CONNECTIONS OF THE CEREBRAL CORTEX

I. THE ALBINO RAT. B. STRUCTURE OF THE CORTICAL AREAS

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EIGHTEEN PLATES (THIRTY-SEVEN FIGURES)

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INTRODUCTION

This paper is a partial report on a program of study of the cerebral cortex. The first phase of the project deals with the cerebral cortex and its connections in a lower form, using the albino rat. This is the second part of the prerequisite survey of cortical structure as revealed by cell and myelin stains. The first part, which appeared in the previous issue of this journal, contains the outline of the program and the references to literature. It was concerned principally with the identity and topography of the cortical areas. The present communication deals with the structure of the individual areas and makes a point of comparing in parallel preparations the appearances in cell- and myelin-sheath stains.

Weil- and thionin-stained sections of adjacent sections are illustrated at the same scale. All sections were cut in celloidin at 40 μ, and are reproduced at a uniform magnification of 90 X, linear. The sections are truly perpendicular to the surfaces of the cortex, sections at a variety of planes having been utilized. The thionin sections are photographs under identical conditions, so may be relied on to give comparable pictures. The fine fibers in the myelin sections were impossible to photograph, so they were drawn at a magnification of 360 X, using an Abbé camera lucida. Since it is impossible to draw each fiber in the field, these drawings represent only an approximation. From field to field and from day to day differences in interpretation and emphasis were bound to creep in, but every attempt was made to render them comparable to one another.

The study of structure is the basis for identification, definition and limitation of a unit area, so here is the evidence on which the previous paper is based. In that way the main body of this paper may be regarded as the “observations” section of the other. Beyond this there is, of course, the descriptive aspect of the observations themselves. However, the significance of this study should transcend a descriptive end. It is intended only to build a framework for further studies of the connections of the cortex of the rat. This is not
said idly, as most of the material is already prepared and analyzed.

FRONTAL REGION

Area 10, area frontopolaris (FD) (fig. 1). The cortex is thick and the cells are sparse. The infragranular layers are considerably thicker than the supragranular layers. Layer i is thin; layers ii and iii, very thin, are composed of small crenated pyramidal cells, rather closely placed. Layer iv is distinct but thin, equaling the thickness of layers ii or iii. The tiny dark granular cells are not numerous. It is in layer v that this area comes to its full development. It is thick and contains at least two distinct types of cells. Type A, the less numerous, but more conspicuous, is a narrow, dark pyramidal cell of medium size. They are distributed widely through layer v, interspersed irregularly with the cells of type B. Type B is a rather pale, large granular cell. These are without conspicuous processes and are scattered irregularly through layer v, blending with those of layer vi. Layer vi consists of medium-sized rounded granular cells, loosely placed, without processes or special characteristics. Layer vi equals layer v in thickness. There is a thin but distinct layer vi-b below a clear stratum. It consists of medium-sized granule cells similar to those of layer v.

Area 10 is dominated by two great systems of fibers. The radial fibers are best seen in sagittal sections where they may be followed through their full course in one section. As they leave the medulla they sweep forward and peripherally through layer vi and become nearly perpendicular to the surface through layer v where they dwindle. A few fibers can be followed out as far as layer iv. These fibers are numerous, coarse, and basally are arranged in conspicuous fascicles. The other main system is the deep tangential system. These are also quite coarse for fibers confined to the cortex and run in general in a sagittal direction. They are very numerous and occupy a large part of the thick layer vi. In horizontal sections they are seen to form a radiate arrangement converging caudally which can be followed at least to area 3 and probably go to areas 1 and 2. Fibers from the adjacent area 24 join this sheaf. They must form an important sensorimotor associational system, intracortical in the primitive state, possibly becoming subcortical in more complex forms; they require a further analysis. In layer v the non-radial fibers take the form of fine clusters around the cells but particularly basally there are many obliquely running fibers which merge below gradually with the tangential fibers of layer vi. In horizontal sections these fibers seem to pass to the parietal cortex more laterally, i.e., to area 2. There are very few myelinated fibers in the outer part of the cortex and the external horizontal lamina is extremely sparse.
The chief distinguishing characteristics of this area are (1) its thickness, (2) its sparseness of cells, (3) the relative thinness of the supragranular layers and of the granular layer, (4) the dark pyramidal cells in layer v.

*Area 6, area frontalis agranularis (FB) (fig. 2).* Layers ii and iii are somewhat thicker than those of area 10. This is not brought about by any increase in number of cells but rather by a wider dispersion of the crenated pyramidal cells of the same type as those of the area previously considered. Layer iv is more conspicuous, merging with layer iv of the parietal region adjoining, but does not contain any cell-free layer iv-b. The presence of this conspicuous layer iv renders questionable the homology of this with the premotor area, for in man the granular frontal cortex is more rostrally placed while the premotor area has a very poorly developed granular layer. It might thus be more reasonable to compare this area to FC of von Economo. Nevertheless, it is nearer the parietal cortex than the frontal polar area and is immediately adjacent to the motor area 4.

The pyramidal cells of layer v are larger and more numerous than those of area 10. They are confined to a narrower zone partly on account of the reduced relative thickness of layer v in this area. Layer vi is thicker and contains smaller cells than those in area 10.

The fiber picture of area 6 resembles that of area 10. Corresponding to the differences in thickness of the cellular layers the fiber layers are altered. The horizontal fibers in layer v are somewhat more numerous and are directly continuous with the conspicuous fiber layer in iv-b of the parietal cortex adjacent. No drawing was made for the fiber pattern of area 6 because it could not be differentiated in a drawing from that of area 4.

*Area 4, area gigantopyramidalis (FA) (fig. 3).* Layers i to iv form about two-fifths of the thickness of the cortex, which is in marked contrast to the relative proportions in area 10. This accretion is due to a greater exuberance both in layers ii and iii and in layer iv, though more conspicuously in the latter, which contains characteristic granule cells, not as thickly packed, however, as in the parietal area immediately laterally. The absence of any layer iv-b at all distinguishes it from the parietal area. In layer v there are still the two types of cells, but the pyramidal cells are more closely packed, larger and darker than those of areas 6 or 10, and occupy a more distinct lamina due to the relative thinning of layer v. The pyramidal cells in layer v are not true Betz giant cells since they are equalled in size by pyramidal cells in other regions.

The presence of a distinct granular layer in area 4 seems to violate one of the primary principles of cytoarchitectonics and it might be urged that this area should not be equated with area 4.
However, it is immediately adjacent to verified parietal area and sends numerous fibers into the brain stem; moreover, it merges with the other frontal types. We therefore have to admit a distinct lamina granularis in the primitive area 4. Further analysis may demonstrate that in lower forms this region receives direct sensory collaterals which have been dropped out in more complex brains due to the longer circuiting of the stimuli.

The fiber pattern of area 4 is much finer grained than that of area 10. The radial fibers are in minute parallel fascicles. There are few fibers of any sort beyond the basal part of layer v, while in area 10 the fiber pattern is dense as far as layer iii. The lower part of layer vi is crowded with longitudinally running tangential fibers forming part of the parieto-frontal association system.

When judged purely on the basis of cytoarchitectural similarity none of these regions conforms to any other in the human brain, the one which has been most intensively studied. Certainly area 4, which is the most characteristic in its structure of all areas in man, differs in several ways from that designated as area 4 in the rat. This merely demonstrates the fallacy of homologizing cortical areas purely on the basis of their architecture. Yet the regions outlined must be basically correct. The area here designated as frontal, comprising areas 10, 6 and 4 has a general uniformity of structure, but the structure of this region contrasts sharply with that of the parietal areas laterally and the limbic areas medially. Anyone would consider the frontal area a unit. In spite of the large size of area 10, it is impossible to subdivide it further in any consistent manner. If any part is to be designated as area 4, certainly that part which is immediately adjacent to verified parietal cortex should be considered as corresponding to area 4. Area 6, then, is intermediate between area 4 and area 10 in structure, and this is likewise true in man. It must be realized that these areas are designed for a specific functioning, and in the rat brain their connections can hardly be identical with those of corresponding areas of the human brain. Consequently, their structure may be expected to differ. We, therefore, emphasize the principle of functional similarity as the basis for homologizing cortical areas rather than structural similarity taken alone. If we are to draw analogies we must know connections. The area which sends the most abundant fibers into the oblongata and cord must be designated the precentral motor area, no matter what its structure.

Area 8, area frontalis intermedia (FC) (fig. 4). Structurally this area differs considerably from area 10. Almost all the cells are granular in type, and there are only a few pyramids in v. Layers i-iv form about two-fifths of the thickness. The supragranular layers cannot be further subdivided. They are thin and consist of rather closely
placed medium-sized granular cells without a trace of pyramidal structure. Layer iv is equal to the thickness of the combined supragranular layers and consists exclusively of granular cells smaller in size and more widely spaced than those just considered. Layer v has two types of cells. The pyramidal type is conspicuous because of the very narrow dark silhouette of the cell. The pyramidal cells are quite closely spaced but form a single stratum and are not scattered through the thickness of the wide layer v as are those of area 10, hence are fewer in number. The granule cells form a larger proportion of the total of layer v than they do in area 10. They are more closely arranged and begin immediately under layer iv and form a distinct purely granular layer. Thus we speak of v-a which is granular and v-b, which is composed of pyramidal cells together with very few granular cells, and the elements in this sublayer are more widely spaced. Layer vi is composed of quite closely packed round granular cells of large size, larger than those of area 10. This layer is rather thick too but there is no separation below it of a layer vi-b.

The ventral part of the area originally designated as area 8 has a different structure. This portion has a fore-and-aft extent equal to that of area 8. It occupies the dorsal shoulder of the rhinal sulcus. The most conspicuous difference between this area and area 8 is that the pyramids of layer v are very greatly attenuated, to form long narrow dark pencils, closely arranged. This at first was considered to be merely a modification to fit the fancied lateral compression of the basal layers at the shoulder. However, in its full development the region which we will here designate as 8a, differs markedly in structure from area 8 (fig. 5). The supragranular layers are thin and composed of irregular pyramidal cells, small and dark. Layer iv seems missing altogether, but is well developed in the true area 8 adjacent. This allows layer v to come much closer to the surface and the long, dark pyramidal cells form a conspicuous element, as already mentioned. There are also granule cells mixed in with the pyramidal cells, however. Layer vi resembles that of area 8, but is paler.

In fiber preparations the two areas, 8 and 8a differ somewhat. Area 8, proper, is somewhat poor in radiating fibers, whether compared with area 10, dorsal to its more rostral part or whether compared with area 2, which borders it dorsally in its caudal part. There is a definite radiata, however. There are no external striae. Area 8a, on the other hand, has a wealth of long radiate fibers which extend far out to layer iii and seems always to be cut in a true longitudinal direction in transverse series. This would suffice to designate a separate area if the myeloarchitecture alone were being studied. These fibers curve with a distinct lateral convexity. Just outside layer vi is a conspicuous stratum of horizontally directed fibers in some of area 8a.
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which does not extend into area 8. These fibers connect medially with area 51b. In the more caudal part the stratum becomes more conspicuous and in 51b forms a distinct lamina between v and vi. The horizontal layer of fibers in the deeper strata which is such a conspicuous part of area 10 is missing in areas 8 and 8a so that the radial fibers dominate the picture. The oblique stratum of fibers in layer v of area 10 is likewise missing. Instead, there is an irregular criss-crossing of fibers running in all directions. The external horizontal lamina is greatly reduced.

Area 11, area prefrontalis (fig. 6). The cellular layers of area 11 are distinct, but there is little variety or specialization of cellular type. The cortex is thick, as is the frontal cortex generally. The supragranular layers are fused and composed of uniform rather pale granulous cells. Layer iv has fewer and smaller cells than the layers bordering it, hence forms a light streak. Layer v again has a concentrated cell population, and the cells are not much larger or darker than those of the supragranular layers. On high power they are seen to be drop-shaped. The sixth layer is more cellular than the adjacent 10, due to a diminished number of fibers.

The fibers of area 11 are predominantly radial. These are fine, separate, and make a pronounced arc in the sagittal section as they change from an anteroposterior course in the medulla to turn basally. They run through layer v and, in diminished numbers, to layer iv. There are a few scattered irregular wisps in v and a very little external horizontal lamina.

PARIETAL REGION

Area 2, area postcentralis caudalis (PC) (fig. 7). Layers ii-iv equal about one-third of the total thickness of the cortex. They are minutely and closely granular, which lends a uniform band-like appearance to the outer layers. This is in contrast to the darkness and irregularity of the infragranular layers. Layers ii and iii are uniform and thin. In the rostral sections and the dorsal part of the more caudal sections the supragranular layers are composed of purely pyramidal cells. However, through a considerable extent of the middle group of sections the ventral half of the area has purely granular cells in the supragranular layers. In the caudal part of area 2 the supragranular layers are pyramidal. Layer iv is rather narrow but very intensely granular. It has a distinct lower edge so that it forms a marked band and contrasts strongly with the cell-poor layer below. In the ventral region, there are many minute pyramidal or rod-like intensely stained cells. These are variable in outline and perhaps might better be called fusiform in type. They are scattered through layer 4 and constitute about one-twentieth of the cells but
are conspicuous because they are so much more deeply stained than the pale granules.

The presence of a subdivision of area 2 with layers ii and iii composed of granular cells and layer iv having these conspicuous fusiform cells might justify the separation of a distinct area. This is coupled with a less well marked v-a and a more uniformly granular and closely celled infragranular region. Whether this merits identification as a special region is not known but will here be referred to as area 2a.

In all parts of area 2 layer v may be divided into strata a and b. Stratum a is distinct because of its relative paleness though there are many granular cells present, but the heavy granular nature of layer iv is above and the conspicuous pyramidal cells of v-b below make it relatively pale. V-b is almost exclusively pyramidal. The cells are rather closely placed but of medium size. They are similar to the large pyramidal cells of area 3. In area 2a they are less well developed although perhaps as numerous. Layer vi is fairly thick and uniform and composed of small granular cells. They are more densely arranged in area 2a. In the caudal part they become somewhat sparser and show the fasciculation or rod-like arrangement characteristic of the parietal cortex in man. There is a distinct cellular vi-b.

Myeloarchitectonically, area 2 can be easily separated from all other parietal areas, as it contains the greatest wealth of fibers of any cortical region. The more obvious fibers may be divided into three groups. (1) There are multitudinous radiating fibers extending from the external capsule directly outward for a long distance as far as layer iv. These are usually arranged in the form of small pencils which keep their separateness as far as the granular layers. (2) The tangential stria of Baillarger, corresponding to the internal stria, occupies layer v-a. It consists of a fine fibrous feltwork with a predominating transverse grain. (3) The inner tangential layer, occupying the lower half of layer vi. This layer is as thick as the external capsule and is extremely rich in fibers, which radiate into the frontal region. They probably run from parietal to frontal, since after large parietal lesions intracortical granules are present frontally. It probably constitutes the main parietal-frontal or sensori-motor connection.

Area 3, area postcentralis oralis (PA) (fig. 8). Area 3 contains many large pyramidal cells in the fifth layer. Actually there are more large pyramidal cells than in area 4, but area 3 is differentiated sharply from the motor cortex by the marked and very granular fourth layer. Cytologically it belongs clearly to the parietal type. It is the most completely stratified of all of the cortical areas.
The supragranular layers are fairly thick and definitely pyramidal. Layer iv consists of closely packed minute granular cells which form a distinct thin stripe separating it from the layers above and below. Layer v is clearly divided into a cell-poor a and a heavily pyramidal b. The pyramidal cells are quite numerous, fairly large and very darkly staining. They have long well developed apical processes. Layer vi, in contrast to that of area 2, is fairly densely celled. The cells are medium-sized, and purely granular. There is a distinct thin cellular vi-b. When one compares cell- and fiber-stained sections it becomes clear that vi-b is created by the intense accumulation of tangential fibers in the lower part of vi.

*Area 1, area postcentralis intermedia (PB, PD)* (fig. 9). In spite of its small size this area is distinct from area 3 medially and area 2 laterally. It is characterized by a tendency of the layers to run together. The chief factor contributing to this appearance is the lack of any condensation of cells in layer iv. This gives the supragranular layers a pale uniform appearance. Moreover, there is no pale v-a, though there are numerous well marked pyramids in v-b, as in area 3. The dark fusiform cells so characteristic of area 2 cease abruptly at the junction with this area.

Fiber studies reflect the differences in the cellular appearance. There is less of a tendency toward stratification, but there is a rich plexus in the middle zone like that in area 2. The basal longitudinal fibers are a part of the same stratum as in the neighboring areas.

*Area 7, area parietalis superior (PE)* (fig. 10). Layers ii to iv suddenly becomes reduced to half the thickness found just above in area 2. Layer ii is thin and closely packed. Layer iii is thin and has closely arranged faintly pyramidal cells. Layer iv is much reduced but still has a separate existence. Layer v-a is present but not well marked and v-b has fewer and smaller and narrower pyramidal cells. Layer vi is thinner and considerably denser. In myelin preparations it has the characters of the parietal cortex. It contains many radiate fibers which merge with those of area 2. It does not have a stria of Ballesta in the fifth layer but instead has a definite transverse or tangential fiber lamina located in the outer part of layer vi. The deep horizontal lamina of the parieto-frontal region is found here too, of course.

In its cell and fiber pattern area 7 is a generalization of the parietal type. The proportions of the layers are similar to other parietal types in which ii-iv = v-vi, more or less. However, layer iv is not as dense, there is no distinct cell-poor v-a, and vi is denser of cells. The fiber pattern reflects this picture. There are many fewer radiate fibers and these disappear half way through the cortex. The basal tangential lamina in layer vi is abundant at the dorsal surface of area 7
but is quite gone at its lower edge. Hence, it must arise or end
in this area to a large extent. In fact, one can see the fibers turning
peripherally to outer layers of the cortex. There is a distinct in-
tensification of the plexus in the outer part of layer vi, which is apart
from the relative fiber loss in the deeper part, further demonstrating
the independence of these two laminae. The stria of Baillarger in
v-a is much reduced, but the radiate fibers still extend out to layer
iv. Ventral to area 7 this parietal fiber pattern suddenly breaks
down, another indication that 7 is a part of the parietal cortex.

*Area 40, area supramarginalis (PF) (fig. 11).* Layers ii to iv sud-
denly become reduced to half the thickness found just above in area
2. Layer ii is thin and closely packed. Layer iii is thin and has
closely arranged faintly pyramidal cells. Layer iv is much reduced
but still has a separate existence. Layer v-a is present but not well
marked and v-b has fewer and smaller and narrower pyramidal cells.
Layer vi is thinner and considerably denser. In myelin prepara-
tions it has the characters of the parietal cortex. It contains many radiate
fibers which merge with those of area 2. It does not have a stria of
Baillarger in the fifth layer but instead has a definite transverse or
tangential fiber lamina located in the outer part of layer vi. The deep
horizontal lamina of the parieto-frontal region is found here too, of
course.

*Area 39, area agranularis (PG) (fig. 12),* may be considered as
intermediate in type between parietal and occipital cortex. The
cortex is thinner than in other parietal regions. This is caused by the
marked thinning of layer vi. Layers ii to iv make up half the cortex.
They are practically inseparable from one another as they all present
the appearance of small granular cells rather closely spaced. A cell-
poor stratum below layer iv is not present. Layer v is very thin
and not divided into sublayers. Pyramidal and granule cells are
present. There are only a few pyramidal cells and these are not dark
or large. The thin layer vi consists of rather closely arranged, quite
small, granular cells.

In myelin preparations area 39 shows a reduced radiata when com-
pared with the other parietal regions, appearing more like area 18
next to it except that there are fewer radial fibers. There is a broad,
rather heavy stratum of tangentially running fibers in layers v and vi
which seem to continue to the optic areas medial to it and to the
auditory area ventrolateral to it. Area 41, the auditory area, seems
to be quite strongly connected with this region. From what is known
of the function of area 39 in man this would seem to be just what is
called for in its connections and thus it might constitute the
germ of the great sensory correlation area of the parietal lobe. Caud-
ally the connection with area 41 becomes a striking feature in the
section and in some of the preparations there is a wider space between the cells in layer v and in the upper half of layer vi. The horizontal fibers extending in both directions seem not to be intrinsic to area 39. They are thinnest in their central part and increase noticeably and are extended broadly into the optic and auditory regions. Caudally the character of the cortex in this sector changes gradually and subtly to conform clearly to the occipital type, having very little differentiation of any sort in the cortex. Nevertheless both optic and auditory association fibers continue to feed into this narrow transitional zone.

TEMPORAL REGION

*Area 41, area auditoria (TD)* (fig. 13). The identifying characteristics of the auditory cortex are easy to recognize but difficult to describe, that is, in cell preparations. In fiber preparations it is very clear-cut. The cortex is somewhat thicker than that of the adjacent areas. It is, broadly-speaking, parietal in type but has an irregular look which seems to be due to the wide variety of cells in all of the layers. It is the only area thus far described which has dark fusiform cells in layer vi. The junction between layer iv and v is about half way through the cortex. Layers ii and iii are thin and the cells vary between pyramidal and granular in type. Layer iv is moderately thin and not well distinguished from the supragranular layers but on higher magnification it seems to consist of a large number of small granule cells. Interspersed with these are scattered small fusiform or irregular elements. Layer v is of moderate thickness and not well separated from layer iv. It consists of a wide variety of pyramidal cells, light and dark, small and large. Any classification into types would have to depend on a study of the processes and the courses of the axons. The cells of the auditory cortex were studied by Cajal in Golgi preparations in 1911, and later Lorente de Nó ('22) made an exhaustive study of the structure of this area in the rat. Interspersed with the cells in the middle part of the cortex are darkly stained cigar-shaped irregularly disposed glia cell nuclei. Only in the auditory cortex are these nuclei conspicuous. Layer v-b contains few cells and the pyramidal cells are absent. It is here that the transverse fiber stratum is developed to its greatest extent. Layer vi, of moderate thickness, contains lightly staining cells closely placed, though under a low power they present a homogenous appearance; under high power they are shown to have a diverse morphology. Occasional dark fusiform or trapeziform cells are located here. There is a definite layer vi-b of flattened pale cells.

In myelin preparations the auditory cortex has a characteristic structure so that its location and limits can be easily determined. This
depends on a greater wealth of fibers than in any of the surrounding areas and particularly it depends on the presence of a heavy tangential stratum occupying layers v and vi. The radiata extends out to layer iii but is only moderately well developed. Layer iv contains some tangentially running fibers, both dorsoventrally and rostrocaudally directed, but the great mass is found in layer v-b which consists chiefly of fibers dorsally directed which diminish as they reach areas 18a and 39. The fibers of this layer do not continue ventrally far beyond the limits of area 41. These fibers seem to be derived from layer vi and many can be seen arching dorsally and externally to reach stratum v-b. In the outer part of layer vi the fibers seem to run tangentially in all directions. There are many fibers in the deep part of layer vi. They run mostly longitudinally or obliquely dorsoceudally. In tangentially cut sections of the cortex one can see the deep layers of fibers directed caudally and somewhat dorsally as outlying continuations of the fiber sheaths of the external capsule just below. The bundles of the radiata are here cut in cross section and the dorsally directed fibers passing from layers vi to v previously mentioned are also here well exhibited. The tangential fibers in the infragranular layers probably form associational systems between the auditory receptive cortex and adjacent areas and are thus an important element in cortical mechanisms. In higher or larger forms the cortex is unable to carry the increased mass of fibers, so these tracts become shifted to the cerebral medulla. Naturally, the displacement of so large a component of the infragranular cortex is reflected by a changed cell picture. One who bases his cortical studies entirely on cell stains will not be in a position to discover the cause for such a change and may make false homologies.

Area 20, area temporalis (fig. 14). Consonant with its small size, area 20 has an unspecialized histology. The cortex is moderately thin and contains no fibrous lamina. Layers ii and iii are thin and composed of small dark pyramidal cells. Layer iv is thin also and has few granular cells. Layer v is thin, rather sparsely celled and contains a number of long, narrow, rather dark, pyramidal cells with long apical dendrites. Layer vi is fairly thin and contains granule cells closely spaced and without the modifications seen in 41. There is a thin layer vi-b also. The fiber pattern is much less developed than in 41. There are a few radiate fibers but tangential laminae are absent, except for a diminishing extension of the deepest fibers of 41. There are a few heavy longitudinally running fibers in vi-b.

Area 36, area ectorhinalis (TF) (fig. 15). Structurally, area 36 is characterized by its lack of any specific differentiation of layers and its paucity of fibers. The entire cellular part of the cortex is com-
posed of small, mediumly pale, granulous cells. The supragranular layers are a little denser, but thin, and the fifth layer is composed of larger cells on which a fine colorless apical process can often be seen. Myelin stained preparations show few fibers, except for a considerable stratum of tangential fibers in the basal half of layer vi. These connect with the basal tangential fibers of area 41, hence are probably auditory associative.

**OCCIPITAL REGION**

*Area 17, area striata (OC) (fig. 16).* Area 17 is thin but contains numerous closely placed granule cells interrupted by layer v, where large cells are seen in open spaces. Layers ii to iv equal layers v to vi in thickness. Layers ii and iii are merged as a single layer equal to the thickness of layer iv. The cells are of a small pyramidal type. Many of them are polyhedral and almost granulous but the tiny apical process is visible. Layer iv is distinct and consists of very closely packed granule cells of small size, but rather darkly staining. Layer v is thin and has an open structure. Its most conspicuous occupant is a broad pyramidal cell often with almost the proportions of an equilateral triangle, staining dark and sending basal processes in all directions of the tangential plane. This type is characteristic of the visual cortex and was described by Cajal. There are also smaller pyramidal cells of various sizes, not stained as darkly as these. Layer vi is relatively thick and the cells consist of two types: flattened but large granular cells and scattered much larger elements of a bun-like shape. There is a tendency for the granule cells to form horizontal strata. The visual cortex has been thoroughly analyzed by Cajal (‘11) and in later years by O’Leary (‘41). In any estimation of the functional significance of structures of the visual cortex of the rat it must be borne in mind that the albino rat has very poor eyesight.

Area 17 has the fewest myelinated fibers of all the sensory receptive areas. A radiata is present and extends through 4 but is markedly suppressed in quantity. There is a uniform stratum of tangentially running fibers located in layers v and vi. These fibers are more numerous in the lateral part of the area and extend freely into area 18a laterally, but not conspicuously into area 18 medially.

*Area 18, area occipitalis (medialis) (OB) (Fig. 17).* Area 18 is a little thinner than 17. There is a severe reduction of layers ii-iv. In fact, the cortex has become so uniformly granular, without stratification, that it is difficult to distinguish the layers. The supragranular layers, very thin, are composed of small, dark, lozenge-shaped cells. Layer iv is much closer to the surface and is strikingly reduced when
compared with area 17. The infragranular layers are thicker, denser, and more uniform than in 17. There is no relatively clear stratum below layer iv, and there are fewer and smaller pyramidal cells. In the caudal parts of the area they are less numerous or absent in some sections, layer v here being made up of an almost uniform group of rather dark granular or trapezoidal cells much resembling layer vi. Layer vi is definitely denser than in 17 and has smaller and darker granule cells. The differences in the infragranular layers can be shown in fiber preparations to be due to the lack of fibers in 18. The very few fibers in 18 are largely basal and run in a fore-and-aft direction. There is no obvious fiber connection with area 17.

*Area 18, area occipitalis (lateralis) (fig. 18).* The uniformity of appearance of this area is due largely to the decreased number of granule cells in layer iv, and to the substitution of clear spaces for granule cells in layer v. The entire cortex is predominantly granular as is associative cortex in the rat generally, except for the presence of pyramidal cells in layer v, which are, however, small, not very dark, and about equilateral.

Area 18a is also poor in fibers both radial and tangential. In its rostral part it contrasts markedly with its contiguous areas, since these are sensory receptive (41, 17), and it contains more radial and tangential fibers than caudally. Caudally, where it forms a caudal margin to 17, it blends laterally with fiber-poor and unspecialized areas and is poorer in fibers itself, so it is difficult to distinguish from areas 36 and 35. Horizontal fibers in layers v and vi of area 17 are numerous near its medial edge, but decrease toward its central part. The same is true to some degree for area 41.

**INSULAR REGION AND RHINAL SULCUS**

It is interesting to follow the character of the cortex through the entire extent of the rhinal fissure. In the most rostral two or three mm of its extent the fissure is very deep and the cortex forming its base is in sharp contrast to that of area 8 which is adjacent to it. The upper wall of the sulcus forms area 25a, with an undifferentiated granular cortex of the six-layered type. The lower wall is formed by 51b, a part of the limbic region which will be described later. There are three cellular layers, a fairly dense outer layer, an intermediate layer composed of granule cells and separated from the other layers by a clear area and a rather thick deep layer composed of faint granule cells. In the next couple of mm the rhinal sulcus is shallower and the underlying cortex is rather like the cortex more rostrally, but the intermediate layer contains darker cells with long darkly stained processes (area 8a). In the next several mm, that is, in about
the middle of the extent of the rhinal fissure, is the region generally considered as the insula.

This is designated *area 13, area insularis ventralis* (fig. 19). This resembles the cortex just described in that there are apparently three layers. The outer layer is much thicker, but compensatorily more diffuse, and is composed of uniform granular cells. There is no trace of any separate layer iv. The intermediate layer is thin and its cells become frankly pyramidal but small. The basal layer proper is thin and has only a few flattened cells, but of the same type as those seen more rostrally. The most striking feature about this cortex, however, is the presence of a still deeper layer of closely arranged small dark granule cells. This is generally considered to be the prototype of the claustrum and somewhat clinches the analogy of this region to the insular cortex, since the extent of the claustrum coincides with the insula of man. The cortex has, however, by this time become quite thick. The sulcus is shallow and the cortex at its base nearly equals the thickness of the adjacent neocortex dorsally. This cortex varies somewhat as it is traced backward and the claustrum migrates a little ventrally. The three-layered appearance gets less and less evident, then, as one travels caudally. The cortex becomes thicker and the layers merge.

As the caudal half of the rhinal sulcus begins, a new pattern is formed. The three-layered appearance of the cortex is lost altogether. The cortex is uniform and open, consisting of granule cells very widely spaced and not arranged in any particular strata, which gives something of a polka-dot look to the cortex in this region. Layer v has small pyramidal cells and the granule cells of layer vi are flattened. Thereupon follows a transitional region in which the cortex gradually changes type to reach that of the caudal third of the rhinal sulcus. This type consists of a cortex markedly thinned yet based on the six-layered plan. Layer i is very thick. Layers ii to iv are fused together in one single band of moderately dense small granule cells. This seems to be characteristic of all parts of the rhinal sulcus. Layer v is quite thin and the cells are flattened but provided with terminal dendrites. Layer vi is also thin and the cells are markedly flattened. This type is *area 35, the area perirhinalis*. Towards its caudal end the cortex remains uniform but becomes even thinner. The pyramidal cells in layer v are not noticeable and the whole cortex consists of one almost undifferentiated layer of granule cells, except that those of layer vi are still definitely flattened.

Little needs to be said concerning the fiber plan of the cortex bordering the rhinal sulcus since it is uniformly very poorly provided with fibers. Rostrally there are a few radial and oblique fibers near the base and a few longitudinal fibers. In the middle part there are
only a few radial fibers, no others, and the caudal extreme there are no fibers visible in the ordinary myelin preparations.

Area 14, area insularis dorsalis (IA) (fig. 20). Area 14 may be considered as showing an intensification of the characters which differentiate area 40 from area 2. It presents, in general, a darker appearance than the parietal areas because the cells are more closely packed and the granular cells are darker. On first glance it seems to be divided into three zones. The outer zone is formed by a confluence of layers ii to iv. All of these are granulous and uniform to make a homogeneous band. In some sections there seems to be no layer iv. The middle band is characterized by long, dark, fusiform or pyramidal cells. These are not scattered at all levels as in the parietal region but form a distinct stratum. There are other cells in layer v also, these generally appearing as mediumly stained polygons. These are mostly in the outer region which we shall call v-a. The pyramids are in the inner region, v-b. Layer vi stands out as a band because it consists of closely placed uniform, small, granular cells. In fiber preparations, area 14 resembles the structure of the parietal region, of which it may really form a part. It would be mere hairsplitting to take a transitional area like area 14 and attempt to state whether or not it belonged to one or other region which, like parietal and insular, may be well enough marked in the human brain, but only by forced analogy can be made to fit into a definite region of the rat’s brain. Numerous radiate fibers emanate from the external capsule and there is a suggestion of a horizontal lamina below layer v. This cortex as well as that of 13 undergoes some modifications at various transverse levels. At times it is difficult to separate from 40. The marked dropping out of the thick layer of granule cells which begins in area 40 is the best criterion of 14 and also suggests that it does not properly belong to the parietal lobe.

CINGULATE REGION

Area 24, area cingularis anterior ventralis (LA) (fig. 21). Area 24 is characterized by the fusion of all the layers below the second in spite of the fact that it is a thick cortex. It is entirely occupied by ovoid or round cells of a granular uniform nature, staining mediumly darkly. Layer i is very thick. Layer ii forms a dark outer band, the cells being about twice as dense as below. Layer vi has somewhat smaller and lighter cells. In myelin preparations area 24 is outstanding by the presence of a thick and strong external fiber stratum in layer i. These fibers run mostly longitudinally and have a long course, stemming from the hippocampus. They can be followed easily through their course from the caudal end of the brain over the entire
length of the callosum. Rostrally they expand in front of the genu and drop ventrally to join the medial olfactory stria. Their further analysis is outside the province of this paper. The structure of area 24 in rat and man are quite similar. There are also numerous radiate fibers which continue outward nearly to layer ii, gradually thinning and separating. In the basal third are a considerable number of fore-and-aft running fibers which seem to belong to the cingular system.

*Area 32, area cingularis anterior dorsalis (fig. 22).* Area 32 differs from 24 in being thinner and entirely composed of pale oval cells, without even the denser outermost lamina. It also lacks the conspicuous radiata and longitudinal running fibers in myelin preparations, but retains the tangential lamina in layer i. Thus area 32 is nearly devoid of myelinated fibers except in its outermost lamina. This area was consistently regarded as 32 by Brodmann in his comparative studies, but it is questionable whether it conforms to the human area 32.

*Area 25, area pregenualis (FM) (fig. 23),* resembles 32 in its thinness and lack of differentiation, but the cells are smaller, darker, closer and narrower. It also is poor in fibers but at its basal part has a tangle of fine fibers, and likewise carries an extension of the external tangential lamina.

The pattern of 25a (fig. 24) is best seen in sagittal section. In thionin stained sections the layers are blended and without special differentiation. The outermost cellular layer is a little denser than those below and there is a faintly marked increase in size and density of the cells in layer v. The sixth layer is composed of numerous flattened granular cells. The transition to 51a is very abrupt. Weil-stained sections show a poorly marked irregular network of fibers in v and a few radial fibers in vi, which, however, are very oblique due to space requirements.

*Area 23, area cingularis posterior ventralis (LC2) (fig. 25).* It is similar in structure to area 24 but presents an intensification of the local differences in structure of 24. Thus, layer i is thicker. The condensation of granule cells in layer ii is greater and the layer is thicker and more pronounced. The granule cells of the middle zone are larger and more distinctly ovoid. The tangential or zonal lamina is considerably thicker and there are more radiate fibers in the basal region coming from the cingulum. Caudally area 23 becomes rapidly diminished by being crowded dorsally by the developing 29b which takes up the position just over the callosum. Simultaneously 29c insinuates itself between area 23 and 4 so that within a few sections 23 is reduced to a thin wedge and so disappears.

*Area 29b, area retrosplenialis granularis (LE) (fig. 26).* Area 29b shows a similarity to the other cingular areas 24 and 23. Structurally
area 29b may be said to represent a further intensification of the characteristic features of 23. Layer i is even thicker; ii is very darkly staining and filled with very closely packed tiny dark granule cells, which appearance enables the area to be spotted instantly in a section in any plane. Within a narrow zone these cells become gradually sparser so that in the deeper layer there seems to be a typical but thin layer iv. The middle zone constituting layer v occupies two-thirds of the cellular part of the cortex. It is uniformly filled with rather large ovoid cells only moderately stained. Layer vi is thin and contains very small and faint granule cells. In fiber preparations area 29b can be positively identified because it is the only cortical area which contains two distinct and well marked external tangential fiber laminae. The outer is identical with the one already mentioned in 24 and 23. As the hippocampus is approached, that is, as the sections become more caudal, the fibers are more numerous and coarser. The deeper and unique fiber layer occupies layer iv; thus, there is a clear lamina between the two fiber layers which corresponds to the heavily celled layer ii. The fibers here interweave among the cells but seem to have a predominantly fore-and-aft orientation. In layer vi there are numerous longitudinally running fibers which seem to form a part of the same system as the cingulum. Basally, near the cingulum there are even isolated bundles running likewise rostro-caudally. This area has a more generous radiata than those more rostrally and the fibers continue to and even through the deeper horizontal fiber lamina. In addition to this there is a criss-crossing of fibers running in various directions in layer v.

*Area 29c, area retrosplenialis granularis c (LE)* (fig. 27). Structurally, it differs considerably from 29b. Layer i is much thinner. The supragranular layers still form a distinct band and the large round granular cells, though closely placed, are not nearly as condensed as in 29d. There is a clear space in the region of layer iv. Layer v is thin and contains medium-staining ovoid cells for the most part but some approach the pyramidal contour. Layer vi is very thick, constituting half the thickness of the cortex. The granular cells are tiny, pale and sparse. Fiber preparations delimit this area quite sharply and show strong contrast to the structure of 29b. In the first place there is no trace of a deeper tangential stratum of fibers below layer ii. The outer horizontal lamina is much reduced but continuous with that of 29b. All of the thick infragranular region is occupied by a very heavy growth of radiate fibers emanating from the prominence of the cingulum. The radiata here is as prominent as in any part of the brain. The density of the fibrillation of the infragranular layers is augmented by the presence of large numbers of longitudinally directed fibers. These can be seen to emanate from
the cingulum on its medial aspect. Basally, they are in the form of small bundles and they may be followed three-quarters of the way through the thickness of the cortex where they end in layer iv. The basal part of the cortex is formed of large fascicles of coarsely myelinated fibers belonging to the cingulum. The thick infragranular layers are filled with fine fibers, most of which are longitudinally directed. In sagittal and horizontal connections they seem to connect 23 with 27. In the caudal part of 29c the entire cingulum breaks into bundles within the cortex, the longitudinal fibers of vi diminish, but the intrinsic plexus in v remains. The external horizontal stratum is thin in this area and caudally joins that of 29b to pass into the hippocampus.

PYRIFORM REGION

All of this cortex constitutes heterogenetic formation of Brodmann or allocortex of von Economo. The cortex of the various areas considered up to this time belong to the homogenetic formation of Brodmann or the isocortex of von Economo. The pyriform cortex and the hippocampal formation later to be considered lack the six-layered plan on which the cortex in other regions of the brain is based. It is to be remembered that this sextilaminar arrangement is not necessarily dependent on microscopic appearance of the adult brain, for in many parts of the isocortex one or more layers are absent or fused together into homogeneous looking structure. It was, however, based by Brodmann on the appearance of the cortex in its development. The pyriform and hippocampal cortex never have a six-layer plan. Usually there is only an external layer corresponding to layer i, but which contains ramifications of the olfactory striae, a cellular layer, usually rather dense and not subdivided, and sometimes a deeper fibrous layer. It is largely on the appearance of the cellular layers that the subdivision into the various subareas is made. The various subdivisions of area 51 will now be analyzed.

Area 51a (fig. 28). Layer i is thick and contains definite cells of varied morphology, usually stellate. The outer main cellular layer is composed of densely packed large dark granular or triangular cells. The basal layer is cell-poor, considerably thicker than the outer layer and contains a wide variety of cells with mostly an oblique orientation of their processes. Some are granular and some fusiform, light and dark. In its caudal part, the morphology of 51a changes somewhat. The outer layer loses its denseness and it might be questioned whether a separate designation should not be given to it here. However, the fiber picture indicates an essential uniformity. Layer i and the outer cellular layer are quite free of myelinated fibers. The basal layer has irregular fibers in its outer part but deeper these
fibers become organized to become parallel. They tend to run in an antero-posterior direction and their medial and deeper parts are continuous with the end of the external capsule. In the lateral part and in the middle and caudal sections they run obliquely laterally to associate with the cortex of the insular region. Many other fibers of the caudal part run dorsally into the amygdala. To analyze these fibers properly would require a great deal of space. They belong to the lateral portion of the basal forebrain complex of fibers. The more medial ones run into the diencephalon; the more lateral ones remain in the basal part of the cerebrum.

Area 51b (fig. 29) resembles 51a in the possession of a very dense outer band of medium sized cells of granular type, but differs from it in the absence of a heavily myelinated lateral olfactory tract, and further, in the presence of a thick layer of medium sized ovoid or irregular cells, separated from the dense outer layer by a cell-poor zone. Some of the cells of this intermediate zone are of a special variety, small, dark and stellate.

The fiber picture is characteristic also. All the space below the outer cell zone is uniformly filled with irregular groups of fine, wavy, radial fibers. These do not stem from the external capsule as do radiate fibers of the isocortex. Even at the narrow rostral end this characteristic pattern can be made out. These radial fibers are more numerous in the oral half, indicating that olfactory fibers of secondary nature from more medial and rostral regions terminate here. In its caudal half 51b exhibits another group of fine fibers running almost directly medially to end in the deeper amygdaloid nuclei. In the intermediate zone these fibers blend with those described before. There are also a few true radiate fibers from the external capsule. Area 51d of Rose is here regarded as the caudally expanded part of 51a.

Area 51e. In appearance 51e (fig. 30) is rather similar to 51b. There is an outer zone of intensely granular cells corresponding to layer ii and an inner looser layer of rounded granule cells separated from the previous layer by a clear interval. This latter layer is much thicker than layer ii. There are distinct longitudinally running fibers in layer i of 51e separated by layer ii from an irregular network of fibers between the two layers. These emanate from the olfactory bulb and form the most medial fibers of the olfactory stria. They migrate dorsally, round the callosum and contribute to the external fiber lamina of the cingular cortex, potentially reaching the hippocampus caudally.

Area 51f is composed of a thick mass of cells of light granular nature without local structural modifications. 51e seems to crowd down over the surface of 51f so that apparently a continuation of 51f constitutes the deeper layer described for 51e. This region is imme-
diately succeeded caudally by the structure of the olfactory tubercle. 51g has the typical structure of the olfactory bulb proper and will not be described in detail here.

Olfactory tubercle. Under a layer i of variable thickness lies a thin stripe of cells with characteristic sinuous curvature. Sometimes these cells reach the surface. They are continuous with the outer layer of 51a but are smaller and less intensely stained, appearing as small granule cells. At the medial extreme this layer has a small hook on it. Underneath this lamina are the conspicuous islets of Calleja, which are small ovoid masses of intensely stained, closely packed cells separated by an almost cell-free region. The islets are more numerous rostrally. The structure of the laminated part of the olfactory tubercle is much thinner than that of other parts of the cortex but there is a diffuse nuclear portion which can not be considered as being a part of the cortex in any sense.

RETROHIPPOCAMPAL REGION

The region comprising areas 28, 29, 47, and the subiculum may be considered a posterior division of the pyriform region as Gray does ('24), or as transitional to the hippocampus, hence retrohippocampal. The observable olfactory connections are certainly very slight; while on the other hand the connections of the fibers clearly show an association with the hippocampus, and the structure of the cortex presents a definite six-layer plan, though profoundly modified. These areas also form a series of bands concentric with the posterior arc of the hippocampus and will be considered here seriatim, progressing toward the hippocampus.

Area 28b, area entorhinalis b (HB) (fig. 31). Parts a and b of area 28 differ considerably, and since b represents an intensification of the characteristics of the area, it will be considered first. It is thick and consists of three well marked cellular bands. The characteristic and diagnostic layer is the most external one. This consists of a thin band of very intensely stained and closely arranged polyhedral, sharply stellate cells. It is thin and in some places is incomplete, forming islets. No other area has a comparable layer. It is a specialization of layer ii. There is a distinct, thin, cell-poor lamina below this and underneath lies a layer of irregular, mediumly-stained, medium-sized, sharp processed pyramidal elements with long apical dendrites and no trace of granule cells in their midst. This represents a layer iii, as it blends with that layer in more typical cortex adjoining. Below this is a thin, but sharply marked, cell-poor layer. This occupies the position of layer iv. The deepest band of cells conforms to layer vi. Layer v is suppressed, but a few pyramidal cells may be
traced from the adjoining cortex into this layer near the boundary of the area, hence the clear layer referred to corresponds to iv, and not v. Layer vi is thick and composed of uniform granule cells.

The myelin preparations at hand show only a few long radiate fibers emanating from the posterior forceps and the clear layers are not occupied by myelinated fibers. Zunino’s published figures of the rabbit show an intense plexus in this area, so it is not to be regarded as devoid of axons.

*Area 28a, area entorhinalis a (HB) (fig. 32).* The outer and middle cellular bands characteristic of area 28 are nearly blended. The outer ones have become modified into dark lozenge-shaped closely arranged elements. The middle band (layer iii) is very thick and consists of rather widely spaced pointed lozenge-shaped elements; these are paler and more swollen medially. The separation between the middle and inner bands, replacing layer iv, is narrow but sharp. Layer vi, just below, is thick and uniformly composed of pale cells.

The fiber picture of 28a is striking and unique. It is dominated by radial fibers. These radiate from the caudal extreme of the external capsule in definite fascicles through vi. At iv there is a rearrangement or a thin plexus. In iii there is a rearrangement of the fibers into smaller fascicles and a reduction in their number. On reaching ii the fibers apparently break up into a fine pericellular plexus. In the deepest part of the thick layer i there are a few horizontal fibers.

*Area 49, area parasubiculare (HC) (fig. 33),* represents a further reduction of the cellular layers, as layer iii (ii?) is missing. Thus, the only layers containing many cells are ii and vi. This leaves a great clear stratum between two broad layers uniformly filled with medium-staining cells. Those in ii have a definite apical process, but those in vi are small and ovoid.

Myelin preparations exhibit many bundles of parallel fibers radiating from the inner layer of the callosum at its caudal extreme, breaking up conspicuously in an abundant plexus in layer iv, and reforming a radiata, this time close and more homogeneous, but mixed with a network which gradually diminishes peripherally.

*Area 27, area presubiculare (HD) (fig. 34),* continuous with area 49 behind and with the subiculum in front, has a reduced layer pattern similar to that of 49, but here the broad cell-poor inner zone is reduced or nonexistent. The two areas further differ in that here all of the cells are smaller, darker, and more closely packed. Thus 27 is characterized by a nearly unbroken extent of tiny oval cells.

The dorsal part of the area presents a more homogeneous appearance, and layer vi is reduced. This forms area 27b. In the ventral part the outer and inner cell layers are better separated, layer vi is thicker and there is a distinct dense outermost cell layer corresponding
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to layer ii. This forms 27a. The outermost zone is also discernible in 27b.

Fiber preparations show a fair number of radiate fibers which curve out of the posterior forceps to break up in a most elaborate pericellular plexus in the outer cellular band. Layer vi is heavily shot through with bundles of horizontal fibers, which induces the cells to be disposed in horizontal bands. The deeper part of layer i contains numerous tangential fibers. These are the beginning of the outer tangential stratum which is so marked a feature in the cingular region, diminishing gradually as they proceed to the more rostral parts of the brain.

The subiculum (HEI) carries the reduction of layers to its logical conclusion — only one layer remains. This is layer vi. The outer layers terminate abruptly at the forward edge of 27. The subicular cells are ovoid with apical processes, moderately spaced and mediumly stained. The deepest ones are smaller and flattened.

The hippocampus proper is structurally a continuation of the subiculum, except that the cell bodies are packed together in a narrow band, leaving a clear zone above and below, which, as is well known, is filled with their dendritic ramifications. Being dendrites they are not myelinated, so these zones are nearly clear in myelin preparations also.

The fascia dentata forms the most internal circle of the concentric cortical areas. Here instead of a compact vi, layer ii is heavily developed. Here again the cell bodies are closely packed, but the dendrites have only an outer dendritic bouquet. This accounts for the marked infolding. Below this layer there are scattered cells which seem to represent layer v and are not continuous with the hippocampal cell layer.

The structure of the hippocampal and subicular regions was intensively studied by Cajal ('11) and Lorente de Nó ('34).

AMYGDALA

The structure of the amygdaloid region sets it off from the truly cortical areas adjoining, for it lacks the dense cellular laminae and vertical orientation of cells that characterizes the pyriform and hippocampal formations.

Medial amygdaloid nucleus (fig. 35). Microscopically, the medial amygdaloid nucleus consists of a bun-shaped mass of cells arranged indiscriminately. The area is nearly devoid of myelinated fibers, but the nucleus is known to contribute to the stria terminalis (Loo, '31).

Cortical amygdaloid nucleus (fig. 36). The cells of the cortical amygdaloid nucleus are larger and darker than those of the medial
nucleus and have a perceptible alignment which causes them to resemble cortex more closely. It is peculiar also in that it forms a pronounced hump, with a concavity toward the surface. Medially and laterally its cells are conspicuously continuous with cortex. There are very few myelinated fibers in this area. This is apparently the area designated as 51d by Rose in the mouse. The caudal part is considerably thinner than the rostral part and perhaps constitutes a separate formation.

DISCUSSION

The stratigraphic analysis of the cortical areas forms the basis for their establishment and identification. Thus, the data reported in the main body of this paper constitutes the evidence and justification for each of the cortical areas distinguished. Long ago Brodmann laid down three postulates to guide the formulation of cortical areas: (1) the area should have a uniform structure; (2) the area should be found in related forms in the mammalian series; (3) the main regions should have a constant structure. These principles guided the present study and well corroborated Brodmann's views. The doctrine of specific cortical areas has certainly been well upheld by the present work and it is believed that analogies to higher brains have been carried further than previously.

The cell pattern and myelin pattern have been correlated more closely in this study than has usually been done in work of this sort. True, the Vogts devoted much attention to myeloarchitectonic studies, but these were pursued for their own sake and the areas which they proposed did not correspond to those determined by cell studies.

As a result of the close correlation between the study of cells and fibers in this work, certain generalities which can be useful in interpretation of microscopic sections of the cortex have become evident. They will be itemized here.

1. Each area can be distinguished from all other areas solely on the basis of myelinated fiber patterns.

2. In the cortex only the axons have myelin sheaths. In most areas infragranular layers have numerous myelinated fibers while the supragranular layers have very few. Com-
binning the above the main mass of the intercellular material in the supragranular layers is dendritic while in the infragranular layers it may or may not be predominantly axonal.

3. The spaces occupied by cells and by myelinated fibers are for the most part reciprocal of one another in layers iv-vi. By the previous postulate this is not true of the supragranular layers.

4. In layers i to iii the cellular interspaces are a fair indication of the richness of the dendritic network, but in the lower layers the many extrinsic and radiate fibers render conclusions on this subject impossible when based on cell and fiber preparations alone.

5. The pattern of fibers for any area is not as uniform as is that of the cells nor can it be expected to be uniform in the mammalian series. This is apparent when one recalls that the cells are intrinsic while the fibers are largely extrinsic.

6. In layer iv-vi the myelin picture represents a fair approximation of the total fiber picture. In layers i to iii it is hardly to be taken into consideration at all. Most of the fibers are of two sorts, radiate and tangential. For the most part the afferent and efferent fibers are identical with the radiate fibers while the tangential fibers are associational within the area or through the adjacent areas.

7. The tangential and oblique fibers of layer vi are associational fibers to adjacent cortical areas. Hence the interareal associational system of the rat is mostly intracortical though in higher forms it drops below the cortex. The tangential and oblique fibers of layer v are generally of a more local nature than those of layer vi, that is, are roughly intra-areal.

8. The cortical afferents seem to end in layer iv by fine intercellular ramifications. Fine irregular intercellular networks in general represent terminal axonal plexuses.

9. When the radiata persists to layer iv without much diminution it is largely afferent. When the radiata decreases as it passes outward to layer v it is largely efferent.

10. The external horizontal stratum of fibers is almost universal in the neocortex but varies considerably in inten-
sity. It is best developed in the cingular region and fairly well in somesthetic and visual regions.

11. There are more fibers in the dorsal part of the cortex, fewer ventrally. This corresponds to the greater differentiation in the dorsal part of the cortex.

12. There are but insignificant associational connections between the pyriform and the general cortex.

The extent of development of myelinated fibers in any cortical area is largely correlated with the variety of cell types and degree of cell layering. In areas of reduced myelin fiber content the cells are generally granular, round, medium in size and uniform throughout all layers (this observation does not hold for the cingular region). In this way we may classify the cortical areas by relative degree of evolution. For example, areas 2, 41 and 10 are well developed, while 20, 36, 39 and 40 are relatively undeveloped. These observations conform well with what is known of the connections, functions and phylogenetic age of the respective areas.

As areas evolve they acquire more fibers, a greater stratification and develop a more specialized cytology. Thus in a higher animal, an area cannot be expected to have a structure identical with that in the rat, though it was developed from a corresponding germinal area.

During the evolution of a region it expands, its connections become more complex and local conditions may bring certain connections to dominate in one part of that area. In this way local specialization of function sets in and this is reflected in the layering, cell types and fibers of that locale, until a new area is recognizable. The late formation of the zones which act as suppressor areas when stimulated is an example of this differentiating process.

The correlated study of cells and fibers seems so natural an approach that one wonders that it has not always been the method in architectural studies of the cortex. To be sure, it was the approach used by Cajal in his studies in all parts of the nervous system. It was intensively pursued by Campbell in the cerebral cortex, but was neglected by Brodmann,
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who confined his studies to cells, and by C. and O. Vogt, who studied mostly myelinated fibers. The modern tendency is away from any such correlation. This is unfortunate, since even when parallel studies are prosecuted the picture is woefully incomplete.

Reflecting on the results of inadequacy of experience, one is par force reminded of the analogy of the cave in the exordium of the seventh book of Plato's Republic. The perikarya of the cells are but shadows of the objects on the wall of the cave, and the spectators, this time by choice, form concepts of things they never really see. Their curiosity should prompt them to examine the objects themselves — in this case by the aid of the Golgi and Cajal methods. To continue the analogy, we may even take the objects in our hands and examine them if we inspect the results of experimental lesions.

Such is the spirit which motivates the project in hand. This pair of papers aims beyond the descriptive aspect. First it attempts to find whether the cortex can be divided into clear-cut units. Having achieved this, the units can be attacked individually and compared with similar units in other species.

Each area has its own structural pattern which can be described, though not explained at this stage. Every distinguishable point in each cortical area must be recorded, for it may be of significance. However, and here is the crux of the matter, every unexplained observation is only a question. If the observation has been properly made, it is only a question well stated. It must be answered by other methods. Ultimately, these questions must be answered in terms of relation to the entire mechanism, intrinsic and extrinsic. Only thus may the whole picture become an integrated one and significance be comprehended.

SUMMARY AND CONCLUSIONS

The identification and arrangement of the cortical areas of the albino rat have been determined on the basis of cell-
and myelin-stained material sectioned in various planes. The picture presented by each area has been characterized and illustrated by means of sample strips taken perpendicular to the surface. Some 40 cortical areas are distinguished. Individuality and boundaries of the areas were determined on the basis of appearances alone. The identification, expressed here in Arabic numerals as proposed by Brodmann, has been made with regard to accumulated evidence on connections and probable evolutionary patterns of the cerebrum. It is believed that the parietal cortex has been subdivided in a manner that will enable areas to be equated with those of higher forms. Thus, 3, 1 and 2 occupy a prominent place, while 7 and 39 are, as expected, smaller. Motor, premotor and frontal areas have been distinguished and the frontal region has been divided into polar (10) and basal (8, 11) areas. The auditory cortex (41) is identified, changing radically the pattern formerly claimed for the temporal region of lower animals. The primary sensory receptive cortices are seen to dominate the cerebrum. Sensory associative cortices form marginal strips or fill in chinks. The frontal area is poorly developed. On the other hand, the limbic lobe is markedly developed and presents numerous subdivisions.

The study of the myelin pattern of the cortex has been instructive. Attempting to explain significance of the various categories of fibers, instead as regarding them merely as a means of distinguishing areas, has resulted in the establishment of a number of generalities for which see p. 300. The fact that in the rat a large bulk of the interareal associational fibers are intracortical is an important one for cortical analysis.

The plan here established has been compared with the studies of others on related forms (p. 242).

A plan has been devised to explain the differentiation of cortical areas, the large number that appear in the rat and the conservatism of this arrangement (p. 252).

The place which this survey has in the project of cortical study under way is discussed (p. 302).
Figures 1–36 Sample strips from sections of cortical areas of albino rat. The left side of each pair shows cell bodies as revealed by thionin staining, the right side shows myelinated fibers after staining by Weil's method. All are 40 μ sections at a magnification of 90 × linear. In each case the field illustrated is in a plane perpendicular to the surface so all illustrations are strictly comparable. When the field illustrated seems to vary from the textural description it is to be remembered that the latter is based on a study of many fields.
Figure 1 Area 10, sagittal
Figure 2 Area 6, transverse
Figure 3 Area 4, transverse

Figure 4 Area 8, oblique frontal
Figure 5 Area 8a, oblique frontal

Figure 6 Area 11, sagittal
Figure 7 Area 2, transverse

Figure 8 Area 3, transverse
Figure 9  Area 1, transverse  Figure 10  Area 7, transverse
Figure 11 Area 40, transverse
Figure 12 Area 39, transverse
Figure 13 Area 41, transverse

Figure 14 Area 20, transverse
Figure 15  Area 36, horizontal

Figure 16  Area 17, transverse
Figure 17  Area 18, transverse

Figure 18  Area 18a, transverse
CORTICAL AREAS OF ALBINO RAT

WENDELL J. S. KRIEG

PLATE 10

Figure 19  Area 13, transverse

Figure 20  Area 14, transverse
Figure 21  Area 24, transverse

Figure 22  Area 32, transverse
Figure 23  Area 25, transverse

Figure 24  Area 25a, sagittal
Figure 25  Area 23, transverse

Figure 26  Area 29b, transverse
Figure 27  Area 29c, oblique to all planes

Figure 28  Area 51a, transverse
Figure 29  Area 51b, transverse

Figure 30  Area 51e, transverse
Figure 33 Area 49, transverse

Figure 34 Area 27, oblique to all planes

Figure 35 Medial amygdaloid transverse

Figure 36 Cortical amygdaloid transverse
Figure 37: Thickness of each layer in the several cortical areas of the albino rat taken from truly perpendicular sections.