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Examiner report

on the doctoral dissertation entitled

Assembly of the Saxothuringian orogenic wedge: the Variscan P–T–t record of the metasediments of Erzgebirge, Bohemian Massif

by **Marine Jouvent**

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The thesis of Marine Jouvent is dedicated to the study of the geological evolution of metasediments from Krušné hory (Erzgebirge) that are part of the Saxothuringian orogenic wedge in the north-western part of the Variscan Bohemian massif. A multidisciplinary approach is used with various methods of structural geology, metamorphic petrology, and geochronology. The goal is to understand the evolution of the different units and their assembly, the internal architecture and the timing of the wedge evolution, and to propose a coherent model for the tectonic evolution of the Saxothuringian orogenic wedge in the framework of the Variscan orogeny.

The thesis is organised in two parts, preceded by a preface and followed by a concluding summary. The core of the thesis are Parts I and II written in the form of scientific articles exploring different specific aspects of the problem. Part I is published in a first-class international scientific journal (Journal of Metamorphic Geology). Part II is divided in two subsections that correspond to 1) an article submitted to another international scientific journal (Tectonics), and 2) an article being prepared for publication in yet another high-rank journal (Geochimica and Cosmochimica Acta). The Preface represents an introduction to the thesis, including the description of the geological framework, both local and orogen-scale. The final chapter is a concluding summary of the results and their discussion in a larger perspective. Despite some imperfections the thesis is very well written and illustrated.

The Preface presents the general problem of assembly of orogenic wedges and justifies the selection of the Saxothuringian domain and the Krušné hory region to address this issue. The concrete aims of the study are then presented and the choice of the methods and the general structure of the thesis are explained.

Follows a brief introduction to the geological structure and the chronological evolution of the Variscan orogen in general, and the Saxothuringian domain (and the Krušné hory region) in particular.

Part I is a perfect example of a beautiful multidisciplinary study that combines solid field-based structural data and deformation analysis with petrological data that include state-of-the-art phase-equilibrium modelling based on an excellent meticulous petrographic study.

First, the structural record of the region is presented, based on detailed data from almost 300 outcrops. Four distinct deformation stages D1-D4 are identified, associated with the development of four planar fabrics S1-S4.

The mineral assemblages of individual samples from the different units forming the studied region are then studied in this structural framework in order to associate the metamorphic and structural evolution of the rocks. This study involves careful optical microscopy, analysis of the samples under an electron microscope as well as the quantitative analysis of the chemical composition of key minerals using the electron microprobe.

This is followed by the calculation of equilibrium phase-diagrams using state-of-the-art methods of thermodynamic modelling (THERMOCALC). The sequence of mineral assemblages inferred from the petrographic analysis, and the observed chemical evolution of the minerals (in particular the chemical zoning of garnet), are then used to constrain the pressure–temperature evolution of the samples.

It is argued that the first deformational and metamorphic event (D1-M1) is characterised by a subduction-related HP-LT gradient. Progressive exhumation from the subduction wedge occurred during D2-M2. The D3-M3 event is characterized by MP-MT assemblages representing a Barrovian-type geothermal gradient that results from the ductile thinning of the orogenic wedge. A new geodynamic model is proposed, in which the Erzgebirge part of the Saxothuringian domain represent a spectacular example of active margin evolution characterized by (i) the formation of an accretionary prism, (ii) the building of the orogenic wedge by accretion of subducted continental crust, and (iii) its extensional collapse.

Part II is a geochronological study that aims to attribute absolute ages to the different stages of the tectono-metamorphic evolution of the orogenic wedge. It is divided in two subsections. The first one uses split-stream laser-ablation ICP-MS analyses of monazite in order to obtain simultaneously data on the age (U-Pb dating) and the trace-element chemical composition of the analysed mineral domains. The second one uses Ar-Ar analyses of potassic white micas (and one biotite) by both the step-heating and the in-situ laser-ablation methods. Both sections contain an impressively large amount of high-quality data.

The “U-Pb monazite” subsection shows that the prograde HP–LT evolution is well constrained to ~350–345 Ma in the lower-grade, outer part of the orogenic wedge, whereas the inner, higher-grade part of the wedge is strongly affected by a younger ~330 Ma event. It is worth highlighting that from a methodological point of view it is inferred that this event is capable of resetting the oldest monazite ages even inside large garnet porphyroblasts, without affecting the apparent REE or textural signature.

The “Ar-Ar mica” subsection argues that the geochronological results correspond to cooling ages and allow to reconstruct the exhumation processes of the orogenic wedge. As with the monazite data, the oldest exhumation ages (340 Ma) are recorded in the phyllites of the outer, lower-grade part of the orogenic wedge. However, in all units most step-heating data range 333–325 Ma, which could be related to the ~330 Ma event inferred from the monazite data, and tentatively attributed to the end of the D3 ductile thinning and exhumation during extension.

In summary, as highlighted in the last section (Concluding summary), this study shows the merits of the chosen multidisciplinary approach to reconstruct the Variscan P–T–t evolution of the Saxothuringian orogenic wedge. It is concluded that the wedge can be subdivided into an older outer low-grade part formed by phyllites, and a younger inner part with high-grade gneisses, separated by a transition zone with medium- to high-grade micaschists. The tectono-metamorphic evolution started between ~350-340 Ma with the D1-D2 stage that resulted from an E-W convergence with a subduction towards the east. It was associated with cold geothermal gradients and an inverted metamorphic zoning, typical for a subduction environment. Subsequent crustal thickening was followed by a D3 partial exhumation, Barrovian metamorphic conditions, and an E-W oriented extensional collapse with ductile thinning, dated probably at ~335 Ma. This deformation is also responsible for the present-day architecture of the units in Erzgebirge, displaying a normal metamorphic zoning. The major reorientation of convergence direction in Variscan belt would be responsible for the intracontinental deformation D4 resulting from N-S orthogonal shortening.

The present dissertation is an excellent work revealing a dynamic young researcher that acquired a large amount of high-quality data using cutting-edge techniques. Nevertheless, I would like to propose a suggestion and ask a question.

1) I believe that the introductory section 3.3 must be aimed at readers unfamiliar with the region. This requires a more careful and ordered introduction and description of the various units, their lithological content and relative position. The description should be closely associated with a figure where all the described units are shown. At present, neither the text, nor Fig. 0.6 serve this goal well and I believe both would merit some re-organisation. In particular, some extra effort is needed on figures 0.5 and 0.6 that set the framework of the thesis (some more concrete comments are proposed below).
2) Tectonic evolution - whereas the evolution is relatively convincingly described in general terms at several places of the manuscript, the figures suggest that some aspects remain unclear. In particular, it would be interesting to comment on how the generally east-dipping foliations in most units (in particular the external phyllite units), acquired during the subduction-related D1-D2, and associated with an inverted metamorphic zoning (e.g. Fig. II.12) turn into the west-dipping orientation apparently typical for the end of D3, and associated with a normal metamorphic zoning (Figs. II.23, II.25)

In summary, the thesis brings a considerable amount of new high-quality structural, petrological, and geochronological data that let Marine Jouvent draw innovative conclusions about the tectonic evolution of the Krušné hory and the Saxothuringian orogenic wedge in the framework of the Variscan orogeny in the Bohemian massif.

In my opinion, the thesis makes a significant contribution to the understanding of the Variscan geological evolution of the Bohemian massif and demonstrates the ability of Marine Jouvent to conduct sound and innovative multidisciplinary research in the domain of Earth Sciences. I believe that the thesis is of excellent quality and can be defended. Only for the sake of perfection I'm pointing out below some typos, questions and suggestions that could improve the work, or the papers yet to be submitted.

Rennes, 7 October 2022

Pavel PITRA
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Somme suggestions and corrections
(coded by page number)

p. 2 "units dominated by metasediments to units dominated by gneisses." – specify the difference gneiss / metasediment (and what about paragneisses that are by definition of metasedimentary origin?)

English...
9 - *The* collisional, vs. It; etc. could be improved
10 - despite; on the core; ...
12 - contact in between these units

10 - hanging-wall / foot-wall => top / bottom ?

20 - Algeria not a mountain belt...
Fig. 0.4 - explain all abbreviations (UGU, LGU, PA, ...)

Section 3.3

21 - Fig. 0.5 - not the best map for the purpose of showing the position of ST-TB-MO... errors with respect to the (already rather cluttered) original (crosses on CBP, missing allo/auto in legend, ...) - to be corrected

Fig. 0.6 - granite vs. granitoid; other inconsistencies (metabasite with and without v, eclogite is also metabasite, so what is the difference? ...)
impossible to tell apart fault and zone of strain localisation (line too similar)
as it stands, the figure is more cluttered, but brings few (if any) useful supplementary information with respect to Fig. 0.1

•• some extra effort needed on these two figures that set the framework of the thesis

23 - "protolith age of the cadomian basement is about 550 Ma" - it must be explained before what is meant by cadomian basement (at present this information is only given later). This should also be clearly marked in the associated figure(s) 0.1 / 0.6

It should be explained clearly what is the "Kateřina-Reitzenhein block" and why is it set apart.

GAU, GEUI, GEUII, ECC, MEU, GPU, PU, ... should all be clearly shown on a map.

Schmädicke et al. (1992) does not seem the correct reference, since none (or nearly so) of these units are introduced in this work (the same error survived the reviews of the JMG paper)

24 - Münchberg klippe in the north-west - meant SW?

46 - strange wording "The calculation for the chloritoid-bearing phyllite MJ44 included Fe^{3+} contents was chosen to obtain the observed assemblage which was not reproduced without inclusion of Fe^{3+} and which also fits with the presence of Fe^{3+} in ilmenite."

59 - "thermal and tectono-architecture of lithological complexes" ??

68 - "micaschists dated in part I" ??

69 - "potential overlap with the samples studied on part I." - potential overlap??, on->in

89 - garnet breakdown is invoked to explain the relatively HREE-enriched patterns of matrix monazite. However, most garnet crystals presented in the thesis show no signs of resorption, which is typically associated with Mn enrichment in the outermost rim of the remaining garnet (cf. Fig. I.7e-f)

≈90 - 350 vs. 348-345 Ma in phyllites: geochronologists, including Kylander-Clark, like highlighting (when reviewing someone else's work) that age uncertainties inherent to the LA-ICP-MS method cannot be lower than c. 2% (specifically when taking into account the long term uncertainty associated with the used standards and the instrument). Clearly, they do not apply this constraint to their own work... Nevertheless, do you believe that the stated uncertainties on individual dates (ages) and the difference between the two ages is significant?

91 - "This age can be interpreted as either locally younger domain" - what is meant by the "locally younger domain"?

119 - "white mica closure temperature, assumed to be 350–425°C" - this is not exactly true - the closure temperature depends on various things, in particular the grain size (possibly not important here due to the small grain size in phyllites), but also on pressure (e.g. Lister & Baldwin 1996 suggest TC higher than 500 °C for phengite under blueschist facies conditions)

127 - Wildenfels massif - never described in the thesis, but referred to occasionally. A brief description of at least the lithological content should be given in the beginning of the thesis (typically e.g. Section 3.3)