

THE STRUCTURE OF SEPTATE DESMOSOMES

MICHAEL LOCKE. From the Developmental Biology Center, Western Reserve University, Cleveland, Ohio

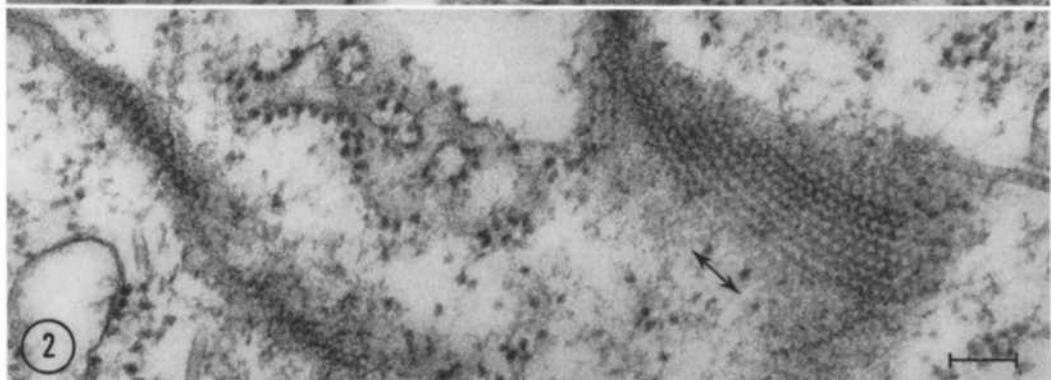
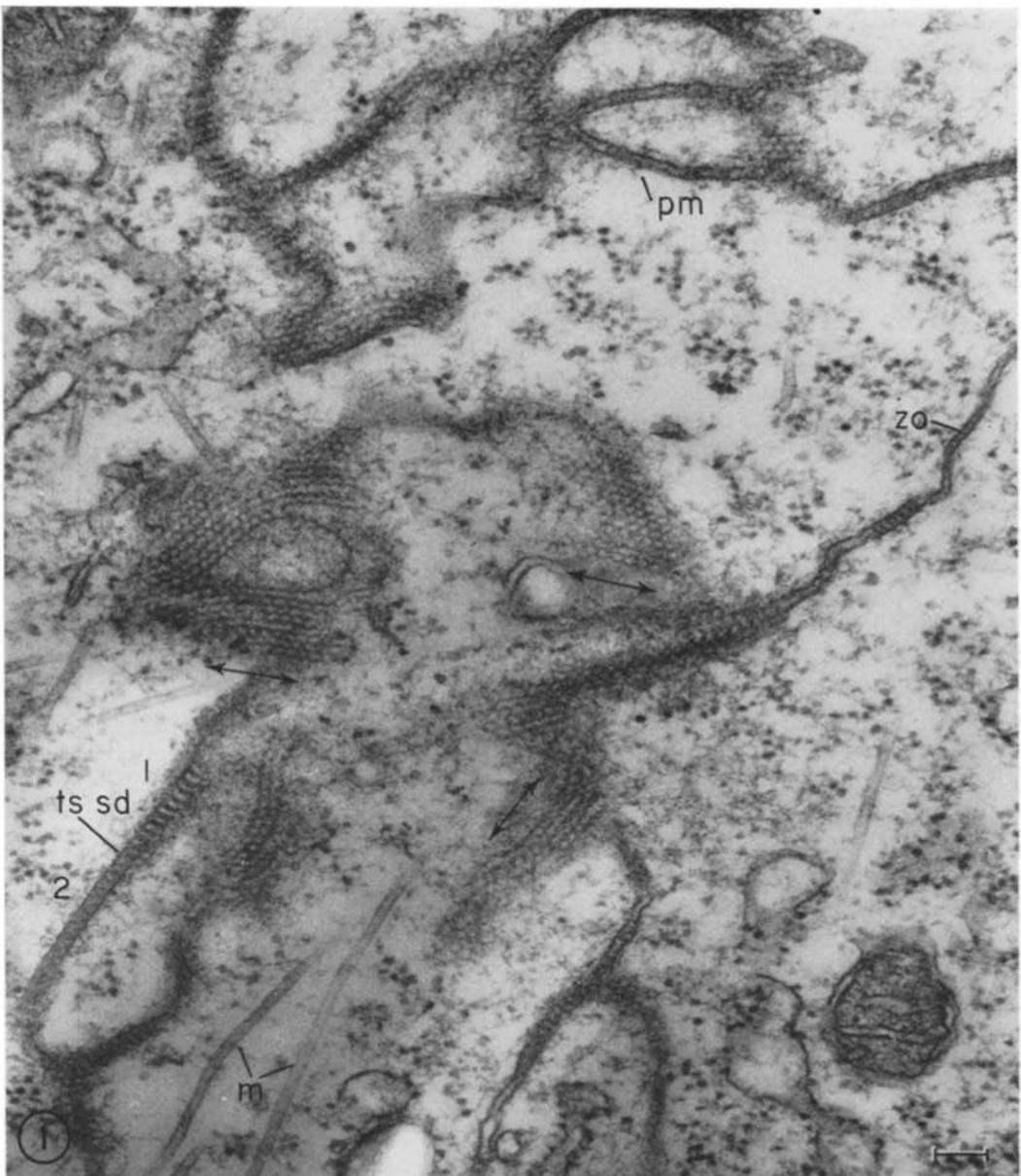
The most common type of specialized adhesive site between invertebrate epithelial cells has been characterized by Wood (13) as a "septate desmosome." He found them in various species of *Hydra* and in flatworms (*Dugesia*). He also drew attention to similar structures in annelids (6), anemones (5), and in echinoderm embryos (1). They also occur in insects (8); in fact, they are probably universally present in invertebrates. The structures in insect eyes described as ultra-tracheoles (3) are also probably profiles of septate desmosomes. In two important papers, the high permeability from cell to cell and the low permeability across the epithelium along the inter-cellular spaces (7) has been correlated with the distribution and form of these junctions (12), but the illustrations and figures of these authors add little to Wood's description of the structure.

Wood defined the septate desmosome as an adherent region between two plasma membranes which are joined together by parallel arrays of lamellae arranged at right angles to the surface. This description seemed to fit the structures uniting insect epidermal cells. However, nearly all the interpretations of the structure are based upon transverse sections of plasma membranes. Recently it has been possible to obtain sections tangential to the surface in the region of these desmosomes which suggest a modification of the original interpretation of the structure. The new structure proposed can be likened to a lipid-

water phase known from *in vitro* studies of liquid-crystals (9).

The structure and distribution of septate desmosomes has been studied in the epidermis of the caterpillar *Calpodes ethlius* (Lepidoptera, Hesperiidae). When seen in transverse section they seem identical with the structures described by Wood. Adjacent plasma membranes are about 140 Å apart and are joined by septa about 85 Å thick which repeat every 190 Å. In tangential sections, however, additional structure is revealed (Figs. 1 and 2). This structure is also mentioned and discussed in references 7 and 12. The septa are not merely straight sheets joining the plasma membranes together, but form a hexagonal network of septa arranged as the walls of symmetrical intercellular compartments. Each space in the net has a mean diameter of about 105 Å. The walls of the spaces are formed from three arrays of septa oriented at 120° to one another, giving an almost perfectly symmetrical pattern with regard to spacing. The arrays of septa themselves are not alike; those in one direction are more dense than the other two. The typical pattern of the septate desmosome is only seen when the section is exactly normal to the dense array of septa. If the section is in some other plane the intercellular space may appear almost uniformly dense. The dense arrays may be an intermediate stage between a perfectly hexagonal pattern and separate parallel septa. The simple situation of a single array of septa de-

FIGURES 1 and 2 Tangential and transverse profiles through a number of septate desmosomes in the epidermis of *Calpodes ethlius* (Lepidoptera, Hesperiidae). Material fixed for 1½ hours in glutaraldehyde, postfixed in osmium tetroxide, embedded in Araldite, sectioned rather thickly to obtain the complete thickness of a desmosome, stained with saturated uranyl acetate in 70 per cent alcohol for 10 minutes followed by lead citrate for 5 minutes. Most of the plasma membranes have septate desmosomes sectioned tangentially. ↔ indicates the axis of the main septa. The pattern is almost symmetrical, showing that the density of the main septa is not an artefact caused by tilting the membrane relative to the plane of section. *m*, microtubules; *ts*, desmosome cut transversely. At 1 the section is transverse to the membranes and normal to the main septa. The typical bars of the septate desmosomes can be seen. At 2 the section is still transverse to the membrane but no longer normal to the main septa, and the intercellular space appears uniformly dense. *pm*, normal plasma membranes without desmosomes; *zo*; *zonula occludens* showing a repeat pattern in the intercellular material. Fig. 1, $\times 78,000$; Fig. 2, $\times 93,000$.



scribed by Wood (13) might easily deform into this hexagonal pattern, or conversely. The hexagonal pattern of the septate desmosomes resembles the hexagonal pattern described in synaptic discs (10) but is about twice the size.

The distribution of the septate desmosomes is similar to that of the *macula adhaerens* or desmosome of vertebrate material, (2) but they probably occur in strips or may even extend round the cell. They occur between the cells towards the cuticular side but usually not immediately next to it. On the haemocoel side there may be a large intercellular space and it appears very much as if the desmosomes have the mechanical function of preventing the cells from parting further. Near to the cuticle the membranes may be closely appressed in tight junctions like the *zonulae occludentes* (2) or they may appear more like the *zonulae adhaerentes* (2). The intercellular material in the tight junctions is frequently discontinuous with a repeat pattern like the junctions in synaptic disc membrane complexes (10). Septate desmosomes also occur densely on the processes which epidermal cells extend between one another, and on tracheolar extensions. The distribution of septate desmosomes suggests that they are structures primarily concerned in adhesion.

If we accept the hypothesis that most membranes have their lipid component arranged in a double layer (10), then a probable arrangement of the lipid component in the hexagonal pattern of the septate desmosomes is that given in Fig. 3. The septa would be structurally similar to plasma membranes as their thickness suggests. Until patterns of this sort are described as arising spontaneously in the carbohydrate or protein components of membranes, the simplest hypothesis is that the lipids are the prime movers and the cause of variations in architecture. There is a structural parallel with lipid-water systems described on the basis of x-ray diffraction studies by Luzzati and Husson (9) (see also Gray, reference 4). They deduced the structure of lipid-water liquid crystals in a number of phases

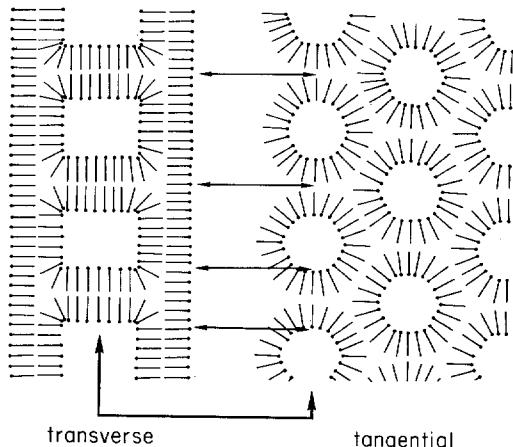


FIGURE 3 Diagram of a possible arrangement of the lipid component of the septate desmosomes, showing the similarity to lipids in the hexagonal phase.

including a lamellar phase similar to normal membrane structure, and a hexagonal array of cylinders, the middle or hexagonal phase, similar to the structure postulated for septate desmosomes. These phases were seen with the electron microscope in phospholipid-water mixtures (11), where the hexagonal phase repeated every 42 to 45 Å. This is only about $\frac{1}{4}$ of the size of the septate desmosome hexagonal pattern. The difference in size could be due to the greater complexity of its components, including the protein part. In the artificial systems, the phase depends upon the temperature and upon the proportion of lipid to water. If there is a similarly dependent equilibrium between lipid in the double layer of the plasma membrane and lipid in the hexagonal arrays of the septate desmosomes, it is possible that cells may control their adhesions to one another by minor local alterations in the proportions of lipid and water.

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REFERENCES

1. BALINSKY, B., An electron microscope investigation of the mechanism of adhesion of the cells in a sea urchin blastula and gastrula, *Exp. Cell Research*, 1959, **16**, 429.
2. FARQUHAR, M. G., and PALADE, G. E., Junc-
- tional complexes in various epithelia, *J. Cell Biol.*, 1963, **17**, 375.
3. FERNÁNDEZ-MORÁN, H., Fine structure of the light receptors in the compound eyes in insects, *Exp. Cell Research*, 1958, **5**, 586.

4. GRAY, G. W., Molecular Structure and the Properties of Liquid Crystals, New York, Academic Press, Inc., 1962.
5. GRIMSTONE, A. V., HORNE, R. W., PANTIN, C. F. A., and ROBSON, ELAINE A., The fine structure of the mesenteries of the sea anemone *Metridium senile*, *J. Micr. Sc.*, **99**, 523.
6. HAMA, K., Some observations on the fine structure of the giant nerve fibers of the earth worm *Eisenia foetida*, *J. Biophysic. and Biochem. Cytol.*, 1959, **6**, 61.
7. LOEWENSTEIN, W. R., and KANNO, Y., Studies on an epithelial (gland) cell junction. I. Modifications of surface membrane permeability, *J. Cell Biol.*, 1964, **22**, 565.
8. LOCKE, M., Pore canals and related structures in insect cuticle, *J. Biophysic. and Biochem. Cytol.*, 1961, **19**, 589.
9. LUZZATI, V., and HUSSON, F., The structure of the liquid-crystalline phases of lipid-water systems, *J. Cell Biol.*, **12**, 207.
10. ROBERTSON, J. D., Unit membranes: A review with recent new studies of experimental alterations and a new subunit structure in synaptic membranes, in *Cellular Membranes in Development*, (M. Locke, editor), New York, Academic Press, Inc., 1964, 1-79.
11. STOECKENIUS, W., Some electron microscopical observations on liquid-crystalline phases in lipid-water systems, *J. Cell Biol.*, **12**, 221.
12. WIENER, J., SPIRO, D., and LOEWENSTEIN, W., Studies on an epithelial (gland) cell junction. II. Surface structure, *J. Cell Biol.*, 1964, **22**, 587.
13. WOOD, R. L., Intercellular attachments in the epithelium of *Hydra* as revealed by electron microscopy, *J. Biophysic. and Biochem. Cytol.*, 1959, **6**, 343.