Tectonostratigraphic model for underfilled peripheral foreland basins: An Alpine perspective

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ABSTRACT

Advances in the development of quantitative models of foreland basin stratigraphy have outpaced the observational data used to constrain the input parameters in such models. Underfilled peripheral foreland basins comprise a broad threefold subdivision of depositional realms that translates into three stratigraphic units which are commonly superimposed during basin migration; these units are here termed the "underfilled trinity." The three units of the trinity reflect (1) carbonate deposition on the cratonic margin of the basin (the lower unit), (2) hemipelagic mud sedimentation offshore from the cratonic margin of the basin (the middle unit), and (3) deep water turbiditic siliciclastic sedimentation toward the orogenic margin of the basin (the upper unit). Theoretical predictions of how such a complex basin fill initiates and evolves through time are not currently available; hence this study reviews the stratigraphy of underfilled peripheral foreland basins and provides a unique data set comprising rates of thrust advance and basin fill migration for the Tertiary foreland basin of the European Alps.

The Paleocene to Oligocene Alpine foreland basin of France and Switzerland comprises a well-developed underfilled trinity that is preserved within the outer deformed margins of the Alpine orogen. Structural restorations of the basin indicate a decrease in the amount of basin shortening from eastern Switzerland (68%) to eastern France (48%), to southeastern France (35%). Structurally restored chronostratigraphic diagrams allow rates of basin migration to be calculated from around the Alpine arc. Paleogeographic restorations of the Nummulitic Limestone (lower unit) illustrate a radial pattern of coastal onlap on to the European craton. Time-averaged rates for northwestward coastal onlap of the underfilled Alpine basin across Switzerland were between 8.5 and 12.9 mm/yr. Time-equivalent westward to southwestward coastal onlap rates in France were between 4.9 and 8.0 mm/yr. The direction of migration of the cratonic coastline of the basin was parallel to the time-equivalent thrust motions, and oblique to the Africa-Europe plate motion vector. By comparing rates of thrust propagation into the orogenic margin of the basin to rates of coastal onlap of the cratonic margin of the basin, it is possible to suggest that the Alpine foreland basin of central Switzerland migrated with an approximately steady state geometry for at least 210 km northwestward over the European craton. The westward and southward decrease in the basin migration rate around the Alpine arc was associated with an increase in the degree of syndepositional normal faulting on the European plate; this is thought to relate to the opening of the Rhine-Bresse-Rhône graben system.

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INTRODUCTION

Peripheral foreland basins develop in response to the load of the thickened crust that results from continental collision (Dickinson, 1974; Beaumont, 1981; Allen et al., 1986). The sedimentary infill of foreland basins records the interaction between the growth of the thrust wedge, the isostatic adjustments of the cratonic lithosphere to thrust loading and additional bending moments, eustasy, and the surface processes that redistribute material from the mountain belt into the surrounding basins. Numerical models have tried to simulate the growth of thrust wedge–foreland basin systems, and attempted to evaluate the significance of individual parameters and how they interact (Jordan, 1981; Stockmal and Beaumont, 1987; Flemings and Jordan, 1989; Sinclair et al., 1991; Johnson and Beaumont, 1995). The challenge for field geologists studying foreland basins is to test the validity of these models, and to provide input on the rates and styles of the tectonic and surface processes that develop during the evolution of their basin. This study provides a synthesis of the tectonic and stratigraphic evolution of underfilled peripheral foreland basins from around the world, and then focuses on the most thoroughly documented of these: the Tertiary Alpine foreland basin of France and Switzerland (Fig. 1).

Numerous publications have demonstrated how peripheral foreland basins evolve from an underfilled to a filled or overfilled depositional state (Graham et al., 1975; Labaume et al., 1985; Covey, 1986; Homewood et al., 1986; Houseknecht, 1986; Tankard, 1986; Ricci-Lucchi, 1986; Grotzinger and McCormick, 1988; Coakley and Watts, 1991). The definition of the depositional state of a basin requires a reference frame within which the degree of filling can be defined. Computer-generated basins define the degree of filling of a flexural depression with reference to the point of zero lithospheric deflection on the cratonward margin of the basin (Flemings and Jordan, 1989). However, when studying the fill of ancient basins, locating this point is not always possible, with a few notable exceptions (DeCelles and Burden, 1992). Therefore, in ancient settings, the degree of filling of the basin is commonly approximated from the long-term trends in the sedimentary facies found in the basin; i.e., deep marine facies equate with underfilled, shallow marine–distal continental facies equate with filled, and fully continental facies equate with overfilled (Tankard, 1986; Homewood et al., 1986; Labaume et al., 1985; Sinclair and Allen, 1992). This use of sea level as the reference frame implies that mean sea level and the elevation of the stable craton do not differ significantly (within ~200 m) when considering the long term (>5 m.y.) development of the basin. The use of sedimentary facies as an indication of basin filling can only be applied to long-term trends in sedimentation, and facies that are used to identify an underfilled state must have been deposited in significant (>200 m) water depths.

The controlling factors on the degree of filling by siliciclastic sediments shed from mountain belts into their neighboring foreland basins have been assessed using quantitative models (Stockmal and Beaumont, 1987; Flem-