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The new database "Tectonic Boundaries" at the Geological Survey of Austria

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4 Text-Figures, 2 Tables, 1 Appendix

fault database structure
hierarchical classification
nomenclature
nappe boundary
fault system

Contents

Abstract

In order to understand the tectonic evolution of an orogen as complex as the Alps, the knowledge of deformation along major faults is an important key for developing kinematic models. In this contribution, we present a scale-independent database for tectonic boundaries in Austria, with the aim of collecting and structuring available kinematic information in a searchable way. The database contains a hierarchical classification scheme for tectonic boundaries, which sorts (brittle) faults and (ductile) shear zones into groups of local, regional or transregional importance. In addition, the database contains information on location, orientation, timing and kinematics of tectonic boundaries. Here, we focus on the structure of the database and the description of collected parameters. We additionally provide a review of definitions for the different hierarchical levels used in the presented database (e.g. fault, shear zone, fault system, nappe boundary), together with illustrative examples. Kinematic information for each tectonic boundary is temporally sorted into so-called geoevents, which are also defined. Part of the database related to the geological map of Austria at the scale of 1:1,000,000 is published as an openly accessible Web-Application (https://www.geologie.ac.at/services/webapplikationen/multithematische-geologische-karte/) at the website of the Geological Survey of Austria (GBA) and should serve as a common source for structured regional geodynamic knowledge.

Die neue Datenbank „Tektonische Grenzflächen" an der Geologischen Bundesanstalt

Zusammenfassung

Von entscheidender Bedeutung für das Verständnis der tektonischen Entwicklung in einem komplexen Orogen wie den Alpen ist das Wissen um die zeitliche Abfolge von Deformation entlang bedeutender Störungssysteme. Um diese kinematische Information in einer abrufbaren, übersichtlichen und strukturierten Art und Weise zu sammeln und zugänglich zu machen, präsentieren wir hier eine maßstabsunabhängige Datenbank für tektonische Grenzflächen in Österreich. Diese beinhaltet einerseits ein hierarchisches Klassifikationsschema der tektonischen Grenzflächen, bei der Störungen und Scherzonen in Gruppen von lokaler, regionaler bzw. überregionaler Bedeutung zusammengefasst werden, andererseits Informationen über Verortung, Orientierung und Bewegungssinn der jeweiligen Störungen sowie der entsprechende zeitliche Rahmen. Die hier vorliegende Arbeit fokussiert sich vor allem auf die Struktur der Datenbank sowie auf die verwendeten Parameter. Zusätzlich werden hier die Bezeichnungen der unterschiedlichen hierarchischen Klassen (z.B. Störung, Scherzone, Störungssystem, Deckengrenze) definiert und mit Hilfe von Anwendungsbeispielen verdeutlicht. Kinematische Informationen zu den einzelnen tektonischen Strukturen werden zeitlich sogenannten Geoevents zugeordnet, die hier definiert werden. Ein Teil der Datenbank, angewendet auf eine österreichweite geologische Karte im Maßstab 1:1.000.000, steht der Öffentlichkeit als Web-Applikation (https://www.geologie.ac.at/services/webapplikationen/multithematische-geologische-karte/) der Geologischen Bundesanstalt (GBA) zur Verfügung und soll als gemeinsame Basis für strukturiertes regionales geodynamisches Wissen dienen.

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Introduction

Geological investigations in Austria and the Eastern Alps started as early as the 19th century (e.g. SEDGWICK & MURCHISON, 1832; HAUER & JAHN, 1867–1871; SUESS, 1875). Concepts, theories, and methods of geological studies have changed drastically since then. Presently, due to an increasing amount of available data in general and digital data in particular, geological maps as the base of information are replaced gradually by such digital data sets. Systematically used hierarchical classifications are important by-products in the course of the generation of digital data sets. So far, the Geological Survey of Austria has developed classifications for lithological and tectonic units (SCHIEGL et al., 2008, and references therein). While these have been widely adopted, the boundaries of tectonic units, here named tectonic boundaries, have not been treated accordingly.

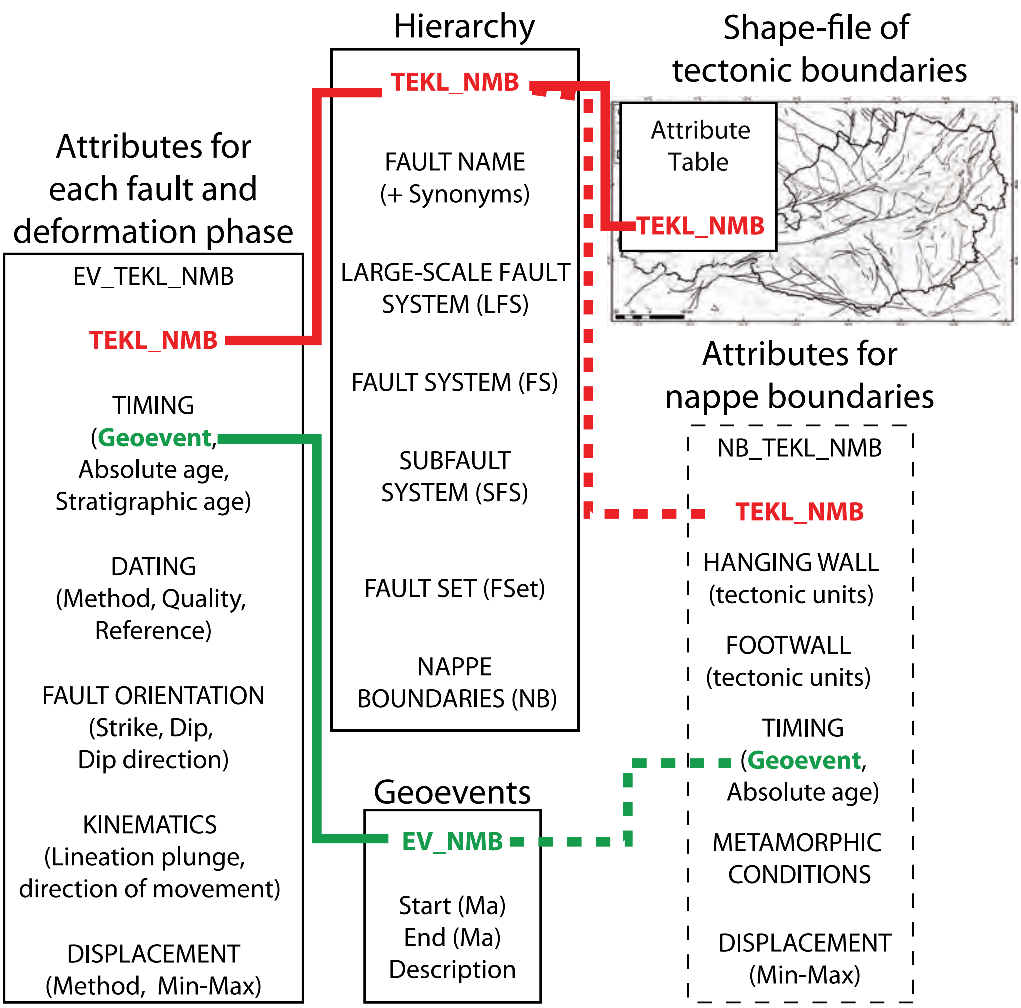
In this contribution, we present the structure of the database for tectonic boundaries developed at the Geological Survey of Austria. For this purpose, we developed a hierarchical classification for (brittle) faults and (ductile) shear zones presented here, similar to the classification scheme used for tectonic units (e.g. nappe systems, nappes). However, solving ambiguities in the naming and definition of tectonic boundaries has been an important task during the generation of the database. For example, the term "fault" ["Störung"] is used in Austria mostly for brittle structures, whereas the term "shear zone" ["Scherzonen"] is used for ductile ones. Special attention is drawn to the definition of "nappe boundaries" ["Deckengrenzen"], focusing on its immediate applicability in the field.

In the first part of this contribution, we propose a hierarchical classification scheme for tectonic boundaries and define the types of tectonic boundaries distinguished in the database. In its second part, we introduce the structure of the database and the associated attribute lists. The tectonic boundaries mentioned in the text are extensively described in the appendix.

Hierarchical classification scheme

A hierarchical ranking between generalized regional structures and precise differentiation of single faults is a necessary condition in order to apply the content of the database to different scales from overview maps to local maps. Therefore, we introduce a hierarchical ranking between tectonic boundaries with respect to their regional importance. In this section, we define the terms that are used to describe the different levels of tectonic boundaries in the database. The structure of the hierarchical classification scheme is shown in Text-Figure 1.

In general, the determining parameters for classifying and ranking tectonic boundaries are their present-day spatial



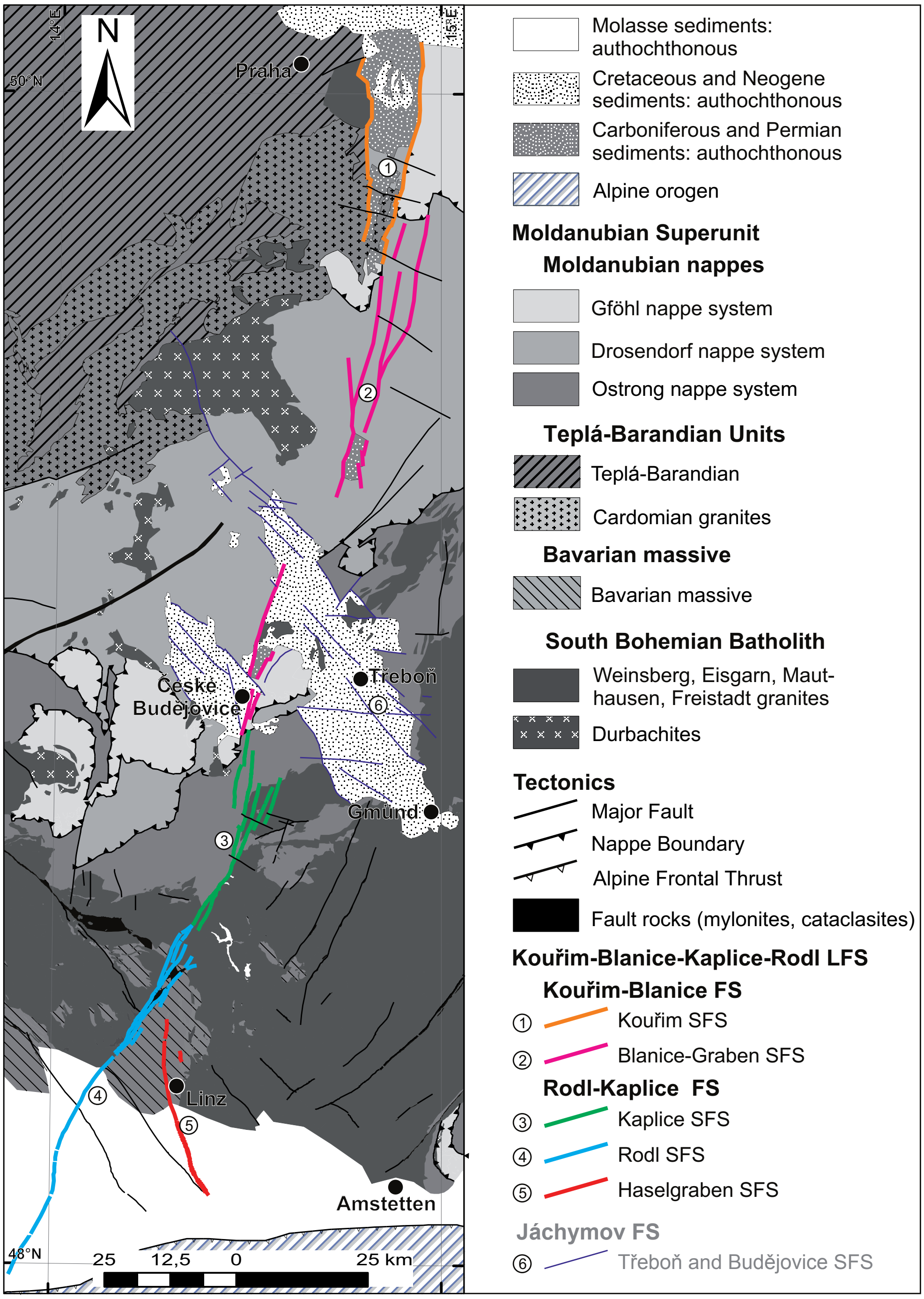
Text-Fig. 1.
Schematic overview of the database structure and the hierarchical classification of tectonic boundaries. The attribute table for nappe boundaries is not implemented, but is shown here with the future links to the already existing database.

relationships, the recent map-view expression at the surface as well as their kinematic linkage during at least one geological event (or geoevent, see section “Geoevents or GeologicEvents“). The assignment of a specific fault to a fault system (see sections “Large-scale Fault System”, “Fault System”, and “Subfault System”) is defined by a common contemporaneous deformation phase with comparable direction of movement. However, single fault segments might be previously deformed during older or reactivated during younger deformation phases. In contrast to tectonic units, where all lower-level tectonic units are related to higher ones (e.g. nappes as part of nappe systems), the complexity of faults made it necessary to keep the hierarchical sorting more flexible. Therefore, faults are assigned to higher hierarchical levels only where a larger kinematic and overall tectonic pattern made it sensible.

Large-scale Fault System (LFS) [Großstörungssystem]

A Large-scale Fault System (LFS) corresponds to the highest level of the classification scheme and describes an alignment of connected and kinematically related fault systems (see chapter “Fault System”) that extend transregionally, typically over hundreds of kilometers. In the hierarchical ranking, fault systems are merged into a LFS if their extent and impact on the orogenic evolution are of transregional importance.

For example, the Kouřim-Blanice-Kaplice-Rodl LFS is ca. 250 km long and approximately NNE–SSW trending (Text-Fig. 2). This LFS is a long-lasting structure within the Moldanubian Superunit that extends from the Kouřim Furrow (Czech Republic) to the Eferding Basin (Austria), where it is partly covered by Miocene sediments, but con-



Text-Fig. 2.
Subdivision of the Kouřim-Blanice-Kaplice-Rodl LFS into the Kouřim-Blanice FS and Rodl-Kaplice FS. The FSs are then subsequently divided into SFSs. For details, see text and Appendix 1 (A1–3). Modified after Chab et al. (2007) and Krenmayr et al. (2006).

tinues as a subsurface feature until the northern Alpine front (BRANDMAYR et al., 1997; WAGNER, 1998; ZACHARIAS & HÜBST, 2012). It has a long and multiphase history, starting with NE–SW trending left-lateral mylonitic deformation during Pennsylvanian and Permian times, predominantly observed in its southern parts (BRANDMAYR et al., 1995; BÜTTNER, 2007; IGLSEDER, 2013). It continues to the North as horst-and-graben structures filled with upper Pennsylvanian to Permian sediments (MARTÍNEK et al., 2001) and associated Permian dykes (KOSLER et al., 2001; VRANA et al., 2005). The Kouřim-Blanice-Kaplice-Rodl LFS is reactivated with left-lateral strike-slip faulting during Cretaceous and Miocene times, as indicated by deformed sedimentary deposits. A detailed description of the Kouřim-Blanice-Kaplice-Rodl LFS is given in Appendix 1 (A1).

Fault System (FS) [Störungssystem]

A Fault System (FS) corresponds to an alignment of connected and kinematically related faults and/or shear zones active during at least one or potentially several geological events and that may contain different deformation styles (modified after NEUENDORF et al., 2005). The faults within a fault system must be related spatially and kinematically at least during one main deformation event.

For example, the Salzach-Ennstal-Mariazell-Puchberg (SEMP) FS (RATSCHBACHER et al., 1991a, b; DECKER et al., 1994; LINZER et al., 2002) is a 400 km long ENE–WSW trending fault system consisting of several faults (Text-Fig. 3). It forms the northern margin of the lateral extrusion wedge of the Central Eastern Alps between the northern margin of the Tauern Window and the Vienna Basin (LINZER et al., 2002). The common main deformation phase is Miocene left-lateral displacement related to the eastward extrusion of the Central Eastern Alps. A detailed description of the Salzach-Ennstal-Mariazell-Puchberg FS is given in Appendix 1 (A2).

Subfault System (SFS) [Teilstörungssystem]

A Subfault System (SFS) is a part of a fault system defined by spatial, temporal or kinematic characteristics that are different from the overall deformation of the related FS during at least one main deformation event. In addition, shear displacement structures containing at least a ductile and a brittle part are hierarchically considered as a SFS. For example, the Brenner SFS consists of the ductile low-angle Brenner Shear Zone and the steeper brittle Brenner Fault (see also sections "Shear Zone" and "Fault").

Using again the Salzach-Ennstal-Mariazell-Puchberg FS as an example, this specific FS is subdivided into smaller subfault systems, the Salzach SFS, the Ennstal SFS, and the Mariazell-Puchberg SFS (Text-Fig. 3). In this case, the subdivision of the SEMP SF is dictated by differences in thermal conditions, observed amount of displacement, strike and deformation partitioning. Along the Salzach SFS, ductile structures are exposed within a narrow fault zone north of the Tauern window and change to brittle-ductile conditions towards the east. However, mostly brittle deformation is observed along the Ennstal SFS and Mariazell-Puchberg SFS. The major difference between the Ennstal SFS and Mariazell-Puchberg SFS is the amount of observed displacement. While displacement along the Ennstal SFS adds up to 60–70 km, displacement of about 40 km along the Mariazell-Puchberg SFS is distributed over a broad zone of splay faults and decreases towards the Vienna Basin (LINZER et al., 2002). A detailed description of the Salzach SFS, the Ennstal SFS, and the Mariazell-Puchberg SFS is given in Appendix 1 (A3).

Fault Set (FSet) [Störungsset]

A Fault Set describes an alignment of parallel trending faults that are kinematically and temporally linked, but where the spacing between the single fault zones exceeds the displacement observed along the fault. It does not correspond to the term "fault zone" ["Störungszone"], which describes (a set of) several closely spaced faults with similar strike values (SCHULZ & FOSSEN, 2008).

This "fault set" category is mostly used for parallel oriented faults in the Northern Calcareous Alps, which are subdivided into five groups striking NNE–SSW, NE–SW, ENE–WSW, E–W, NW–SE, respectively (Text-Fig. 4). The faults within each fault set share the same sequence of deformation events that mostly occurred within late Eocene–Miocene times and which are mostly related to the eastward extrusion of the Eastern Alps (PERESSON & DECKER, 1997a, b; LINZER et al., 2002). A detailed description of the fault sets is given in Appendix 1 (A4).

Shear Zone (SZ) [Scherzone]

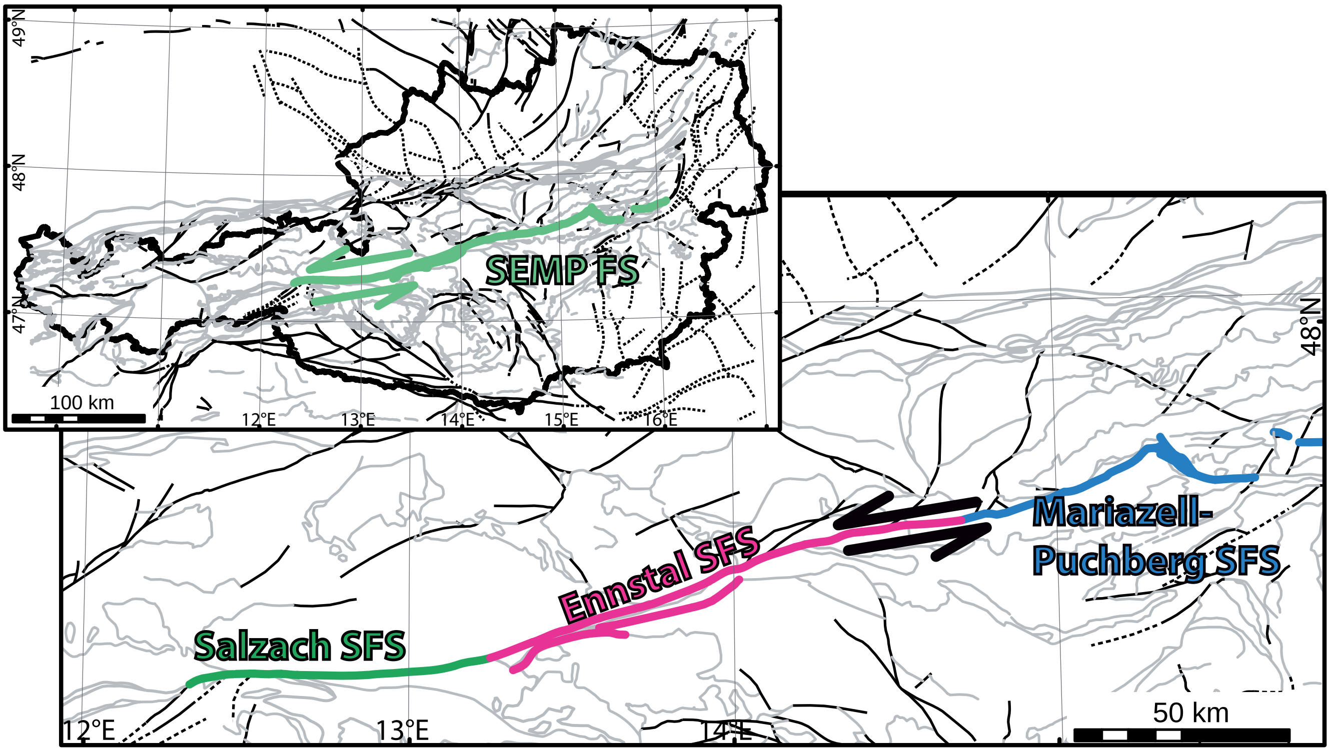
The term shear zone (SZ) is used here as a broad planar zone of relatively intense localized, non-coaxial deformation (PASSCHIER & TROUW, 1996). In our nomenclature, deformation in shear zones is dominated by ductile deformation mechanisms (SCHULTZ & FOSSEN, 2008, and references therein) involving dynamic recrystallization, diffusive mass transfer, dislocation creep and/or grain-boundary sliding. It includes the term "Mylonite Zone" ["Mylonitzone"] describing relatively thick zones of intensive ductile shearing (MAWER, 1986).

The Brenner Shear Zone, for example, is the ductile part of the Brenner SFS. It is an approximately N–S striking, W-dipping low-angle mylonitic normal fault, along which the Tauern Window was exhumed (e.g. FÜGENSCHUH et al., 1997; ROSENBERG & GARCIA, 2011).

Fault (F) [Störung]

The term fault (F) is used here in the sense of a discrete deforming interface separating two rock masses along which one mass has slid past the other (NEUENDORF et al., 2005). In our nomenclature, deformation in faults is dominated by brittle deformation mechanisms (SCHULTZ & FOSSEN, 2008, and references therein) involving fracturing, frictional sliding and/or cataclastic flow, as well as diffusive mass transfer. In the old German-speaking literature, and especially in Austria, both terms "Verwerfung" and "Bruch" were commonly used for faults. Especially the term "Bruch" is still used for brittle normal faults. Here, we follow the concept of SCHULTZ & FOSSEN (2008) and use the term "fault" for a tectonic boundary where mainly brittle deformation is observed.

The brittle Brenner Fault, for example, strikes parallel to the Brenner Shear Zone, but overprints the latter as a steeply west-dipping cataclastic zone (e.g. PREY, 1989; FÜGENSCHUH et al., 1997; ROSENBERG & GARCIA, 2011).



Text-Fig. 3.
Subdivision of the SEMP FS into SFSs (based on Linzer et al., 2002). Upper left inset shows the location of the SEMP FS on the geological overview map of "Rocky Austria" (Schuster et al., 2014). For details, see text. Geographic projection using the Bessel ellipsoid, 1962.

Subfault (SF) [Teilstörung]

A subfault (SF) is a subordinated discrete interface separating two rock masses along which one mass has slid past the other, belonging to an ordinated fault (Neuendorf et al., 2005). At the moment, this term is not used in the database, but will be necessary for the application to local maps at small scales.

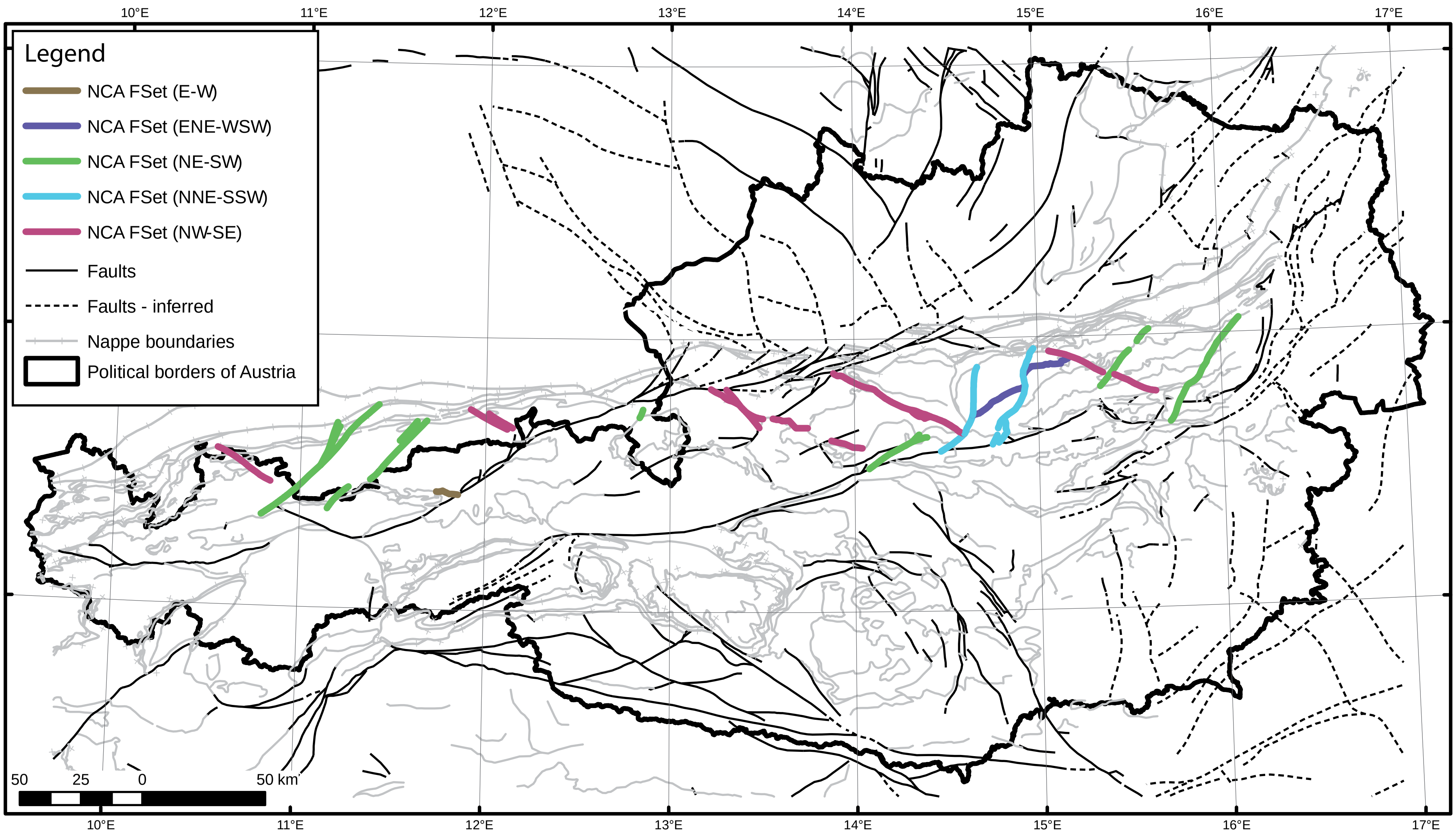
Nappe Boundaries [Deckengrenze]

Nappe boundaries play an important role in Alpine geology. Therefore, they are considered as a special category of tectonic boundary. The term describes a discrete, brittle or ductile, shearing horizon between tectonic units (e.g. nappes, nappe systems). In this definition, "discrete" refers to map scale, since in the field a nappe boundary can correspond to a diffuse tectonic mélange zone with elements of both units that it separates. Usually, it corresponds to the surface accommodating the initial movement at the basis of a nappe, decoupling it from the substratum and subsequently leading to a significant displacement along the dip-slip component. Initially, nappe boundaries dip at both high and low angles, depending on their specific tectonic environment. They might be deformed (tilted, overthrusted, folded) during later deformation events. Nappe boundaries can be active during several geological events and may contain different deformation styles (brittle or ductile). In INSPIRE and GeoSciML data specification, nappe boundaries can be described as ShearDisplacementStructures (CGI, 2017; Schiegl et al., 2008, and references therein). Due to the fact that nappe boundaries are treated as a stand-alone category in the database, a separate attribute table for nappe boundaries will be included in the future (Text-Figs. 1 and 4).

In the case of one nappe (in the hanging wall) being displaced on top of more than one nappe in the footwall, the associated nappe boundaries are separated into segments. For the description of the segments, we propose that they are defined by the tectonic units of the same hierarchical class (subnappe/nappe/nappe system/tectonic subunit/tectonic superunit) that are separated by this specific nappe boundary segment. The footwall unit is named at first position, e.g. "the nappe boundary between the Gstoder and Bundschuh nappes" or "the nappe boundary between the Koralpe-Wölz and Ötztal-Bundschuh nappe systems"). Several segments at the base of a certain nappe can then be jointly described, e.g. "the base of the Bundschuh nappe".

Geoevents or GeologicEvents

Following the definition of INSPIRE and GeoSciML data specifications (CGI, 2017), geoevents (or GeologicEvents) are geological events that lead to a reorganization of geological units. Geoevents must be determined by a certain period and at least one geological process. If necessary, certain boundary conditions for a specific geoevent can be given (CGI, 2017; Schiegl et al., 2008, and references therein). Using this concept, we compiled a list of geoevents (Tab. 1), focusing on the evolution of the Eastern Alps as described by Schuster & Stüwe (2010), Schuster et al. (2014) and Schuster (2015). However, during specific geoevents, the observed deformation history along a certain fault system, and especially along different fault sets in the Northern Calcareous Alps, is more complex than in other parts of Austria (e.g. Linzer et al., 2002). In order to reflect this close sequence of deformation events and provide the opportunity to include as much informa-



Text-Fig. 4.
Tectonic boundaries data set highlighting fault sets in the Northern Calcareous Alps (NCA). The different fault sets have been mainly active during Eocene-Miocene times, but timing of deformation and kinematic information differ from set to set. For details, see text and Appendix 1 (A4). Tectonic boundaries used in the database adopted after the geological overview map of "Rocky Austria" (Schuster et al., 2014) are shown in black lines. Nappe boundaries are shown in light grey. For orientation purposes, the thick black solid line marks the outline of Austria. Geographic projection using the Bessel ellipsoid, 1962.

tion as possible into the database, we subdivided certain geoevents (EV07, EV11, EV12) into subevents, which are labeled with lower case letters (e.g. EV12a to EV12d). In order to expand the list of geoevents given in Table 1, we propose a similar subdivision for existing geoevents and the use of intermediate numbers for newly defined events between already defined events (e.g. EV07.5 between geoevents EV07 and EV08). Those intermediate numbers are also used for geoevents with limited effect on Austrian geology.

We want to stress the fact that deformation along a tectonic boundary (either along an entire FS or just one fault within a FS) may exceed the timing of one single geoevent. These geoevents are not supposed to reflect every detail of Alpine orogeny, but should be treated as helpful, but not rigid instrument to search for certain snapshots in time. For example, deformation along tectonic boundaries sorted to EV12c is related to the lateral extrusion of the Eastern Alps. By sorting into geoevents, searching for faults contributing to this specific process or checking if deformation along a specific fault fits into the overall kinematic pattern at this time is easy to achieve. Additionally, note that the short descriptions of geoevents in Table 1 do not exactly correspond to the time interval given in the international chronostratigraphic chart, but are merely representative of the main geological period where the geoevent occurred.

Structure of the database

The database was generated for tectonic boundaries shown on the geological overview map of Austria at the scale of 1:1,500,000 ("Rocky Austria", SCHUSTER et al., 2014). It can however be adopted for any scale. The tectonic boundaries are treated as line objects in a shapefile (popular geospatial vector data format for GIS software), which is linked via a key number, the so-called TEKL_NMB, to a database containing fault names, general orientation and kinematic information, as well as information about single deformation events, where available. The structure of the database is shown in Text-Figure 1, where red and green lines between the boxes illustrate the links between tables and shapefiles. So far, the database comprises only faults and fault systems that are not considered as nappe boundaries.

Elements of the database

In the following section, we list each table of the database and describe the containing parameters in detail.

AUS_GEOL_EVENTS contains the description of geoevents reflecting the geodynamic history relevant for Austrian geology (SCHUSTER, 2015; Tab. 1). In addition, the geoevent EV13 refers to fault activity during the Quaternary. Faults that are considered seismogenic, either by earthquakes (e.g. LENHARDT et al., 2007) and/or by paleoseismological studies, are related to geoevent EV13a.

AUS_KIN_SENSE lists possible relative movements along a tectonic feature (reverse, thrust, reverse dextral or sinistral, normal, low- or steep-angle normal, dextral or sinistral normal, strike-slip, sinistral, dextral).

TGF_ATTRIBUTE_LIST is the core of the database. It contains characterization of single deformation events observed at faults or fault systems and connects these to geoevents (described in AUS_GEOL_EVENTS, Tab. 1). The attributes contain timing (relative or absolute, depending which one is available), spatial orientation (strike and dip direction), shear sense, orientation of lineation, etc… and are described in chapter "Database attributes" and Table 2. For example, assuming a fault that was formed during the Permian as a ductile sinistral shear zone and later reactivated as normal fault during the lateral extrusion of the Alpine orogenic wedge, this fault would be as two entries in this list, each containing the characteristics of one deformation event.

NB_ATTRIBUTE_LIST is a separated attribute list for nappe boundaries, containing information about the metamorphic conditions and the timing of the movement along a specific nappe boundary. This list will be added in the near future.

FAULTS_SELECTION: List of fault names and hierarchical sorting of faults to fault sets, fault systems, and/or large-scale fault systems. In this table, fault names are linked also to the key number (TEKL_NMB).

TEKL_NMB (key number): Unique number for each fault, shear zone, fault set, and (sub-/large-scale) fault system, linking the database to the shapefile. 1–99 are used for large-scale fault systems, 100–499 for fault systems, 500–999 for subfault systems and fault sets, 1000–9999 for shear zones containing mostly ductile deformation, 10000–49999 for faults containing mostly brittle deformation. In the future, nappe boundaries will be included by using the numbers 50000–99999.

Database attributes

As mentioned above, the attribute list (TGF_ATTRIBUTE_LIST) is the core of the database where not only the orientation of the tectonic features is defined, but also kinematic information as well as the timing and dating method of a specific deformation event (Tab. 2). Importantly, the attribute list is constructed in such a way that most of the attributes are not obligatory, but as much as available data can be stored. One attribute set (one row) per tectonic feature (fault, shear zone or LFS, FS, SFS or fault set) and deformation phase is considered. In the future, a second attribute list for nappe boundaries (NB_ATTRIBUTE_LIST) will be included, specifying characteristics such as hanging and footwall of the nappe boundary, the metamorphic conditions during deformation along the nappe boundary, timing, direction of movement, and, if available, the amount of displacement.

Conclusions

We developed the structure of a database for tectonic boundaries, originally applied to the geological overview map of Austria at the scale of 1:1,500,000 (SCHUSTER et al., 2014). Importantly, the database and its structure presented here are scale-independent and can be adopted for geological overview maps as well as for smaller areas, even at local scale. The database is twofold and includes a hierarchical classification of tectonic boundaries as well as

Geoevent	Short description	Start	End	Description
EV01	Ordovician	485	460	Magmatic event, extensional processes at the northern margin of Gondwana (von Raumer et al., 2013).
EV02	Pre-Variscan	460	380	Ongoing extension at the northern margin of Gondwana and formation of a subduction zone system in the Rheic ocean (Kroner & Romer, 2013).
EV03	Variscan (Devonian–Carboniferous)	380	320	Variscan orogeny: collision of Gondwana and Laurussia (Kroner & Romer, 2013).
EV04	Late Variscan	320	290	Late Variscan orogenic collapse and plate reorganization (Kroner & Romer, 2013); initiation of post-Variscan shear zones in the Moldanubian Superunit and formation of intramontane basins.
EV04.5	Permian–Cretaceous	290	66	Formation of the Central European Basin System (CEBS) and tectonic activitiy therein (Scheck-Wenderoth et al., 2008).
EV05	Permo-Triassic	290	225	Extensional event; lithospheric thinning without correlation to Variscan collapse; intense magmatism and HT/LP-metamorphism with peak at about 270 Ma.
EV06	Triassic–Jurassic	225	170	Tectonic quiescence in continental areas.
EV07	Jurassic	170	150	Subduction and obduction processes in the Neotethys oceanic realm (Schuster, 2015).
EV07a	Jurassic	170	160	Intraoceanic subduction of the Adriatic plate below the European plate in the Neotethys ocean.
EV07b	Jurassic	160	150	Obduction of oceanic lithosphere onto the margin of the “Adriatic spur” (Frisch et al., 2010).
EV07.5	Jurassic-Cretaceous	170	90	Formation of passive continental margins and spreading in the Penninic ocean (Piedmont-Liguria and Valais oceans) (Schmid et al., 2004).
EV08	Upper Jurassic	150	135	Lithosphere-scale transcurrent movements; separation of the “Adriatic spur” in a northern and southern part.
EV09	Eo-Alpine (Early Cretaceous and Cenomanian)	135	92	Start of southeast-vergent Alpine subduction and formation of the Alpine orogenic wedge (AOW).
EV10	Eo-Alpine (Late Cretaceous)	92	66	Ongoing southeast-vergent Alpine subduction and exhumation of the Eo-Alpine metamorphic belt.
EV11	Neo-Alpine (Paleogene)	66	23	Subduction of the Penninic ocean; subsequent continental subduction and collision of Adriatic and European plate in the AOW.
EV11a	Neo-Alpine (Paleogene)	66	45	Southeast-vergent subduction of the Penninic ocean; formation of an accretionary wedge.
EV11b	Neo-Alpine (Paleogene)	45	23	Continental subduction and subsequent collision between Adriatic and European plate in the AOW; exhumation of Neo-Alpine HP-rocks.
EV12	Neo-Alpine (Neogene)	23	2.6	N–S-directed shortening and E–W-directed “lateral extrusion” in the AOW (Ratschbacher et al., 1991a, b); mostly brittle deformation in the Austroalpine units.
EV12a	Neo-Alpine (Neogene)	23	17.2	N–S shortening in the AOW.
EV12b	Neo-Alpine (Neogene)	17.2	16.4	NE–SW shortening in the AOW; transition from thrusting to extrusion.
EV12c	Neo-Alpine (Neogene)	16.4	9	Lateral E–W extrusion in the AOW.
EV12d	Neo-Alpine (Neogene)	9	2.6	E–W shortening and N–S extension in the AOW.
EV13	Neo-Alpine (Quaternary)	2.6	0	Quaternary activity of faults.
EV13a	Seismogenic (Quaternary)	0.1	0	Seismogenic faults or faults with proven paleoseismological events.

Tab. 1.
Definition of geoevents relevant for Austria based on Schuster & Stüwe (2010), Schuster et al. (2014), and Schuster (2015). Ages in the columns “Start” and “End” are given in million years before present. CEBS – Central European Basin System, AOW – Alpine orogenic wedge. For details, see chapter “Geoevents or GeologicEvents“.

a compilation of related kinematic information. The classification includes definitions for the used hierarchical terms (Section 2). Special attention is drawn to the definition of nappe boundaries, focusing on its immediate applicability in the field. Kinematic information for each tectonic feature is sorted into so-called “Geoevents” (Tab. 1) that were defined following Schuster & Stüwe (2010), Schuster et al. (2014), Kroner & Romer (2013), and Schuster (2015). In addition, we have shown that a hierarchical classification of faults and shear zones is possible, even though the used classification scheme must provide the flexibility to skip certain (or all) hierarchical levels.

The application of the database to the multi-thematic geological map of Austria at the scale of 1:1,000,000 is available for public access via Web-Application at the Geological Survey of Austria and should serve as a common source for structured regional geodynamic knowledge. Definitions compiled for large-scale fault systems (LFS), fault systems (FS), subfault systems (SFS), and fault sets used in the Web-Application are available in the Online Thesaurus of the Geological Survey of Austria (https://www.geologie.ac.at/services/thesaurus).

Attribute	Description	Options
TEKL_NMB	**Unique number for each fault, shear zone, Fset, SFS, FS or LFS.**	**See FAULT_SELECTION.**
GEOEV_NMB	Described deformation phase is sorted to a specific geoevent.	EV1–EV13a (see Table 1).
EV_U_AGE_ABS	Upper numeric age in Ma before present.	Numbers required.
EV_L_AGE_ABS	Lower numeric age in Ma before present.	Numbers required.
EV_U_AGE_STR	Upper stratigraphic age control.	Stratigraphic chart of Austria.
EV_L_AGE_STR	Lower stratigraphic age control.	Stratigraphic chart of Austria.
EV_DAT	Dating of deformation via absolute values or relative chronology.	Absolute/relative.
EV_DAT_MET	Dating method used to obtain timing of deformation.	Sedimentary deposits; correlation; U-Pb; Sm-Nd, Lu-Hf; Rh-Os; Ar-Ar; K-Ar, Rb-Sr; FT; U-Th-He; cosmogenic; lichenometry, dendrochronology, radiocarbon.
EV_DAT_COMM	Comment on the dating method.	Text specifing the dating method.
EV_QUAL	Quality of the data.	Proofed; proofed underground; interpreted from seismics; interpreted from boreholes; interpreted from models; interpreted from lineaments; not proofed; suspected.
EV_REF	**Reference of the given dating data above.**	**First Author_Year.**
DEF_TYPE	Deformation type.	Brittle, ductile, brittle-ductile.
OR_STR	**Fault orientation (strike).**	**N–S, NNE–SSW, NE–SW, ENE–WSW, E–W, WNW–ESE, NW–SE, NNW–SSE.**
OR_DIPDIR	**Fault orientation (dip direction).**	**N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, SW, WSW, W, WNW, NW, NNW.**
OR_DIP	**Fault orientation (dip).**	**Vertical (90°–85°), steep (85°–60°), modest (60°–30°), low-angle (30°–5°), horizontal (5°–0°).**
KIN_VALUE	Plunge of the kinematic lineation (slickenline, stretching lineation).	Subhorizontal, N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, SW, WSW, W, WNW, NW, NNW.
KIN_DIREC	Movement direction of the hanging wall.	Top-to-N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, SW, WSW, W, WNW, NW, NNW.
KIN_SENSE	Relative block movement (sense of shear).	See section “AUS_KIN_SENSE”.
KIN_DISPL_TYPE	How was fault offset determined? Options are only suggestions; if major units or tectonic features are displaced, they can be included here.	Paleogeographics; crosscutting; field/micro fabrics; displacement on maps; boreholes/seismics; paleoseismicity; seismicity; not sure.
KIN_DISPL_MIN	Minimum displacement in km.	Numbers required.
KIN_DISPL_MAX	Maximum displacement in km.	Numbers required.
COMMENT	General comment, additional references.	Text.

Tab. 2.
List of attributes to describe one deformation event along one specific tectonic feature. Attributes highlighted in bold are mandatory. For more information, see chapter “Structure of the database”.

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Appendix 1.

Description of tectonic boundaries from the geological database mentioned in the publication.

A1. Large scale Fault Systems (LFS)

Kouřim-Blanice-Kaplice-Rodl LFS	BRANDMAYR et al. (1995, 1997); BÜTTNER (2007); IGLSEDER (2013); KOŚLER et al. (2001); MARTÍNEK et al. (2001); VRANA et al. (2005); WAGNER (1998); ZACHARIAS & HÜBST (2012)	This ca. 250 km long, approximately NNE–SSW (and partly NE–SW) trending LFS extends from the Kouřim Furrow, following the Blanice Furrow, the basins of Třeboň and České Budějovice via Kaplice (CZE), the Große Rodl Valley to Gramastetten and the Eferding Basin, where it is partly covered by Miocene sediments, but continues in the basin subsurface (BRANDMAYR et al., 1997; WAGNER, 1998; ZACHARIAS & HÜBST, 2012). It includes the Kouřim-Blanice and Rodl-Kaplice FSs and has a long-lasting and multiphase history. Parallel trending structures and conjugated shear zones and faults are correlated with this LFS (e.g. Haselgraben SFS). Proofs of NE–SW trending left-lateral ductile, mylonitic shear zones during late Carboniferous and Permian times are predominantly observed in the southern parts (BRANDMAYR et al., 1995; BÜTTNER, 2007; IGLSEDER, 2013). To the north, it continues as horst-and-graben structures filled with upper Carboniferous to Permian sediments (MARTÍNEK et al., 2001) and associated Permian dykes (KOŚLER et al., 2001; VRANA et al., 2005). The deformation continues with left-lateral strike-slip faulting during Cretaceous and Miocene times, indicated by sediment deposits.

A2. Fault Systems (FS)

Rodl-Kaplice FS	BRANDMAYR et al. (1995); BÜTTNER (2007); FUCHS & THIELE (1968); IGLSEDER (2013); WAGNER (1998)	This ca. 90 km long, approximately NNE–SSW trending FS extends from Kaplice (CZE), following the valley of the Große Rodl to Gramastetten and the basin of Eferding, where it is partly covered by Miocene sediments, but continues in the basin subsurface (BRANDMAYR et al., 1997; WAGNER, 1998). It includes the Rodl and Haselgraben SFSs and shows a long-lasting and multiphase history. Proofs of NE–SW trending left-lateral strike-slip ductile, mylonitic shear zones during late Carboniferous and Permian times are observed. The deformation continues with left-lateral strike-slip faulting during Cretaceous and Miocene times, indicated by sediment deposits. Displacement up to 35 km are suggested (BRANDMAYR et al., 1995; BÜTTNER, 2007; FUCHS & THIELE, 1968; IGLSEDER, 2013; WAGNER, 1998).
Salzach-Ennstal-Mariazell-Puchberg FS	LINZER et al. (2002)	A WSW–ENE striking FS of approximately 400 km in length, running from the western Tauern Window to the Vienna Basin and up to 70 km of sinistral offset. The deformation holds a gradient from ductile (W) to brittle ductile (central region) to brittle (E). The Salzach-Ennstal-Mariazell-Puchberg FS is composed from West to East from the Salzach (brittle northern edge of the Tauern Window), the Ennstal (southern edge of the northern Calcareous Alps) and the Mariazell-Puchberg SFSs (LINZER et al., 2002).

A3. Subfault Systems (SFS)

Ennstal SFS	LINZER et al. (2002)	This approximately E–W trending SFS reaches from the "Wagrein Tertiary" Basin to the Hieflau Basin. It is the middle segment of the Salzach-Ennstal-Mariazell-Puchberg FS. Miocene left-lateral displacement along the Ennstal SFS amounts to 60–70 km, being the highest displacement observed in the Salzach-Ennstal-Mariazell-Puchberg FS (LINZER, et al., 2002).
Haselgraben SFS	IGLSEDER (2013, 2014a, b)	This ca. 15 km long, N–S trending SFS extends from Hellmondsödt, following the Haselgraben Valley to Linz. It is part of the Kaplice-Rodl FS and includes ductile parallel trending shear zones with left-lateral kinematics active during the late Variscan event (EV04). In analogy to the Rodl SFS a continuation of brittle left-lateral movement during Cretaceous and Miocene times is suggested (IGLSEDER, 2013, 2014a, b).
Mariazell-Puchberg SFS	LINZER et al. (2002)	This approximately E–W trending SFS extends from the Hieflau Basin to the Vienna Basin. It is the eastern segment of the Salzach-Ennstal-Mariazell-Puchberg left-lateral displacement of about 40 km along the Mariazell-Puchberg SFS is distributed over a broad zone of splay faults and decreases towards the Vienna Basin (LINZER, et al., 2002).
Rodl SFS	BRANDMAYR et al. (1995); BÜTTNER (2007); FUCHS & THIELE (1968); IGLSEDER (2013); WAGNER (1998)	This ca. 55 km long, approximately NNE–SSW trending SFS extends from Rybník (Dolní Dvořiště) (CZE), following the valley of the Große Rodl to Gramastetten and the basin of Eferding, where it is partly covered by Miocene sediments, but continues in the basin subsurface (BRANDMAYR et al., 1997; WAGNER, 1998). It includes partly parallel trending shear zones and faults and shows a long-lasting and multiphase history. Proofs of NE–SW trending left-lateral strike-slip ductile, mylonitic shear zones during late Carboniferous and Permian times are observed (BRANDMAYR et al., 1995; BÜTTNER, 2007; IGLSEDER, 2013). The deformation continued with left-lateral strike-slip faulting during Cretaceous and Miocene times, indicated by sediment deposits. Displacement up to 35 km are suggested (FUCHS & THIELE, 1968).
Salzach SFS	LINZER et al. (2002)	This SFS runs at the northern margin of the Tauern Window and forms the western part of the Salzach-Ennstal-Mariazell-Puchberg FS. Ductile left-lateral strike-slip deformation structures are exposed along a 50 to 100 m-wide fault zone north of the Tauern Window and change to brittle-ductile conditions towards the East.

A4. Fault Sets (FSets)

Northern Calcareous Alps (NCA) FSet (NW–SE)	Peresson & Decker (1997a, b)	NW–SE trending faults within the Northern Calcareous Alps include, but are not restricted to: Gosaukamm Fault, Gosausee Fault, Hochwart Fault, Lofer Fault, Schanitzsattel Fault, Windischgarsten Fault, Wolfgangsee Fault. These faults formed in the late Eocene–Oligocene as right-lateral strike-slip faults. During Pannonian E–W compression, these NW–SE striking faults were reactivated as left-lateral strike-slip faults (Peresson & Decker, 1997a, b).
NCA FSet (NE–SW)	Peresson & Decker (1997a, b)	NE–SW trending faults within the Northern Calcareous Alps include, but are not restricted to: Annaberg Fault, Isar Fault, Leutasch Fault, Loisach Fault, Pernitz Fault, Phyrn Fault, Saalach Fault, Salzsteig Fault, and Torscharten Fault. These faults formed during Middle Miocene times as left-lateral strike-slip faults. During Pannonian E–W compression, these NE–SW striking faults were reactivated as right-lateral strike-slip faults (Peresson & Decker, 1997a, b).
NCA FSet (NNE–SSW)	Peresson & Decker (1997a, b)	NNE–SSW trending faults within the Northern Calcareous Alps include, but are not restricted to: Göstling Fault, Leonsberg Fault, Untersalzachtal Fault, Weyer Fault. Even though they may have been active during Oligocene and Miocene times as strike-slip faults, the main deformation phase of this FSet occurred during Middle Miocene E–W extension, where the faults had normal movement (Peresson & Decker, 1997a, b).
NCA FSet (E–W)	Peresson & Decker (1997a, b)	E–W trending faults within the Northern Calcareous Alps include, but are not restricted to: Ebner Fault, Königsberg Fault, and Spullersee Fault. These faults probably formed during Oligocene–Early Miocene times as reverse faults. During post-Miocene N–S extension they might have been reactivated as normal faults (Peresson & Decker, 1997a, b).
NCA FSet (ENE–WSW)	Peresson & Decker (1997a, b)	It is a fault set of ENE–WSW trending faults within the Northern Calcareous Alps (NCA). These faults probably formed during Middle Miocene times as left-lateral strike-slip faults. During Pannonian E–W compression, they might have been reactivated as right-lateral strike-slip faults (Peresson & Decker, 1997a, b).