

Fig. 7. Electron micrograph of the basal portions of the granular supporting cells (GC) containing rough endoplasmic reticulum (ER) and mitochondria (M). GCs set on the basal lamina (BL). D, desmosome; MC, mantle cell; N, nucleus. $\times 12,000$.

Fig. 8. Electron micrograph of the mantle cells (MC). Note the numerous tonofilaments (F). Mantle cells are adjacent to the granular supporting cells (GC). Desmosomes (D) are seen between the adjacent MCs. G, Golgi apparatus; GCN, nucleus of granular supporting cell; M, mitochondrion; MCN, nucleus of mantle cell; R, ribosome. $\times 15,000$.

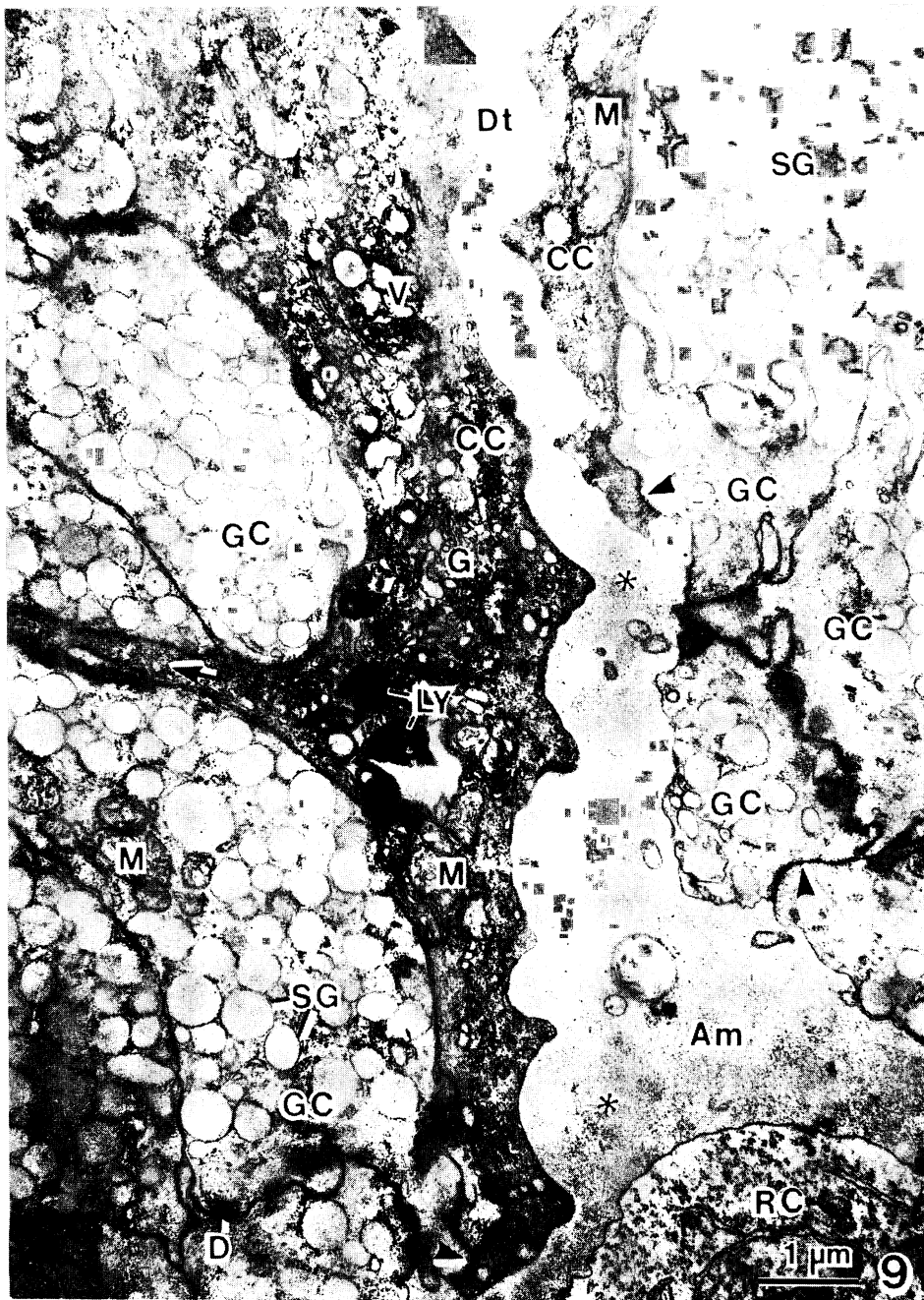


Fig. 9. Electron micrograph of the channel cells (CC) with electron dense cytoplasm, lining the wall of the duct (Dt) which is coated with a fuzzy material (asterisks). The basal process (arrow) intervenes in the intercellular space between the apical portion of the granular supporting cells (GC). Arrowheads show tight junctions. Receptor cell (RC) faces the ampullary lumen. Am, ampulla; D, desmosome; G, Golgi apparatus; LY, lysosome; M, mitochondrion; SG, secretory granule; V, vacuole. $\times 13,500$.

NGCs. Nerve endings were found in contact with their basal surface (Figs. 3, 4). Their cytoplasm was distinguished from others by the presence of numerous vesicular and tubular structures (Fig. 4).

(2) Granular cell: The GCs extended completely from the basal lamina of the sensory epithelium to the ampullary lumen. They were more numerous than the NGCs. Most GCs were located in the peripheral or external part of the organ, and taller than the RCs and NGCs. They projected far over the apices of the RCs, and their nuclei came to the upper level than those of the RCs (Fig. 1). Some GCs, which occurred between the NGCs in the central part of the organ, were comparable in height to the NGCs, and their nuclei were located deeper than those of the RCs. The luminal surface of the GC had stubby microvilli (Fig. 2). The apical portion was filled with a great number of secretory granules of about 0.2–0.8 μm in diameter (Figs. 1, 5, 9). The content of the granules was variable in electron density and showed the PAS-positive reaction. Among the secretory granules, mitochondria, lysosomes, multivesicular bodies and free ribosomes were detected (Fig. 5). Only scattered tonofilaments were found in the peripheral cytoplasm. The supranuclear region was characterized by the well-developed Golgi apparatus and lamellae of rough endoplasmic reticulum arranged longitudinally. Cisternae of the rough endoplasmic reticulum were distended and filled with an electron dense substance. Immature secretory granules were seen near the cis-side cisternae of the Golgi apparatus (Fig. 6). The basal portion had an oval nucleus, developed rough endoplasmic reticulum, mitochondria, and tonofilaments (Fig. 7). Some tonofilaments were converged to form the hemidesmosomes. GCs were adjoined to NGCs, GCs and CCs by tight junctions at the terminal bars, and by also desmosomes formed between the lateral cell membranes (Figs. 2, 7, 9).

(3) Non-granular cell: The NGCs also basically reached the basal lamina of the sensory epithelium and apically the ampullary lumen. They completely surrounded each one of the individual RCs except for the luminal surface (Figs. 1, 3). Their apical portions flattened to form a calyx with those of the neighboring NGCs, holding an RC within, whereas the basal portion always took a cylindrical shape (Figs. 1, 3). The luminal sur-

face was studded with a small number of short microvilli, and never projected over the luminal surface of the RCs (Fig. 2). The apical cytoplasm was characterized by abundant tonofilaments and scattered secretory granules. These granules were less in number, smaller in size, but electron denser than those of the GCs (Fig. 2). The middle portion, which came to be adjacent to the basal portion of the RC, was particularly rich in organelles such as the Golgi apparatus, developed rough endoplasmic reticulum, free ribosomes, unspecialized dense bodies and multivesicular bodies (Fig. 4). The basal portion was always located deeper than the RCs, and showed fine structures resembling the GC (Figs. 1, 3).

(4) Mantle cell: Three to five layers of MCs formed the outermost part of the organ (Fig. 1). The MC was elongate or semilunar in shape. It did not completely extend from the ampullary lumen to the basal lamina. An elongate nucleus was centrally located (Fig. 8). The cytoplasm was filled with tonofilaments. Rough endoplasmic reticulum, Golgi apparatus, and mitochondria occurred in the perinuclear region (Fig. 8). No secretory granule was found. The MC was locked together with the neighboring MCs and GCs by a number of desmosomes and interdigitations (Fig. 8).

(5) Channel cell: A single layer of CCs formed the duct wall of the organ, and continued to the ordinary epidermal cells. At the base of the duct, the CCs overlapped a part of the apical surface of the GCs, and frequently intervened between the GCs with their cytoplasmic processes (Figs. 1, 9). The luminal surface of the CC was wavy in outline. A pycnotic nucleus was centrally located in the cell. Mitochondria, Golgi apparatus, lysosomes, free ribosomes, and vacuoles were observed in the perinuclear region. The cytoplasm was characterized by densely packed tonofilaments which caused its higher electron density (Fig. 9).

The luminal surface of the cells was also coated with a fuzzy substance in the ampullary and the duct regions (Fig. 9). Such substance, however, showed no sign of condensation to form a cupula-like structure.

Discussion

In the present study, we have distinguished GCs and NGCs in the supporting elements of the

Silurus small pit organ on the basis of their relationship to the RCs and the amount of secretory granules, although both cells have several common features of fine structures with those of the ampullary (Szabo, 1974) and the ordinary lateral line organs (Hama, 1965). Szabo (1974) described the SCs as the basal accessory cells of the same type in the sensory epithelium of the ampullary organs in other fishes. Particularly, the small pit organs in other catfishes have only a single type of supporting cell in the sensory epithelium except for the case of the extraepithelial secretory cell islet in *Kryptopterus* (Mullinger, 1964; Wachtel and Szamier, 1969; Szabo, 1974; Gelinek, 1978).

Cells like the GCs, containing extremely numerous secretory granules in their apical cytoplasm, have never been reported to occur in the ampullary organs, even in those of weakly electric fishes that have two or three types of supporting cells (Szamier and Bennet, 1974; Derbin, 1974), nor in the ordinary lateral line organs of which supporting cells have well-developed Golgi apparatus and rough endoplasmic reticulum in the cytoplasm (Hama, 1965).

Since the apical portion of NGCs is flattened and other portions are very similar to those of GCs, the NGC will be impossible to be distinguished from the GC when examined by light microscopy. Therefore, they have been overlooked heretofore. Morphology of the NGCs, surrounding almost completely individual RCs in the form of a thin cytoplasmic lamella, may suggest their function of a mechanical support and an insulator for the RCs. Moreover, it is more likely to be of nutritive function for the RCs rather than of secretory function.

Filamentous or jelly-like substance has been noticed in the lumen of many ampullary organs in which supporting cells contain more or less the number of secretory granules (Mullinger, 1964; Wachtel and Szamier, 1969; Derbin, 1974; Szabo, 1974; Gelinek, 1978; Frizsch and Wahnschaffe, 1983), and are considered to be neutral mucopolysaccharides (Szabo, 1974; Frizsch and Wahnschaffe, 1983). The amorphous or fuzzy substance in the present material is also assumed to be mucopolysaccharides and a product of the GCs because of their PAS positive secretory granules. This substance seems to be a watery fluid which may facilitate the conduction of electric stimuli. A structure like a cupula has been

described previously in a cut-tailed bullhead (Sato, 1957) and *Gymnarchus* (Szabo, 1965), but it was not observed in the ampullary organs of *Silurus*, gymnotid fish (Lissmann and Mullinger, 1968), *Gymnarchus* (Mullinger, 1969), *Amiurus* (Mullinger, 1964) and *Sorubim* (Gelinek, 1978). The cupulalike structure seems to be an artifact. The absence of a cupula in these organs may be taken as a facilitating factor for the approach of environmental ions to the RCs, as earlier suggested in the sea eel pit organ (Hama, 1978).

The CCs lining the duct wall of the *Silurus* small pit organ correspond to the apical accessory cells of other fishes (Szabo, 1974). The fine structure of the CC is very similar to those of the outermost degenerating epidermal cells, the channel cell in *Amiurus* organ (Mullinger, 1964), and the flattened epidermal cells in *Sorubim* (Gelinek, 1978) and *Kryptopterus* (Wachtel and Szamier, 1969). Such similarity indicates that the wall of the duct may have emerged from the invagination of the outermost epidermal cells. On the other hand, the walls of the superior parts of the ampullae in other species have been described as lined by one of the channel (ampullary) cells (Mullinger, 1964), flattened epidermal cells (Gelinek, 1978) and apical accessory cells (Szabo, 1974). All of these cells are known to be devoid of secretory granules. In the *Silurus* small pit organ, it is lined exceptionally by the GCs.

The MCs surrounding the sensory epithelium is characterized by numerous tonofilaments in common with the corresponding cells in the ampullary organs of other animals (Mullinger, 1964; Frizsch and Wahnschaffe 1983), and in the ordinary lateral line organs of the conger eel (Hama, 1965). They are basically similar to the ordinary epidermal cells in many aspects of their fine structures except for their flattened shape.

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ナマズ小孔器における支持要素の微細構造

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