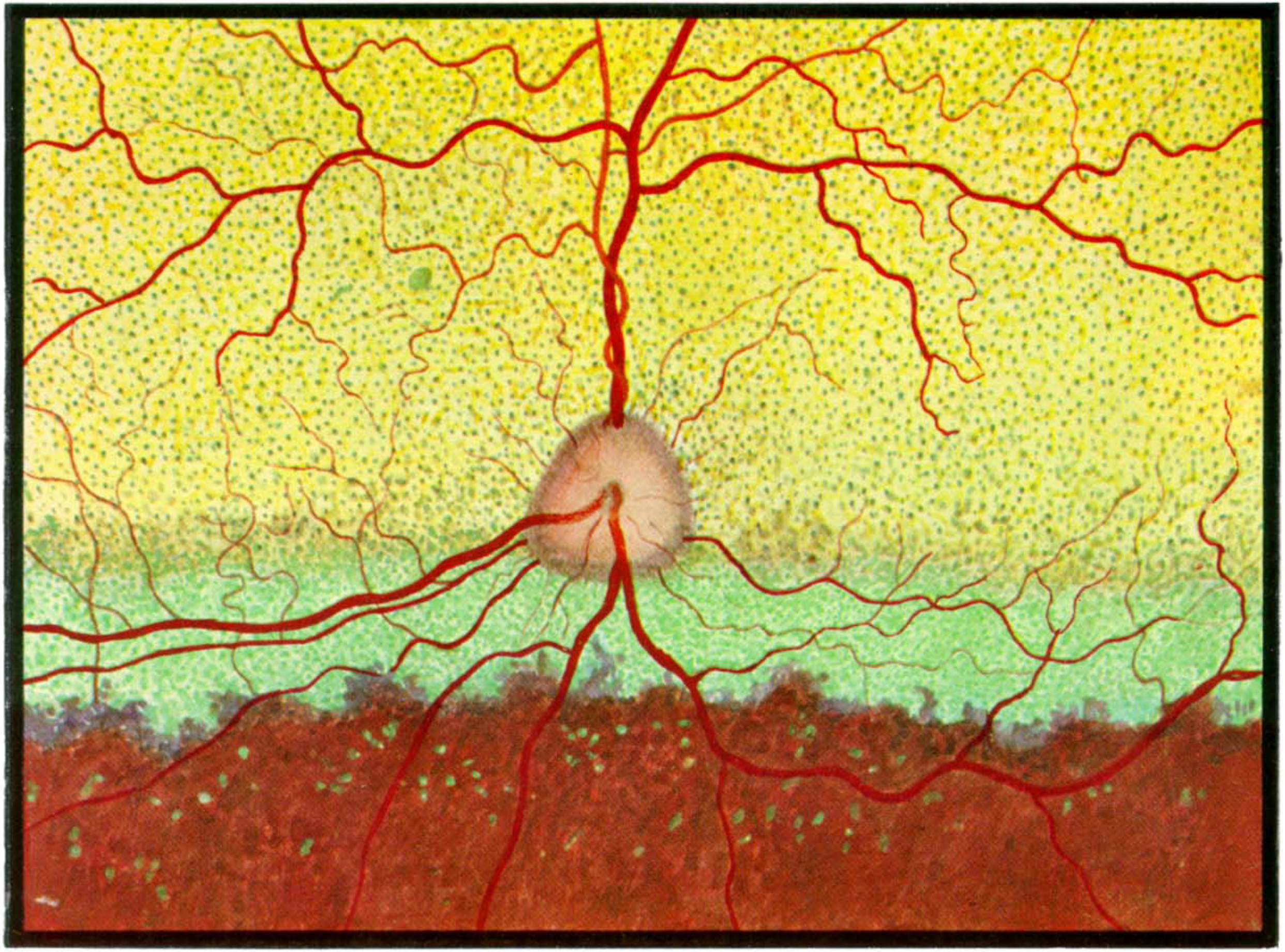

FIGURE 25. *Canis lupus*. Wolf.

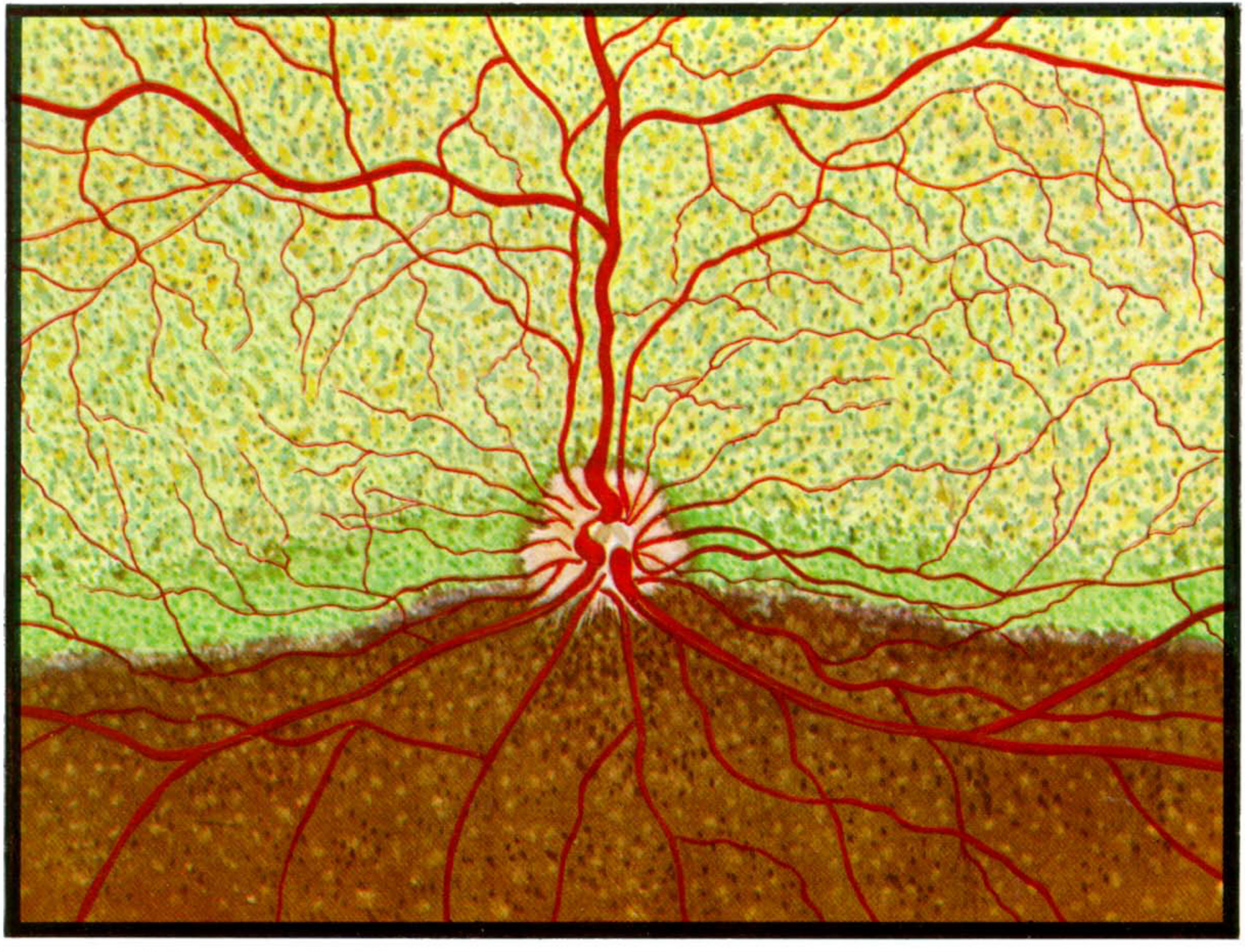

FIGURE 26. *Vulpes vulpes*. Red fox.

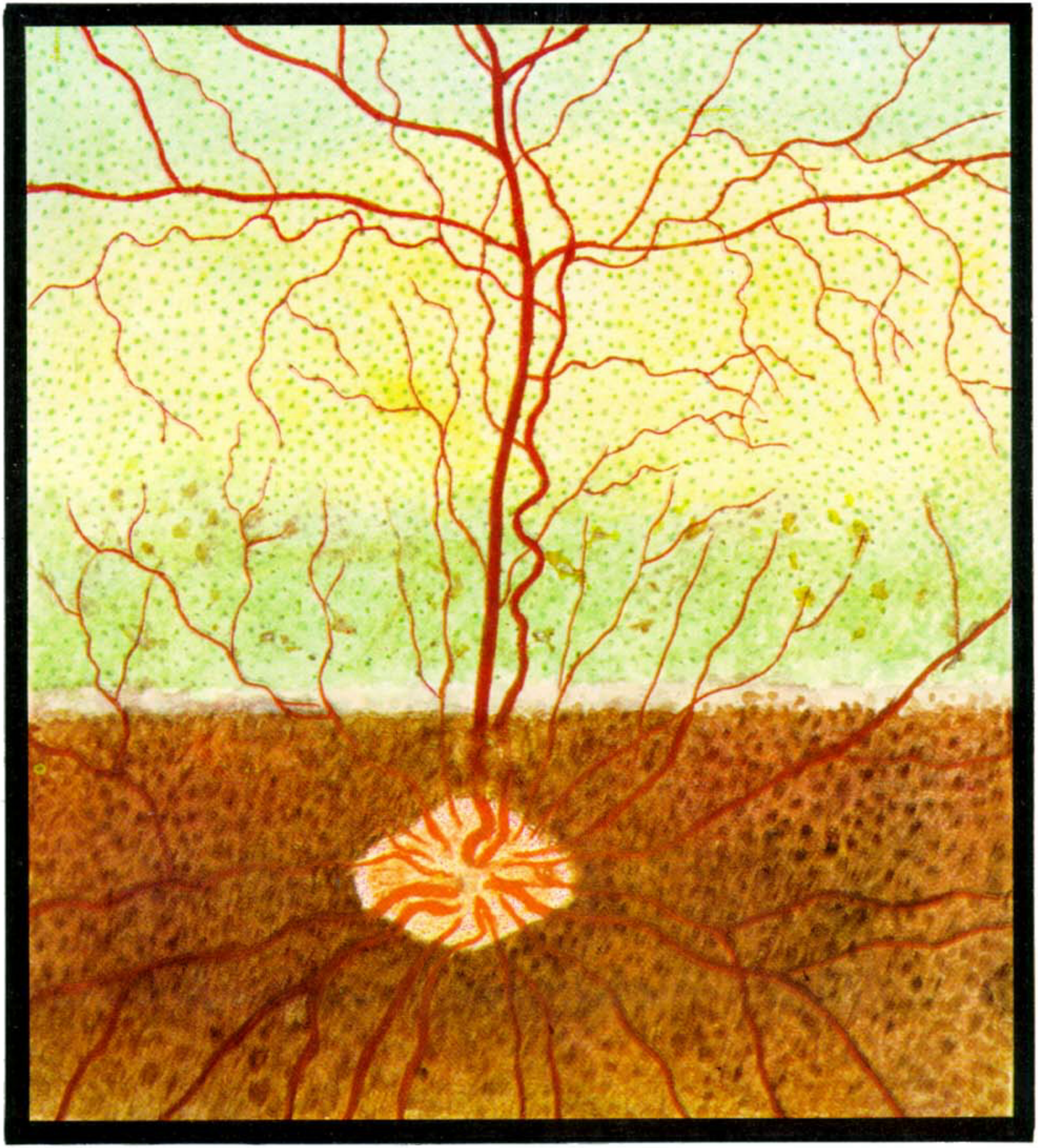

FIGURE 27. *Alopex lagopus*. Arctic fox.

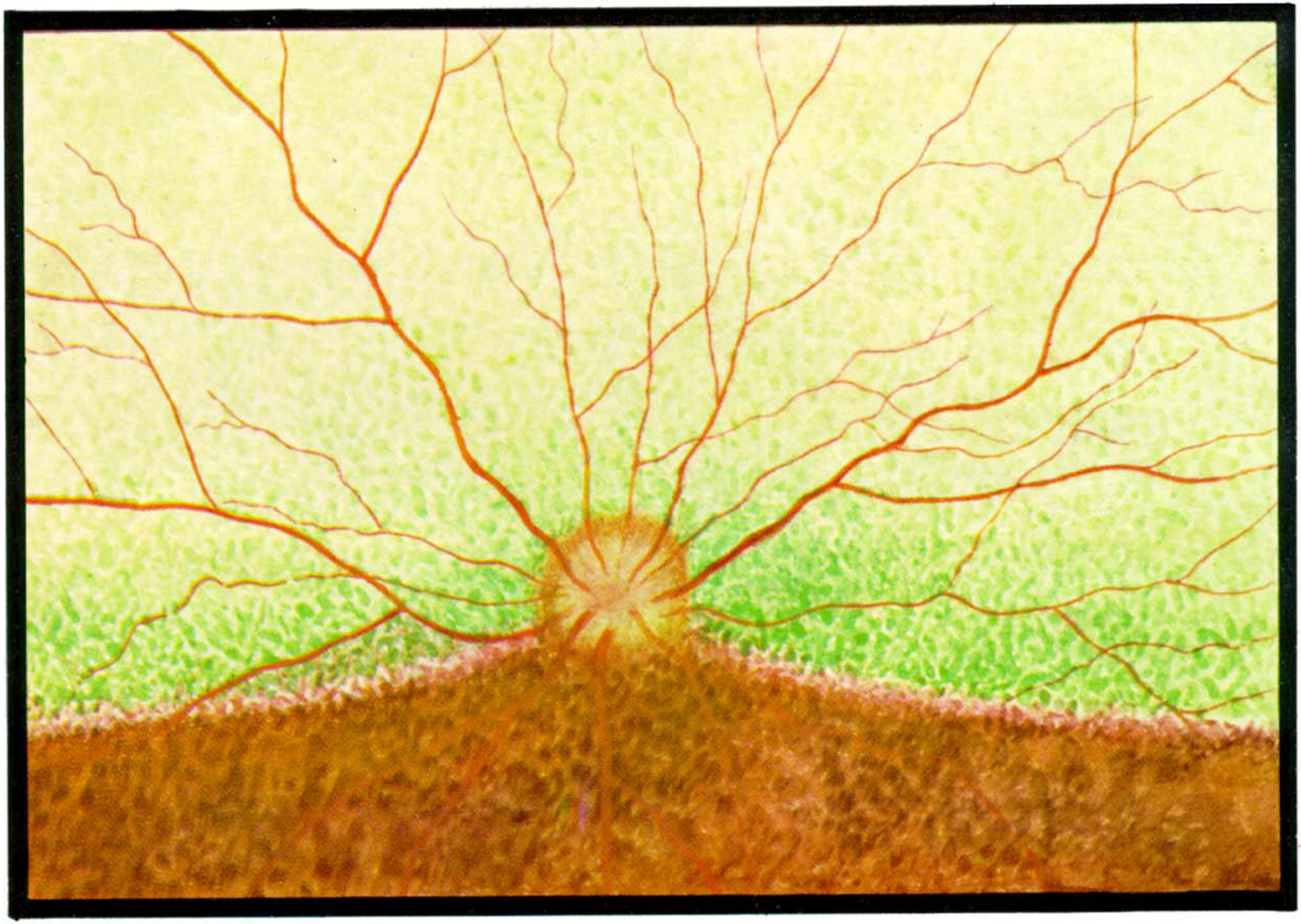

FIGURE 28. *Mustela putorius*. European polecat.

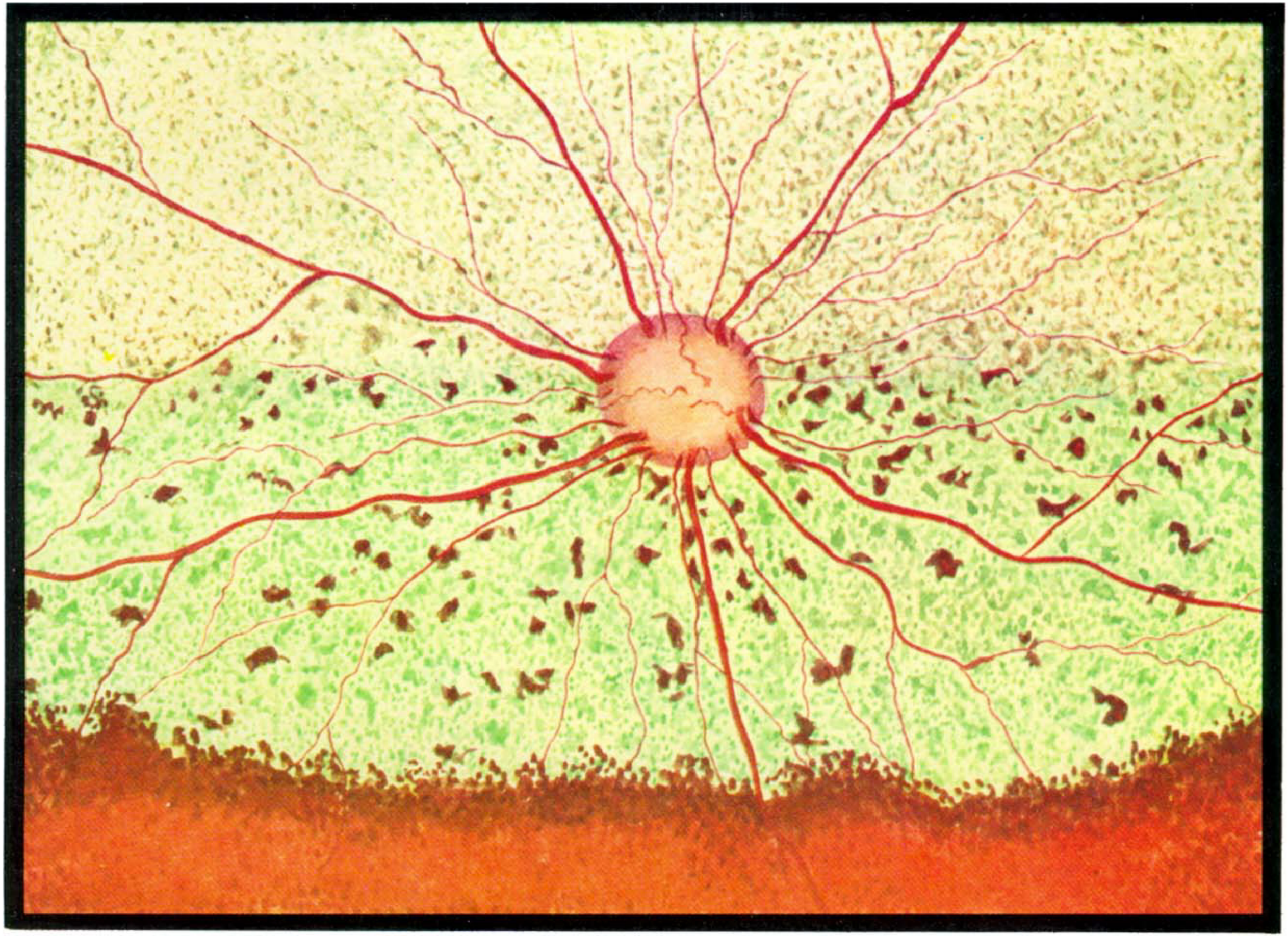

FIGURE 29. *Martes martes*. Pine marten.

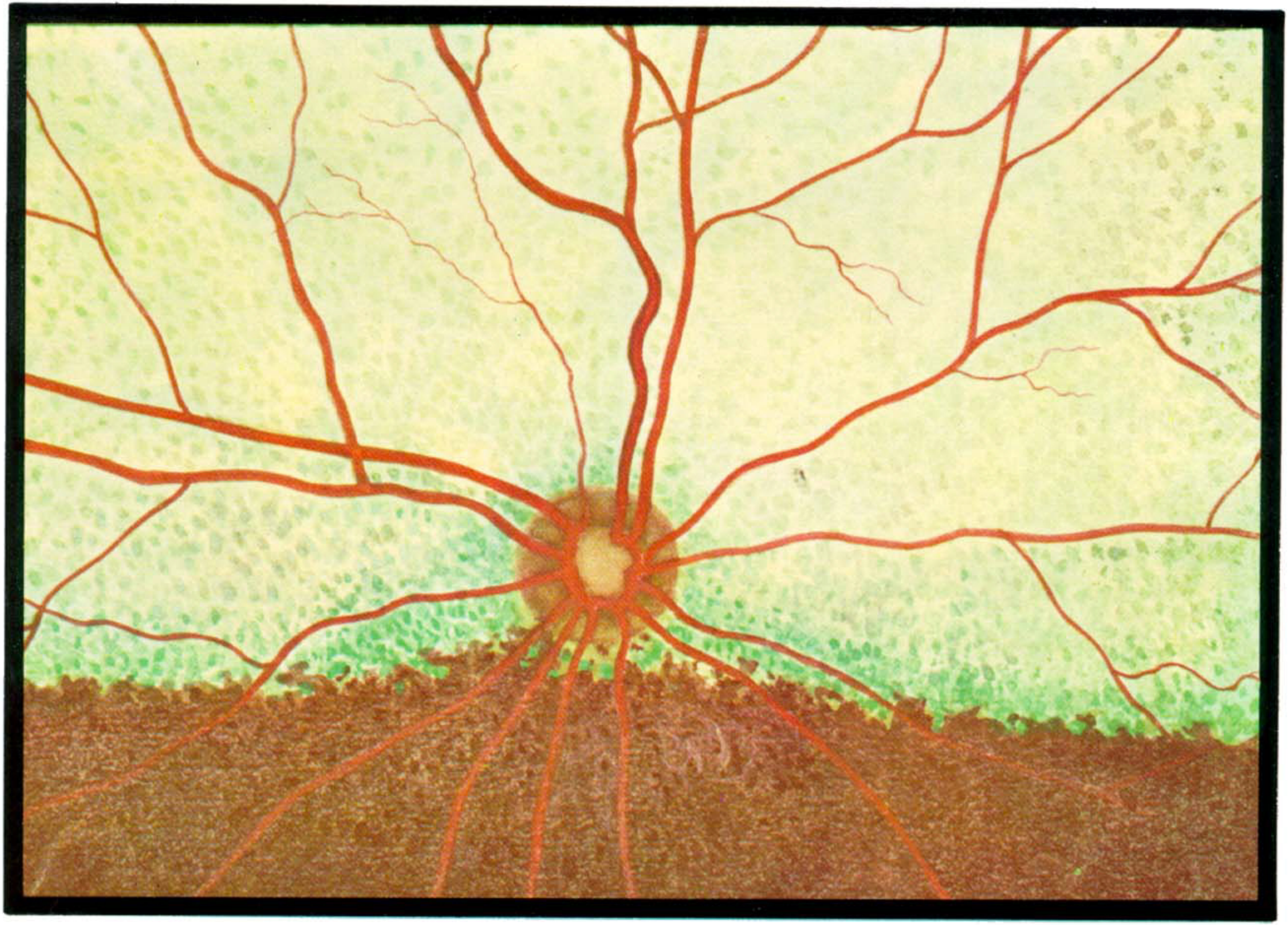

FIGURE 30. *Ictonyx striatus*. Zorilla.

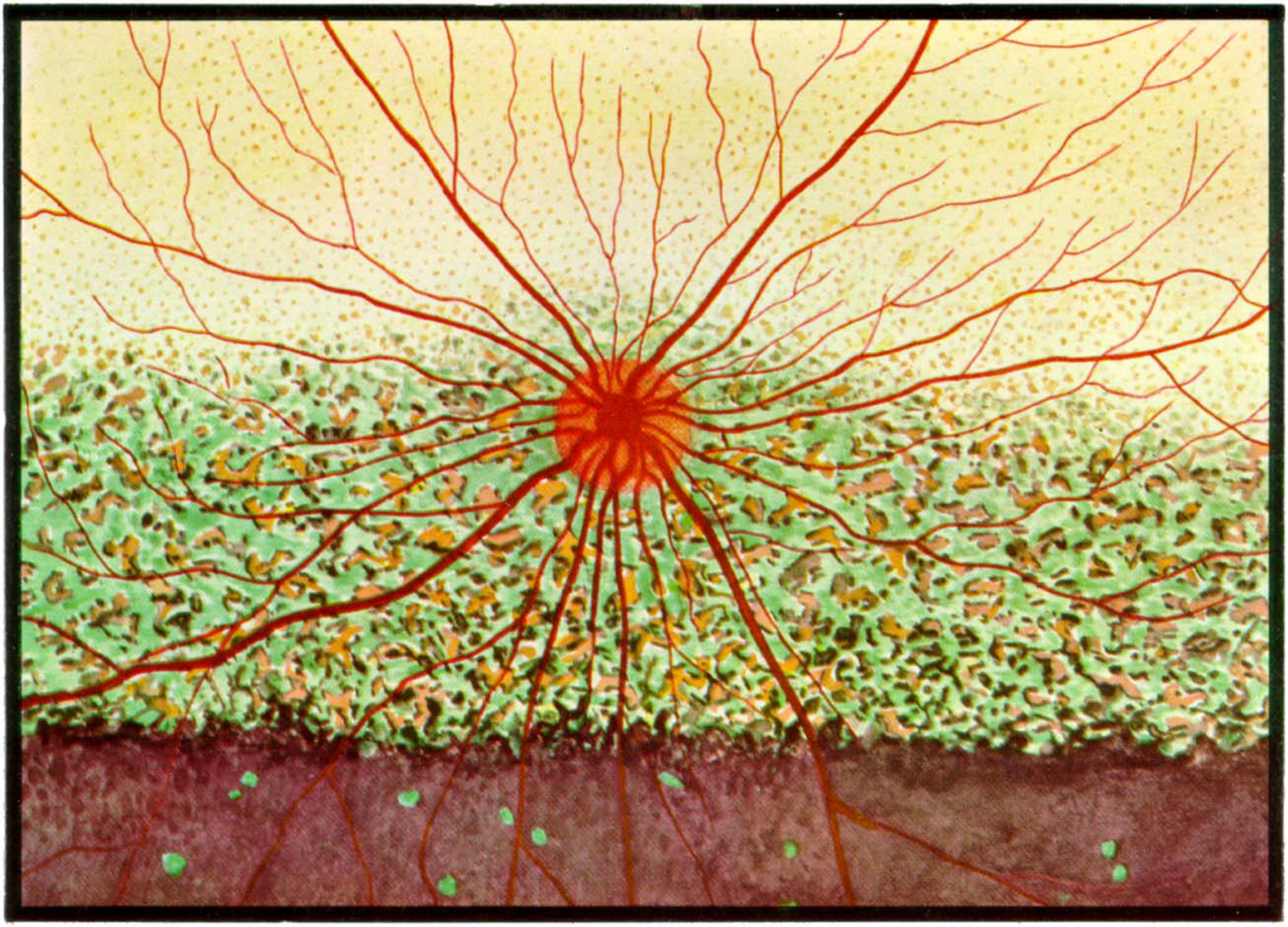

FIGURE 31. *Lutra lutra*. Eurasian otter.

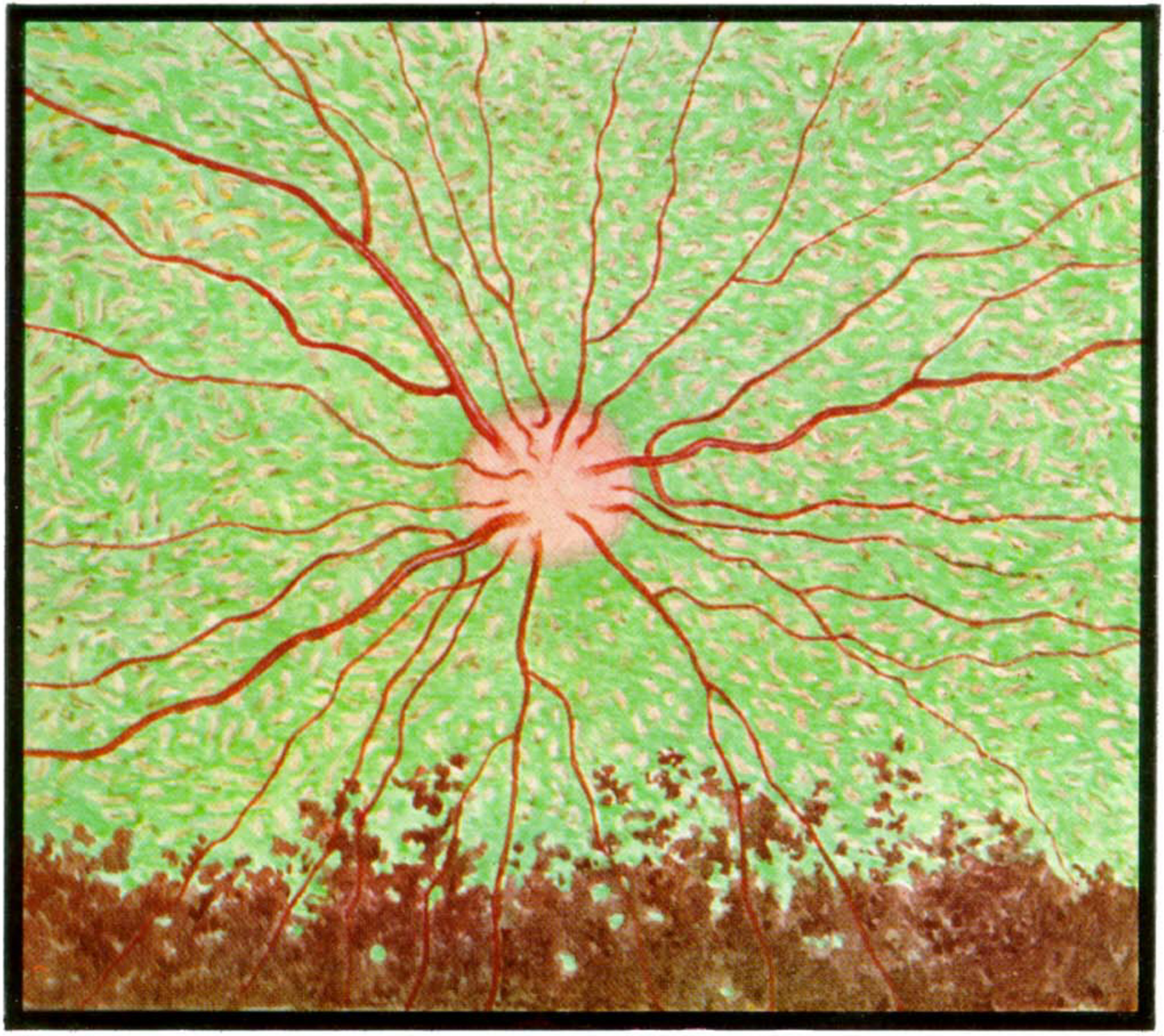

FIGURE 32. *Nasua nasua*. Coati.

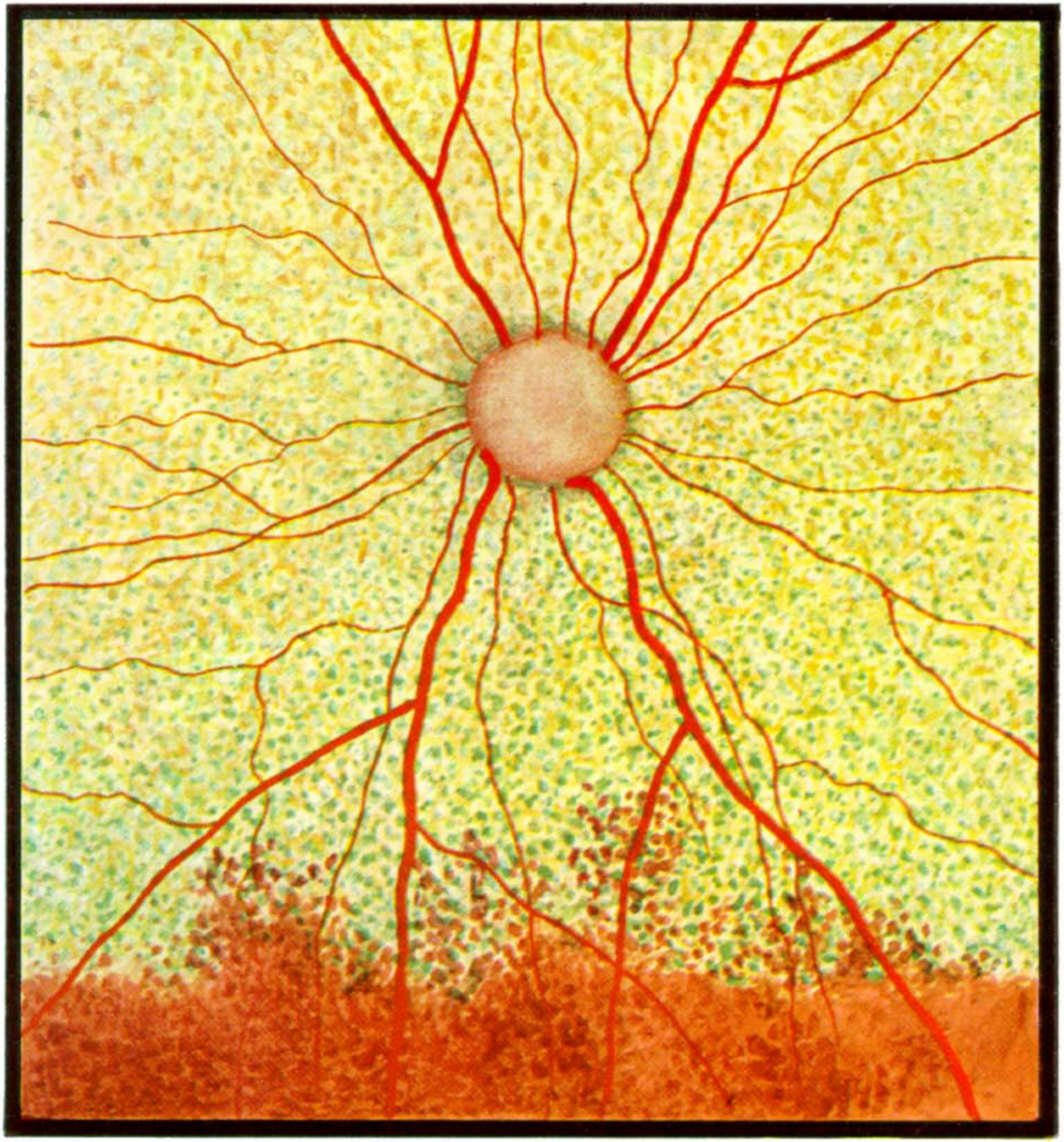

FIGURE 33. *Potos flavus*. Kinkajou.

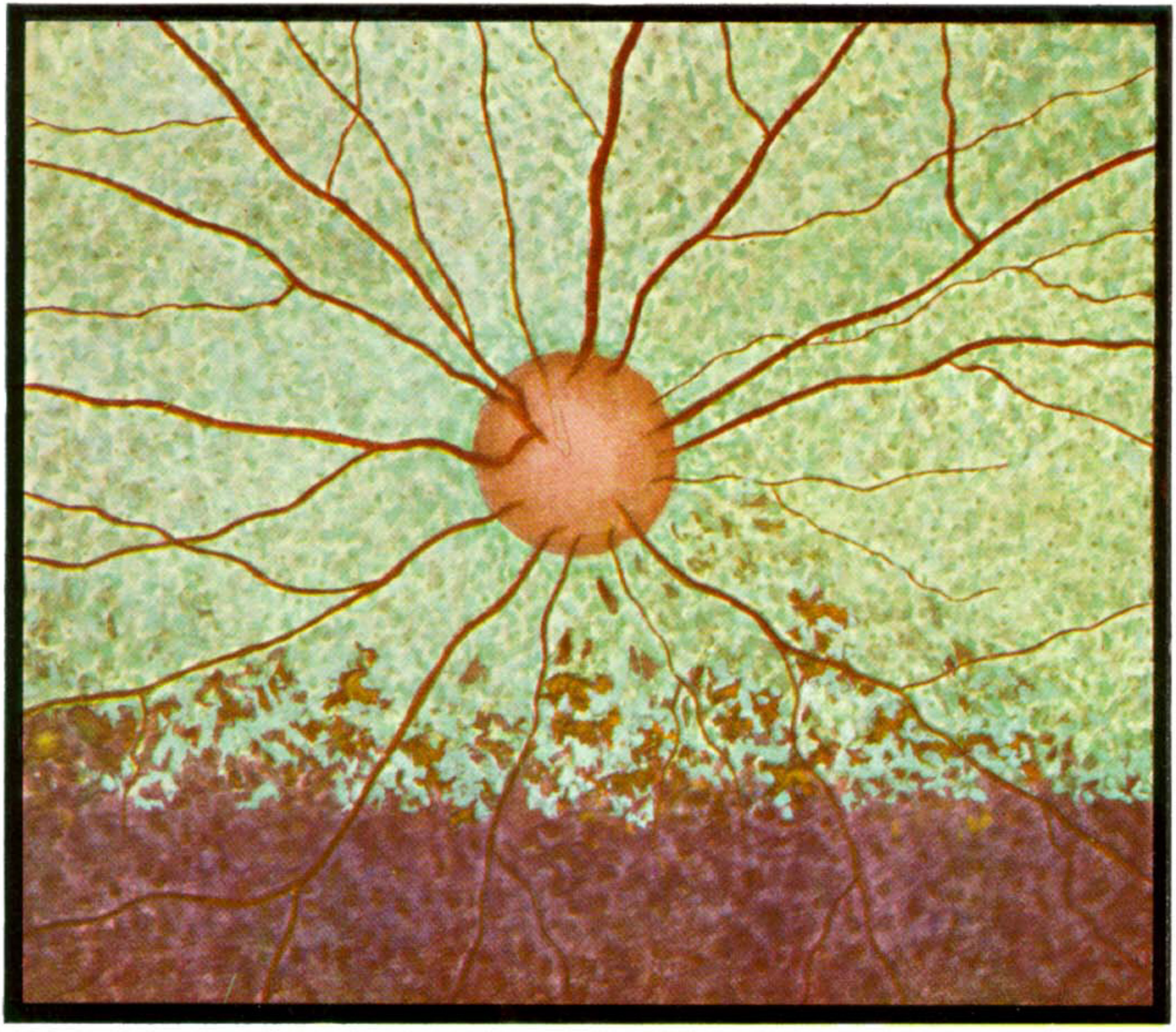

FIGURE 34. *Melursus ursinus*. Sloth bear.

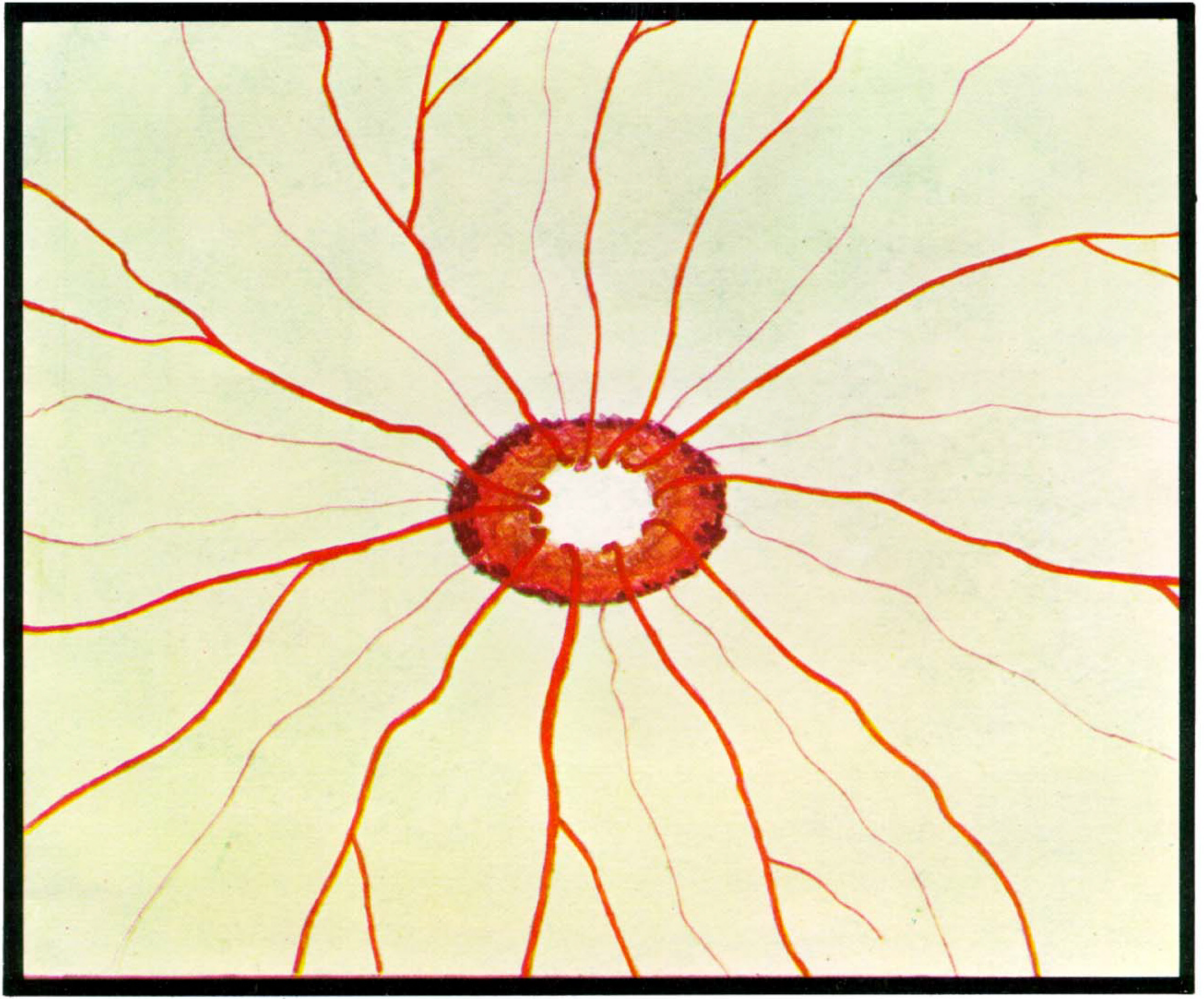

FIGURE 35. *Physeter catodon*. Sperm whale.

FIGURE 36. *Bos taurus*. British wild bull.

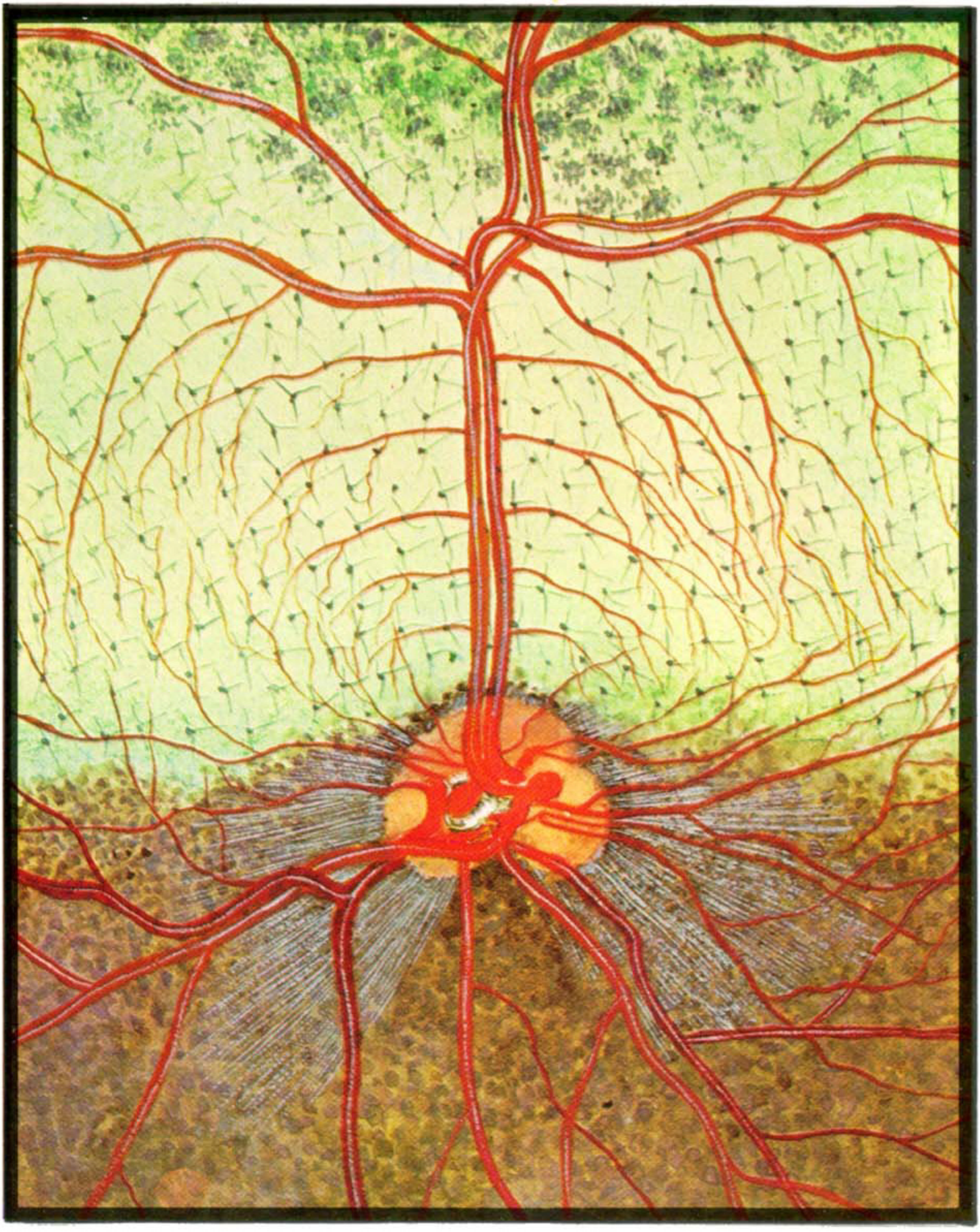

FIGURE 37. *Ovis musimon*. Mouflon.

FIGURE 38. *Capra hircus*. Domestic goat.

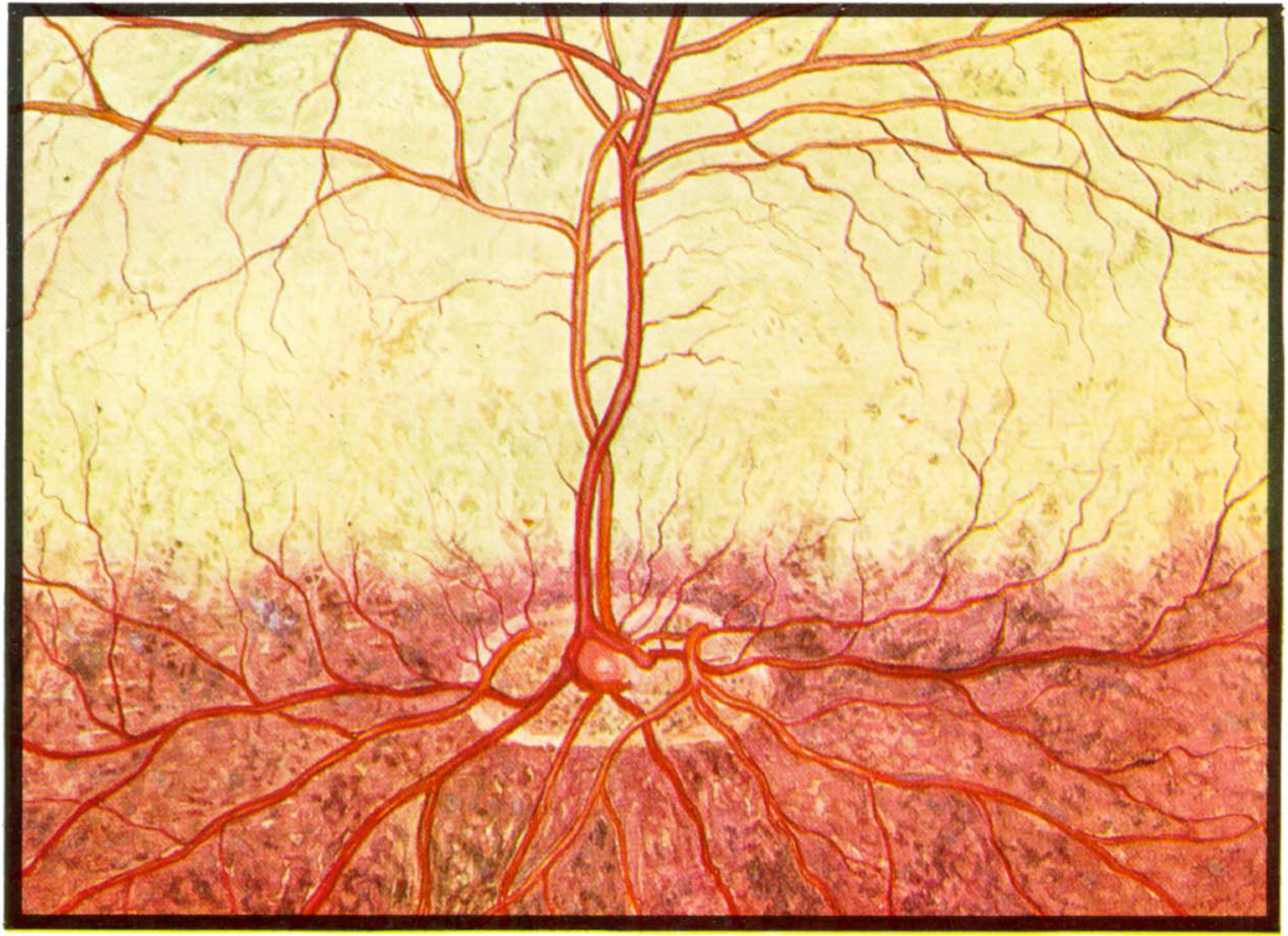

FIGURE 39. *Gazella dorcas*. Dorcas gazelle.

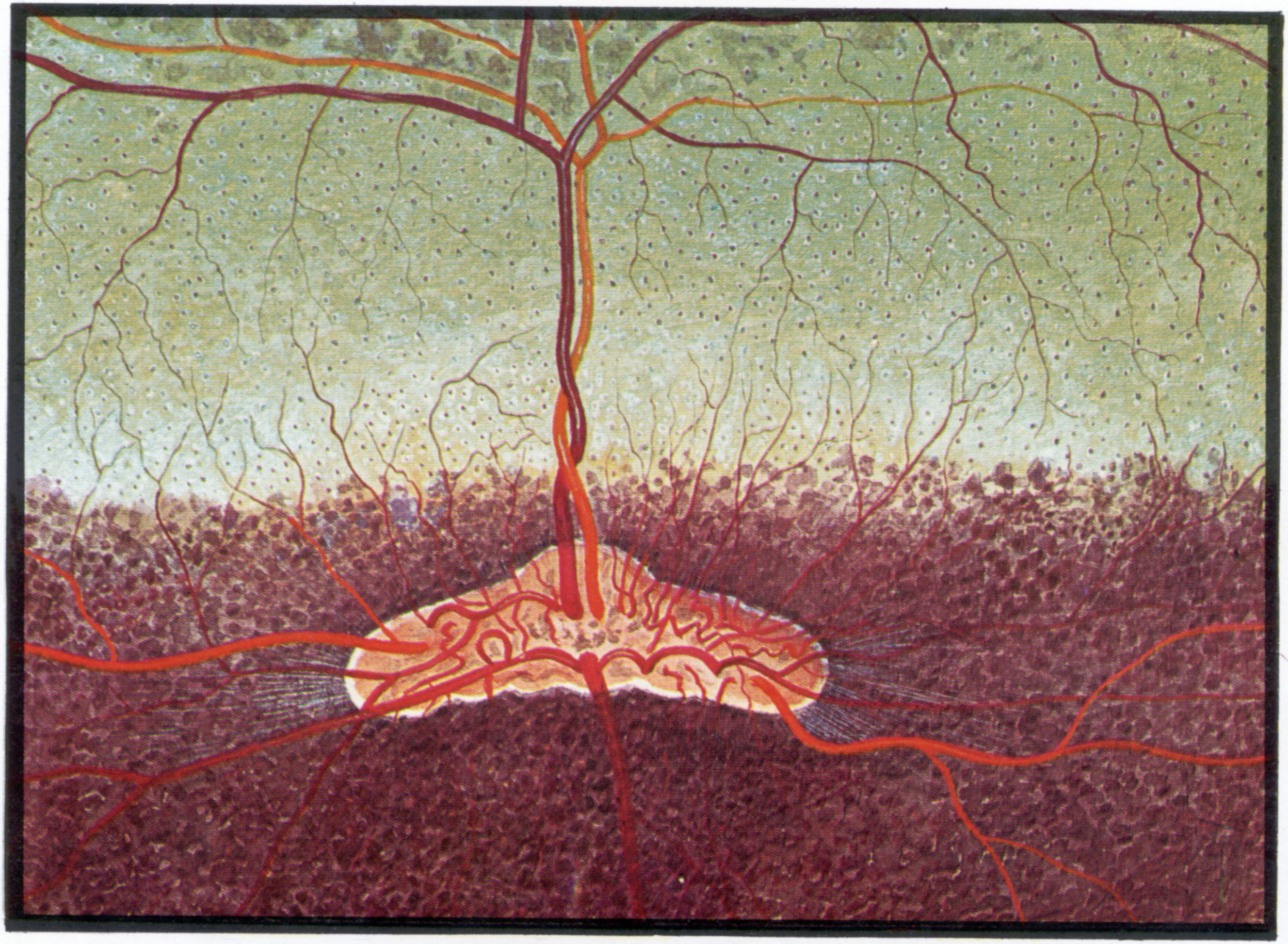

FIGURE 40. *Rangifer tarandus*. Reindeer.

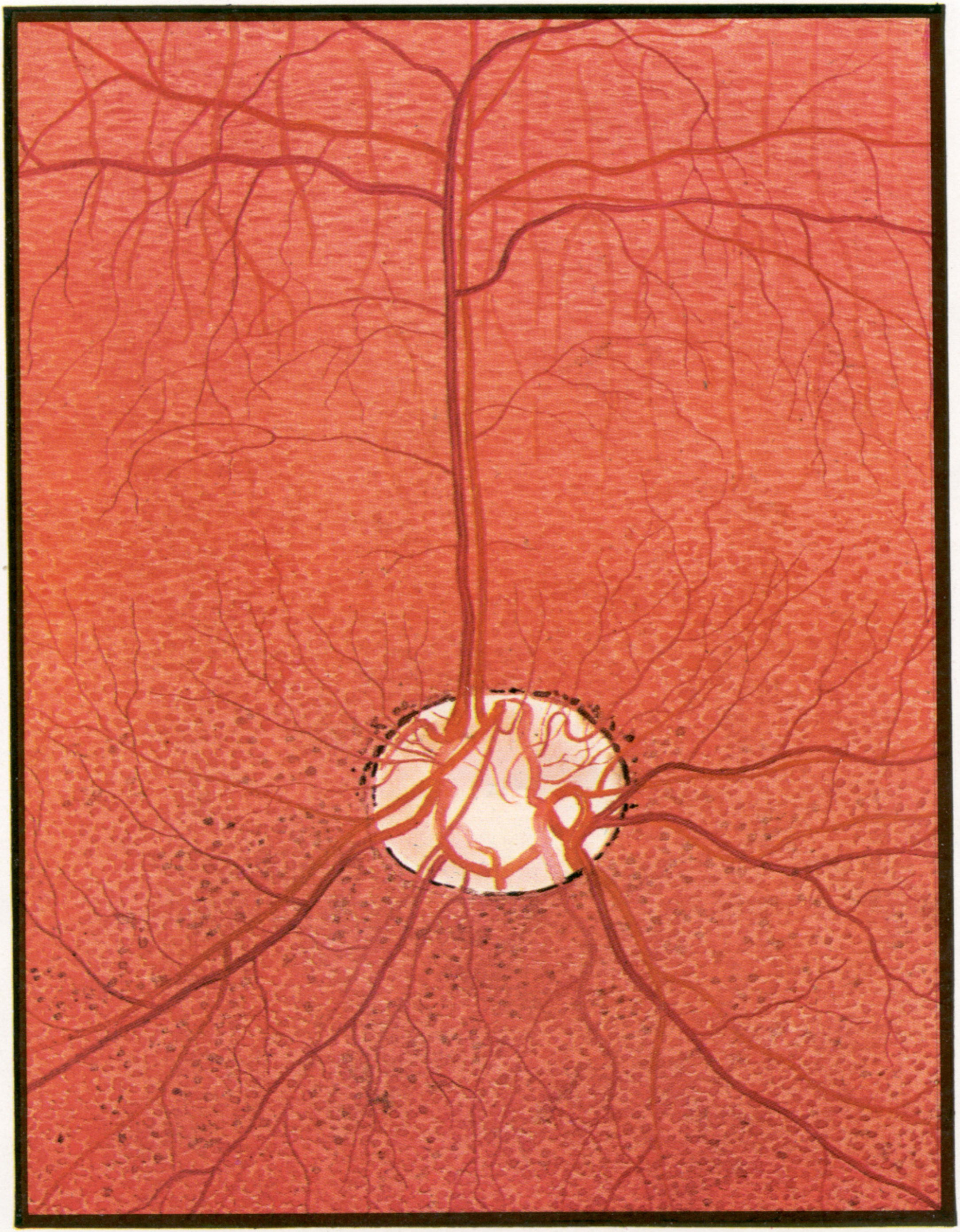

FIGURE 41. *Lama glama*. Llama.

FIGURE 42. *Equus caballus*. Domestic horse.

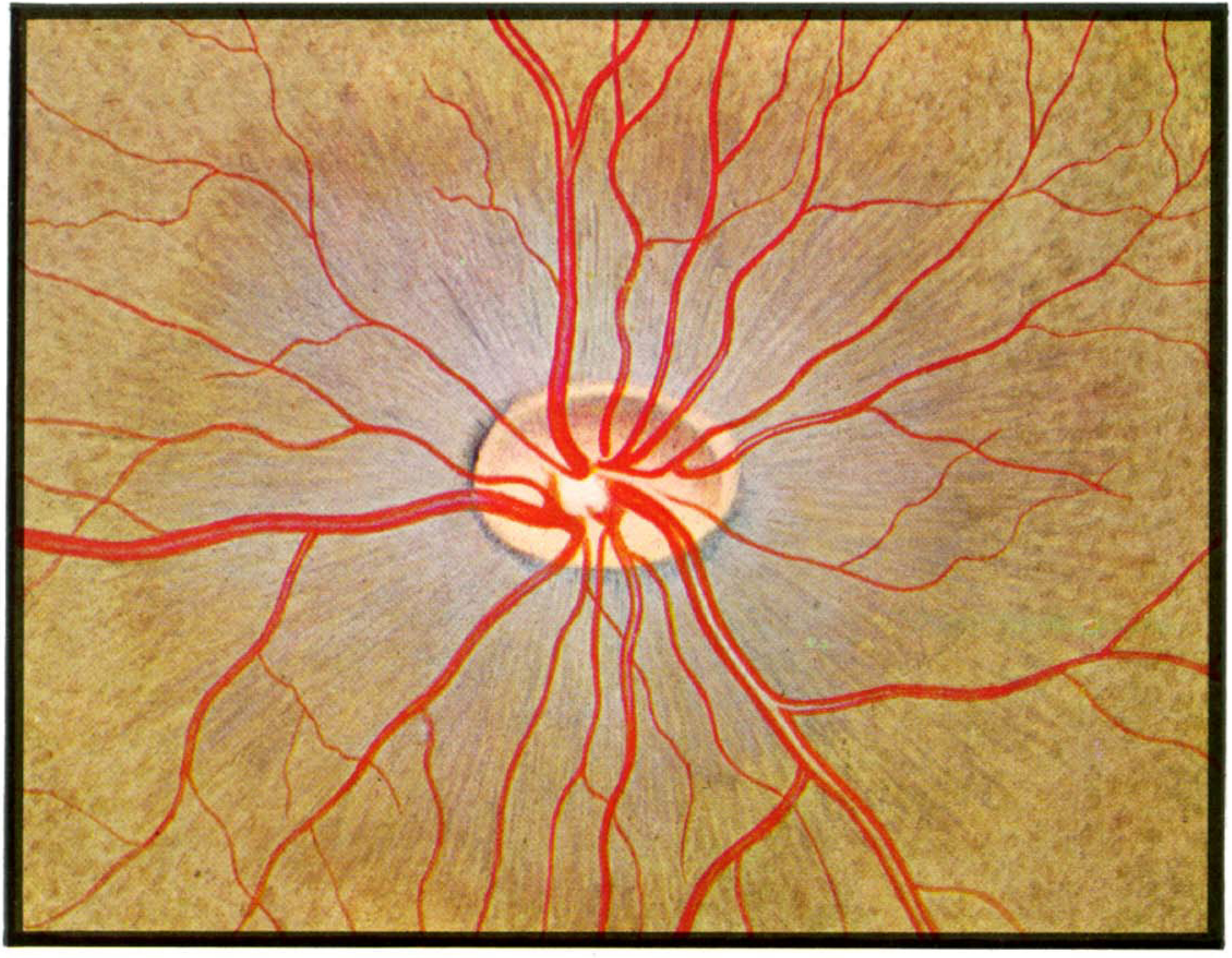

FIGURE 43. *Sus scrofa*. Domestic pig.

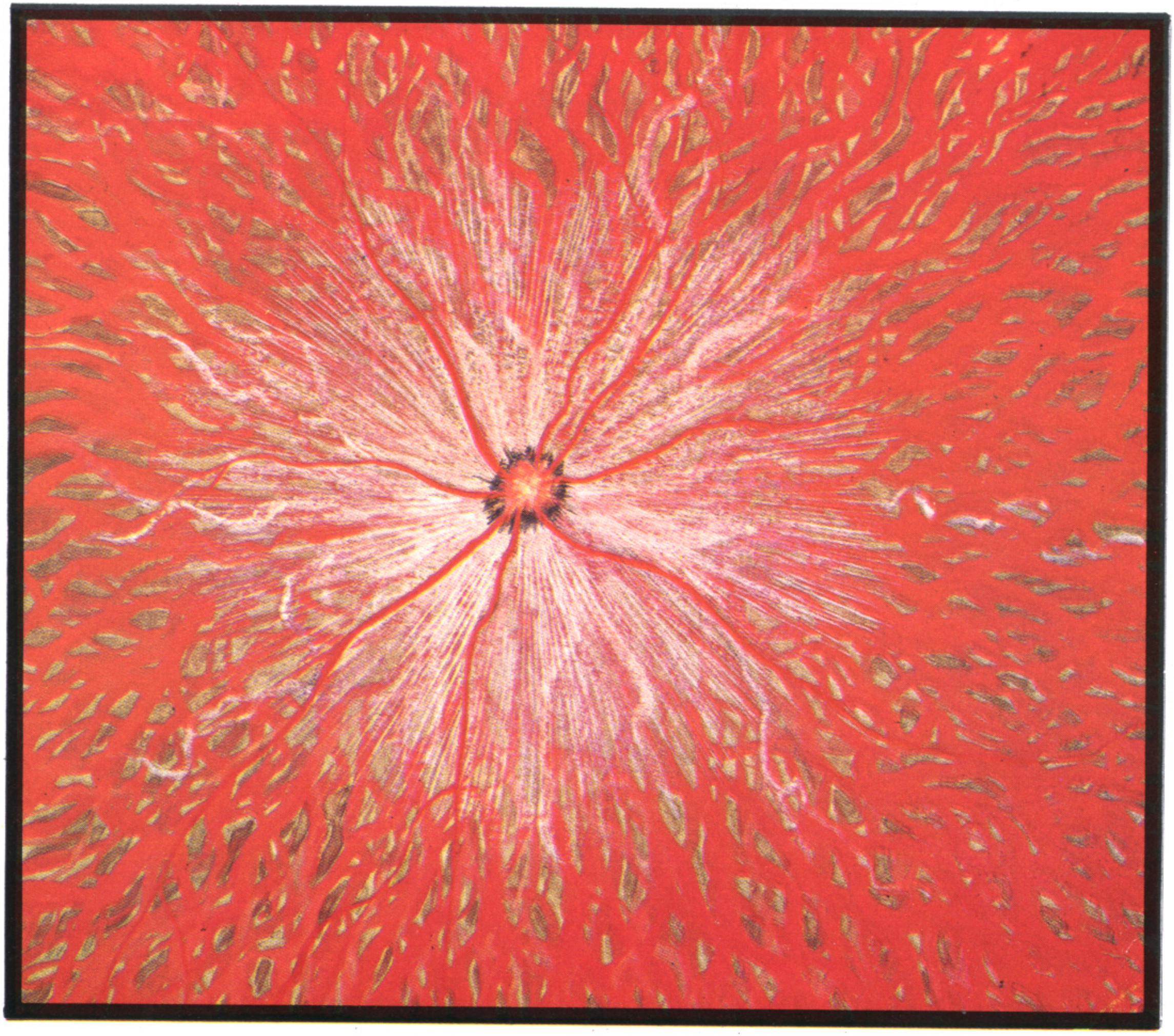

FIGURE 44. *Eliomys dryas*. Garden dormouse.

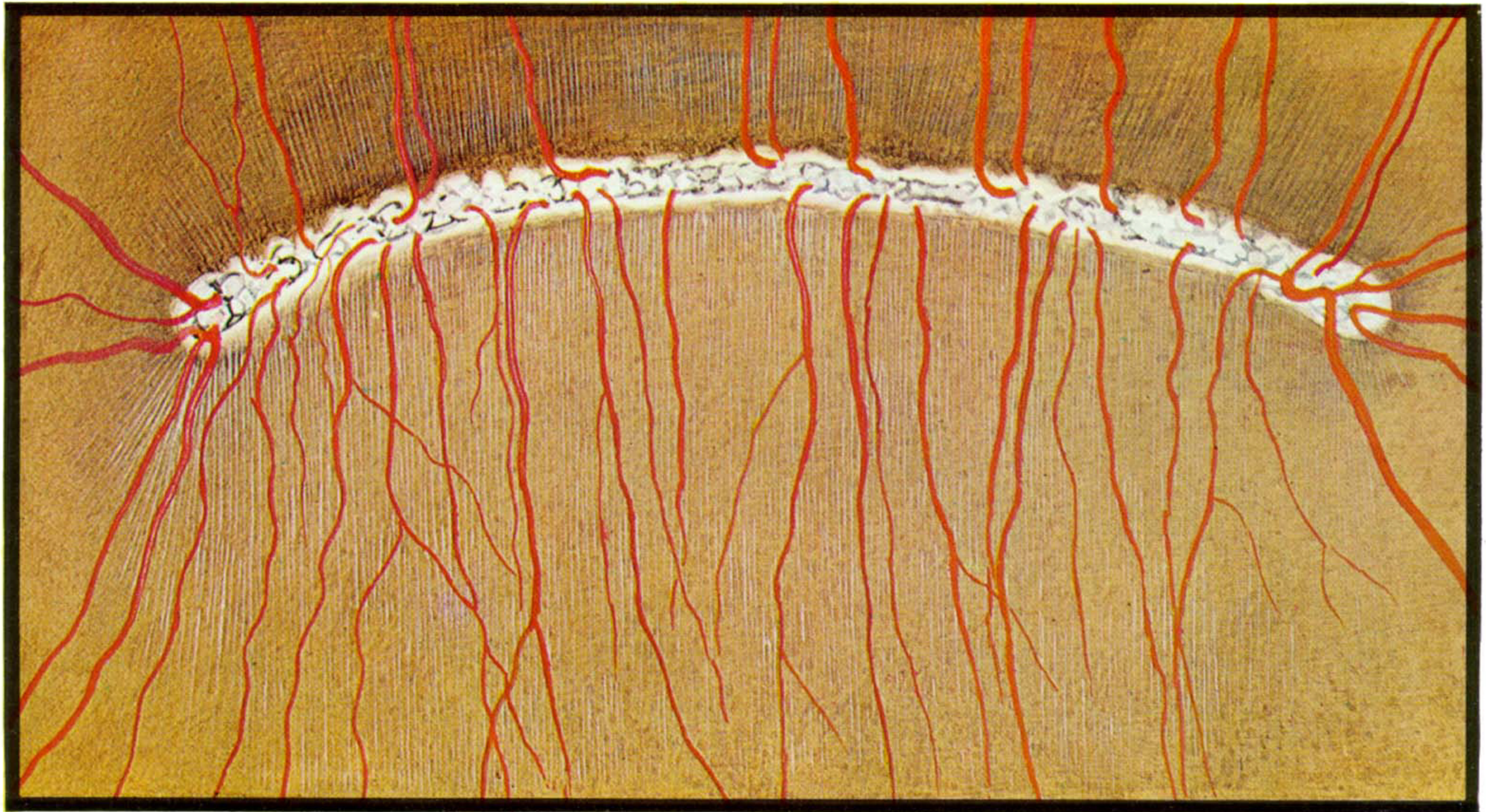

FIGURE 45. *Citellus citellus*. Ground squirrel.

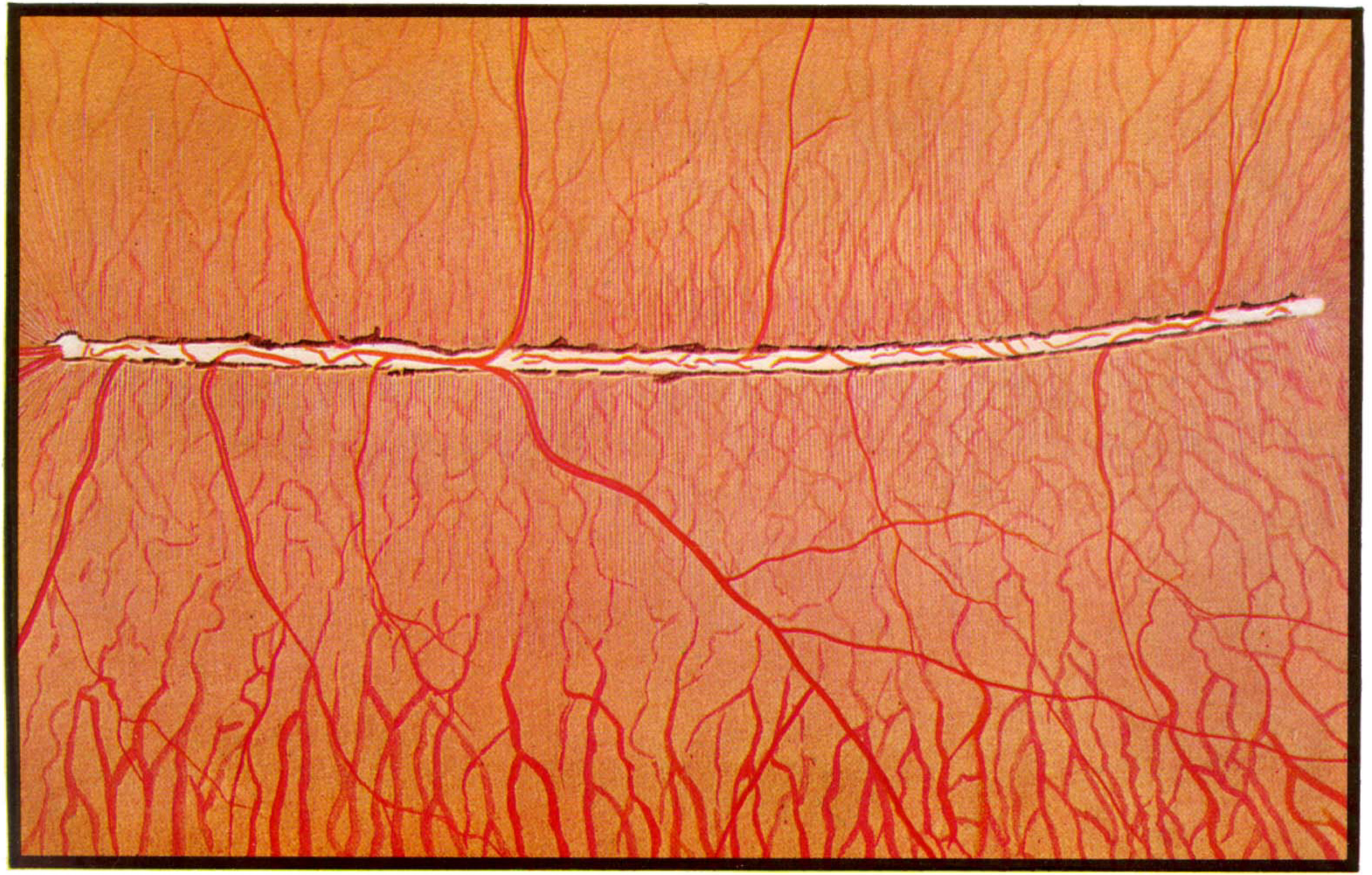

FIGURE 46. *Cynomys ludovicianus*. Prairie marmot.

FIGURE 47. *Myocastor coypus*. Coypu.

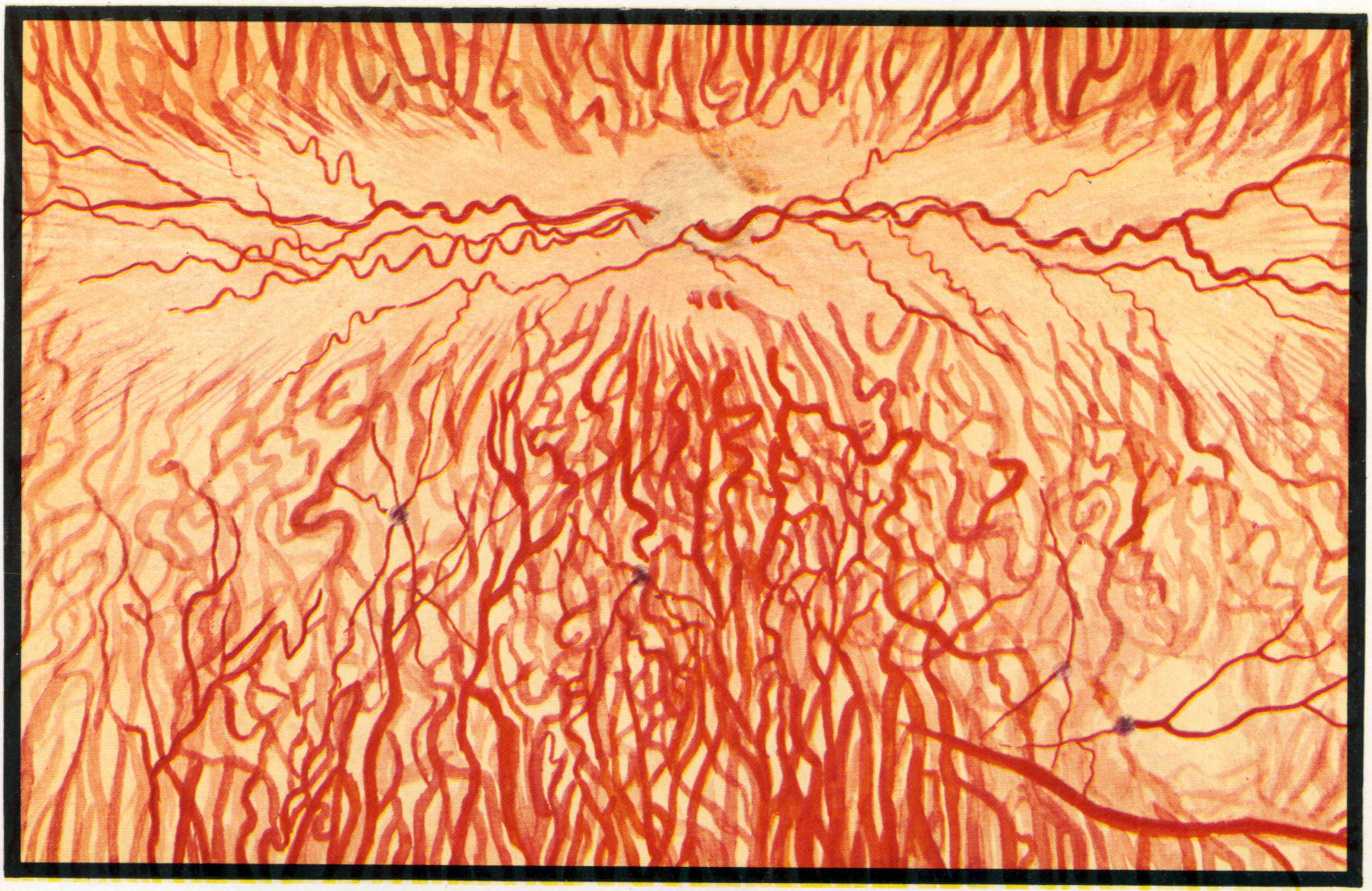

FIGURE 48. *Oryctolagus cuniculus*. Albino rabbit.

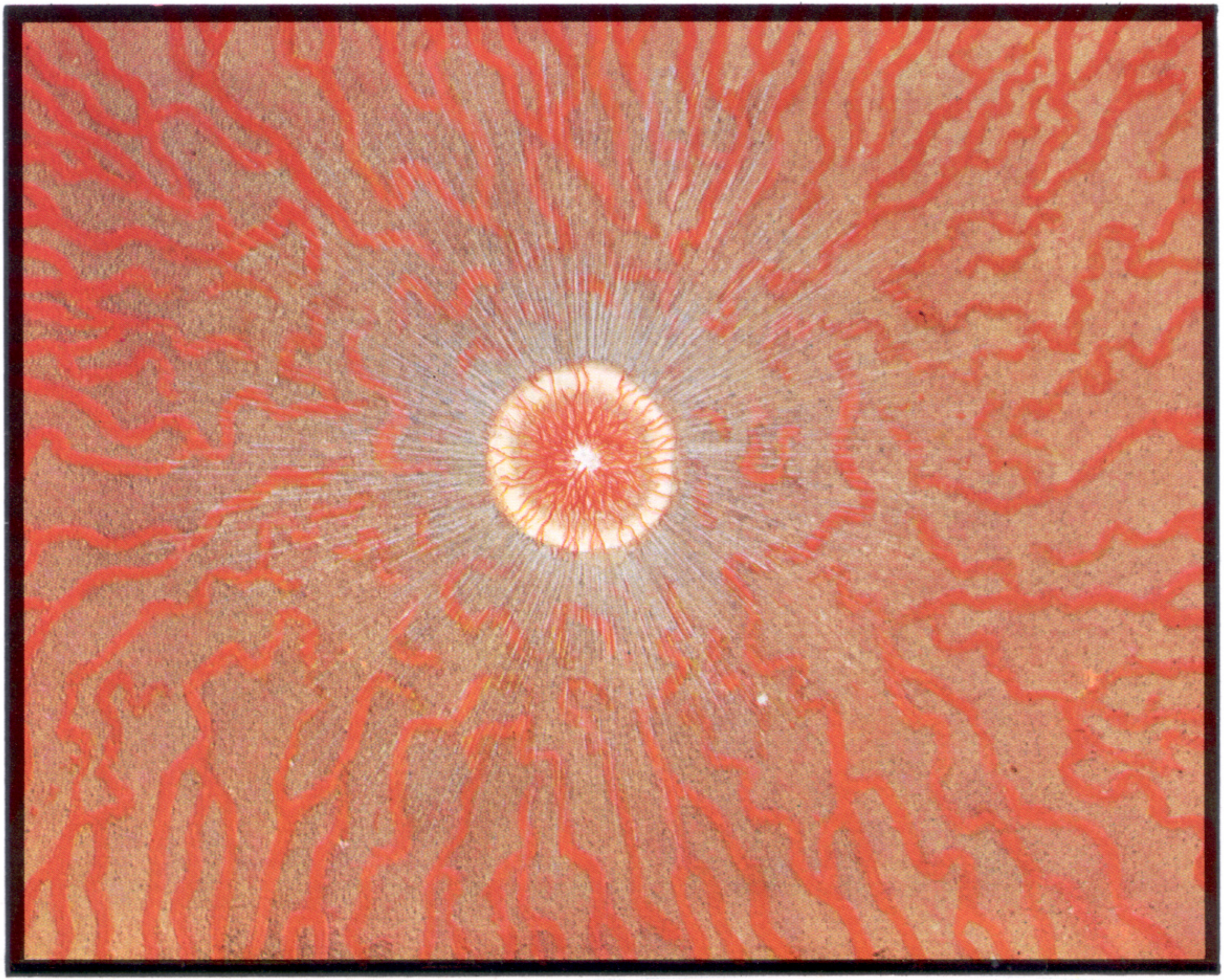

FIGURE 49. *Dendrolagus bennettianus*. Bennett's tree kangaroo.

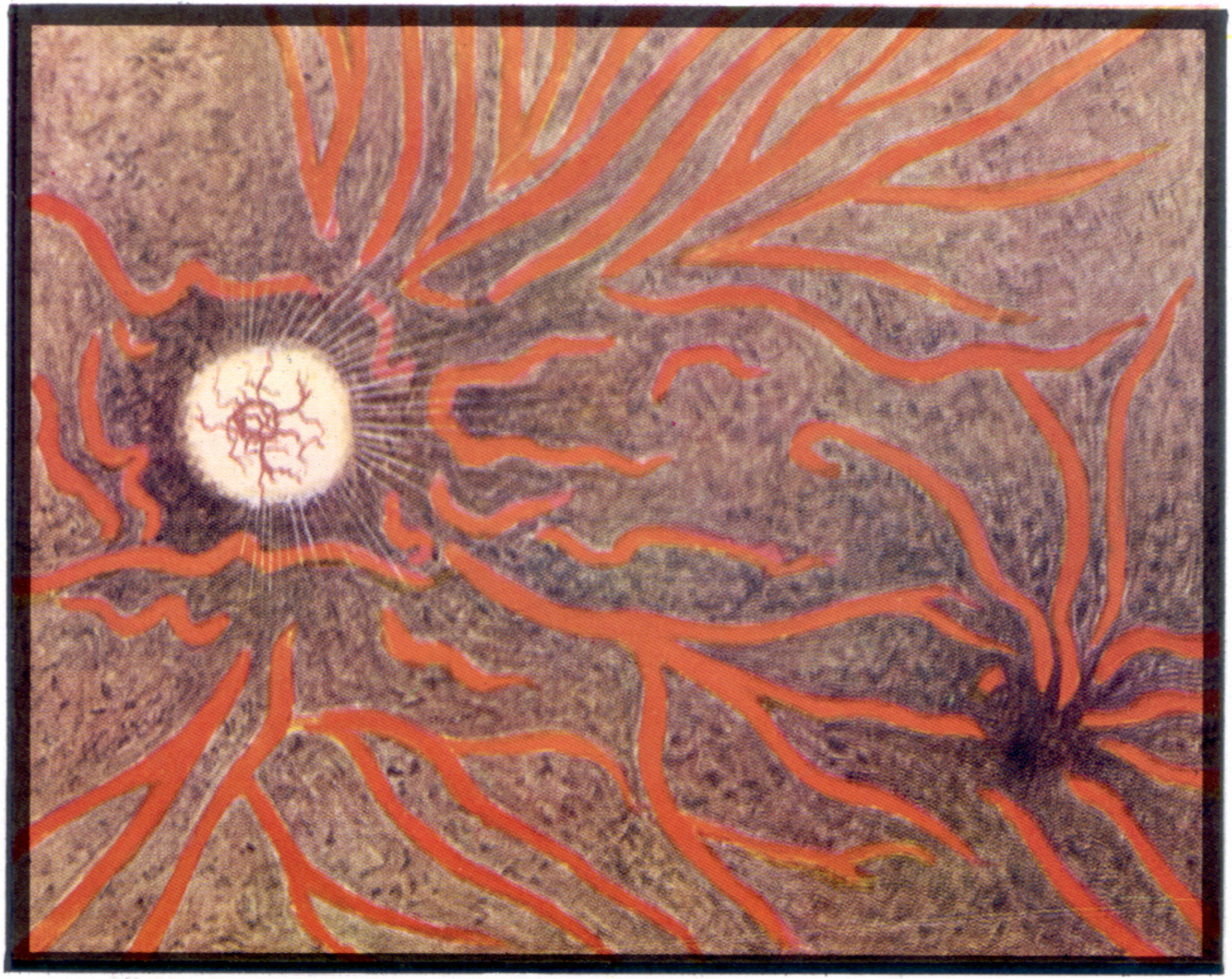

FIGURE 50. *Petaurus norfolcensis*. Flying opossum.