Deta Gasser, Emilie Bruand

Tectonic and metamorphic evolution of the Chugach Metamorphic Complex, Alaska: A progress report

Abstract

In this contribution we present a progress report of a research project conducted by the authors in the framework of two PhD theses at the *Department of Earth Sciences* at the *University of Graz*. In this project, the tectonic and metamorphic evolution of a metamorphic complex is studied by combining different petrological and geochronological approaches. First petrological results constrain the metamorphic conditions in the core to 600–700°C / 4–9 kbar and to <550°C in the outer part of the complex. First geochronological results are expected to be obtained in late 2009. The results will be used to formulate and constrain a geodynamic model for the evolution of this metamorphic complex.

1 Introduction

Sediments deposited on the surface of the Earth undergo various processes that change their mineralogical and chemical composition as well as their structure when they are buried and heated up in diverse tectonic settings. These processes are generally summarized under the term *metamorphism* (eg. Bucher and Frey 2002). To observe such metamorphic rocks at the Earth´s surface, they have to be exhumed from depth after a metamorphic event. The exact physical conditions (pressure and temperature) and timing of both metamorphism and exhumation events puzzles geologists since the beginning of geological science and understanding them needs a strong co-operation between different sub-fields of geology such as petrology, tectonics and geochronology (eg. Stüwe 2007).

In this contribution we present a progress report of two PhD theses conducted by the authors at the *Department of Earth Science* at the *University of Graz* under the supervision of Prof. Kurt Stüwe. In this project we try to quantify physical conditions and timing of both metamorphism and exhumation of a naturally occurring metamorphic complex in south-eastern Alaska. The project started in October 2007 and is funded by *FWF project Nr. 19366-N10* for a period of three years.

2 Geological Setting and Project Aims

The *Chugach Metamorphic Complex* (*CMC*) is a ~370 km long and 10–50 km wide zone of metamorphic rocks exposed in the Chugach Mountains in south-eastern Alaska (Hudson and Plafker 1982; Figs. 1 and 2). It developed in meta-sedimentary rocks of the Chugach terrane, which mainly consists of greenschist-facies sandstones, slates and minor basalts of the Valdez group (Nielsen and Zuffa 1982). The Chugach terrane is bordered by the Border Ranges Fault in the north and the Contact fault in the south, which are both long-lived, complex fault zones with compressional and dextral strike-slip components (Pavlis and Roeske 2007). The Chugach terrane is part of a group of similar terranes that have all been subsequently accreted to North America in a subduction zone context (eg. Wrangellia, Chugach, Prince William and Yakutat terranes; Fig. 1). The Yakutat terrane still actively collides with the Prince William and Chugach terranes in the south-eastern corner of Alaska (Berger et al. 2008; Fig. 1). The subduction and collision of this terrane leads to active volcanism in the Wrangellia terrane and to the creation of major topography and intense glaciation in the Chugach-St. Elias Mountains (Figs. 1, 2 and 3a).

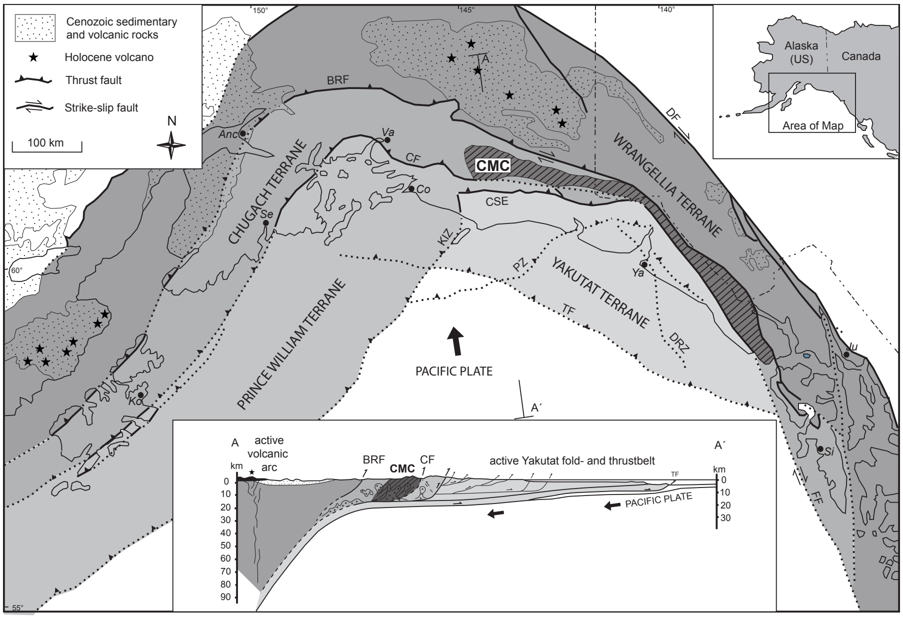

Fig. 1: Tectonic overview map and cross-section of southern Alaska. Abbreviations: *TF* transition fault, *PZ* Pamplona zone, *KIZ* Kayak Island Zone, *DRZ* Dangerous River Zone, *CSE* Chugach St Elias Fault, *CF* Contact Fault, *FF* Fairweather Fault, *BRF* Border Ranges Fault, *DF* Denali Fault.

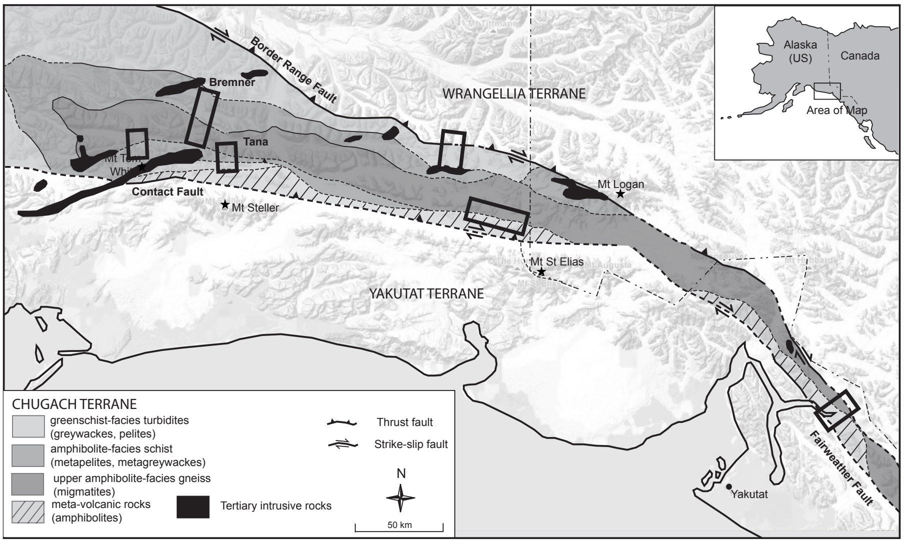

Fig. 2: Geological map of the *Chugach Metamorphic Complex* (*CMC*). Black quadrangles are the field areas visited during field seasons 2008 and 2009.

The *CMC* itself consists of an outer schist zone of lower amphibolite facies grade and an inner gneiss zone of upper amphibolite facies grade including migmatites that are surrounded by lower grade phyllites (Fig. 2). Numerous plutonic bodies from few meter to several kilometer size cross-cut both the schist and gneiss zones. The complex is not symmetric in N-S and E-W direction: it has a much wider schist zone in the north than in the south and gets much narrower from east to west (Fig. 2).

Due to the rugged topography, high glaciation and inaccessibility of the Chugach-St. Elias mountains, the geology of the *CMC* is not well known (Fig. 3a). It was first described by Hudson and Plafker (1982) and was subsequently studied locally by Sisson et al. (1989), Sisson and Pavlis (1993), Pavlis and Sisson (1995), Harris et al. (1996) and Pavlis et al. (2003). Despite these local studies, an integrated understanding of the physical conditions and the exact timing of metamorphism in the *whole* metamorphic complex is lacking. This is insofar important as the *CMC* is (a) located in an unusual geodynamic setting close to an active subduction zone where normally no metamorphism from the type of the *CMC* is expected and (b) has a peculiar asymmetric shape that allows studying the metamorphic conditions in areas of different width of the metamorphic zone.

In order to obtain integrated petrological and geochronological informations over the whole complex, our project uses the following approach. In a first step, extensive field work was carried out in selected key areas covering the most important areas of the whole complex (Fig. 2, black boxes). In a second step, the project is separated in two parts, whereof each part corresponds to one PhD thesis. The first thesis tries to answer the question: "What are the metamorphic pressure and temperature conditions reached in the *CMC* from N to S and from E to W?" by combining modern petrological and geochemical analyses using different techniques (electron microprobe, raman spectrometer, *XRF*) and petrological computer modelling. The second thesis works on the question: "What is the exact timing of heating, peak metamorphism and cooling reached in the *CMC* from N to S and from E to W?" by applying different radiometric decay systems in minerals to date different geological events in the whole complex. In a third part, the information obtained during the previous two steps is combined in order to construct a coherent geodynamic model that describes the tectonic and metamorphic evolution of the *CMC*. From this model, geodynamic parameters such as heating and cooling rates and metamorphic field gradients will be extracted.

In the sections below, we describe the actual state of the project, first results and an outlook.

3 Field work

Apart from few local geological maps, the only regional geological map available from the *CMC* is a reconnaissance map at the scale 1:250 000. In order to get more detailed but still regional information on the *CMC*, seven weeks of field work were conducted in summer 2008 and three weeks of field work in summer 2009. We chose six different areas covering key localities of the *CMC* in order to get information from the western, central, eastern, northern and southern parts of the *CMC* (Fig. 2). The field areas were only accessible by small bush air planes, and during the 6–10 days camps we stayed in tents on glaciers or moraines. We mapped each field area at the scale of 1:10 000 and collected a total of 182 rock samples in the first field season. The *rock types* encountered include (a) low-grade phyllites, sandstones and conglomerates (Fig 3b), (b) greenschists, (c) low-to middle-grade biotite- and andalusite-bearing schists, (d) middle-grade biotite-, garnet-, and/or sillimanite-bearing schists, (e) high-grade biotite-, garnet- and/or sillimanite- and Kfeldspar-bearing (partly migmatitic) gneisses (Fig 3c), (f) high-grade amphibolites, and (g) magmatic rocks such as granite, tonalite and diorite. The *structures* observed are (a) a first, low-grade S1 foliation and corresponding folds in the low-grade phyllites, (b) a second, penetrative, higher-grade flat-lying S2 foliation in the middle-grade schists, and (c) a steeply dipping, pe-

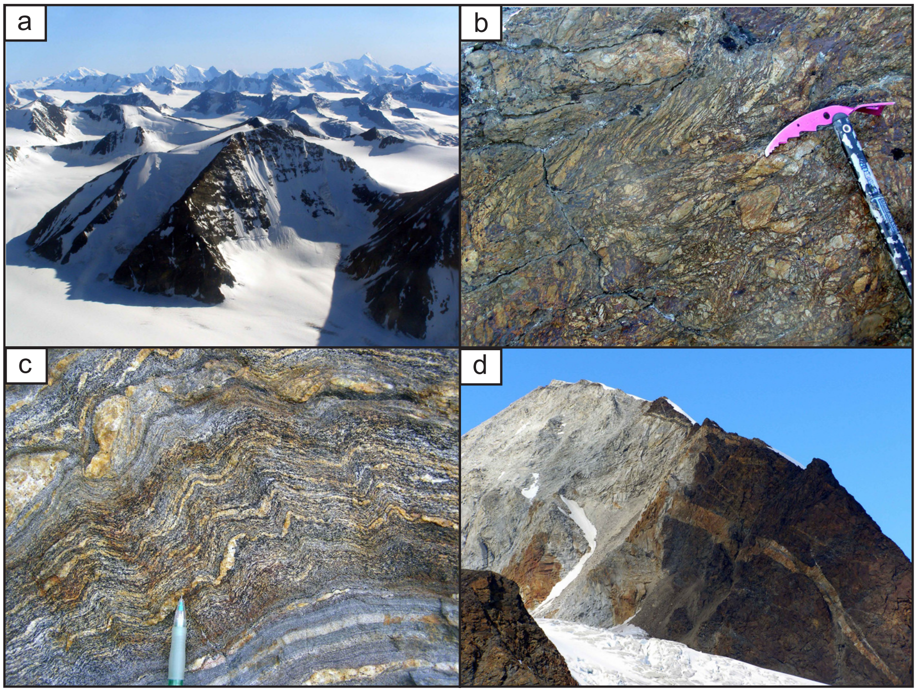

Fig. 3: **(a)** The highly glaciated eastern Chugach mountains where the *CMC* is exposed. **(b)** folded low-grade conglomerate. **(c)** high-grade folded and foliated gneiss **(d)** Plutonic rock (white) intruding sedimentary rock (dark).

netrative, high-grade S3 foliation in the central gneiss zone, that corresponds to a less penetrative steep-dipping S3 foliation in the schist zone. Lineations on all three foliations are E-W striking and horizontal to shallow-dipping. We summarized all information from the field work on sketches, field maps, cross-sections and stereoplots of structural data from each field area.

4 Pressure and temperature conditions of metamorphism

In order to constrain the pressure and temperature of peak metamorphism, the mineralogical assemblages and chemical compositions of mineral phases of each rock sample collected during field work are studied in detail. Thin sections of rock slices are investigated both with optical and electron microscopy in order to identify all mineral phases present and to measure their exact chemical composition. With the help of several experimentally calibrated thermometers and geobarometers, we calculated the temperatures and pressures present at the time of mineral crystallization at the metamorphic peak. First temperature results calculated by a biotite-garnet thermometer (Kaneko and Myiano 2006) are ~600–

650°C in the schist zone and ~650–700°C in the inner gneiss zone (Fig. 4). Temperatures and pressures calculated with the help of an internally consistent thermodynamic data set using the software THERMOCALC (Holland and Powell 1998) give as well values of ~600–650°C and ~6.1–6.4 kbar for the schist zone and 4.4–9.2 kbar for the gneiss zone (Fig. 4). A trend of increasing pressure in the gneiss zone from W to E is observed as well as a slight increase in temperature from the schist to the gneiss zone. Temperature for greenschist facies rocks (phyllites) as well as for the entire *CMC* are calculated with the *RSCM* thermometer (Beyssac et al. 2002) based on the crystallization degree of graphite measured by *Raman spectroscopy*. First results for the phyllites in the northern part of the complex give temperatures in the range of 520–550°C, and 430–450°C for

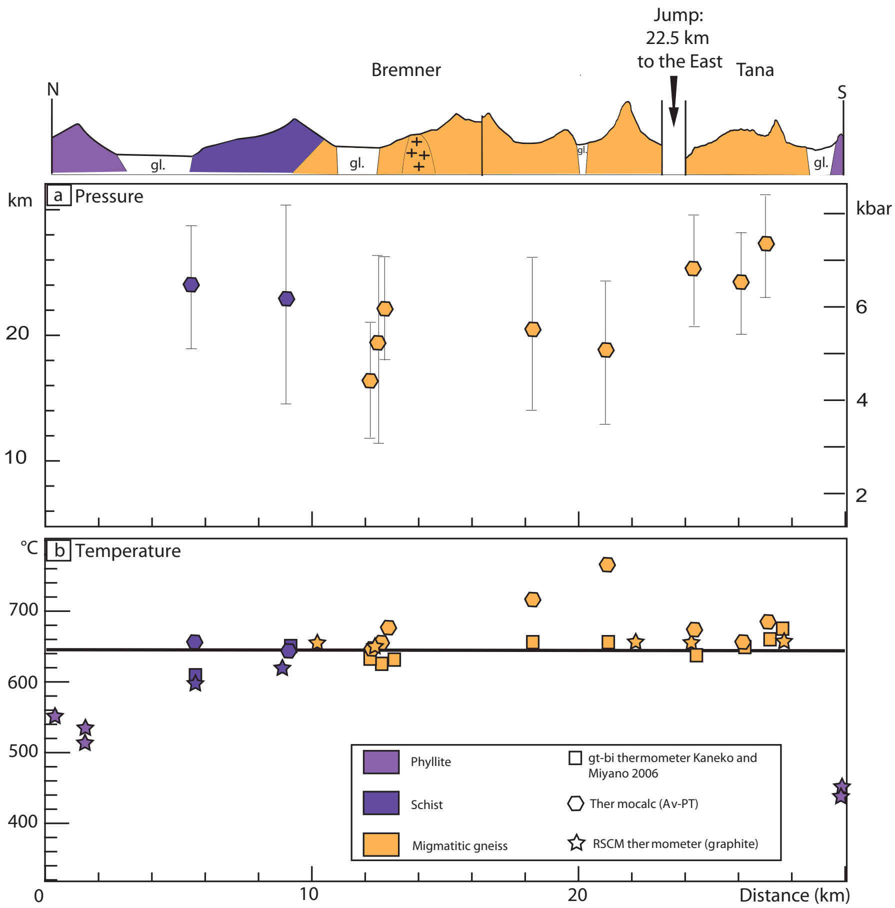

Fig. 4: First pressure-temperature results from Bremner and Tana transects (for location of the transects see Fig. 2). **(a)** Pressures obtained by Thermocalc modelling, **(b)** Temperatures obtained by three independent methods.

the phyllites in the southern part of the complex (Fig. 4). At the moment of writing, those informations are combined on plots covering the whole *CMC* in order to better understand the spatial variations of these variables (eg. Fig. 4), and in order to densify the sample network where necessary. In addition, the chemical composition of the whole rocks is measured in order to study the influence of the composition of the rock on the mineral reactions occurring.

5 Geochronology

In order to constrain the age of peak metamorphism as well as the duration of heating and cooling, a series of radiogenic element decay systems is used to calculate both crystallization as well as cooling ages of certain minerals. In our project we concentrate on the following systems:

U/Th-Pb system in monazite: Monazite is a mineral that generally crystallizes during prograde metamorphism between 550–650°C depending on the bulk chemistry of the sample. Monazite incorporates both *U* and *Th* during crystallization, but no *Pb*. All *Pb* measured in a monazite crystal therefore results from the radiometric decay of *U* and *Th*. With the help of the decay constants and half-lives of theses systems the age of crystallization of the monazite grain can be calculated (eg. Williams et al. 2007).

U/Th-Pb in zircon: This method is based on the same radiometric decay systems as the one described above. The only difference is that the mineral zircon does not grow during prograde metamorphism, but generally during melting of the rocks above about 650–700°C. Its age therefore is in general a good proxy for the timing of peak metamorphism (eg. Rubatto et al. 2001).

Ar-Ar dating of mica: The ^{40}K *isotopes* incorporated in micas such as biotite and muscovite decay to ^{40}Ar after crystallization of the mica. At high temperature, the produced ^{40}Ar diffuses out of the crystal and gets lost. However, below a certain temperature (the closing temperature) the ^{40}Ar gets trapped in the crystal structure of the mineral. The concentration of ^{40}Ar measured in a mica crystal is therefore a good proxy for the time at which the crystal cooled below the closure temperature of the system (eg. Dougall and Harrison 1999).

Obtaining such geochronological ages is time-consuming due to the need of separating the datable minerals from their rock matrix (in the case of zircon and micas) or documenting them in detail in thin sections (in the case of monazites). Zircons and monazites are generally very small (10–100 µm) and not easy to handle. Furthermore, expensive mass spectrometers not available at the *Univer-*

sity of Graz are needed to measure the radiometric element concentrations in the samples. At the stage of writing, 20 *Ar-Ar* samples, 14 zircon samples and ~17 monazite samples are prepared for mass spectrometer analysis. The *Ar-Ar* samples will be measured by the first author at the geochronology laboratory of the *University of Florida* and the zircon samples at the sensitive-ion-microprobe (*SHRIMP*) at the *Australian National University* in Canberra in summer 2009. The monazite samples will be measured at the Electron microprobe facility at *Montan University Leoben* and the *LA-ICPMS* facility at *University of Vienna* in autumn 2009. Most age results are expected to be obtained in late 2009.

6 Outlook

The research project presented in this contribution combines different petrological and geochronological approaches in order to get an integrated interpretation of the tectonic and metamorphic evolution of a naturally occurring metamorphic complex. Half-way through the project, the logistically complex fieldwork, the basic petrological analyses and the mineral separation for geochronology are successfully conducted. In the remaining time, the petrological data will be used to calculate and interpret metamorphic field gradients using phase diagrams, the geochronological ages to calculate and interpret heating and cooling rates. Those informations will help to formulate and constrain geodynamic models to explain the tectonic and metamorphic evolution of the *Chugach Metamorphic Complex*.

References

Berger, A., Spotila, J., Chapman, J., Pavlis, T., Enkelmann, E., Ruppert, N., Buscher, J. (2008) Architecture, kinematics and exhumation of a convergent orogenic wedge: A thermochronological investigation of tectonic-climatic interactions within the central St. Elias orogen, Alaska. Earth and Planetary Science Letters 270, 13–24.

Beyssac, O., Goffé, B., Chopin, C., Rouzaud, J.N. (2002) Raman spectra of carbonaceous material in metasediments: a new geothermometer. Journal of Metamorphic Geology 20, 859–871.

Bucher, K., Frey, M. (2002) Petrogenesis of Metamorphic Rocks. Springer Verlag, 7th edition, 341 p.

McDougall, I., Harrison T.M. (1999) Geochronology and Thermochronology by the 40Ar/39Ar Method. Oxford university press, 2nd edition, 269 p.

Harris, N.R., Sisson, V., Wright, J., Pavlis, T. (1996) Evidence for Eocene mafic underplating during fore-arc intrusive activity, eastern Chugach Mountains, Alaska. Geology 24, 263–266.

Holland, T.J.B., Powell, R. (1998) An internally consistent thermodynamic data set for phases of petrological interest. Journal of Metamorphic Geology 16, 309–343.

Hudson, T., Plafker, G. (1982) Paleogene metamorphism of an accretionary flysch terrane, eastern Gulf of Alaska. Geological Society of America Bulletin 93, 1280–1290.

Kaneko, Y., Myiano, T. (2006) Erratum to “recalibration of mutually consistent garnet-biotite and garnet-cordierite geothermomethers”. Lithos 86, 347.

Nielsen, T.H., Zuffa, G.G. (1982) The Chugach terrane, a Cretaceous trench-fill deposit, southern Alaska. In: Laggett, J.K. (ed) Trench-forearc Geology: Sedimentation and Tectonics on Modern and Active Plate Margins, 213–227.

Pavlis, T.L., Roeske, S.M. (2007) The Border Ranges Fault System, southern Alaska. In: Trop, J.M. et al (eds) Tectonic Growth of a Collisional Continental Margin: Crustal evolution of Southern Alaska. Geological Society of America Special Paper 431, 95–128.

Pavlis, T., Sisson, V. (1995) Structural history of the Chugach metamorphic complex in the Tana River region, eastern Alaska: A record of Eocene ridge subduction. Geological Society of America Bulletin 107, 1333–1355.

Pavlis, T., Sisson, V., Marty, K. (2003) Constrictional flow within the Eocene forearc of southern Alaska: An effect of dextral shear during ridge subduction. In: Pavlis T. et al (eds) Geology of a transpressional orogen developed during ridge-trench interaction along the North Pacific margin. Geological Society of America Special Paper 371, 171–190.

Rubatto, D., Williams, I., Buick, I (2001) Zircon and monazite growth in response to prograde metamorphism in the Reynolds Range, central Australia. Contributions to Mineralogy and Petrology 140, 458–468.

Sisson, V., Hollister, L., Onstott, T. (1989) Petrologic and age constraints on the origin of a low-pressure/high-temperature metamorphic complex, southern Alaska. Journal of Geophysical Research 94, 4392–4410.

Sisson V., Pavlis, T. (1993) Geologic consequences of plate reorganization: An example from the Eocene southern Alaska fore arc. Geology 21, 913–916.

Stüwe, K. (2007) Geodynamics of the Lithosphere. Springer Verlag, 2nd edition, 493 p.

Williams, M., Jercinovic, M., Hetherington C. (2007) Microprobe Monazite Geochronology: Understanding Geologic Processes by integrating composition and chronology. Annual Reviews in Earth and Planetary Sciences 35, 137–175.

Kurzbiographie

Msc. Emilie Bruand, born 1984 (in France). MSc in Earth Sciences at the University of Clermont-Ferrand. Since 2007 PhD student in metamorphic petrology at the Department of Earth Sciences (University of Graz). FWF-granted project under the supervision of Ao.Univ.-Prof. Dr. Kurt Stüwe: *Tectonic and metamorphic evolution of the Chugach Metamorphic Complex, southeastern Alaska.*
Contact: emilie.bruand@uni-graz.at

Msc. Deta Gasser, born 1982 (in Switzerland). MSc in Earth Sciences at the ETH Zürich and University of Trondheim; ETH-medal for outstanding diploma thesis. 2006/07: Research Assistant, Institute of Geology – University of Neuchatel. Since 2007 PhD student in tectonics and geochronology at the Department of Earth Sciences (University of Graz). FWF-granted project under the supervision of Ao.Univ.-Prof. Dr. Kurt Stüwe: *Tectonic and metamorphic evolution of the Chugach Metamorphic Complex, southeastern Alaska.*
Contact: deta.gasser@uni-graz.at