Comment and Reply on "Short-lived 1.9 Ga continental margin and its destruction, Wopmay orogen, northwest Canada"

COMMENT

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Using accurate geochronologic data, Hoffman and Bowring (1984) have convincingly documented the extremely short time span involved in the destruction of the 1.9 Ga Coronation passive margin. This considerably refines and reduces previous estimates (Hoffman, 1980) of the time span involved in the Wilson cycle of the Wopmay orogen. Subsequently, they concluded that "certain differences in detail between this collided margin and those of Phanerozoic age may be related to subduction of newly rifted lithosphere."

Without wanting to detract from the results of their lucid analysis, we question the implicit assumption made in their conclusion regarding the uniqueness of the role of subduction of newly rifted lithosphere to be restricted to early Proterozoic Wilson-type orogenies. Subduction of newly rifted lithosphere upon the closing of small rifted basins is documented to play a dominant role in Phanerozoic orogenies as well. This is particularly evident in the Alpine orogeny, for which Trümpy (1982) and Winterer and Bosellini (1981) demonstrated that at most 50 m.y. was involved in closing of the central Alpine basins and the destruction of a thickly sedimented Jurassic passive margin in the southern Alps, respectively. Recently, we have demonstrated that age-dependent subduction and a related compressive regime (England and Wortel, 1980), upon the closing of small and newly rifted basins and the induction of thermal upper-mantle anomalies by subducted spreading ridge segments (Vlaar, 1983), explain many features of Alpine orogeny (Vlaar and Cloetingh, 1984). This concerns in particular the absence of island-arc volcanism (Trümpy, 1982) in the Alps. These features do not conform to the standard concepts of subduction of oceanic lithosphere and a long time span of the Wilson cycle as usually applied and attributed to Phanerozoic tectonics (Fig. 1, left). On the basis of an extensive survey of the tectonic framework of central and western Europe, Zwart and Dornsiepen (1978) have pointed out that collision and closing of short-lived oceans of minor size during the Phanerozoic is not limited to the Alpine orogeny but is the dominating cause of Variscan orogens as well.

Casting evolutionary frameworks of the Wilson cycle in terms of opening and closing of wide oceans (e.g., Turcotte and Schubert, 1982) seems, therefore, to be more inspired by an actualistic comparison with the present size of the Atlantic Ocean than by a consideration of more pertinent geological observations. The same can be said for arguments, made on the basis of the present-day absence of oceanic lithosphere older than 200 Ma and the increase with age of the gravitational instability of oceanic lithosphere, for spontaneous foundering and subduction of oceanic lithosphere when that particular age of 200 Ma is reached (Hynes, 1982).

As pointed out by one of us (Cloetingh) at the Hedberg research conference on continental margin geology (Galveston, Texas, January 1981), transformation of passive into active margins by spontaneous foundering of old unstable lithosphere is inhibited by the considerable strength of the lithosphere. Therefore, a discussion of the time span involved in the transition from passive to active continental margin must deal with the assessment of the possibilities for lithospheric rupture. Our model studies (Cloetingh et al., 1982, 1983) have shown that flexure induced by sediment loading dominates the stress state at passive margins. We have demonstrated that, owing to the continuing accumulation of sediments at passive margins, the stress level induced increases with the age of the margin. An important new feature following from rheological considerations (Cloetingh et al., 1982, 1984) and implemented in our thermomechanical models for the evolution of passive margins is that the strength of the lithosphere at the margin increases with age as well. We found that stresses generated at passive margins of large ocean basins are generally insufficient to induce lithospheric failure and transformation into active margins. This offers an explanation for the enigma that gravitationally unstable oceanic lithosphere at the margin of the Atlantic is not subject to subduction. Extensive sediment loading on mechanically weak passive margins of newly rifted basins, however, creates a high stress level in comparison to lithospheric strength and was shown to be an effective mechanism for basin closure. Our modeling demonstrated that if after a short evolution (a few million years) of a Phanerozoic passive margin subduction has not yet started, continuing aging of the passive margin alone does not result in conditions more favorable for transformation into an active margin. These findings led us to propose the modification of the

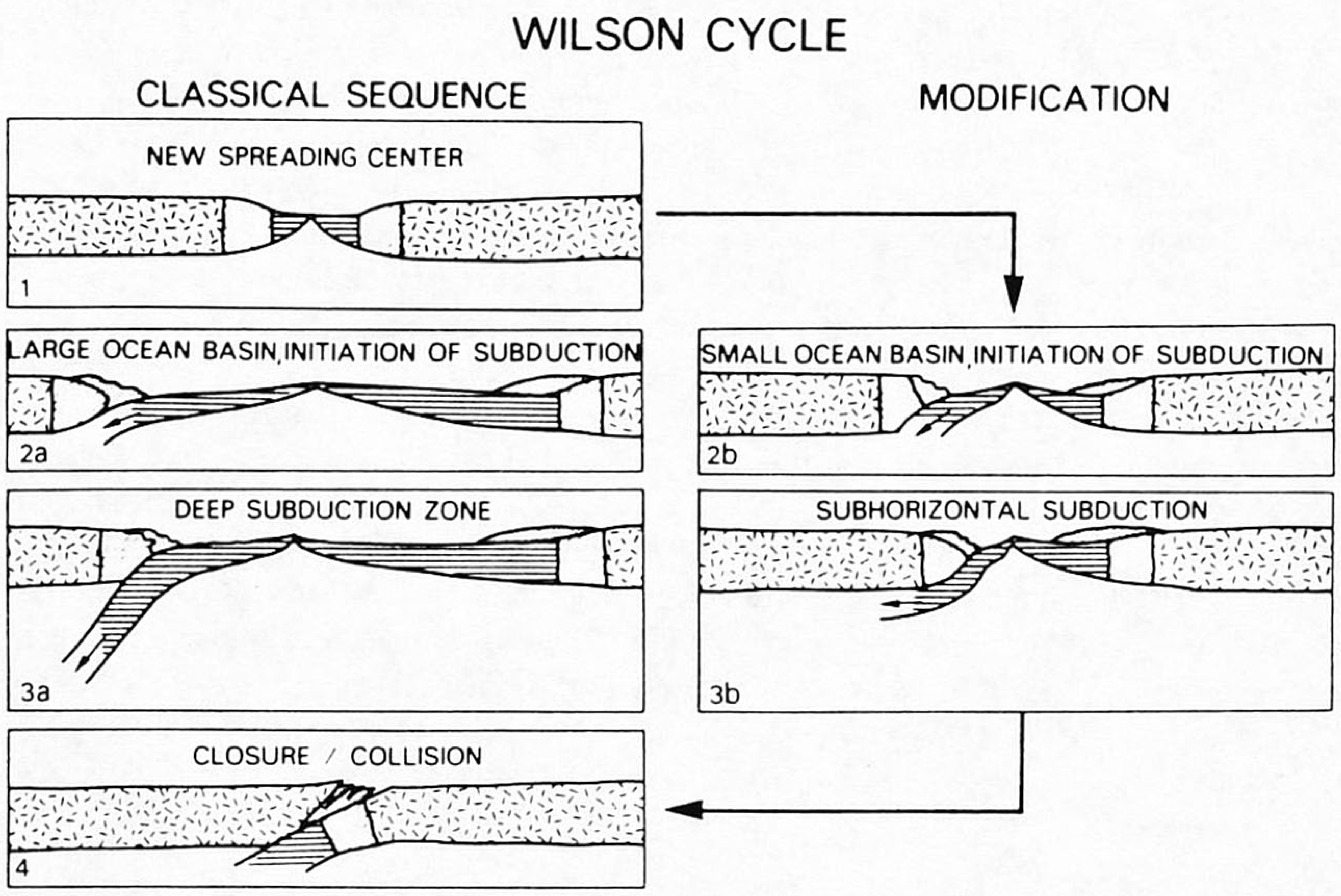

Figure 1. Scenarios for Wilson cycle. Left: Classical scenario, in which rifting is followed by formation of large ocean basin. Initiation of subduction involves old oceanic lithosphere, producing deep subduction zone. Right: Preferred scenario for Proterozoic and Phanerozoic Wilsonian orogenies, in which closure of newly rifted basin by initiation of subduction of young lithosphere occurs, with implications for tectonics and volcanism which differ from those associated with deep subduction zone. Patterns indicate passive-margin sediments and continental, rift-stage, and oceanic lithosphere.

classical sequence of the Wilson cycle concept in Phanerozoic geology (Fig. 1, right).

Probably in Proterozoic time, due to steeper temperature gradients in oceanic lithosphere, plates were weaker, implying a lower stress level required to transform passive margins into active margins, facilitating the closure of small, newly rifted basins. Nevertheless, considering the results of our model calculations and the abundant geologic evidence in support of the key role that small, newly rifted basins play in Phanerozoic orogeny, we must conclude that rapid passive-margin evolution as thoroughly established now for the Wopmay orogen by Hoffman and Bowring (1984) is not a characteristic feature restricted solely to early Proterozoic tectonics.

REPLY

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As we have always been much more impressed by the similarities between the Wopmay and Phanerozoic orogens than by the differences (Hoffman et al., 1970; Hoffman, 1973, 1980), we welcome Cloetingh et al.'s Comment on our paper (Hoffman and Bowring, 1984). Indeed, we find in it no real conflict with our interpretation. A secular decrease in the rate of oceanic-plate recycling would require a secular increase in the *maximum* but not in the minimum duration of passive continental margins. Of course, the data from the Wopman orogen alone do not prove that conditions were different at 1.9 Ga. Data are needed from the many other collided continental margins of about this age that are preserved on several continents. The purpose of our paper was to show that, through a combination of aggressive geological field work and modern U-Pb zircon chronology, the duration of very ancient passive margins can be accurately determined. Ultimately, such data may provide an empirical test of the hypothesis of secular change in the mean age of oceanic lithosphere.

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Comment and Reply on "Abundant and diverse early Paleozoic infauna indicated by the stratigraphic record"

COMMENT

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A welcome development in ichnology is the recent increased interest in the significance of the early Paleozoic record of bioturbation. Miller and Byers (1984) posed important questions on the total bioturbation record of the early Paleozoic. They made several references to Ausich and Bottjer (1982) that warrant clarification.

We described the Phanerozoic history of tiering (vertical structure) in benthic marine suspension-feeding communities from soft substrata in nonreef, shallow subtidal shelf and epicontinental sea environmental settings (Ausich and Bottjer, 1982). We did not treat the total record of bioturbation of suspension-feeding and deposit-feeding communities, nor the record of deposit-feeder body fossils. Thus, the initial statement by Miller and Byers (1984, p. 40), "Several papers in the last few years have asserted that early Paleozoic communities lacked significant infaunal suspension- and deposit-feeding components (Bambach and Sepkoski, 1979; Thayer, 1979; Ausich and Bottjer, 1982; Sepkoski, 1982)," which implies a consideration of the total record of early Paleozoic infaunal suspension- and deposit-feeding communities, incorrectly cited us (Ausich and Bottjer, 1982) as making this assertion. Miller and Byers (1984, p. 40) then stated that conclusions reached in Ausich and Bottjer (1982), as well as other papers, on infauna were "drawn largely from the record of body fossils—i.e., the skeletal remains of predominantly shelled animals. Evidence in the rock record of biological destruction of sedimentary structures formed at the time of deposition, including general bioturbation and discrete tracks, trails, and burrows, has been given only cursory attention." This is a misunderstanding of what was presented in Ausich and Bottjer (1982, p. 174, note 4): "Both body and trace fossils that have consistently been interpreted as representing suspension-feeding organisms are included." Miller and Byers (1984) were correct in implying that we did not consider general bioturbation, but analysis of general bioturbation in sedimentary rocks does not necessarily measure infaunal tiering levels of suspension-feeders. Rather, these tiering levels are best studied by examination of discrete burrows as well as body fossils. An extensive survey of discrete trace fossils from throughout the Phanerozoic