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**Evaluation of the doctoral thesis "Evolution of the Bohemian Massif: Insights from numerical modeling" by RNDr. Petra Maierová of the Faculty of Mathematics and Physics at the Charles University in Prague**

This thesis addresses several aspects of the complex questions posed by the geological evolution of the Bohemian Massif. Carefully selected questions are investigated through elegantly designed numerical models. These models range in nature from fundamental proof of concept to sophisticated exploration of parameter spaces. The design of these models is both careful and creative, and they advance our understanding of the Bohemian Massif. The conception and execution of the modeling is sufficiently broad as to allow application to a wider variety of geological problems. The text is clear and well-written, featuring thoughtfully chosen illustrative figures. The thesis consists of four chapters, two of which have already been published in peer-reviewed scientific journals.

In Chapter 1, the author reviews the current state of understanding of the structure and evolution of the Bohemian Massif. This exceptionally broad survey ranges across geology and petrology, seismic imaging by a variety of methods, gravity structure, magnetics, heat flow, radiogenicity, and inferred tectonic history. Both the unusual breadth of this summary and the attempts to interrelate constraints from largely unrelated methodologies are impressive. Many such attempts (including a few of my own) at synthesis of disparate constraints on complex systems focus upon only two or three such components, rather than upon the great diversity of components that the author has included and illustrated here.

In Chapter 2, the author begins by explaining the structure of the numerical models developed and employed for these analyses. This section features an unusually clear exposition of the methodological details, and it is here that the creativity of the author's scientific approach first becomes evident. In addition to using the existing Elmer software package, the author has greatly expanded it by devising complicated external procedures for evaluating key parameters and by developing sophisticated solvers to address an important set of phenomena: advection of the free surface, operation of the surficial processes of erosion and sedimentation, advection of tracer particles, imposition of flexure and isostasy, and post-processing for determination of gravity anomalies. (Having devised a few Elmer procedures myself, for modeling structural consequences of planetary contraction, I can attest to the high level of creativity and expertise necessary for the author to have accomplished this work.) It is the subsequent section, however, which made the deepest impression upon this reader. Here the author attempts (and brilliantly succeeds) to validate the numerical model by undertaking a series of tests, for comparison of her results to analytical solutions and to other published models. The selection of tests applied here is simply excellent, and several of them exhibit some fascinating numerical behavior. The author explores and provides compelling diagnoses of the effects of a number of subtle but important aspects of the modeling: size of time steps, fineness of discretization, schemes for particle advection, methods of stabilization, schemes for averaging, use of integration points or elements, and density of particles. The figures chosen to illustrate the associated subtleties are especially clear. The sheer scope of this testing is particularly impressive in that such thorough validation can seldom be found in published work, perhaps in part because it is all too seldom performed with such rigor. (I am certain that, in the future, this section will become required reading for those of my own students who seek to perform such sophisticated modeling.)

In Chapter 3 (which has already been published), the author addresses the problem of exhumation of lower crustal material during development of the Bohemian Massif. The goal of the study is to determine if a model, which does not include the common invocation of heat transfer by lithospheric delamination, can successfully generate features consistent with a set of observational geological constraints: pressure-temperature conditions, turnover and channel-flow deformation, rapid exhumation, and topographic evolution. The author succeeds in this effort, convincingly demonstrating that radiogenic heat sources (in underthrust felsic crustal material), when combined with tectonic convergence and subsequent indentation, can indeed yield results consistent with observations, thereby providing a plausible alternative to previous scenarios invoking lithospheric delamination. This study, which aims to generate a specific result within a given set of free parameters, is nicely complemented by a different approach in the subsequent chapter.

In Chapter 4 (which also has already been published), the author explores the apparent dichotomy between gravity-driven vertical mass exchange (e.g., diapiric overturn with channel flow) and crustal-scale folding (e.g., doming), both of which have been cited as dominant processes in different parts of the Bohemian Massif. Rather than demonstrating the feasibility of attaining a specific scenario outcome, as was done in the previous chapter, this study proceeds to a sophisticated exploration of the parameter space. By focusing upon the carefully selected parameters of convergence rate, radiogenic heating, and erosion efficiency, the author is able to map out a continuum of behavior between end-member cases, while constraining threshold parameter values governing transitions between regimes. In simplified summary, high rates of radiogenic heating are found to favor gravity-dominated deformation and flow (such as are characteristic of the Moldanubian terrane), and high convergence rates are found to favor fold-dominated deformation (as in the West Sudetes terrane). In the process of performing this analysis, the author devises a clever classification scheme for the results of various model cases, concentrating upon factors such as degree of folding, narrowness of the infrastructure-superstructure transition zone, occurrence of subhorizontal channel flow, and time required for exhumation of felsic lower crust. Also notable here is the author's assessment of pressure-temperature-time (P-T-t) paths of metamorphism. The illustration of the effects of model parameters upon the morphology of P-T-t paths, presented in Figure 4.9, is remarkable for its clarity. Furthermore, the author's use of clouds of tracers in P-T-t space in Figures S1 and S2 – rather than the more common use of a single tracer particle claimed to be "typical" – is particularly to be applauded. Finally, this chapter closes with a nice summary of possible weaknesses in the author's necessarily simplified model, pointing the way for future investigations.

Overall, Chapters 3 and 4 represent applications of the author's numerical method (outlined in Chapter 2) to some of the outstanding questions about the evolution of the Bohemian Massif (as summarized in Chapter 1). The author's method, however, clearly is sufficiently general and extensible as to be applicable to a variety of other problems. Indeed, the author herself has already applied it to the modeling of oceanic subduction with variable thermal conductivity (Maierová et al., *J. Geophys. Res.*, 2012). I can also imagine fruitful applications to other problems, ranging from convergence between South America and the southern Lesser Antilles (featuring deep emplacement of felsic material from the Venezuelan crust beneath the arc volcanic center of Grenada) to continental accretion of arc terranes onto western North America (featuring heat flow influenced by shallowly dipping subduction). As the author notes in closing, incorporation of melting and melt migration into the model also promises to yield additional insights in the future.

I would like to ask the author several questions, to further explore a few specific aspects of her studies.

1) The review of various seismological studies in Chapter 1 seems to suggest that there may be some disagreement in interpretation between studies as to whether the Teplá-Barrandian crust is thicker or thinner relative to the Moldanubian crust. Are there compelling reasons to favor one interpretation over another?

2) Given that radiogenic heating appears to govern much of the behavior observed in Chapters 3 and 4, how significant an effect upon the model results might you expect the inclusion of latent heats (of metamorphism or melting) to have?

3) The thermal model focuses upon radiogenic sources, convection, and solid-state advection. Metamorphic attainment of granulite grade, however, involves liberation and transport of substantial volumes of fluid or melt. To what extent might advective heat transport by such fluids be likely to perturb your models of thermal evolution?

4) One potentially significant simplification incorporated into the models of Chapters 3 and 4 is that flow in the lithospheric mantle is prescribed kinematically rather than solved dynamically. Given the implication of this simplification for the treatment of convective heat transfer and crust-mantle coupling, might you speculate as to which aspects of the model results would likely be most sensitive to changes in lithospheric mantle flow?

5) Chapter 4 (page 120) briefly notes the absence of ultramafic bodies in the cores of observed crustal antiforms, in the context of dominant wavelengths of folding and controlling contrasts in crustal competency during collisional scenarios. Might you briefly expand upon this comment, in terms of the implications of the presence or absence of exposed ultramafic (e.g., peridotite) bodies for approaches to collisional modeling?

6) In Chapter 3, Figure 3.5 traces the P-T-t evolution of felsic lower crustal material, overlaid upon observed P-T regimes from field sampling. The observed regimes appear to relate primarily to conditions of peak metamorphism followed by a short segment of rapid exhumation. Model curves (such as the green path), however, trace a longer period of exhumation, including retrograde metamorphism to amphibolite and lower grades. Is there much field evidence (e.g., pseudomorphs, relict inclusions, zoned rims, disequilibrium assemblages) recording retrograde metamorphism to such lower grades?

7) Further pursuing the preceding question, are the muscovite inclusions in granulites from the West Sudetes or along the margins of the Moldanubian root (noted on page 117) persuasively interpreted as incomplete prograde relicts, or might they conceivably relate to retrograde revolatilization?

8) One simplification inherent in the models in Chapter 4 is the approximate treatment of crustal rheology (as noted briefly on page 119). Might you briefly speculate as to how incorporation of more complex rheology (e.g., inclusion of diffusion creep) would likely shift the deformational behavior observed in your models?

9) Bohemian granulites are commonly interpreted to have formed at high-pressure conditions from felsic igneous (or very occasionally pelitic) protoliths, either by deep subduction or homogeneous crustal thickening. However, the Lišov granulites appear to have formed at lower pressures – i.e., in the spinel rather than garnet peridotite regime – than other Moldanubian granulites. Does this contrast in peak pressure have any implications for your modeling, or is the diversity of P-t paths in your Figure S1 sufficient to accommodate such pressure variations?

I recommend that this work be accepted as a doctoral thesis.

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