Computational Approaches to Understanding Surface Heat Flow, the Metamorphic Rock Record, and Subduction Geodynamics

by

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A dissertation

submitted in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy in Geosciences

Boise State University

November 2021

BOISE STATE UNIVERSITY GRADUATE COLLEGE

DEFENSE COMMITTEE AND FINAL READING APPROVALS

of the dissertation submitted by

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Dissertation Title: Computational Approaches to Understanding Surface Heat Flow, the Metamorphic Rock Record, and Subduction Geodynamics

Date of Final Oral Examination: August 27, 2021

The following individuals read and discussed the dissertation submitted by student Buchanan C. Kerswell, and they evaluated the student's presentation and response to questions during the final oral examination. They found that the student passed the final oral examination.

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DEDICATION

To my mentors, colleagues, friends, and loved ones who take special interests in my life.

This work is yours as much as it is mine.

ACKNOWLEDGMENT

This work was only possible through the efforts of many individuals. My advisor, Dr. Matthew Kohn, deserves special recognition for his contributions, mentorship, and relentless support during the course of my studies. Dr. Taras Gerya and the Geophysical Fluid Dynamics group at the Institut für Geophysik, ETH Zürich, generously offered their high-performance computing resources from the Euler cluster, invaluable instruction, discussion, and support on the numerical modelling methods, and many free meals in Zürich. Additional high-performance computing support from the Borah cluster was provided by the Research Computing Department at Boise State University. Thanks to Dr. D. Hasterok for providing references and guidance on citing the large dataset in chapter three. Special thanks to Dr. Philippe Agard, Dr. Laetitia Le Pourhiet, and graduate students at Sorbonne Université for their incredible expertise and showing me the best of summertime Paris. Thanks to many anonymous reviewers, graduate students, and colleagues for helpful comments on technical aspects of each chapter. My deep appreciation of metamorphic rocks and Alpine geology was formed thanks to outstanding field excursions expertly guided by EFIRE and ZiP graduate students, faculty, and affiliates. Funding for this work was provided by the National Science Foundation grant OIA1545903 awarded to Dr. Matthew Kohn, Dr. Sarah

Penniston-Dorland, and Dr. Maureen Feineman. Datasets and code for reproducing this research are available at https://github.com/buchanankerswell.

ABSTRACT

Pressure-temperature-time (PTt) estimates from high-pressure (HP) metamorphic rocks and global surface heat flow (SHF) rates evidently encode information about pressure-temperature-strain (PTS) fields deep in subduction zones (SZs). Previous work demonstrates the possibility of decoding such geodynamic information by comparing physics-based numerical models with empirical observations of SHF and the metamorphic rock record. However, antithetical interpretations of (non)uniformity with respect to PTS fields are emerging from this line of inquiry. For example, while mechanical coupling depths inverted from SHF are narrowly distributed among SZs, maximum pressure-temperature (PT) conditions inverted from exhumed metamorphic rocks are relatively wide-ranging, and yet also uniformly distributed across pressures up to 2.4 GPa. This dissertation scrutinizes (dis)similarities among SZs inferred from large numerical and empirical datasets by applying a variety of computational techniques. First, coupling depths for 13 modern SZs are predicted after observing coupling in 64 numerical geodynamic simulations. Second, spatial patterns of SHF are assessed in two-dimensions by interpolating thousands of SHF observations near several SZ segments. Third, PTt distributions of over one million markers traced from the previous set of 64 SZ simulations are compared with hundreds of empirical

PTt estimates from the rock record to assess the effects of thermo-kinematic boundary conditions (TKBCs) on deep mechanical processing of rock in SZs. These studies conclude the following. Mechanical coupling between plates is primarily controlled by the upper plate lithospheric thickness, with marginal responses to other TKBCs. SHF interpolations show high variance within and among SZ segments, suggesting local, rather than widespread, continuity of PTS fields deep within SZs. Computed marker recovery rates correlate with TKBCs, and are therefore expected to vary among SZs. Finally, computed PTt distributions of markers show patterns consistent with transient, localized recovery from a cooling, serpentinizing plate interface. Together, this work encourages more antireductionist and diversified views of subduction geodynamics until SHF and PTt datasets can more precisely distinguish (dis)similarities in PTS fields within and among SZs. Strategically scaling PTt and SHF datasets in the future will improve computational precision and confidence, and thus will advance subduction zone research.

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LIST OF ABBREVIATIONS

HP high-pressure

PT pressure-temperature

PTS pressure-temperature-strain

PTt pressure-temperature-time

SHF surface heat flow

SZ subduction zone

TKBC thermo-kinematic boundary condition

LIST OF SYMBOLS

GPa	Gigapascal
K	Kelvin
Z_{UP}	Upper plate thickness
$Z_{coupling}$	Mechanical coupling depth
Φ	Thermal parameter
$\vec{v}_{conv}$	Plate convergence velocity
$^{\circ}C$	Celcius
km	kilometer
t_{slab}	Oceanic plate age

CHAPTER 1:

INTRODUCTION

Keypoints::

- Large proxy datasets are key for inferring information about geodynamics deep in SZs
- Computational approaches leverage large datasets to infer, build, and test models about SZ geodynamics

CHAPTER 2:

EFFECTS OF THERMO-KINETIC BOUNDARY CONDITIONS ON MECHANICAL PLATE COUPLING IN SUBDUCTION ZONES

Keypoints:

- Mechanical coupling responds strongly with changes to upper plate thickness
- Inverting backarc surface heat flow allows coupling depth estimation
- Consistent backarc heat flow would support common coupling depths

CHAPTER 3:

A COMPARISON OF HEAT FLOW INTERPOLATIONS NEAR SUBDUCTION ZONES

Keypoints:

- Inconsistent spatial patterns characterize heat flow near subduction zones
- Investigations favour 2D interpolations over 1D transects
- Developing composite interpolation schema and scaling datasets will improve SZ research

3.1 Abstract

Heat fluxing through the Earth's surface provides indirect observations of pressure-temperature-strain (PTS) fields deep in SZs. Global heat flow databases, therefore, are invaluable for generating and testing belief about SZ geodynamics. Here we argue that investigating surface heat flow (SHF) in two-dimensions by interpolation, rather than

in one-dimension by projection, forms better interpretations about spatial continuity of deep processes. We directly compare interpolations based on the First (spatial continuity) and Third (similarity) Laws of Geography applied to the most updated global heat flow database. We observe inconsistent spatial patterns and of SHF in magnitude and variance near subduction zones, regardless of interpolation method. The implications include discontinuous PTS fields at depth, countering hypotheses of commonly thin upper plate lithospheres and mechanical coupling depths among subduction zones. Strategic scaling of SHF datasets will improve interpolation precision and confidence—leading to better tools for distinguishing differences within and among SZs. We propose new data acquisition and composite interpolation schema as avenues for future SZ research.

REFERENCES