PERGAMON

Journal of Structural Geology 22 (2000) 1523–1525

JOURNAL OF STRUCTURAL GEOLOGY

www.elsevier.nl/locate/jstrugeo

Book review

Exhumation Processes: Normal Faulting, Ductile Flow and Erosion

Edited by Ring, U., Brandon, M.T., Lister, G.S., and Willett, S.D. Geological Society Special Publication no 154. ISBN 1-86239-032-0. List price: 89.00 (UK), $148.00 (US). GSL Price: 39.00 (UK), $65.00 (US).

This book provides an excellent summary of the current state of knowledge regarding extensional and erosional processes that exhume rocks. The editors provide an introductory chapter that summarizes many of the types of processes that have been covered in the literature and they present some of the unanswered problems relating to exhumation. The following papers are individual studies of exhumed terrains from all over the world. These papers are organized into three sections that cover: (1) subduction-related settings; (2) collision-related settings; and (3) divergent or rift-related settings. It is convenient to have such a comprehensive compilation of exhumation research in a single volume. This book will prove to be invaluable for all researchers of exhumed rocks and would make an excellent source book for a graduate seminar on the topic.

In the introductory chapter Ring et al. review and summarize the role of tectonics and the role of erosion in exhuming rocks. Terminology used in exhumation studies is defined before the authors move on to discuss exhumed rocks in settings of oceanic and continental rifting, subduction zones and continental collision zones. The authors conclude that collisional processes are more effective at exhuming rocks than rifting processes. This paper also looks at the individual role of processes such as normal faulting, erosion, and ductile thinning. Existing data suggests that erosion generally exhumes rocks at faster rates than other processes, but that erosion is fastest in areas of active tectonism especially when the climate is wet. The efficiency of normal faulting for exhuming rocks depends on such things as fault angle, rate of extension etc. Ductile thinning is more difficult to quantify. The methods used in exhumation studies, such as thermochronology and thermobarometry are also summarized. A special section is dedicated to the discussion of ultrahigh-pressure rocks, their settings, and mechanisms for their formation and exhumation. Finally the authors present some of the unsolved issues related to exhumation such as: is there a relation between exhumation rate and exhumation process? How well do ultrahigh-pressure rocks preserve a record of their exhumation? What is the relation between ultrahigh-pressure metamorphism and magmatism?

The first section of the book includes five papers that deal with exhumation in subduction settings. Sedlock presents a discussion of the geology of a high-pressure, low-temperature terrain in Baja, Mexico. The conclusion for this area is that extension dominated from 97–30 Ma and normal faulting was the primary mechanism responsible for exhuming the high-pressure rocks. It is not revealed why there is this extension in a compressional subduction complex, though buoyancy is ruled out as a driving mechanism.

Ring and Brandon cover the exhumation within an accretionary wedge in the Franciscan Complex of California. Their method is strain analysis using mineral fibers. The resulting conclusion is that there has been coaxial deformation with solution mass transfer as the primary mechanism to accommodate this deformation. The exhumation was dominantly due to erosion of a forearc high.

In a paper focused on the high-pressure rocks of Crete, Thomson, Stöckhert and Manfred summarize thermobarometric and thermochronologic data of lower plate rocks of a detachment system in a subduction setting. These authors conclude that retreating subduction was responsible for the extension which, coupled with buoyancy, exhumed the high-pressure rocks.

Rawling and Lister describe the tectonic setting of New Caledonia and the complex subduction history of the region. Based on detailed structural analysis they present a model of alternating extension and compression in New Caledonia that would have buried continental and oceanic rocks and then brought them back to the surface.

Wintsch, Byrne and Toriumi worked in northwestern Shikoku, Japan on the structure and metamorphism of the Sanbagawa blueschist belt. They found a strike-parallel stretching lineation with a structurally

PII: S0191-8141(00)00076-6

underlying down-dip lineation. These structural observations together with P-T-t determinations led the authors to the interpretation of oblique northward accretion of Shimanto rocks synchronous with eastward extrusion of the Sanbagawa rocks. The vertical component of this extrusion exhumed these blueschist rocks.

The second section of the book (seven papers) focuses on exhumation in collisional settings. Thermal and mechanical modeling of P-T-t data from the Lepontine region of the central Alps by Schlunegger and Willett addresses the area's exhumation history. Their numerical experiments suggest that for much of the last 40 million years convergence/accretion have been matched by erosional exhumation. The exception to this was the period 25–15 million years ago when tectonic exhumation dominated.

Vanderhaeghe, Burg and Teyssier compare core complex-type settings of the Canadian Cordillera and the Variscides of the French Massif Central. They analyze P-T estimates and sedimentologic/structural data in order to examine the metamorphic and erosional histories of each area. They deduce that erosional exhumation dominated during compression and crustal thickening, but that each area then experienced heating and melting of the deep crust which resulted in collapse of the orogen and tectonic exhumation of migmatitic crustal rocks.

Calvert, Gans and Amato present new $^{40}Ar/^{39}Ar$ data for a region of the Seward Peninsula in Alaska. This region consists of amphibolite and granulite facies gneissic rocks. The thermochronologic data suggest rapid cooling between 90 and 80 Ma. The authors invoke a model of diapiric emplacement for these high-grade rocks. This idea contrasts with previous interpretations of exhumation due to compression or extension, but the author's base their interpretation on a lack of evidence for exhumation-related faults.

Glazner presents model results for numeric experiments relating pluton size, density, initial depth, and erosion rate. The goal of this modeling was to understand how and why dense plutons arrive at the earth's surface. Glazner's results indicate that the rise or fall of these intrusives are sensitive to these physical parameters and that this may explain why exposed mafic intrusives are generally small compared to felsic counterparts.

Miller, Gregory, Gray and Foster contribute new $^{40}Ar/^{39}Ar$ ages for rocks from the Samail ophiolite region of Oman. In this region a tectonic window exposed a high-grade lower plate surrounded by a metamorphosed upper plate that is overlain by the Samail ophiolite. The $^{40}Ar/^{39}Ar$ ages for muscovite come from both the lower plate and the upper plate and fall into three age categories: (1) 119–82 Ma for lower plate rocks; (2) 82–79 Ma for lower plate rocks with lower-pressure mineral assemblages; and (3) 76–70 Ma for upper plate rocks. Though there is a possibility that older ages are the product of excess Ar, the author's favor a model where lower plate rocks were exhumed (119–82 Ma) prior to thrust emplacement of the upper plate nappes (82–79 Ma). High level extensional activity finally exhumed upper and lower plates together (76–70 Ma).

In order to investigate the exhumation history adjacent to the Alpine fault of the Southern Alps, Batt, Kohn, Braun, McDougall and Ireland used U–Pb, Rb–Sr, K–Ar, $^{40}Ar/^{39}Ar$, and fission track methods on pegmatitic rocks to constrain the cooling history of a portion of the Southern Alps. The result was inferred emplacement of the pegmatites at ~68–81 Ma, followed by slow cooling until ~10 Ma when the rate accelerated to ~18°C/Ma until ~5 Ma. At 5 Ma modelling of K-feldspar $^{40}Ar/^{39}Ar$ suggests a reduction in cooling rate until 2 Ma and then an increase to ~350°C/Ma. In order to bring samples to the surface (~0–20°C) at the present there must have been another reduction in cooling rate during the last 1–1.5 Ma. The interpreted cooling path is consistent with an exhumation history resulting from increased plate convergence, surface uplift, and erosion during the last 5–10 Ma.

Garver, Brandon, Roden-Tice and Kamp use fission-track methods on samples from basin settings to examine orogenic exhumation. They summarize how fission tracks are created and some of the considerations that are important when applying fission track methods to detrital grains. The authors then outline four studies in different mountain belts where fission track grain ages were used to estimate timing of exhumation or rates of exhumation. These case studies are given very brief coverage, but they do illustrate, however, that there are different ways that exhumation information can be gleaned from detrital fission track ages and that there are limitations to the method as well.

The third section of this book includes three papers that discuss exhumation in extensional settings. Forster and Lister present details of their mapping of extensional faults and shear zones on the island of Ios in the Cyclades region of Greece. The authors document several phases of extensional deformation followed by a doming of these structures much like many of the detachment faults of the western U.S. Because there have been several generations of extensional faults with anastamosing geometries the resulting map pattern is quite complex. Forster and Lister suggest that the faults on Ios are part of the same system exposed on other Cyclades islands.

Goodwin takes an in-depth look at pseudotachylite from a well-characterized metamorphic core complex (South Mountains) in south-central Arizona. The goal

of Goodwin's work is an understanding of the formation of this particular pseudotachylite and an evaluation of existing models of pseudotachylite formation. Evidence for deformation under greenschist facies conditions and the presence of cataclasite adjacent to pseudotachylite led Goodwin to conclude that pseudotachylite formed above the brittle–ductile transition. Close inspection of the pseudotachylite (TEM and BSE), however, shows that the pseudotachylite was locally overprinted by ductile processes. Goodwin suggests that the reduced grain size in the pseudotachylite region may have localized strain and favored ductile deformation in an otherwise brittle rock. This study also emphasizes rock composition and fabric orientation as important components of pseudotachylite formation.

Foster and John utilize new and existing thermochronologic data from several core complexes in order to gain insight on the timing of initial extension, the slip rates, the paleo-geothermal gradient and the initial depths of detachment faults in the Colorado River extensional corridor of the southern Basin and Range province. Temperature-time plots for $^{40}Ar/^{39}Ar$ and fission track ages for a variety of minerals indicate the onset of extensional exhumation at ~22 Ma. A plot of mineral age versus distance in slip direction also suggests 20–22 Ma for the onset of exhumation. The slope of age versus distance data for low-closure temperature minerals was used to determine slip rates. Resultant slip rates were on the order of 3–9 km/Ma though uncertainties were generally 1–4 km/Ma. Overall these rates are consistent with independent geologic estimates. Apatite-zircon mineral pairs yielded calculations of approximate geothermal gradients at the onset of extension of 17–25°C/km. The authors made a contour map of paleotemperatures at 22 Ma based on fission track and $^{40}Ar/^{39}Ar$ data and by assuming a geothermal gradient they were able to determine the paleodip on the Chemcheui detachment fault. This paper is a comprehensive look at thermochronologic data and many of its uses in an extended terrain.

Overall, this book nicely covers a spectrum of exhumation settings. The papers included also present a variety of techniques that can be used to understand the exhumation process. For anyone with an interest in exhumed rocks, this book should find a place on their bookshelf!

Mary Hubbard
Department of Geology, Kansas State University, Manhattan, KS 66506, USA