This suggests that the basic idea underlying the notion of a cutoff could in principle be more precisely defined in terms of IPV distributions. As far as we can see, such a definition would be entirely consistent with the traditional synoptic view of the essential phenomenon, taking other evidence into account such as wind and temperature fields (cf. Fig. 15) together with observational case studies of the time development of the cutting-off process. For instance section 10.1 of Palmén and Newton (1969, p. 274) describes the birth of a large cutoff cyclone from the cold "polar-source region", with which, at a certain stage of development, "it is still united by an 'umbilical cord' in the form of a shear line". From the information presented it appears that the stage of development referred to is fundamentally similar to that shown in our Fig. 5 for 23 September 1982, even though the orientation, geographical location, and other details are different.

Palmén and Newton describe the polar-source region as 'tropospheric' (*loc. cit.*, and top of p. 284). However, it has become increasingly clear, both from examples like that of Fig. 5 and from the theoretical principles reviewed in this paper, that this concept requires modification if one is interested in questions of dynamical cause and effect. For dynamical purposes an important part of the polar-source region is Kleinschmidt's lower-stratospheric reservoir of high-PV air. At least in cases like that of Fig. 5, the observed development appears to be largely controlled by long-range, quasi-isentropic advection of high-PV air from the lower-stratospheric reservoir. The word 'controlled' is used deliberately here, its use being justified by the invertibility principle. Whereas low temperature advection, for instance, may well appear important from a purely diagnostic point of view in, say, the middle troposphere ahead of the moving IPV anomaly, it can be argued that in terms of cause and effect its importance is actually secondary, in such cases, by comparison with that of IPV advection at higher altitudes. This is because much of the coldness of the free atmosphere beneath the IPV anomaly is attributable to the induced temperature field of the anomaly. As such, it *cannot be advected anywhere* unless

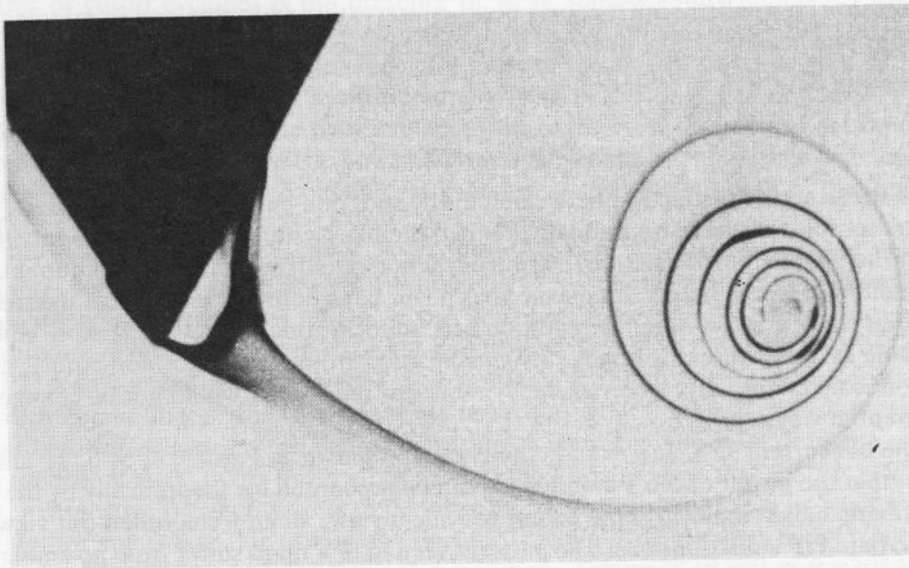

Figure 22. A standard fluid-dynamical experiment showing barotropic vortex rollup visualized by dye injection (Pullin and Perry 1980). A piston, not shown, drives water from left to right with almost constant speed normal to the axis of a wedge of 30° semi-vertex angle; the wedge acts as a source both of dye and of vorticity.