Chapter 7
Conclusion

Abstract Current data suggest that continents are denuded by rivers at a rate of ~ 23 Gt yr^{-1}, most of which (~ 83 %) is accounted for by solid debris and the remaining fraction by dissolved solids. Aeolian dust and ice-rafted rock fragments contribute a less-known proportion. This material transfer does not necessarily reflect the intensity and rate of weathering occurring on the continents because a significant fraction is supplied by outcropping sedimentary rocks, thus intervening in the complex rock cycle. Continental denudation must, therefore, be considered in the context of the composite dynamics of the critical zone, which is significantly affected by anthropogenic interactions.

Keywords Weathering cycle · Denudation · Climate forcing · Anthropogenic forcing · Tectonic forcing · Critical zone · CO_2 sequestration · Erosion · Rivers · Exhumation

7.1 Final Remarks

Our main intention in the preparation of this volume for the Springer Briefs in Earth System Sciences was to present in a concise way, the complex chain of geological events that leads to the denudation of continents. The picture that we try to convey is that of a sequence that begins with mechanical weathering. Rock and chemical attack, appears often mediated by the subtle effect of biology. The whole process of continental wearing down is, in fact, an open system with internal feedbacks (e.g., incipient chemical weathering assists in the action of peripheral forces, such as frost weathering) and the powerful action of interacting external forcing, like climate and tectonics (Fig. 7.1). There is ample evidence that weathering affects climate, for example, sequestering CO_2, and climate, in turn, impacts on the rate at which weathering occurs (e.g., Ruddiman 1997).

Another aspect worthy of attention is the fact that, according to the most recent and comprehensive data set, continents appear to be denuded at a rate of nearly 23

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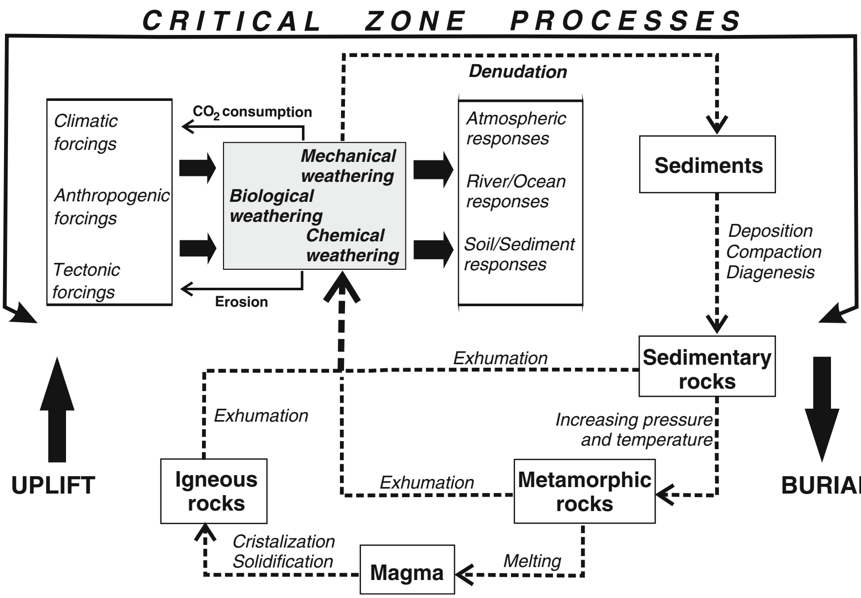

Fig. 7.1 Coupled chemical, physical, and biological weathering processes in the critical zone (embedded in the global geological cycle), which are affected by climate, anthropogenic and tectonic forcing over significantly different timescales. The output from the weathering engine is documented in the response of the atmosphere, hydrosphere, and geosphere

Gt yr^{-1} (Milliman and Farnsworth 2011), ~83 % of which appears to be accounted for by the sediment exported from the continental mass via rivers, and the remaining 17 % corresponds to the total solids that are delivered to the coastal oceans as dissolved matter. Are these figures in agreement with global weathering intensity and rate? Although they are sound approximations to continental wearing down, they do not reflect the significance of **current weathering** in a global perspective, as we will immediately see. Considering metamorphic rocks as either sedimentary or igneous depending on their origin, it is a common knowledge among earth scientists that the great bulk of the Earth's crust consists of igneous rocks (95 %) and only 5 % are sedimentary rocks, forming a relatively thin layer at or near the surface. However, the extent of sedimentary rocks cropping out at the Earth's surface is much larger than that of igneous rocks, so that 75 % of all rocks seen at the surface are sedimentary and only about 25 % are igneous. Therefore, as Gaillardet et al. (1999) have shown and other authors have suggested the sediment flux of a large proportion of the world's largest river systems is, in fact, a recycled material that has already passed once or several times through the Earth's exogenous cycle. Therefore, what the TSS nature and load of major large rivers show, as McLennan (1993) pointed out about 22 years ago, is the signature of the **weathering history** of any individual large river system.

Another aspect that has not been considered in this work is the significance of aeolian transport of dust to the oceans and the significance of ice-rafted debris. Clearly, both contribute to denude continents. However, knowledge on the former has increased significantly during the last decade and fluxes of continental aerosols transported to world oceans are known with increasing certainty for the present-day conditions, and for the recent geological past (e.g., Maher et al. 2010). Due to difficulties that are inherent to the process, the ice-rafted supply of sediment to the world's ocean is less known globally and restricted to specific areas (e.g., Jonkers et al. 2012).

As it is widely known, human actions play a mixed role; they increase erosion employing erroneous soil-use practices and, in contrast, they retain sediments behind dams, as seen in an earlier chapter. This aspect has been thoroughly dealt with by Milliman and Farnsworth (2011).

Concerning the linkage between chemical weathering and global denudation, there are two aspects that contribute to project a blurry image on this particular topic. Although there has been considerable progress on the knowledge concerning the global transfer of continental dissolved phases to the coastal oceans via ground water seepage there is still significant ground to cover. The knowledge is restricted to certain regions, although there is a growing certainty that such dissolved flux is, indeed, significant. The other aspect with still incomplete information derives from the global chemistry of rainfall and snowfall and the relative role played by recycled salts when computing global TDS continental fluxes.

Concluding this monograph, we hope that we have attained the goal that, in showing what is broadly known nowadays, we have also shown where scientists should dig deeper. In so doing, we tried to use updated references, modern concepts and, whenever possible, references to our own work, which was developed in the southern portion of South America.

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