Response

by Marie-Pierre Aubry, John Van Couvering, William A. Berggren, and Fritz Steininger

In his comments on our paper, Dr Remane has objected to our interpretation of the phrase, "correlation precedes definition", as a summary of ICS philosophy. In his view, we have taken this "shorthand" phrase too literally, without regard to the fact that the ICS regulations also advocate consideration of existing conventions, such as historically related stage boundaries or other long-standing usage, in searching for appropriate boundary locations. He has also objected to our characterization of the correlation-first procedure as being a stratigraphy of events superimposed on the rock record, and finally, he disagrees with our assessment that the ICS regulations violate the principle of chronostratigraphic hierarchy.

While Dr Remane complains of being misrepresented in this regard, he has also misrepresented our position, in suggesting that we would advocate a stage boundary for an epochal GSSP without considering its quality as a global chronostratigraphic boundary. In fact, this is far from the approach recommended in the International Guidelines edited by Hollis Hedberg, which we have held up as a model for ICS to consider in improving the current rules. After granting both sides to this discussion a degree of moderation and common sense, however, the philosophical differences between the ICS regulations and the Hedbergian guidelines are still a serious problem, in our estimation.

We agree with Dr Remane that a proposed GSSP must be demonstrably correlatable, before it can be approved by IUGS. As we see it, the crux of the matter is that the ICS rules derive from a school of thought with a preconceived opinion that stage boundaries—Cenozoic stage boundaries in particular—are inherently unsatisfactory for global correlation, being "accidental" in nature and with no more than a provincial meaning at best. With this low opinion of stages, it seems to workers of this conviction that it is not only allowable but preferable to first set a GSSP for an epoch boundary, corresponding to a predetermined concept (usually an important, and sometimes global, event), and only then—or later—to redefine the "component" stages so that their boundaries fit the epoch. In this view, the original meaning of the stages that are selected as global components of higher units is dangerously irrelevant. The "correlation" that precedes their new definition is the existing correlation of the higher unit boundaries; thus, the component stages are adopted in name only simply to fill out the hierarchical structure.

The Hedbergian approach is narrowly, but crucially, different, in a way that validates the stage as the primary (not merely the smallest) chronostratigraphic unit in a progressive hierarchy. Hedberg and his colleagues recognized, of course, that classic stage stratotypes are often bounded by "accidental" physical boundaries—faults, transgressive unconformities, slumps—and that such limits may be hard to correlate. For this reason the Guidelines made provision for separately established "boundary-stratotypes" whose sole function is to define the beginning (or end) of a stage at or beyond the physical limits of the unit-stratotype, in a physical reference point that affords the best possible correlation that is consistent with the historical and conventional usage of the stage. This approach promotes stability in the literature and makes intra-regional and even global recognition of the stage's chronological limits possible.

We have observed that stages defined in the Hedbergian manner for maximum correlatability generally have boundaries that coincide with global geological events, simply because global events, by definition, are reflected in local sequences, and the most important events will tend to have the most conspicuous local effects. Put another way: it would be nearly impossible to select an event of "epochal" quality that was not already, or potentially, equivalent to the boundary-stratotype of a local stage, in most parts of the world. This is not to say that the appropriate boundary-stratotype for a stage will always correlate with the event of greatest magnitude in that general interval. In circumstances where this sets up a conflict between the concept of a higher category unit based on the "big event" and an appropriately defined stage boundary of different age (i.e., the current Eocene-Ypresian debate) we feel that the solution must take into account the

quality and integrity of the stage boundary. Stages are in fact global chronostratigraphic units in their own right, not mere names, and as such their role in the hierarchy cannot be lightly dismissed.

With the parallel development in the late seventies-early eighties of sequence stratigraphy on the one hand, and the integrated magneto-biochronologic scale (IMBS) on the other, it has become possible to describe accurately the architecture of packages of sediments deposited in shallow epicontinental settings—those where unit stratotypes of stages were precisely described. It has been shown that these unconformable packages, referred to as synthem, reflect the geodynamic history of the basin where they occur combined with an eustatic component. Thanks to a combination of methods, including biostratigraphy, chemostratigraphy, tephrostratigraphy, magnetostratigraphy and sequence stratigraphy, the Thanetian-Ypresian succession in northwest Europe, and more particularly in the London Basin, has been described comprehensively in terms of a response to the geodynamic history of the nascent North Atlantic Basin. The base of the Ypresian sequence is a transgressive surface that signals a major change in tectonic dynamics in the North Atlantic region. It marks a widespread transgression induced by tectonic relaxation following intense eruptive volcanism associated with the Icelandic plume. This event was so notable that it can be recognized on the western margin of the North Atlantic Ocean (e.g., on the New Jersey margin) but also in various parts of the Tethys Basin (e.g., in southern Spain). It can thus be seen that the base of the Ypresian Stage reflects a major tectonic event, that affected an area much broader than that where the regional Ypresian deposits occur. The recognition of this surface is indeed critical for deciphering not only the near field but also the far field impact of plate tectonic on sedimentary architecture.

A quick succession of exceptionally pronounced events have been described in early Chron C24r. These include, among others, a disruption of the carbon cycle, a sharp warming event, several biotic turnovers (that are closely spaced, not simultaneous, except apparently for the mammal turnover in North America and the deep sea benthic foraminiferal extinction event), explosive volcanism in the Caribbean region, in the British Tertiary Igneous Province and sluggish atmospheric circulation. We would speculate that the Ypresian transgression marks a return to relative quiescence, and thus can be seen as the last in this succession of extraordinary events spread over an interval of over 1 my. In as much as the Ypresian transgressive surface can be delineated far beyond the North Sea region, that its location in continuous sections can be correlated using various biostratigraphic data, among which the FAD of the calcareous nannofossil species *Tribrachiatulus digitalis* (questions that Dr. Remane raises in his comment on our paper concerning the biostratigraphic and taxonomic reliability of this taxon are answered in Bull. Soc. Geol. France, 2000, t. 171) it constitutes a sound chronostratigraphic horizon, very similar indeed to the base of the Zanclean Stage that serves to define the Miocene/Pliocene boundary.

We believe therefore that the Ypresian Stage, in particular its base, has a significance of its own that serves well stratigraphy in particular and geological history in general. The beginning of the Eocene Epoch has been tied until now to the base of the Ypresian Stage (a notable plate tectonic event thus marking the beginning of the Eocene Epoch, which of course was unknown when the Ypresian Stage was defined). While we may wish to modify the concept of Eocene Epoch, we do not believe it suitable to alter the concept of Ypresian Stage, as strict application of the ICS rules would support. Instead, we would recommend that in agreement with the Hedbergian principles, a stage be introduced whose base would define that of the conceptually modified Eocene Series. In this way, the ICS concern for correlatability of chronostratigraphic horizons would be observed at the same time as the Hedbergian principles would be respected.