relay nuclei project. In contrast, the primary motor cortex has a thin layer 4 and a thick layer 5 (Figure 3–16). Layer 5 contains the neurons that project to the spinal cord, via the corticospinal tract. Association areas of the cerebral cortex, such as prefrontal and parietal–temporal–occipital association cortex, have a morphology that is intermediate between those of sensory cortex and motor cortex (Figure 3–16).

The Cytoarchitectonic Map of the Cerebral Cortex Is the Basis for a Map of Cortical Function

Based primarily on differences in the thickness of cortical layers and on the sizes and shapes of neurons, the German anatomist Korbinian Brodmann identified almost 50 divisions (now termed **Brodmann's areas**; Figure 3–16, bottom). These divisions are based only on the neuronal architecture, or **cytoarchitecture**, of the cortex, such as the size and shapes of neurons in the different laminae and their packing densities. It is remarkable that research on the functions of the cerebral cortex has shown that different functional areas of the cortex have a different cytoarchitecture. In humans, by noting the particular behavioral changes that follow discrete cortical lesions and using functional imaging approaches, such as positron emission tomography (PET; see Figure 1–18) and MRI, we have some insight into the functions of most of the cytoarchitectonic divisions identified by Brodmann (Table 3–2).

From:
Martin, J.H. (1996)
Neuroanatomy: Text and Atlas.
New York:
Appleton + Lange.

Neurons in the Brain Stem and Basal Forebrain Have Diffuse Projections and Regulate Central Nervous System Neuronal Excitability

Despite their vast numbers, most neurons in the mature brain have projections limited to a single central nervous system division or a restricted portion of the cerebral cortex. There are three major exceptions; the first two were considered earlier in this chapter, neurons of the reticular formation and those in diffuse-projecting thalamic nuclei. The third exception consists of groups of neurons in the basal forebrain and brain stem. Neurons in each group use a particular neurotransmitter. Because the projections of neurons in each of these groups can be so diffuse and the locations of the cell bodies somewhat dispersed, we characterize the systems on the basis of the neurotransmitter used.

There are four major neurotransmitter-specific projection systems, which use acetylcholine, dopamine, norepinephrine, and serotonin. Many of the neurons that use one of these neurotransmitters also contain other neuroactive compounds, such as neuropeptides, that are released at the synapse along with the particular neurotransmitter. We are beginning to unravel the postsynaptic actions of the various chemicals released by these systems. Some neuroactive compounds have prolonged actions on neurons and are therefore effective in regulating the long-term excitability of neurons, whereas others have more abbreviated effects for regulating short-term excitability. We are also beginning to discover that some of these compounds can affect metabolic and other functions of neurons by altering the expression of particular genes. Most portions of the central nervous system receives input from one or more of these systems.

Neurons in the Basal Nucleus of Meynert Contain Acetylcholine

The axons of acetylcholine-containing neurons at the base of the cerebral hemispheres project throughout the neocortex and the allocortex. Figure 3–17A shows the projection pattern of the system containing acetyl-

A

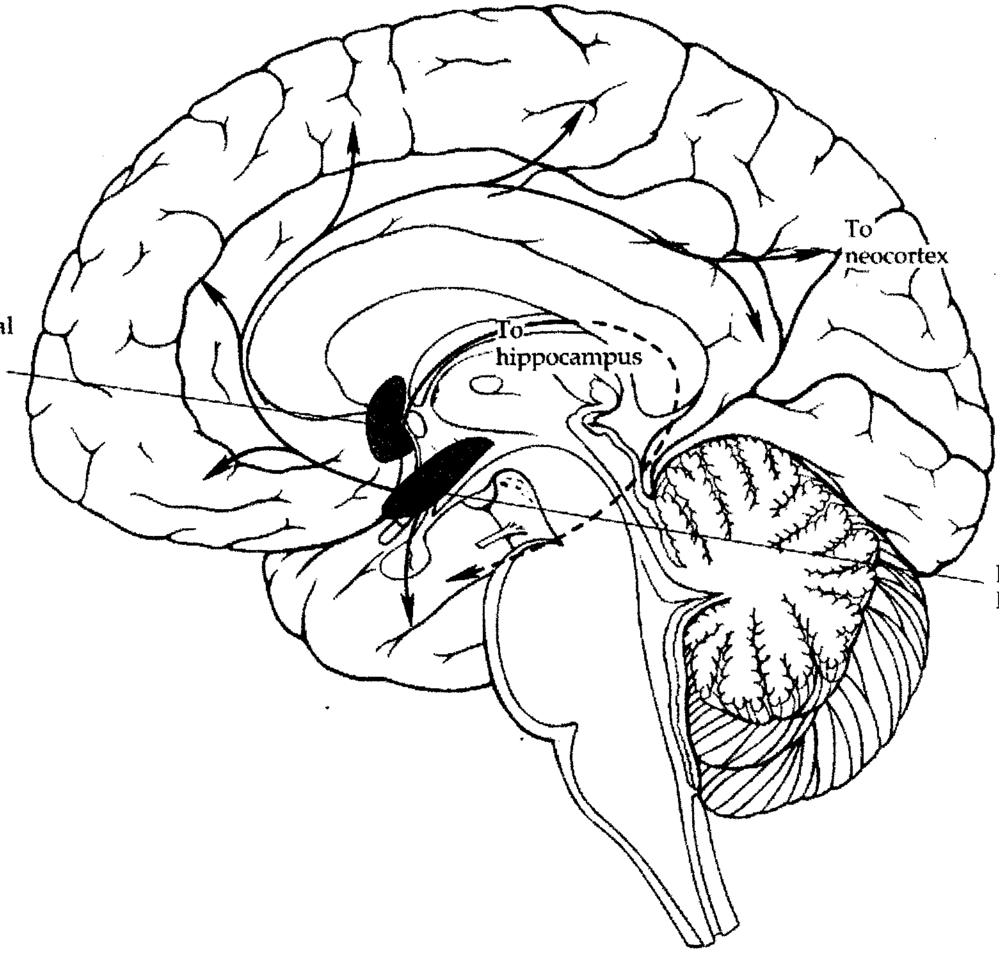

Figure 3–17. Groups of brain stem and forebrain neurons have diffuse projections throughout the central nervous system. ***A.*** Schematic illustration of the diffuse projection pattern of acetylcholine-containing neurons in the basal nucleus (of Meynert), septal nuclei, and nucleus of the diagonal band (of Broca). Many of the axons projecting to the hippocampal formation course in the fornix (*dashed line*). ***B1.*** Dopamine-containing neurons in the substantia nigra and ventral tegmental area. ***B2.*** Norepinephrine-containing neurons in the locus ceruleus. ***B3.*** Serotonin-containing neurons of the raphe nuclei.

choline. The **basal nucleus (of Meynert)** contains the cholinergic neurons that project to the neocortex (Figure 3–17A), both on the medial surface (e.g., the cingulate gyrus) and laterally (not shown in Figure 3–17A). The cholinergic projection to the allocortex, located medially in the temporal lobe, originates from neurons that are located medial to those in the basal nucleus (Figure 3–17A). These medial neurons are in the medial septal nucleus, near the septum pellucidum (Figure AII-23), and the nucleus of the diagonal band (of Broca). In **Alzheimer's disease**, a neurological disease in which individuals lose memories and cognitive functions, these cholinergic neurons degenerate.

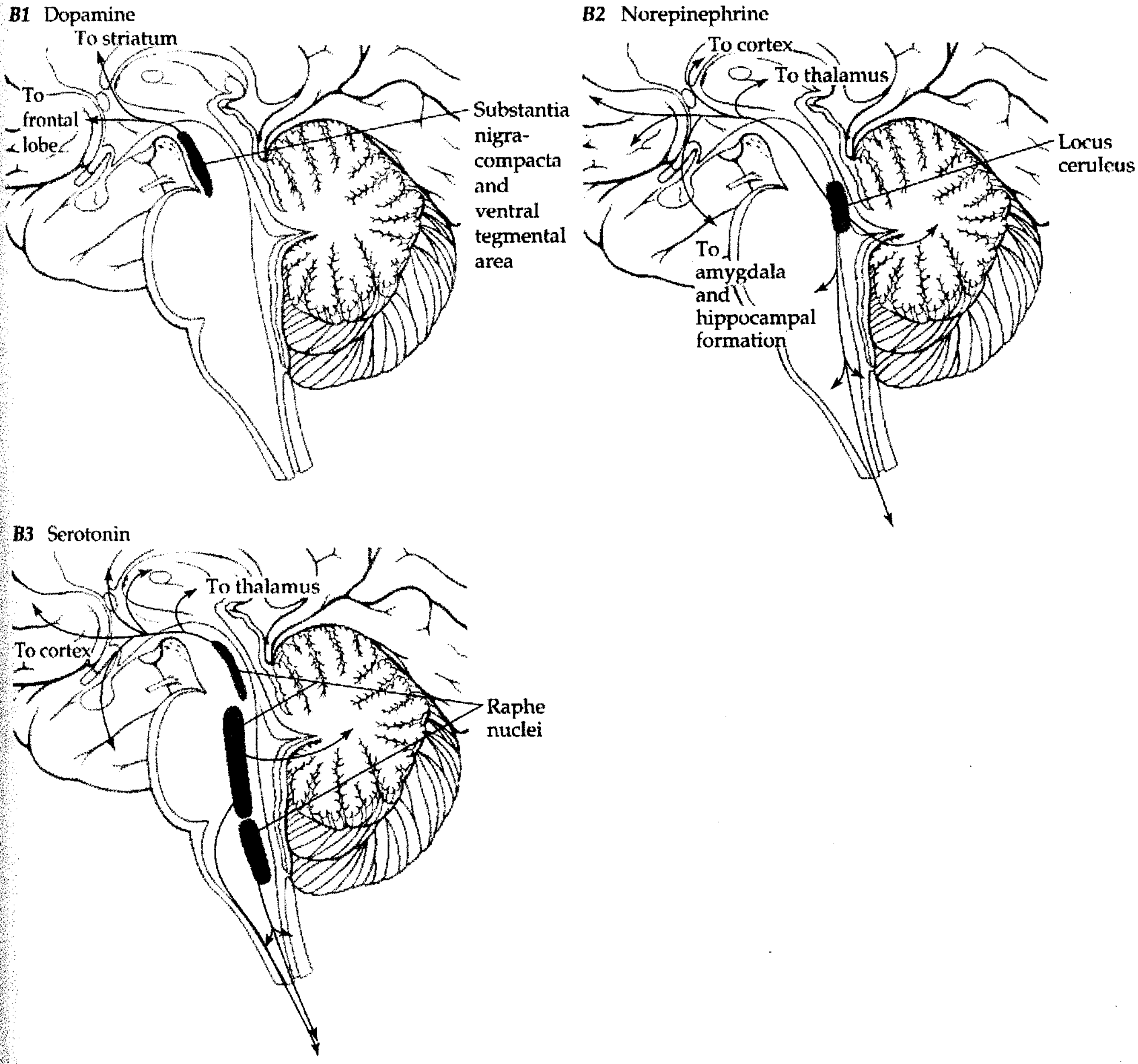

Figure 3–17. (continued)

The Substantia Nigra and Ventral Tegmental Area Contain Dopaminergic Neurons

More is known of the clinical consequences of damage to brain dopamine systems than of the other neurotransmitter-specific systems. The cells of origin of the dopaminergic system are located mostly in the midbrain (Figure 3–17B1), in the **substantia nigra** and **ventral tegmental area**; the major targets of these dopaminergic neurons are the striatum and portions of the frontal lobe. In **Parkinson's disease**, for example, there is a loss of the dopamine-containing neurons. Voluntary movements are dramatically slowed and patients develop a tremor (see Chapter 11). By replacing dopamine in these patients with a drug that acts like dopamine, movement control is improved.

The Locus Ceruleus Gives Rise to a Projection That Uses Norepinephrine

Although there are numerous brain stem nuclei with norepinephrine-containing neurons (Figure 3–17B2), the **locus ceruleus** has the most widespread projections. Based on the projection patterns and the physiological properties of locus ceruleus neurons, this noradrenergic projection is thought to play an important role in the response of the brain to stressful stimuli. The locus ceruleus, through its widespread noradrenergic projections to the cerebral cortex, has been implicated in depression and the anxiety disorder, panic attacks. Additional noradrenergic cell groups are located in the caudal pons and medulla (not shown in figure); these neurons are critically involved in maintaining the function of the sympathetic nervous system, especially in blood pressure regulation.

Neurons of the Raphe Nuclei Use Serotonin as Their Neurotransmitter

The **raphe nuclei** (Figure 3–17B3) consist of numerous distinct groups of brain stem neurons that are located close to the midline. They give rise to an ascending and descending projection. The ascending projection is targeted to the diencephalon and telencephalon and arises predominantly from the raphe nuclei that are located in the midbrain and rostral pons. Dysfunction of this ascending serotonergic projection has been implicated in certain mood disorders. The descending projection terminates in the medulla, cerebellum, and spinal cord and arises mainly from the raphe nuclei in the caudal pons and medulla. One function of the descending spinal serotonergic projections to the medulla and spinal cord is to control the transmission of information about pain from the periphery to the central nervous system.

[redacted]

Spinal Cord Organization

The spinal cord, the most caudal of the major central nervous system divisions, has a central region that contains predominantly cell bodies of neurons (gray matter), surrounded by a region that contains mostly myelinated axons (white matter) (Figures 3–2 and 3–3). Both of these regions can be further subdivided. The **dorsal horn** of the gray matter subserves somatic sensation and the **ventral horn**, skeletal motor function. The **intermediate zone** (Figure 3–2A) integrates sensory and motor functions and contains **autonomic preganglionic neurons.** The **dorsal column** of the white matter carries somatic sensory information to the brain, the **lateral** and **ventral columns** carry both sensory and motor information (Figure 3–2). The spinal cord is **segmented** (Figure 3–4) and the sizes and shapes of the gray and white matter are different for the various segments.

Brain Stem Organization

The caudal medulla (Figure 3–6C) is similar in its organization to the spinal cord. At a more rostral level (Figure 3–6B) the medulla contains nuclei on its dorsal surface that subserve tactile sensation—the **dorsal column nuclei**—and a pathway on its ventral surface that subserves voluntary movement—the corticospinal tract—which is located in the