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„3D seismic interpretation of Early Miocene growth strata in
the Northern Vienna Basin“

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1. INTRODUCTION

1.1. Assignment of tasks

This Master's thesis is focused on the evolution of Early Miocene growth strata overlying the top flysch horizon in the Northern Vienna Basin (see Fig. 1) via seismic interpretation. The software Petrel 2012.1 (made by Schlumberger) is used to map distinct stratigraphic horizons and faults within a 3D seismic volume provided by OMV to gain better understanding of tectonic and sedimentological processes concerning the area of interest to the east of Mistelbach. The mapping is focused on a fault block, which is known as the footwall of the Steinberg Fault. This block is delimited by the Steinberg Fault in the south-east and by another fault system in the north-west (here named: Fault System West). A further focus is on fold-thrust structures formed during Early Miocene out-of-sequence-thrusting of flysch units. The chronology of these deformations should be interpreted by growth strata in the sediment basin. The various fault systems and folds should be investigated and compared to each other. Special attention should be paid to the geometries of growth strata to draw conclusions on the kinematics and timing of deformation. It is attempt to determine ages and temporal succession of thrusts from growth strata analysis.

1.2. Geography

The 3D seismic volume was acquired in the Austrian part of the Northern Vienna Basin to the east of Mistelbach. Two seismic cubes were provided by OMV (Philipp Strauss) predominantly overlapping each other in the area of interest. This Master's thesis is focused on the second cube, which is considerably bigger than the first. The better quality of seismic reflection data made it easier to map the various horizons and faults. On the Earth's surface the resulting rectangle reaches from Gawainstal and Spannberg in the south-west to the border of Austria with Schrattenberg near Poysdorf and Rabensburg in the north-east (see Fig. 1). This area amounts to approximately 420 km² with a recording time of almost 5,000 milliseconds (ms) two-way traveltime (TWT).



Fig. 1: Geological map with place names of the investigated area. The black rectangle (28 km x 15 km) marks the border of the seismic volume. The polygon inside represents the border of the mapped flysch horizon. MGI Austria GK M34 coordinate system including a false easting of 500,000.

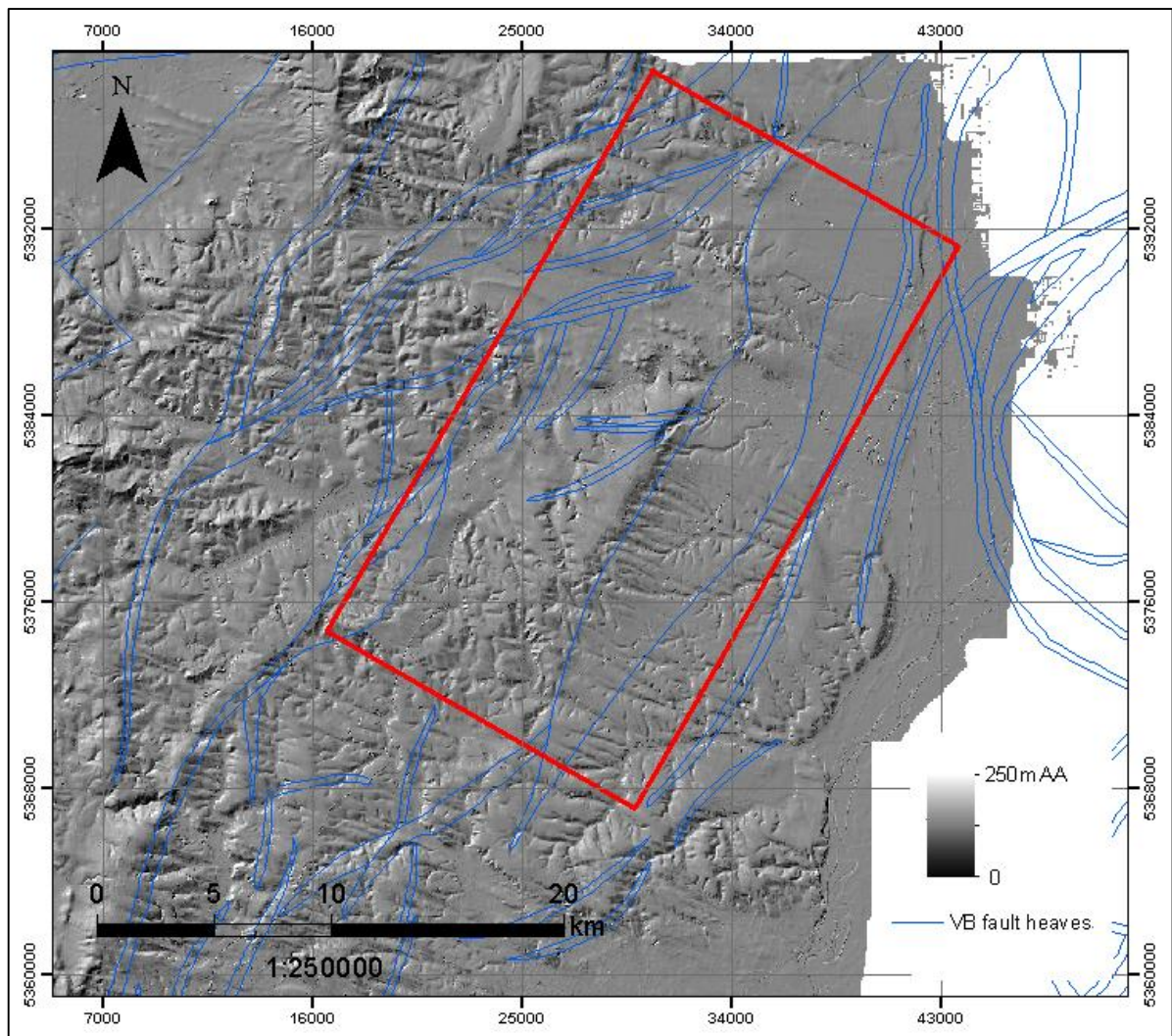


Fig. 2: Digital evaluation model (DEM) of the investigated area with fault heaves (blue). The red rectangle (28 km x 15 km) marks the border of the seismic volume. MGI Austria GK M34 coordinate system.

1.3. Geological overview

From a geological point of view, the whole investigated area with its seismic volume belongs to the Austrian part of the Northern Vienna Basin (Fig. 3).

The ages of the sediments of the Vienna Basin range from Lower Miocene until Postglacial. That equals about 20 million years. The lithological content varies from coarse coastal sediment and river mouths to fine-grained sediments from inside the basin and the formation of limestone in shallow water.



Fig. 3: European paleotectonic map during Middle Miocene, Badenian (13 Ma). Red rectangle marks the investigated area. Modified after Blakey (2011).

A lot of research and documentation was done within the last two centuries concerning the Vienna Basin. A concise description of the research and exploration history of the Vienna Basin is provided by Wessely (2006). Compilations of research results are available from many authors, such as Schaffer (1951), Küpper (1965), Papp (1968), Brix (1970), Thenius (1974), Tollmann (1985) and Brix & Schultz (1993). When seismic surveying became an important element of study, exploration geophysicists like Kröll, Schimunek, Ströbl, Steiger or Winkler provided important novel data from the Vienna Basin (Wessely, 2006). With newly acquired knowledge, a reinterpretation of the structural basin development became necessary. Important results come from, e.g., Royden (1985), Wessely (1988) and Decker & Peresson (1996). Certain sedimentological processes were adapted due to the method of sequence stratigraphy by, e.g., Kreuzer (1986), Weissenböck (1996), Kováč et al. (2001, 2004) and Strauss et al. (2006).

Sequences correlate with a complete cycle of global or local sea-level changes (transgression and regression) bordered by erosional unconformities (Van Wagoner, et al., 1990). Such sequences also represent the different geological units of the Miocene in the Vienna Basin.

They can be subdivided into system tracts such as transgressive system tract, highstand system tract and lowstand system tract which are separated by unconformities (Kreuzer, 1993). A classification of the Miocene strata in the Vienna Basin was provided by Pogacsas & Seifert (1991) and for the Badenian by Kreuzer (1990a) and Kreuzer (1990b).

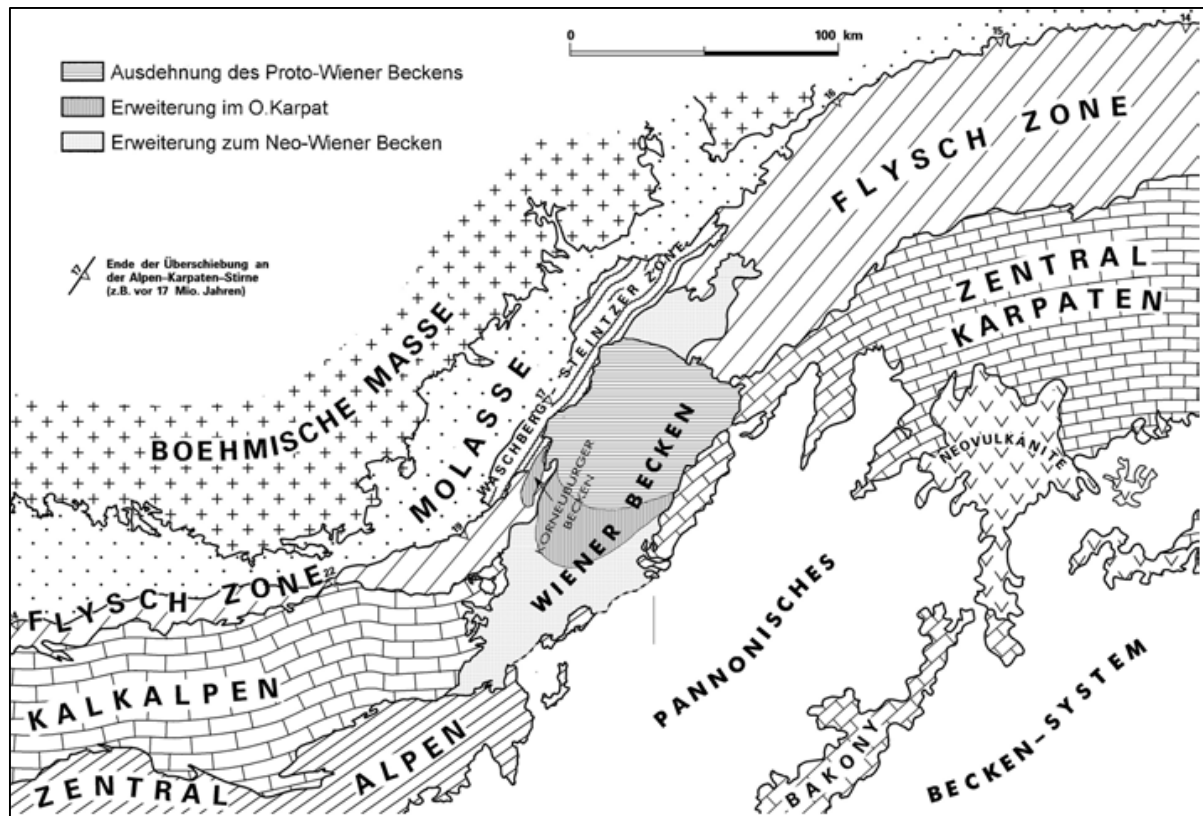


Fig. 4: Location of the Vienna Basin (Wiener Becken) in the Alpine-Carpathian thrust zone. From Wessely (2000).

The Austrian part of the Vienna Basin is located in the east of the country with a noticeable low ground surface. It reaches from about 140 meters (m) at the mouth of the river March to 318 m on the Steinberg at Zistersdorf and more than 380 m at Gloggnitz in the Southern Vienna Basin.

Important outcrops of Miocene lithostratigraphic units are located in the northern, hilly area of the eastern Weinviertel as well as at the basin margins. A good example thereof is the Steinberg with its erosion-resistant plate of Leithakalk and the bordering Steinberg Fault in the east (Wessely, 2006).

The size of the whole sedimentary basin amounts to about 5,000 square kilometers (km²) and is filled by up to 6,000 m thick Miocene sediments. It overlies the Alpine-Carpathian fold and thrust belt.

Tectonics, subsidence and sedimentation can be divided into two different stages (see Fig. 5). The earlier one in the Lower Miocene describes the formation of a wedge-top basin during Alpine-Carpathian thrusting (e.g., Seifert, 1992; Peresson & Decker, 1997;

Hölzel, et al., 2010). The subsequent Middle to Upper Miocene stage is related to a pull-apart basin formation caused by the sinistral Vienna Basin Transfer Fault (Royden, 1985; Ratschbacher, et al., 1991; Peresson & Decker, 1997). Sedimentation processes as well as basin subsidence ended in the Upper Miocene due to a compressional phase (Decker & Peresson, 1996).

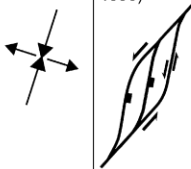
Time of Tops (Ma)	Epoche	Classical Stages	Central Paratethys Stages	Reference horizons (SB1)	Central Vienna Basin			Regional stress field	
					Unit - Name	Lithology	Environment		
	Upper Miocene	Tortonian	Pannonian						
7.8								↔	Compressive (Peresson & Decker, 1997)
10								↕	
10.5								↔	Decker, 1996; Fodor, 1995
11.6	Middle Miocene	Serravallian	Upper Sarmatian						
12.2			Lower Sarmatian						
12.7		Langhian	Bulimina-Rotalia Zone						
13.6			Spiroplectamina Zone						
14.2			Upper Lagenidae Zone						
14.5			Lower Lagenidae Zone						
16.1		Burdigalian	Aderklaa Conglomerate	B1-TAC	Aderklaa Conglomerate Mb.	gravel, cobble, conglomerate, no fossils	braided river system		
16.3			Upper Karpatian	UK4-TK UK3 UK2 UK1	Aderklaa Fm.	sandstone	meandering river, delta		
16.9			Lower Karpatian	LK1-GF	Gänserndorf Mb.	sandstone, mudstone, conglomerate, breccias	meandering river system	↕	
17.2				O3-TB	Bockfliess Mb.	sandstone, mudstone	meandering river system		
(17.2) 17.5				O2					
	Lower Miocene	Aquitainian	Ottangian	O1	?				
18.3			Eggenburgian		?				

Fig. 5: Stratigraphic overview of the Vienna Basin fill. Time axis not to scale. From Hölzel, et al. (2010).

On the crustal scale the Vienna Basin consists of three main tectonostratigraphic units (see Fig. 7). The first one is formed by Neogene sediments and describes the actual Vienna Basin while the second, underlying one is represented by the allochthonous nappes of the Alpine-Carpathian thrusting. The third and deepest main tectonostratigraphic unit, the Subalpine-Carpathian, is formed by autochthonous rocks. (Wessely, 1993)

The evolution of the Vienna Basin is strongly influenced by its location at the east side of the crystalline bedrock of the Bohemian Massif and at the bending area of the Alpine-Carpathian mountain range. In the latest stage of Alpine-Carpathian thrusting, parts of the crust were pressed eastwards in the form of wedges due to a continuing north-south shortening of the Alps resulting from a lack of space. This tectonic process is referred to as lateral extrusion (see, e.g., Ratschbacher, et al., 1991; Decker & Peresson, 1996). It led to large displacement of fault blocks in some areas. The end of thrusting took place in the Karpatian (17 Ma) west to north-east of Vienna, while the age of the termination of thrusting becomes continuously younger further east in the Carpathian thrust belt (see Fig. 4). Last movements occurred in the Pannonian stage (9 Ma) in Romania (Jiricek, 1979). This time difference led to the formation of strike-slip faults between thrust sequences of different age. This idea resulted in the model of Royden (1985) describing the pull-apart mechanism of the Vienna Basin. In this model the pull-apart basin formed at a north-east striking tear fault, which was linked to the active thrusts in the Outer West Carpathians. Wessely (2000) divides the evolution of the basin into three stages called pre-Vienna Basin, proto-Vienna Basin and neo-Vienna Basin (see Fig. 6).

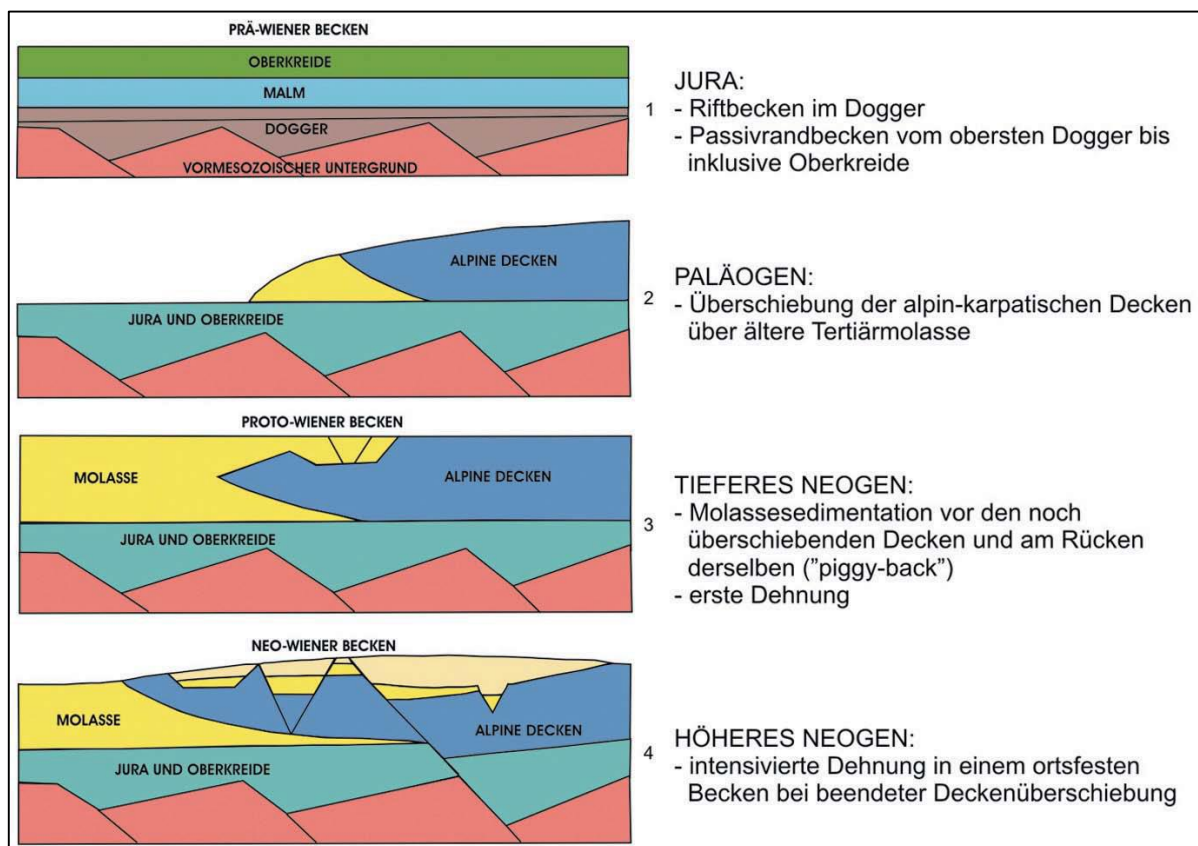


Fig. 6: Evolution of the Vienna Basin starting in Mesozoic. Image from Wessely (2000).

1. Pre-Vienna Basin: In Dogger, a rift basin started to form on top of the crystalline basement of the Bohemian Massif in the area of today's Vienna Basin. Rifting of the European passive continental margin continued through the Late Jurassic until the Cretaceous period (see Fig. 6, Phase 1).

In Paleogene times the Alpine-Carpathian units were thrust over the former passive continental margin and the overlying Molasse foreland basin (see Fig. 6, Phase 2).

2. Proto-Vienna Basin (piggy-back basin stage): Thrusting of the nappes continued from Eggenburgian to Karpatian in a north-western direction. Sediments are transported, not only in front, but also on top of their ridges forming a piggy-back basin (see Fig. 6, Phase 3).

The starting pull-apart effect already led to synsedimentary normal faults evidenced by a different thickness of the Eggenburgian to Karpatian sediments in the hanging wall and foot-wall. Sediments of the Badenian stage, in contrast, overlie these sequences and are mostly intact and with constant thickness leading to an unconformity (see Wessely, 1993; attachment 8; profile 1). The Proto-Vienna Basin has its main distribution area in the north. Tilting of the nappes occurred in a southward direction. Between Ottnangian and Karpatian stage, a phase with strong tectonic movements took place, followed by extreme erosion.

3. Neo-Vienna Basin (pull-apart basin stage): In Badenian the basin reached its current dimensions of pull-apart deformation, lasting during Sarmatian and Pannonian (see Fig. 6, Phase 4). It was fixed because of ceasing alpine thrusting. Further north thrusting continued resulting in extension and a consequently increasing rate of normal faulting (e.g., Steinberg Fault). The previous summary of the basin evolution is mainly based on Wessely (2006).

Sediments of the Lower Miocene (Eggenburgian – Karpatian) could still be interpreted as wedge-top Molasse overlying a basal unconformity of the Alpine-Carpathian fold-thrust units (Wessely, 1993).

During the Lower Miocene, deposition occurred concurrent with an evolving foreland basin in the Molasse unit (Kapounek, et al., 1965) as well as with the thrusting of the allochthon in N- to NW-direction (Linzer, et al., 2002; Zámolyi, et al., 2008). The piggy-back sediments (Eggenburgian – L. Badenian, c. 18-16 Ma) “*post-date Cretaceous to Paleogene folding and thrusting of the Penninic and Austroalpine units. Strata overlies older rocks with an angular unconformity*” (Hölzel, et al., 2010). The facies includes deltaic and fluvatile as well as shallow-marine sediments.

The deposition of wedge-top sediments of Ottnangian and Karpatian age occurred contemporaneously with complex Early Miocene deformation comprising normal faulting (dip: ENE and WSW), thrusting (dip: SE to ESE) and sinistral strike-slip faulting (dip: NW-SE) (Hölzel, et al., 2010). Aside from the central part of the Vienna Basin (Hamilton, et al., 1980), similar

Lower Miocene structures were also investigated in the Slovak part (Kováč, et al., 1989; Marko, et al., 1991; Strauss, et al., 2006).

The evidence for the age of the normal fault activity was inferred from Lower Miocene growth strata identified in 3D seismic data. Thrust faults of the same age could be proven by fault propagation folds and the overlying growth strata. Seismic interpretation as well as analysis of outcrop data from thrust faults which are exposed on the western margin of the Vienna Basin (e.g., the Göller Nappe; GN in Fig. 7) indicate that thrust reactivation and out-of-sequence thrusting occurred in the Lower-Miocene (Hölzel, et al., 2010).

Out-of-sequence thrusting is a phenomenon, typically observed in fold and thrust belts, which shows, contrary to in-sequence thrusting, hinterland propagation of thrusting caused by, e.g., reactivation of older thrusts (Morley, 1988).

In-sequence and out-of-sequence thrusts at the Alpine-Carpathian junction were investigated in detail during the last years regarding paleogeographic positions, thrust distances, timing and thrust velocities (e.g., Zámolyi, et al., 2008; Hölzel, et al., 2010; Beidinger & Decker, 2014).

These tectonic processes were reconstructed at the leading edge of the fold-thrust belt for the late Oligocene and Early Miocene suggesting an earlier termination of in-sequence thrusting in the west followed by out-of-sequence thrusting and a longer lasting period of in-sequence thrusting in the east (see Fig. 8). At least 51 km of total thrust shortening were reconstructed for the time between about 26 and 16 Ma resulting in an average thrust velocity of 4.6 – 5.2 mm/a. (Beidinger & Decker, 2014)

In the Waschberg Unit (WbSU in Fig. 7), which contains the outermost nappes of the Alpine-Carpathian wedge, out-of-sequence thrusting was evidenced and dated to Upper Karpatian (Zámolyi, et al., 2008).

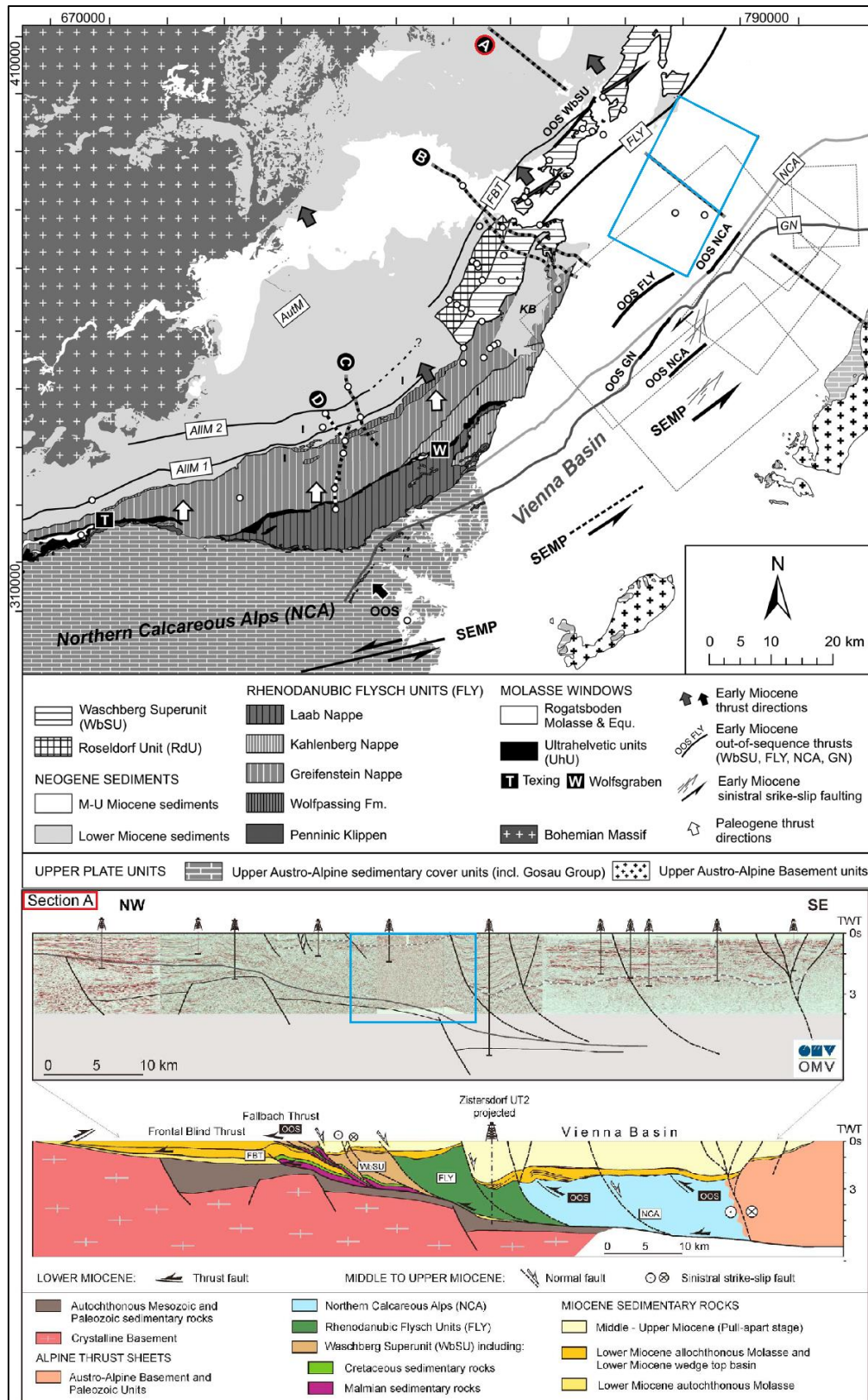


Fig. 7: Geological map (above) with appendant cross section A (below) cutting the investigated area (blue rectangle) in the Vienna Basin. E. Miocene out-of-sequence thrusting (OOS) known for FLY, NCA (Hölzel, et al., 2010), and WbSU (Zámolyi, et al., 2008). Further Early Miocene kinematics from Fodor (1995). Paleogene kinematics from Decker (1993). Grey rectangles locate seismic cubes of previous studies. MGI Austria BMN M34 coordinate system. Modified after Beidinger & Decker (2014).

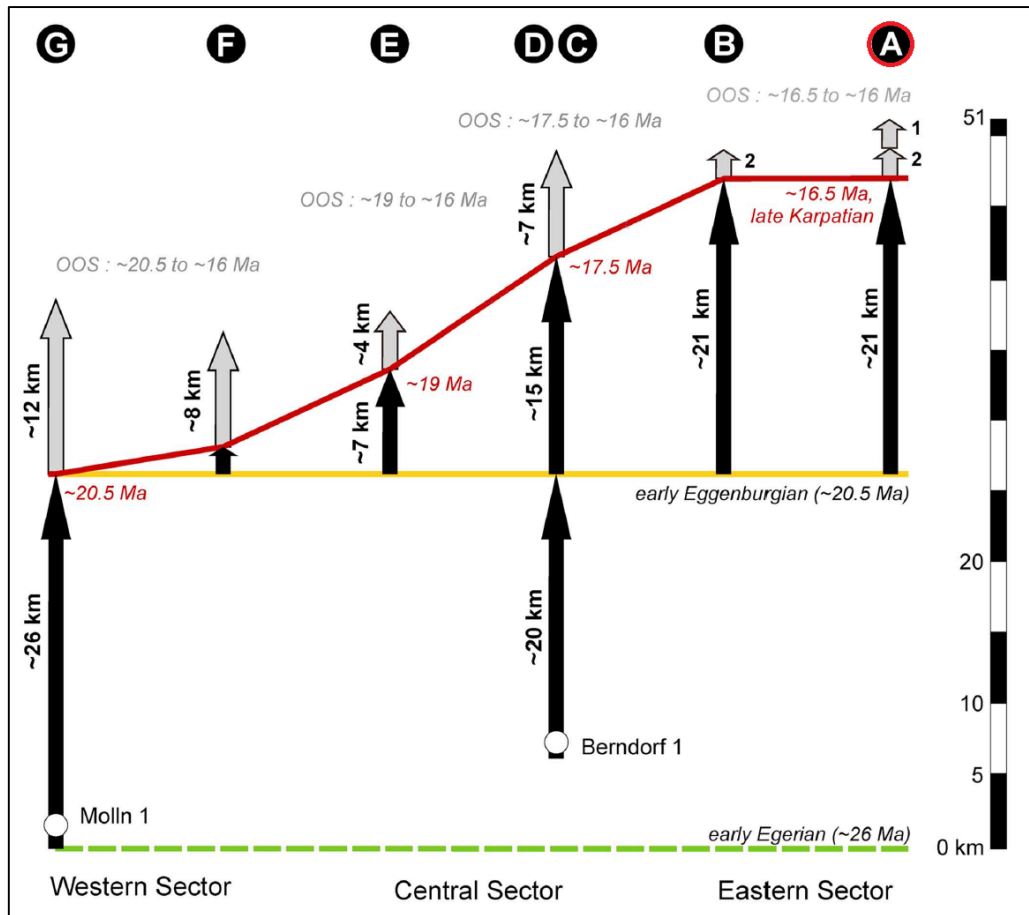


Fig. 8: In-sequence (black arrows) and out-of-sequence (grey arrows) minimum thrust distances compared between 7 cross sections (A-G; see Fig. 7 top for location) in the Vienna Basin. Note that the termination of post-Egerian in-sequence thrusting and the subsequent beginning of OOS thrusting becomes younger from west to east (red numbers). OOS thrusting in section A and B occurred during; 1: Late Karpatian in WbSU; 2: Karpatian, FLY and NCA. Modified after Beidinger & Decker (2014).

The evolution of the Early Miocene piggy-back basin is followed by the pull-apart basin stage starting from Early Badenian that led to a distinct angular unconformity between these two stages (see Fig. 5; Royden, 1985). Therefore, the recent Vienna Basin is known as a thin-skinned pull-apart structure (Royden, 1985; Wessely, 1988; Brix & Schultz, 1993; Lankreijer, et al., 1995; Decker, 1996; Decker & Peresson, 1996). This change in kinematics occurred after the termination of out-of-sequence thrusting in the basin (Beidinger & Decker, 2014). At the end of Karpatian stage, erosion started and the zones of subsidence relocated. Marine Badenian transgressed on different sediment strata of the Lower Miocene and in some places even the underlying flysch horizon. Increasing extension at this time led to subsidence of the basin. Faults are mostly synsedimentary and have different offsets. Noticeable examples are the fault systems of Leopoldsdorf Fault (up to ~4,000 m) and Steinberg Fault (up to ~6,000 m) (Wessely, 1993).

Shallow water areas were formed, e.g., on footwalls of a normal fault showing minor thickness of sediments compared to its surroundings, e.g., the hanging wall of a normal fault. This

difference in thickness is extremely high at the Steinberg Fault between the footwall (“Steinberg Hoch”) and the hanging wall (“Zistersdorfer Tief”). In shallow water areas “Leithakalk” (limestone) developed in Badenian and bioclastic limestone or oolites in Sarmatian. Deep water areas show sandy-marly sedimentation.

Badenian sediments show a high diversity of facies and also of thickness according to the respective depositional environment. In Middle Badenian the limnic facies in the south was entirely replaced by marly basin facies or marine delta sand and the whole sediment supply occurred via mouths of rivers (see Faupl, 2003). The main sediment supply direction was west to east where sand was transported from the Molasse, across the Mistelbach Block, far into the basin center.

A delta system developed from the Lower Badenian forming submarine fans made of several hundred-meter-thick sand sequences that reached until today’s Slovakia. Well data prove such a sand area on the Mistelbach Block.

Focusing on limnic-fluviatile sediments at the basin margins, a so-called “Bunte Fazies” is known on the (northern) Mistelbach Block affecting marine sediments in Badenian (Janoschek, 1951).

The fully marine evolution ended in Upper Badenian due to an interruption of the connection between Paratethys and the Mediterranean Sea. The decreasing salinity led to the extinction of reef organisms of the “Leithakalk”. The desalinization proceeded in Sarmatian and Pannonian, where a last highstand was reached. In Pontian the complete desalinization took place (Faupl, 2003). The previous part describing the facies and sediments of the Vienna Basin is mainly based on Wessely (2006).

1.4. The Mistelbach Block in the Northern Vienna Basin

The investigated area is located in the footwall of the Steinberg Fault. This fault block is known as Mistelbach Block, which is *“bound to the west by the ESE dipping Schratzenberg and Bisamberg faults and to the east by the ESE dipping Steinberg fault system”* (Hamilton, et al., 1999). The following chapter gives a geological overview relating to this fault block and briefly explains the facies distribution in the Lower Miocene.

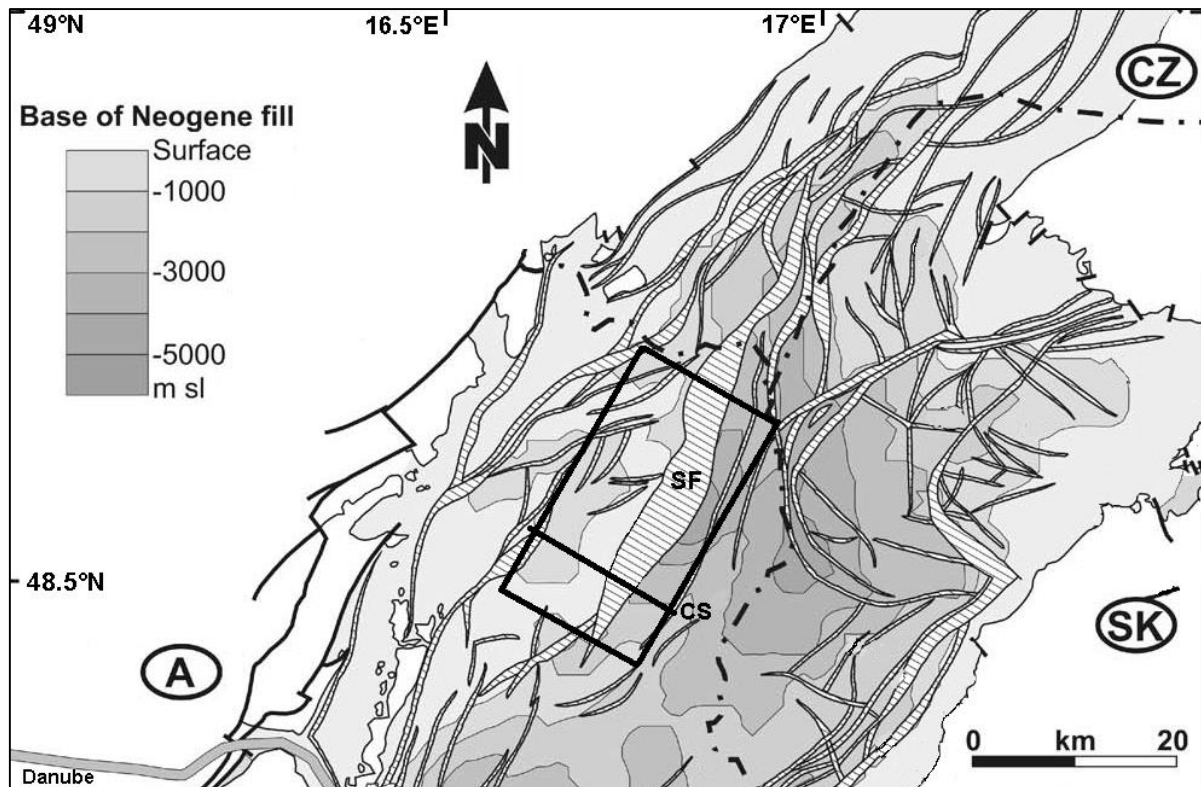


Fig. 9: Structural setting and seismicity of the Northern Vienna Basin (adapted from Hinsch, et al. 2005). Inset: Main structural units in the Eastern Alpine–Carpathian region (modified after Decker 1996). The main map shows the faulted pre-Neogene basement surface (modified after Kröll & Wessely 1993). Black rectangle marks the border of the seismic cube. The mapped area belongs to the footwall of the Steinberg Fault (SF). CS: cross section (see Fig. 12). WGS84 DD coordinate system.

Regarding the geological units of the pre-Neogene basin-floor the seismic cube overlies the Alpine-Carpathian flysch zone including different nappes like Ráca Nappe, Greifenstein Nappe and Kahlenberg Nappe. The Flysch zone was formed between Cretaceous and Paleogene and mostly consists of sandstone. (Wessely, et al., 1993)

In the provided 3D seismic volume the different horizons are all cut at the south-east side by the south-west – north-east striking Steinberg Fault. Most of the horizons are also offset by an apparently older and smaller fault system at the north-west side. Both faults are dipping east-south-east. The area east of the so-called “Steinberg Hoch” and its bordering fault is called “Zistersdorfer Tief” (6,000 m deep) representing a synsedimentary depression which was formed between Badenian and Pannonian stages. A few hundred meters in thickness of the Badenian up to the Pannonian sediments in the footwall equate to several thousands of meters of growth-strata in the hanging wall. The whole Steinberg Fault has a length of around 55 km (see Fig. 9). The synsedimentary movement of this normal fault amounts to about 3 millimeters per thousand years (mm/ka) during its activity (Wessely, 2006).

The investigated area of this Master's thesis is located to the north of the "Matzener Rücken" and, therefore, predominantly marine from the onset of sedimentation in the Early Miocene. From Eggenburgian to Late Karpatian, the major sediment supply occurred from the limnic area south of the "Matzener Rücken" northwards toward the marine basin. According to the facies distribution shown by Jiricek & Seifert (1990) the investigated area (Mistelbach Block) was expected near the coast in a shallow marine environment (Fig. 10).

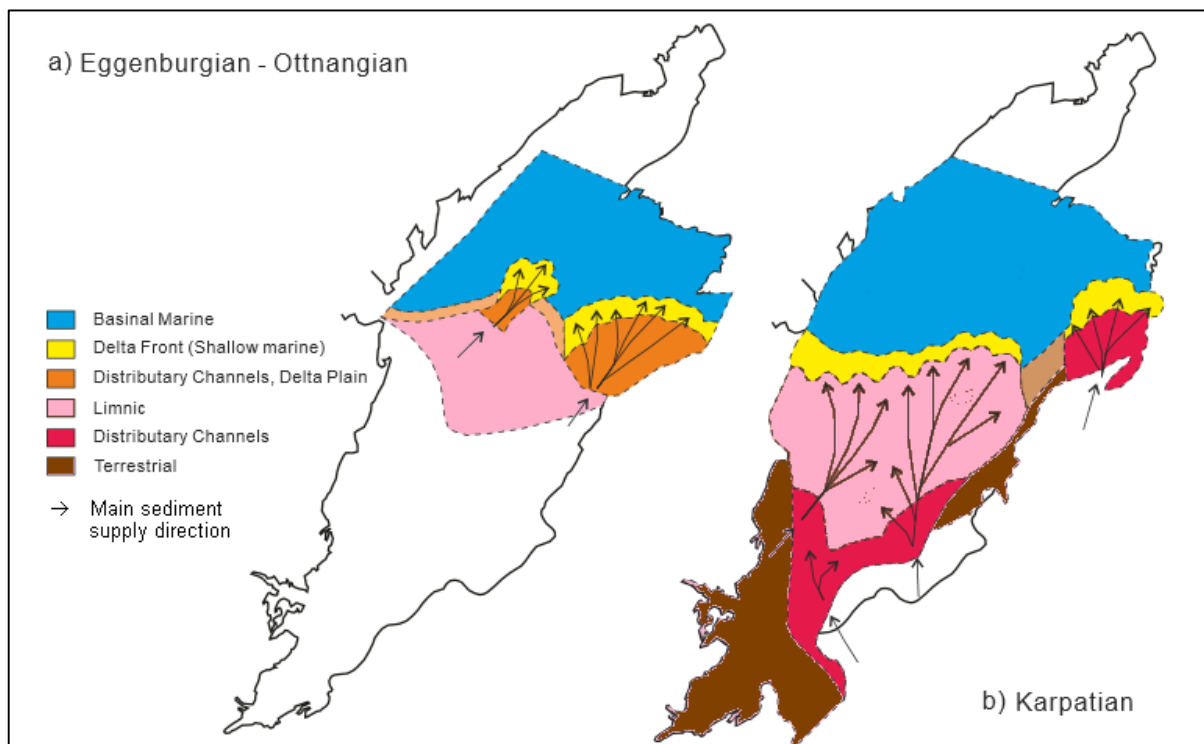


Fig. 10: Evolution of the deposition areas in the Vienna Basin during (a) Eggenburgian – Ottnangian and (b) Karpatian. Modified after Jiricek (1979) and Jiricek & Seifert (1990). Image from Lee (2015).

2. METHODOLOGY

2.1. Reflection seismic

The study of earthquakes and the propagation of elastic waves through a planet or a comparable solid body is called Seismology. A seismic survey on Earth is a scientific method to investigate subterranean, geological structures, often with regard to the exploration for raw materials.

The seismic wave is defined as an elastic wave propagating in rocks with a characteristic velocity (defined by the elastic constant). These waves can be produced artificially by different sources like explosions, air guns, vibrations or hammer blows dependent on the territorial conditions. While there are ships like Seismic Vessels used for marine seismic surveys, the so-called Thumper Trucks (Vibrators) are commonly used for onshore investigations.

Certain boundary surfaces exist, especially in sediments. These are reflection horizons that will change the elastic properties and split up the energy. One part follows the law of refraction and propagates in the subsurface, while the other part is reflected to the Earth's surface. For reflection seismology the amplitude of the reflected wave is defined by the reflection coefficient. This value is dependent from the acoustic impedance which is a product of density and velocity. In general the velocity of seismic waves increases with depth due to increasing density, resulting in a positive reflection coefficient. If this value turns negative a phase change of 180° can be expected. The velocity of longitudinal waves (p-waves) in sediments can vary between 100 meters per second (m/s; unconsolidated sands) and 6,000 m/s (chalk, dolomite).

Frequency (f) and wave length (λ) are important parameters to determine the resolution power. The product of these two parameters is the velocity ($v=f*\lambda$). The common frequency range of these waves in the Earth lies between 20 hertz (Hz) and 80 Hz, resulting in a wave length of tens of meters to several hundred meters.

Reflected seismic waves are recorded at the Earth's surface by geophones. These devices convert the elastic energy into electric energy. Usually there is more than one geophone in use. Groups and extensive patterns of geophones should avoid disturbance waves which can arise from ground shaking, earthquakes, wind, machines, traffic, and so on (Weber & Ströbl, 1993).

A further error source that has to be considered for seismic survey is the fact that *“a seismic profile is not a geological cross section. [...] Lithological boundaries will only be detected if the acoustic impedance changes across the boundary. As the reflection strength depends on the impedance, not every boundary is necessarily imaged.”* (Stoker, et al., 1997)

The interference of waves, as well as the time-depth relation, are also factors that must not be neglected. Furthermore, seismic wave length increases with depth allowing less resolution (see Fig. 11).

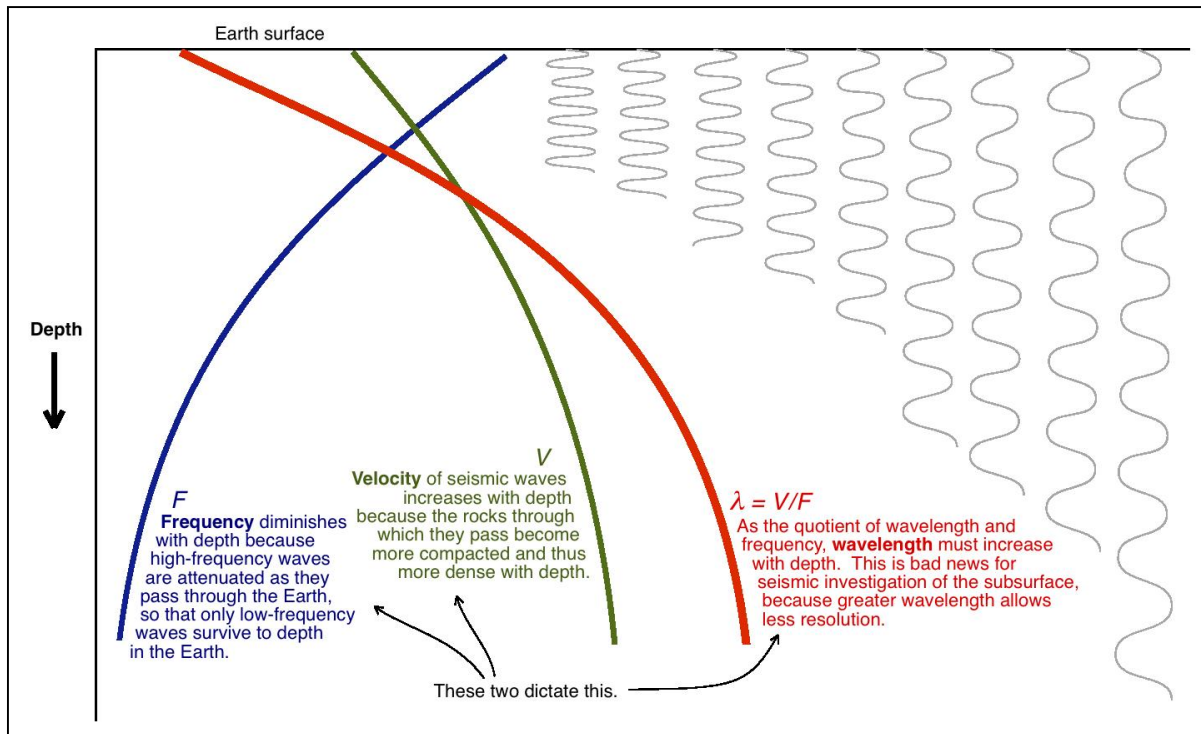


Fig. 11: Graph demonstrates the reason for seismic resolution decrease with depth. From Brown (2004).

2.2. Data

All processed digital data were provided by OMV and handled according to OMV's privacy policy. Altogether 2 seismic volumes, 43 well trace files, 4 checkshot files, a well tops sheet including 36 wells and an already mapped horizon (points with attributes) were used by the seismic interpretation software Petrel 2012.1. Pre-processing, import and final processing of all above-mentioned data were accompanied by many challenges, initial difficulties and problems. Sheets had to be sorted through unnecessary or invalid records and the format, as well as the signs, had to be adapted to be imported and correctly read by the program.

2.2.1. Seismic Volumes

The investigated area is defined by a 3D seismic volume provided by OMV (see Fig. 9 for outline), which depicts the Neogene basin fill of the Northern Vienna Basin and the underlying flysch units. The cube's surface amounts to about 420 km², with 28 km in length and 15 km in width. The Z coordinates are expressed in TWT. This cube includes seismic data from 0 ms at the surface down to almost -5,000 ms picturing the top flysch horizon and its overlying Miocene sediment layers.

At the beginning of the workflow only one 3D seismic volume was provided in TWT (see 8.1; Tab. 3). This phase was used initially to get familiar with the program's functionality and its different features. The top flysch horizon, a channel in the Karpatian sediments and the bordering faults were mapped to get a first impression of the structures.

The second volume provided (see 8.1; Tab. 4) was bigger than the first one and included almost all of the already known geological features. Due to a better quality of the reflectors the whole work was restarted with this cube. However, this volume was also not depth-converted.

At a later date, the additional well data were received, including well traces, well tops and checkshots.

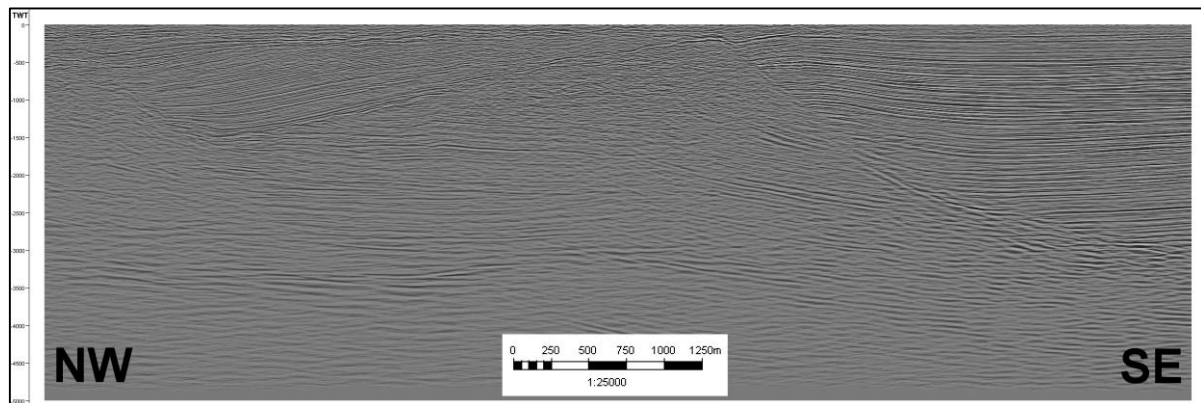


Fig. 12: Seismic Inline through seismic cube (NW-SE) cutting the Steinberg Fault. See Fig. 9 for location.

2.2.2. Wells

The 43 wells are available in the area of Alt-Höfle, Ginzersdorf, Kettlasbrunn, Linenberg, Maustrenk, Mistelbach and Scharfeneck (see 8.2; Tab. 5). Not all of these boreholes are located in the investigated area (see Fig. 15).

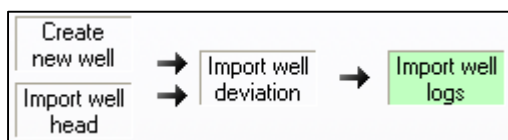


Fig. 13: Suggested import order for wells. From Petrel 2012.1 Help.

Well trace- or deviation files determine the path of the borehole starting from a certain well head at the surface with X and Y coordinates and an offset from MSL (mean sea level). These sheets usually contain MD (measured depth), X, Y, Z, TVD (true vertical depth), DX, DY, inclination and azimuth.

The import dialogue in Petrel requests information depending on the specific format of the file (see Fig. 14). The user has to input the data type, TVD reference, column order and location of the well name. (Petrel Help 2012)

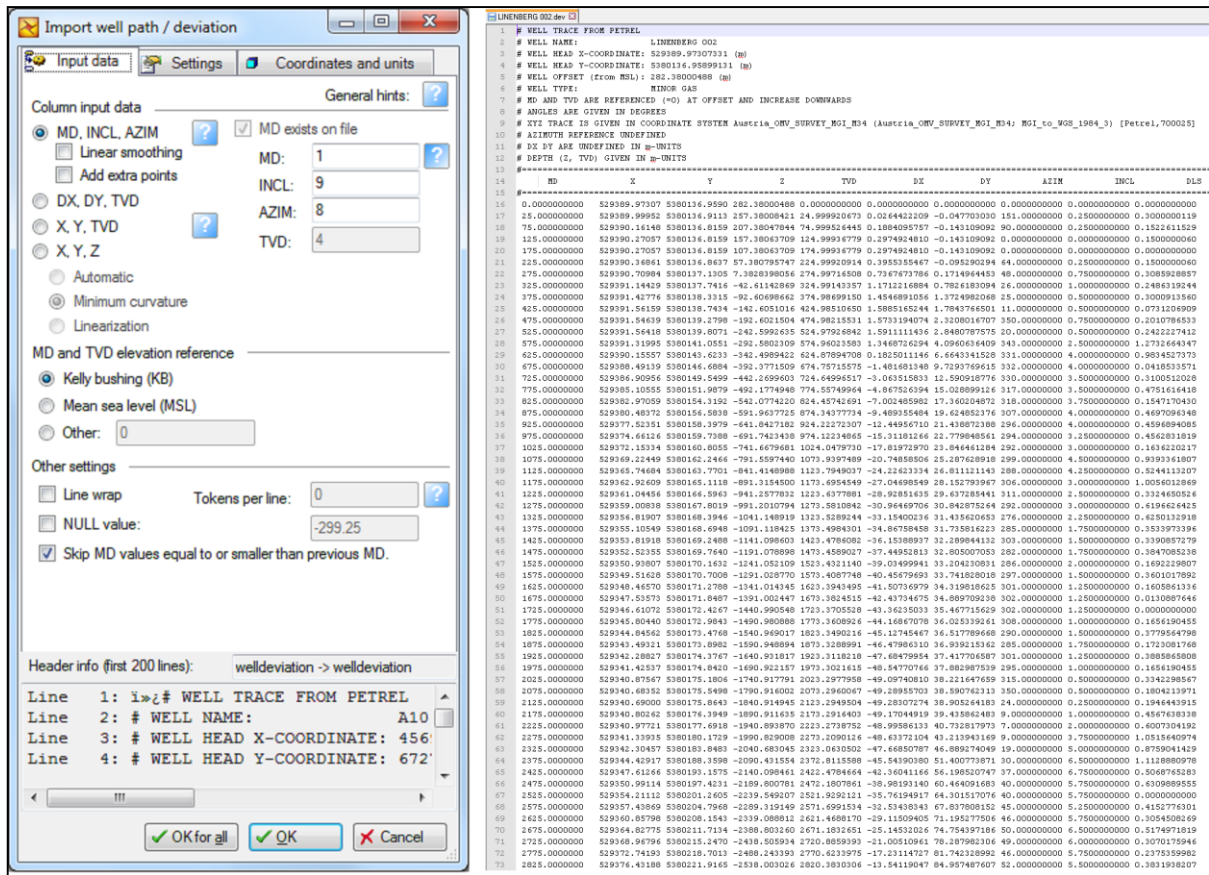


Fig. 14: Import well path / deviation using MD, INCL and AZIM from a deviation file (left; Petrel 2012.1); Example of a deviation file (right; Notepad++).

Tab. 1: Corner coordinates from the processed 3D seismic cube from north to south in diverse geodetic- and coordinate systems (BMN: Österreichisches Bundesmeldenetz; GK: Gauß-Krüger coordinate system).

WGS84 - DMS	WGS84 - DD
48°43'36.3"N 16°44'54.7"E	48.72675° 16.748528°
48°39'27.5"N 16°55'34.0"E	48.657639° 16.926111°
48°30'36.5"N 16°33'24.1"E	48.510139° 16.556694°
48°26'28.6"N 16°44'06.4"E	48.441278° 16.735111°
MGI(Austria) - BMN M34	MGI(Austria) - GK M34
x: 780,638 y: 398,833	x: 30,638 y: 5,398,833
x: 793,762 y: 391,234	x: 43,762 y: 5,391,234
x: 766,594 y: 374,687	x: 16,594 y: 5,374,687
x: 779,816 y: 367,083	x: 29,816 y: 5,367,083

OMV usually works in the particular coordinate system “Austria_OMV_SURVEY_MGI_M34 (Austria_OMV_SURVEY_MGI_M34; MGI_to_WGS_1984_3)” which was used as Coordinate Reference System (CRS) for the entire Petrel Project. The Project Reference Datum is defined in time (SRD = Seismic Reference Datum) and amounts to 130 m which means that 0 ms in time correspond to 130 m above the Adriatic. XY coordinates and standard depth use the unit m while seismic time is specified in ms. Seismic velocity is expressed as m/s.

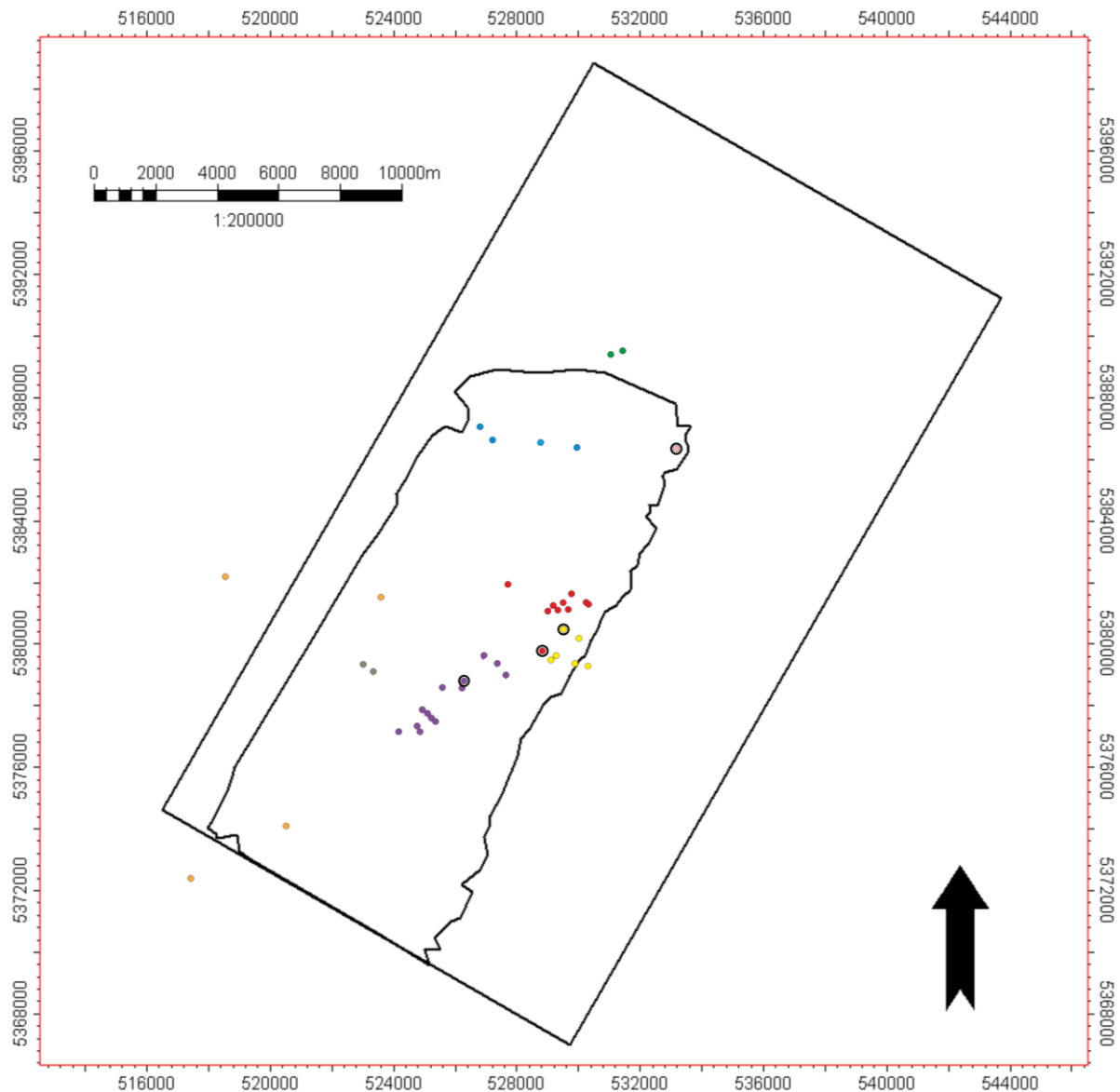


Fig. 15: Overview of the well locations in the investigated area (green: Alt-Höflein; blue: Ginzersdorf; pink: St. Ulrich – estimated location; orange: Mistelbach; red: Maustrenk; yellow: Linenberg; grey: Kettlasbrunn; purple: Scharfeneck). Wells with available checkshot data are indicated with a black circle. MGI Austria GK M34 coordinate system including a false easting of 500,000.

2.2.3. Well Tops

After successful importation and display of the well- heads and traces the well tops were loaded.

In this case well tops are used to mark stratigraphic horizons of certain well traces. In addition to X, Y, Z and MD there are automatically calculated TWT values for some wells (see 8.2; Tab. 5). Though it was mentioned at the handover of these data that one cannot totally rely on all of the information in them. Some of the surfaces are marked wrong or are simply unknown. For instance, there is no Eggenburgian stage expected in these 3D seismic cubes according to new knowledge, even though this label is used for several surface attributes in the well tops data.

Consequently, all these information was used as an orientation guide for a chronostratigraphic classification of the sediment layers. Well tops can represent an important source of information for depth conversion.

2.2.4. Checkshots

One of the main challenges of the seismic reflection method is the time-depth relationship problem.

Seismic volumes were provided for this Master's thesis in time which means that the Z coordinate is expressed in ms describing the duration of a transmitted acoustic wave to be reflected at a certain layer boundary and received again at the surface by geophones (see Fig. 16, right).

Due to the fact that the Z coordinates of well data are usually expressed in depth (m) a correlation with time is necessary to make all of this usable together.

Therefore, OMV provided four checkshot files for this Master's thesis; three of them had an appropriate well trace (see 8.2; Tab. 5).

A checkshot survey is *"a type of borehole seismic data designed to measure the seismic travel time from the surface to a known depth"* (Schlumberger, 2015). Geophones are lowered in the wellbore to check the P-wave velocities (see Fig. 16, left).

These checkshot files contain different MD and corresponding TWT values for certain wells but also the average- and interval velocity for every measured section. Many different information for a well lead to a more realistic time-depth relationship.

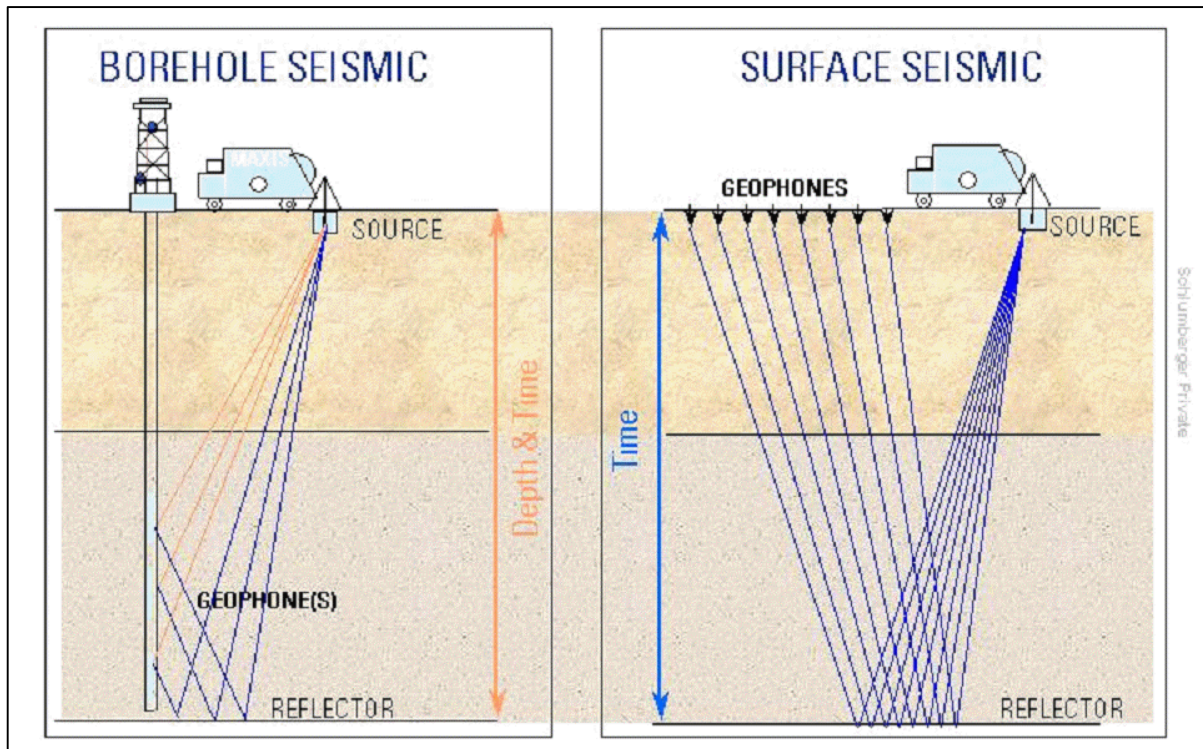


Fig. 16: Checkshot demonstration (left); Surface seismic demonstration (right). Image from Schlumberger (2002-2013).

2.2.5. Horizon

In addition, an already mapped horizon named Top_ Karpat was provided in the form of Petrel Points with attributes. This file contains almost 30,000 records with X, Y and Z coordinates defining a grid of the stratigraphic horizon. It should serve as extra help in clarifying the chronostratigraphic overview. In the end, new stratigraphic results of a (still unpublished) report by Theobalt, et al. (2015) dated this horizon to Lower Badenian as it equals the top of the so-called Iván formation (see Fig. 24 and Fig. 25).

2.3. Workflow

2.3.1. Seismic Data Import

The first seismic volume, provided by OMV, was imported in Petrel with ZGY format called 3D_Mistelbach_cut_UniWien.zgy. *“ZGY format is a compressed format for seismic data. It is vendor specific.”* (petrofaq, 2013)

Therefore, the project settings had to be adapted to match the applied parameters. The coordinate reference system (CRS) is called Austria_OMV_SURVEY_MGI_M34 and has a seismic reference datum (SRD) of 130 m. The unit system is metric so the horizontal unit is m. The CRS includes a “False Easting” of 500,000 and the cartographic transform MGI_To_WGS_1984_3 was used (see Fig. 17). For the second volume the same settings could be used.

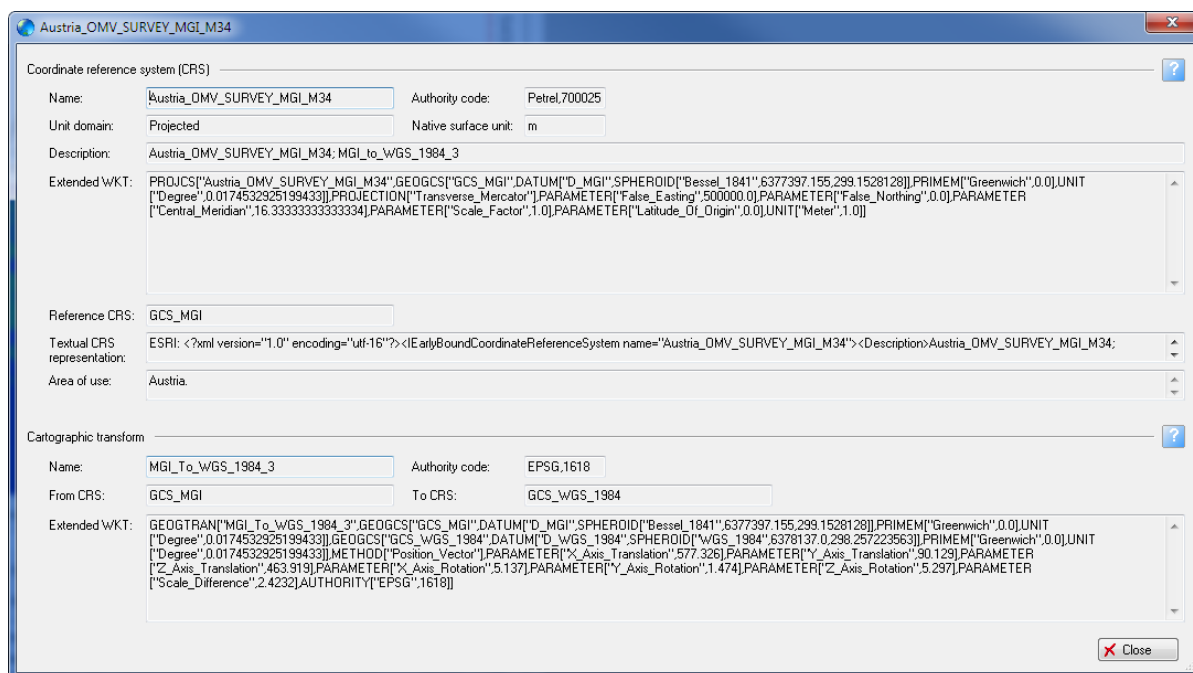


Fig. 17: Used Coordinate Reference System (CRS). Petrel Project Settings.

2.3.2. Horizon Interpretation

The most time-consuming part of the practical work was the mapping of horizons with Petrel. Therefore, the property template Seismic (default) 1 was used to display the seismic reflectors in color. Depending on if the amplitude is positive or negative the reflector is shown as red or blue, respectively. In this case the mapping of all horizons was executed on red reflectors.

Petrel gives the user the possibility to track and map horizons while sliding through the 3D seismic volume. Inline, Crossline (Xline) and Time Slice (Z) are displayed by default. In the provided cubes the shorter, south-west – north-east striking vertical plane is the Inline (Range: 1902-3021; Interval: 25 m) while the longer south-west – north-east striking vertical plane is the Crossline (Range: 2432-2041; Interval: 25 m), intersecting the Inline at an angle of 90°. The horizontal plane is the Time Slice which is especially useful for fault interpretation.

Initially the top flysch horizon was mapped by alternately drawing lines on the Inline- and on the Crossline intersection moving with a plane steps increment of '5' through the cube. The value of '5' corresponds to a horizontal distance of 125 m (Interval: 25 m).

For the horizon interpretation Petrel provides different features like seeded 3D autotracking, guided autotracking or manual interpretation. Seeded 3D autotracking can only be used for very clear and intact reflectors. For this work the method of guided autotracking was usually applied.

For this, the user selects a start- and an end point along the favored reflector. The interpretation automatically follows the event between these two points.

The result of the aforementioned process is a 3D grid indicating the TWT of the appropriate horizon at a certain (x, y) position.

These grids were not only created for the top flysch horizon but also for some overlying Miocene strata.

A distinct reflector was mapped above the flysch forming the top of the growth strata layer.

This was also done for similar horizons resulting from different events. Above, two approximately parallel-running channel systems could be mapped. The first one is bigger and deeper, while the second one is a bit shallower. Both channels are south-west – north-east trending. The topmost horizon mapped in this seismic cube is formed by the provided Top_Karpat horizon.

In case of ambiguity regarding the trend of a reflector an additional arbitrary intersection (Random Line) was inserted. This vertical plane can be turned into the optimal angle where the course of a certain horizon is best visible. Additionally, mapping on such a plane will increase the density of points on the emerging grid and leads to more detailed results.

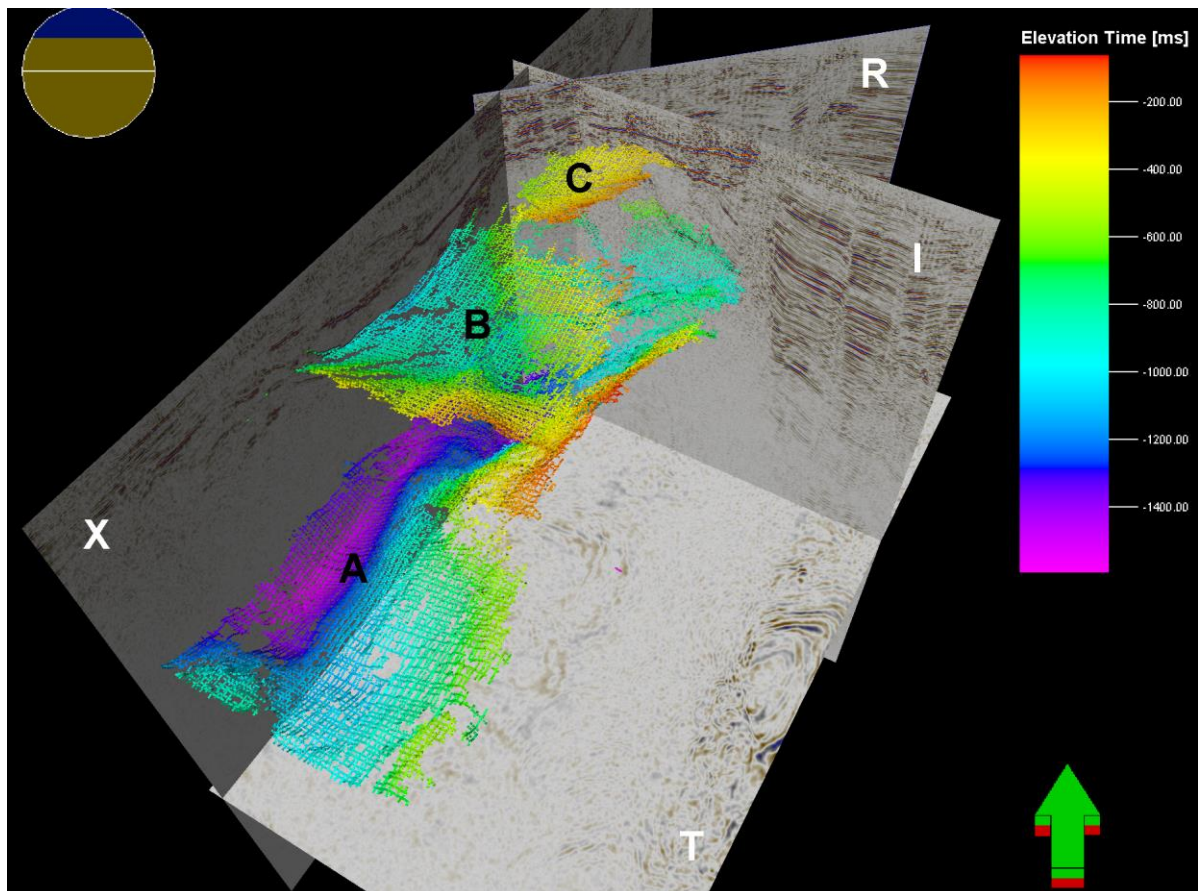


Fig. 18: Petrel 3D Window - Intersecting planes in the cube (I: Inline, X: Crossline, R: Random Line, T: Time Slice) and horizons (A: Top_Flysch, B: Channel_1, C: Channel_2). Z scale exaggerated by factor 5.

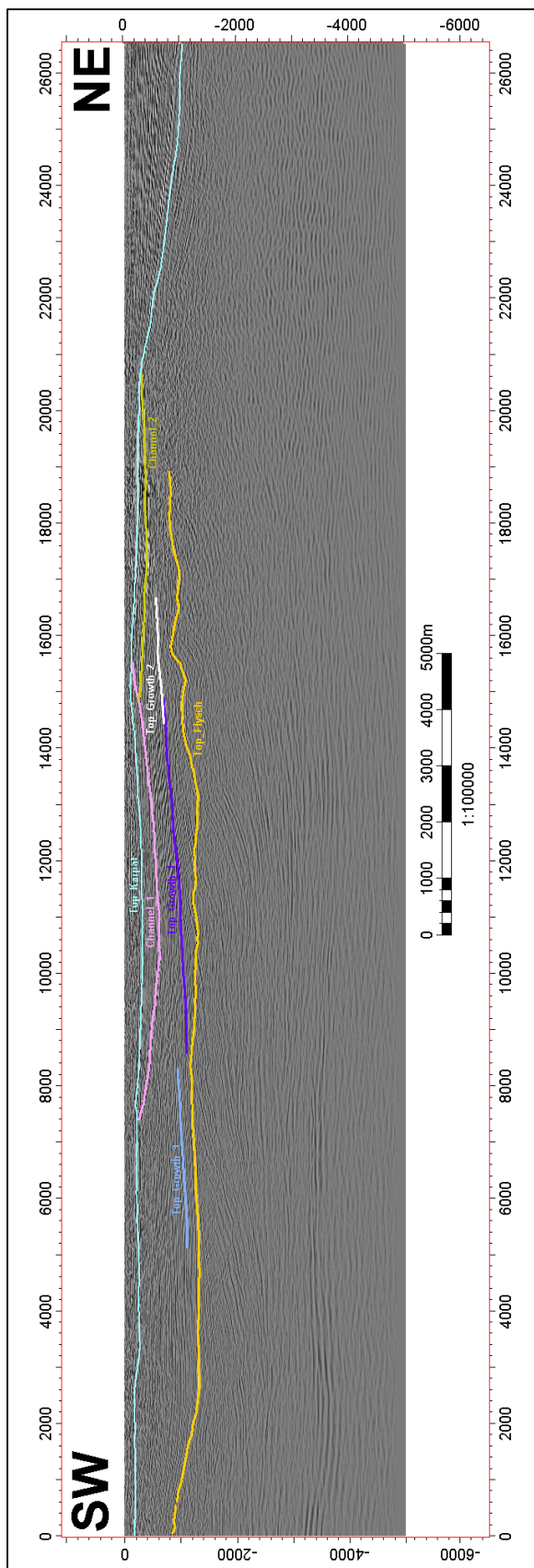


Fig. 19: Xline 2580 picturing mapped horizons. Depth values in ms TWT.

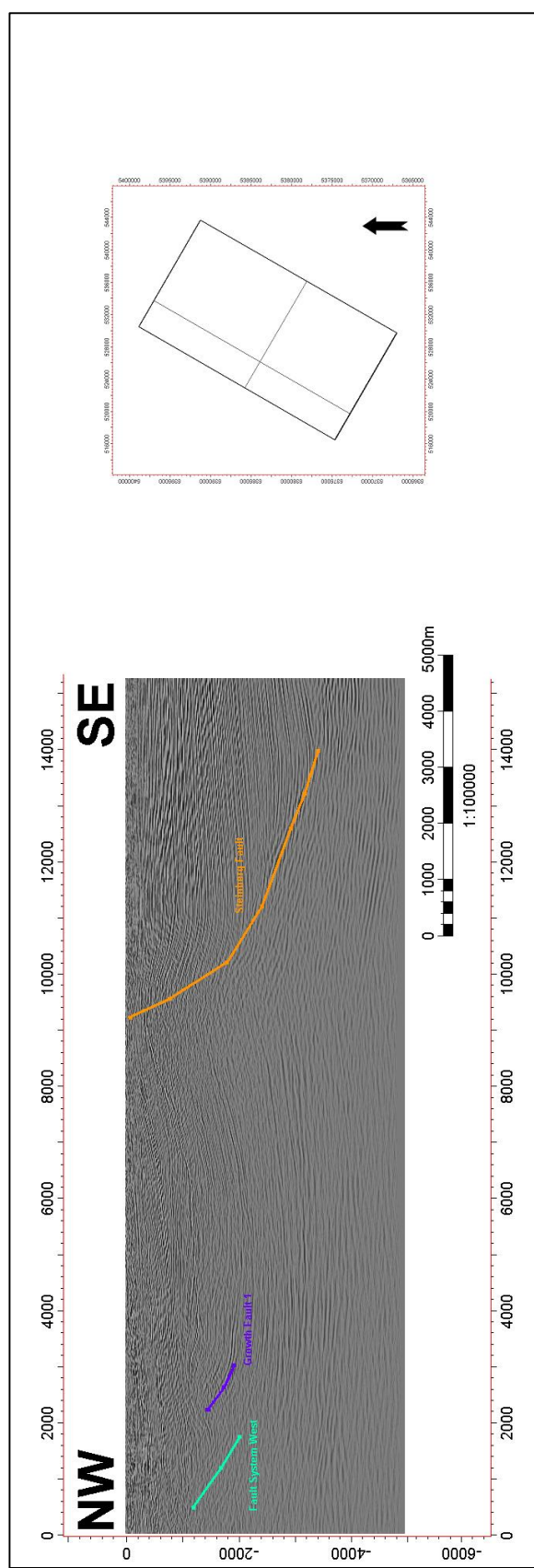


Fig. 20: Inline 2416 picturing important faults. Depth values in ms TWT.

2.3.3. Fault Interpretation

During the Horizon Interpretation it was also necessary to consider fault systems affecting the working area. For this purpose, Petrel provides the action interpreting faults which works similar to the Interpreting grid horizons feature. It allows the user to track faults by drawing lines (connected points), e.g., along truncated or displaced reflectors. By repeating this process step by step on different vertical planes the resulting surface will demonstrate the fault plane.

In contrast to the Horizon Interpretation a fault can also be picked vertically (so that two different points share the same Z value). There are also features like “Seeded 3D fault auto-tracking” or the “Ant-Tracking” algorithm for the Fault Interpretation. However, manual picking was used most of the time to define the appropriate positions of fault surfaces.

Both seismic cubes include one of the biggest faults of the Vienna Basin. The so-called Steinberg Fault has an offset of about 6,000 m and bounds all mapped strata on the south-east side of the seismic volume. The fault surface strikes north-north-east – south-south-west and dips east-south-east. Regarding this TWT seismic volume the fault reaches from the surface (0 ms) down to more than -4,000 ms.

For the fault interpretation it is recommended to use a black-and-white seismic-color-table. The resulting increase in contrast makes it easier for the user to spot offsets between reflectors.

2.3.4. Make Surface

In a further step, the horizon grids were displayed one after another together with the mapped faults in 2D windows to determine their borders. This works in Petrel with the Make/Edit Polygon utility. After correcting errors, identifiable by single peaks in a grid, closed polygons were drawn around the areas of interest. Single lines or points without immediate neighbors were neglected in many cases because of their lack of significance.

In a subsequent process using the Make/Edit surface utility in Petrel the recently created polygons were selected as the boundary for the appropriate horizon interpretation grid. Using a certain interpolation algorithm a comprehensive result surface can be calculated and displayed in 2D as well as in 3D. At this time all resulting surfaces were represented in TWT and no distinct relations to vertical distance or depth could be determined.

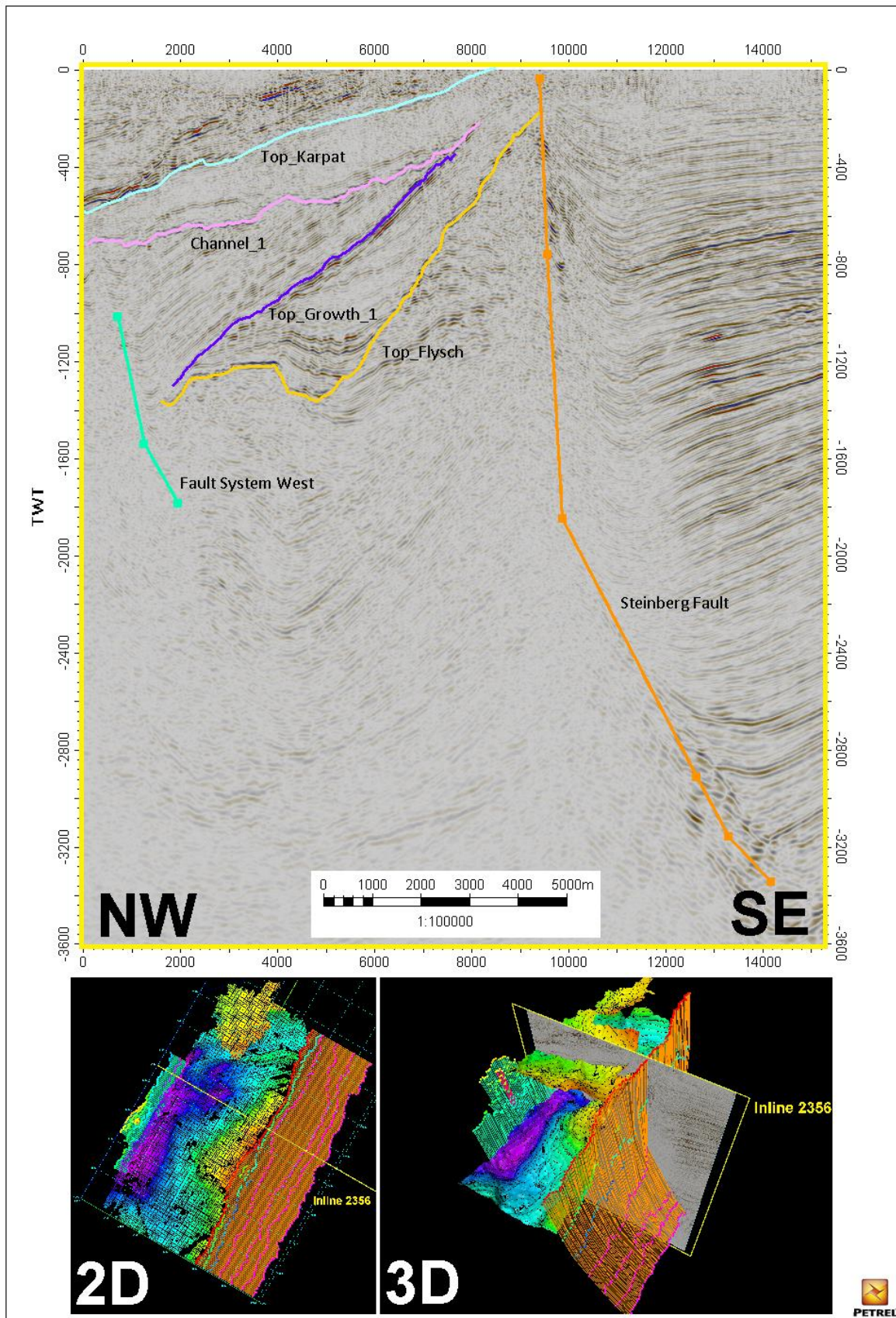


Fig. 21: Inline [2356] intersection plane showing important horizons and faults. Depth values in ms TWT. Z scale exaggerated by factor 5.

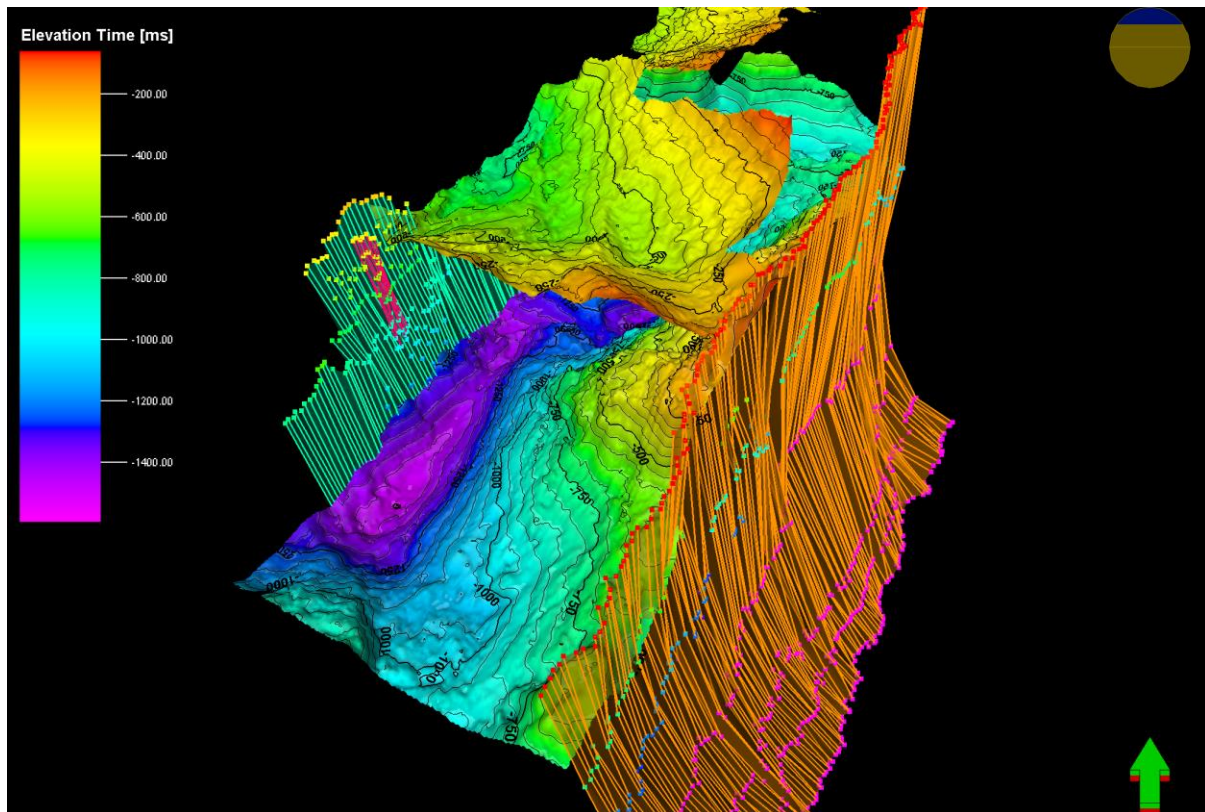


Fig. 22: Petrel 3D Window - Horizon surfaces and bordering Faults (orange: Steinberg Fault; green & red: Fault System West). Depth values in ms TWT. Z scale exaggerated by factor 5.

2.3.5. Time-depth correlation and well ties

The reflection seismology method measures reflection pulses in runtime so that the vertical z units of a 3D seismic cube are originally expressed in time (ms). Well traces and most well top data feature z values expressed in distance (m) leading to the already mentioned time-depth relation problem.

Petrel includes a filter for the view that allows the user to switch between TWT (two-way traveltime) and TVD (true vertical depth). It is also possible to display all features independent from their z units with the selection of 'Any'. Nevertheless, the relation of seismic cubes and borehole data will not respond to reality in this case.

Several methods were tested to find an appropriate solution for this problem and to approximately correlate the mapped horizons to chronostratigraphic units identified in wells.

After the handover of the borehole data some depth conversion methods were executed.

Initially, a simple depth conversion of the top flysch horizon was generated by calculating the average velocity. In the Petrel Well Settings it is possible to make a well report including points with attributes. This report shows the intersection points of the wells (in depth) with the top flysch surface (in time) at certain XY locations. With the knowledge of this information the user is able to calculate a velocity attribute ($v=s/t$). Considering the SRD of 130 m, the unit of milliseconds and the doubled time due to TWT the following formula can be compiled:

$$V_{av} = (Z-130) / (TWT/2000)$$

The resulting attribute was used to make a surface reflecting an average velocity map. In a further step a depth map (TVD) was calculated. Different wells and their intersecting flysch horizon can be displayed now together in a well section window for depth. The same procedure was done for further horizons.

However, the final results were not totally distinct. Reasons for this could be the irregular distribution of wells and the fact that not every borehole reaches the Top_Flysch horizon. Furthermore, this quite steep horizon makes it very difficult to create a reliable velocity map.

In addition, the trial and error of other methods like the Depth Conversion Tool or the Velocity Model did not lead to satisfying results to distinctly correlate the stratigraphic horizons to wells.

Consequently, the checkshot data were used to get an approximate overview of the time-depth relation in the seismic cube and for chronostratigraphic classification. Only checkshot data for the Wells of LINENBERG 002, MAUSTRENK UEBERTIEF 001a and SCHARFENECK OST 001 were useful. In Petrel it is also possible to share a checkshot with neighboring wells. Dependent on distance between the boreholes and dipping of the horizons the provided checkshot data were used to get time information for the other surrounding wells.

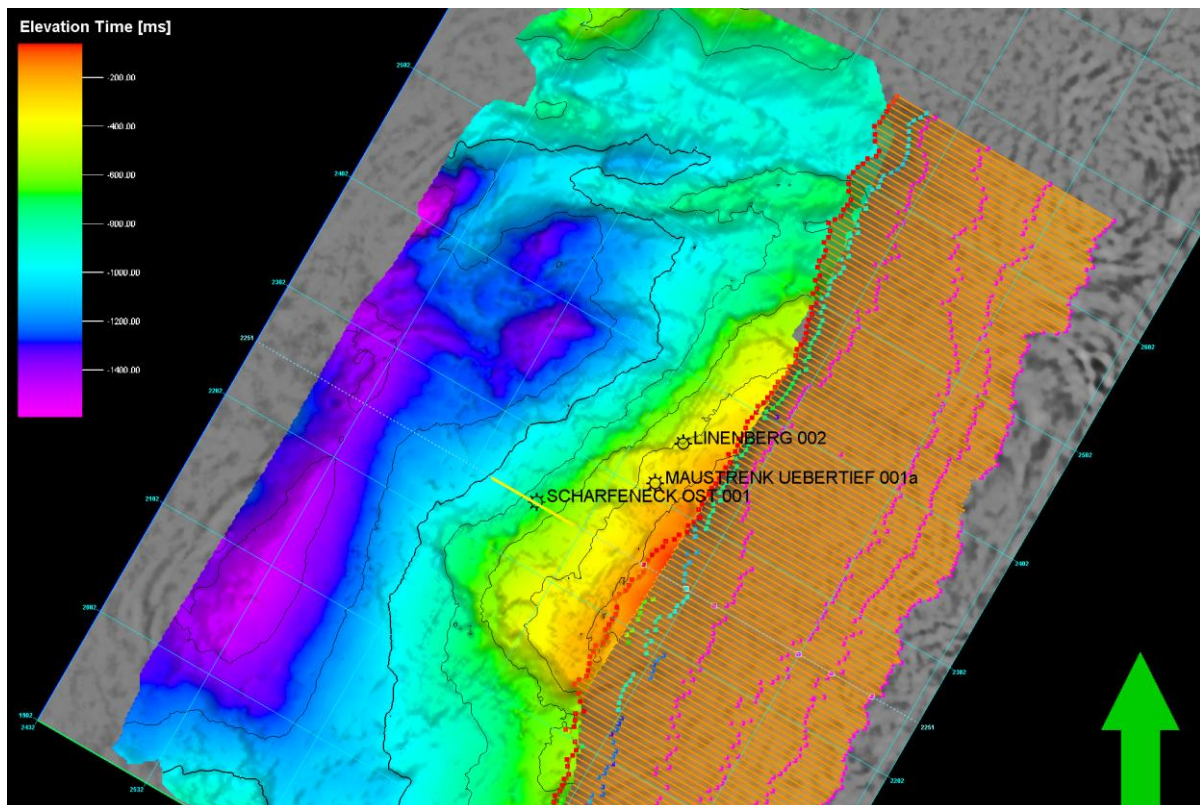


Fig. 23: Petrel 2D Window – Well Heads of checkshot-related boreholes displayed over Top_Flysch horizon.

In the final phase of this Master's thesis, OMV provided sections of a (still unpublished) report by Theobalt, et al. (2015) offering updated stratigraphic results of the Mistelbach Block (see Fig. 24 and Fig. 25). In the end, these studies were used to assign the stratigraphic ages of the mapped layers in this Master's thesis.

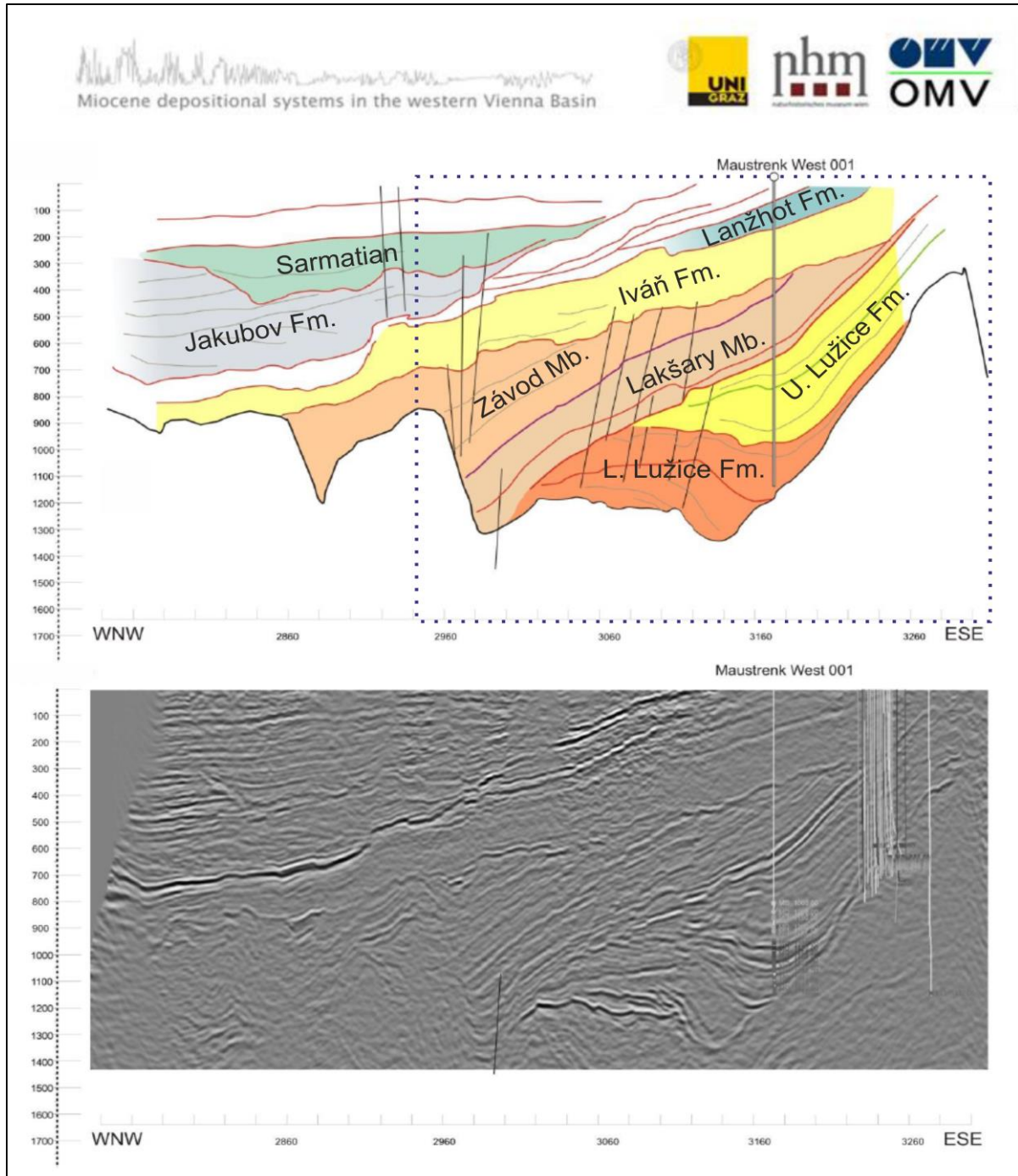


Fig. 24: Stratigraphic units of the investigated area (blue rectangle). Depth values in ms TWT. For relative age correlation see Fig. 25. Modified after Theobalt, et al. (2015).

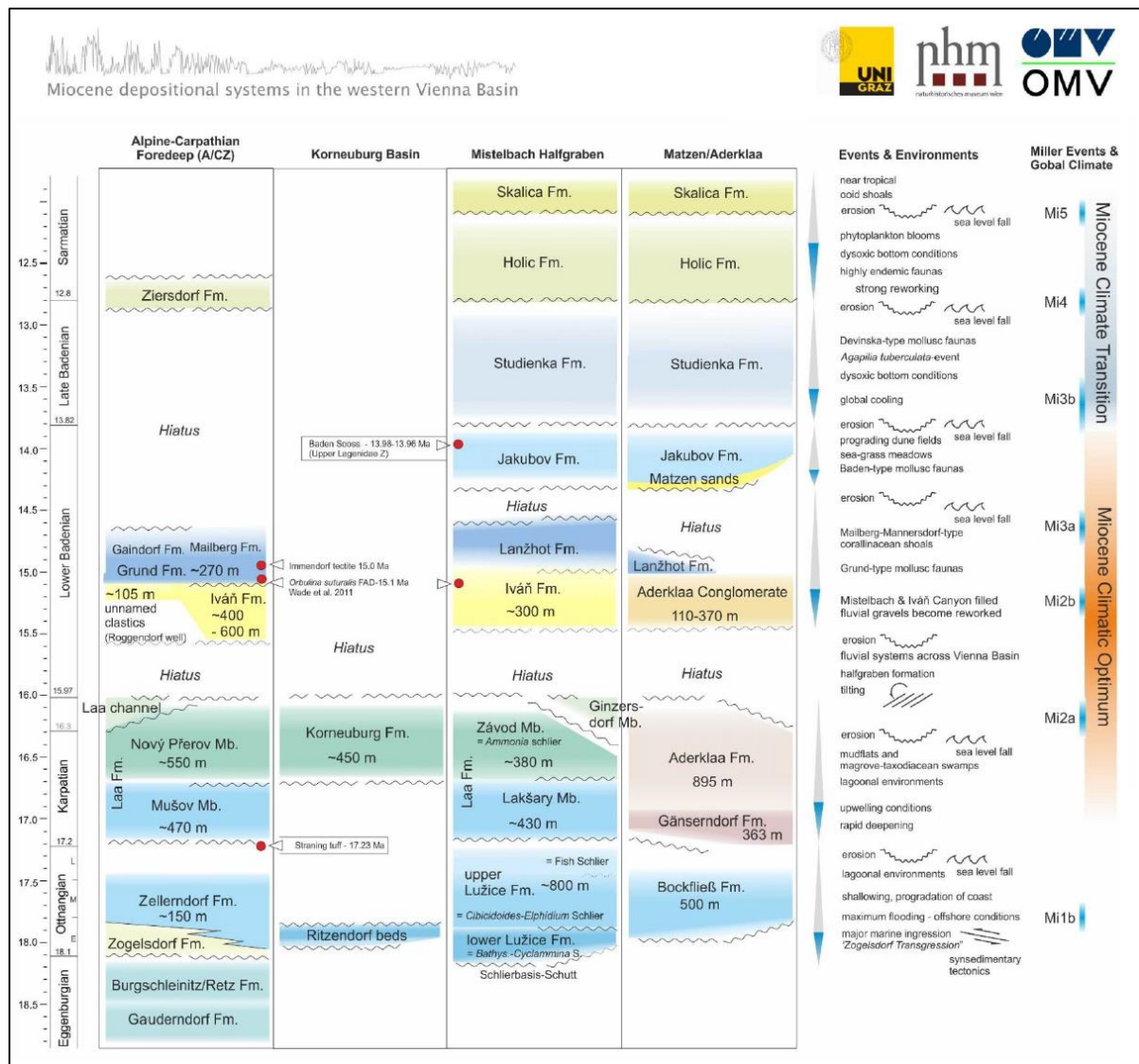


Fig. 25: Stratigraphic units of the Vienna Basin correlated to the Central Paratethys stages, geological events and the global climate changes. Units of the Mistelbach Halfgraben were used for the classification depicted in Fig. 24. Modified after Theobalt, et al. (2015).

2.3.6. Reflection pattern configuration for a seismic facies analysis

A seismic facies can be mapped as a 3D seismic unit composed of groups of reflections whose parameters differ from those of adjacent units (Mitchum, et al., 1977). Analysis of such facies are done by describing and interpreting seismic reflection parameters like configuration (reflection geometry), continuity, but also amplitude, frequency or interval velocity in a depositional sequence.

There are three main groups of reflection configuration patterns describing parallel (including subparallel and divergent), discontinuous and prograding (by lateral accretion of strata) reflector patterns.

Parallel, subparallel, as well as wavy reflections indicate uniform deposition rates expected on a uniformly subsiding surface like a shelf or a basin plain, while a divergent pattern implies lateral variation of deposition rates or tilting of a deposition surface (see Fig. 26, left).

A hummocky pattern might indicate discontinuous point bars or crevasse splays while, e.g., a chaotic configuration pattern argues for coarse-grained fluvial or turbidite channel fills (see Fig. 26, right).

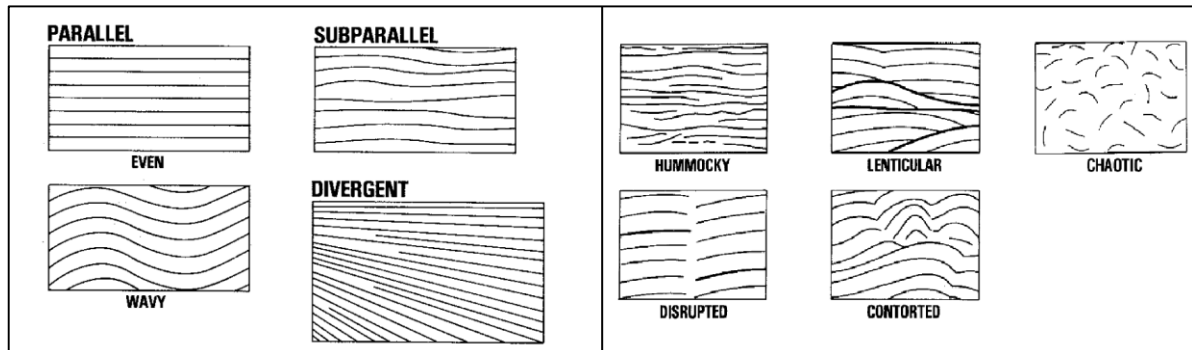


Fig. 26: Types of parallel (left) and discontinuous (right) reflection configuration patterns. Modified after Mitchum, et al. (1977).

Prograding reflection patterns usually refer to clinoforms (see Fig. 27).

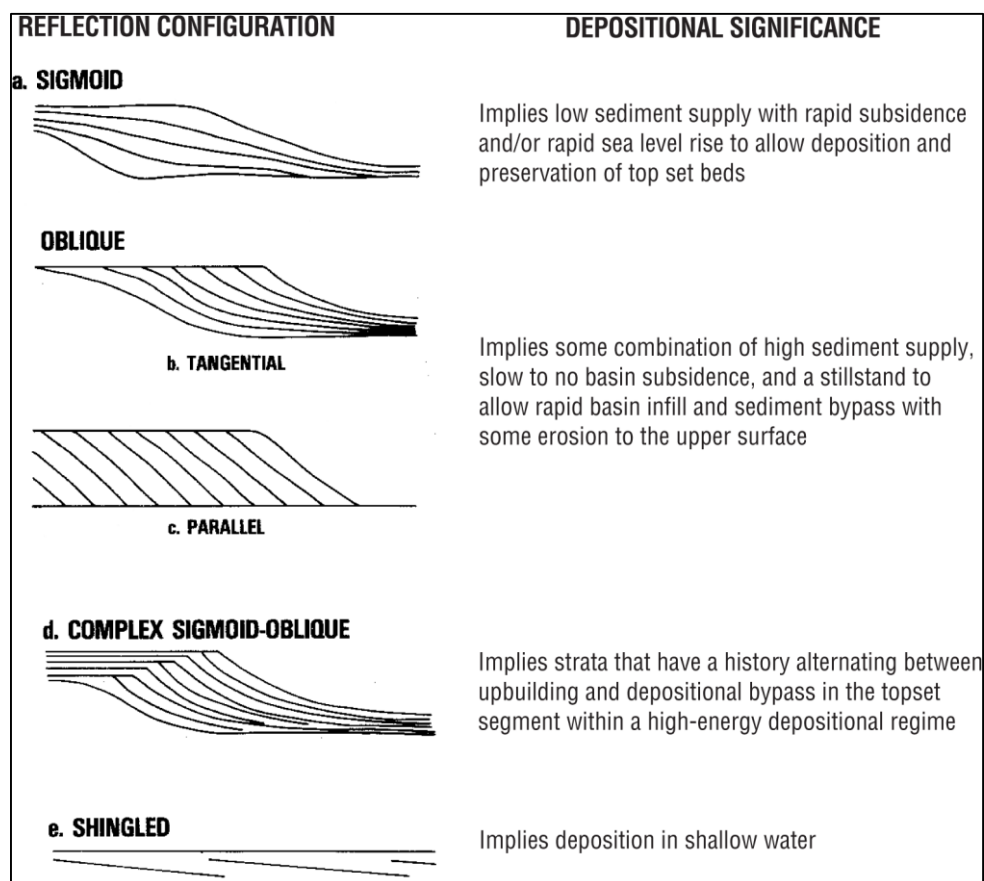


Fig. 27: Types of prograding reflection patterns. From Mitchum, et al. (1977).

A further pattern that might appear in a seismic section is the fill of a channel. A channel can be described as a negative relief feature that truncates underlying strata (see Fig. 28).

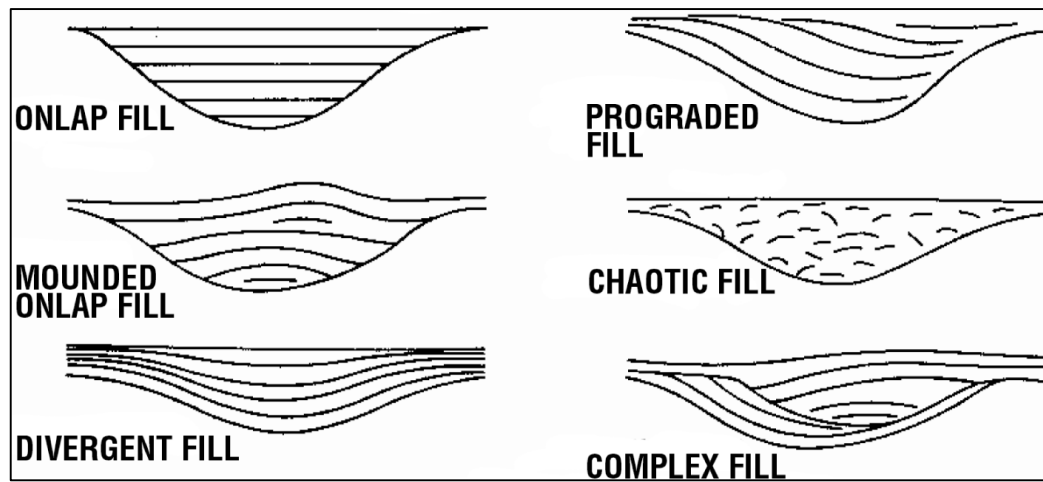


Fig. 28: Types of channel fill patterns. Onlap fill matches the pattern visible in Channel 1 (see Fig. 42). From Mitchum, et al. (1977).

The previous chapter is based on terminology described in Dolson, et al. (1999).

3. RESULTS

3.1. Sedimentary Units

The following chapter summarizes the most important sedimentary units (see Tab. 2) in the provided 3D seismic cube that were determined by horizon mapping (see Tab. 6) in Petrel. Horizons at the boundaries of the sedimentary units were identified because of high acoustic impedance or unconformities between the layers. The approximate stratigraphic ages were adopted from the studies of Theobalt, et al. (2015) by correlating the determined formations and members with the Central Paratethys stages (see Fig. 24 and Fig. 25).

Tab. 2: Overview of discerned sedimentary units, each with their approx. stratigraphic age and their surface boundaries.

Unit	Age	Boundary
Channel 1	L. Badenian (channel fill)	Angular unconformity
Channel 2	L. Badenian (channel fill)	Angular unconformity
Growth strata 3	L. Ottnangian – L. Karpatian	Unconf. pass into conf.
Growth strata 2	L. Ottnangian – L. Karpatian	Unconf. pass into conf.
Growth strata 1	L. Ottnangian – U. Ottnangian	Unconf. pass into conf.
Flysch	Cretaceous – Paleogene	Angular unconformity

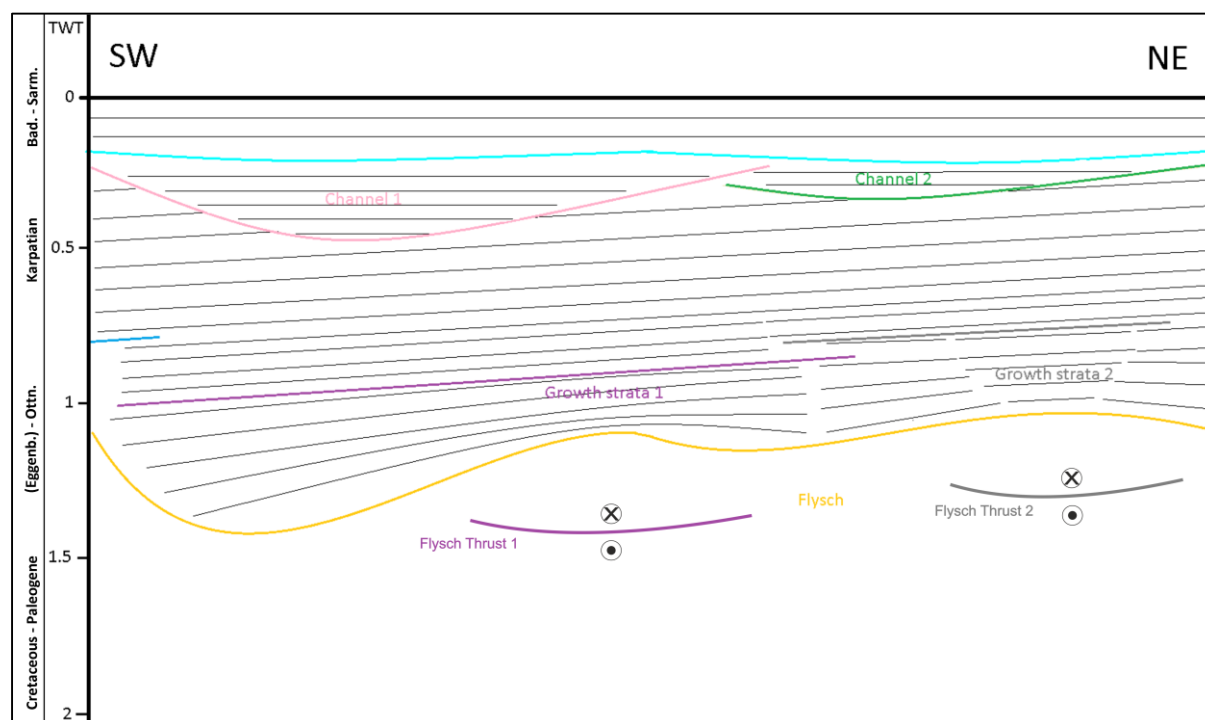


Fig. 29: Schematic cross section (SW-NE) through general flysch thrust direction in the northern area of the seismic cube. Indication of sedimentary units and the approx. stratigraphic age. Depth values in (-) s TWT.

3.1.1. Flysch

In the area of interest the flysch layer represents the pre-Neogene basement of the actual sedimentary basin (Wessely, et al., 1993). In the provided 3D seismic cubes it is the thickest and lowest layer to be distinguished and defined by the Top_Flysch horizon separating it from the overlying Miocene strata. This boundary is clearly visible in most parts of the seismic volume due to a high acoustic impedance. Furthermore there is a distinct angular and erosional unconformity noticeable between the Miocene strata and the flysch nappes (Kreuzer, 1993). These phenomena make it easy to map the horizon. Nevertheless, the amplitude of the reflector decreases in a northward direction leading to loss of reflectivity. Therefore, and due to a lack of well control the horizon was not fully mapped throughout the dataset and about one-third of the surface is missing in the north-eastern part of the seismic cube.

The elevation time of the mapped Top_Flysch horizon reaches from -121.67 ms in the east down to -1538 ms in the west almost requiring the total spectrum of the relevant time scale. The resulting difference of 1416.33 ms is the highest difference in time for a single horizon in the seismic volume (see Fig. 31). Accordingly, the highest point of the Top_Flysch horizon is located directly at the bordering Steinberg Fault (near Zistersdorf). Generally speaking, the surface dips east-north-east and reaches its low at the bordering fault system in the west (see Fig. 31).

The horizon Top_Flysch exhibits three distinct antiforms in the north-western part of the study area. These structures are located in different parts of the 3D seismic block and are interpreted to reflect antiforms resulting from thrusting of the flysch units as indicated by overlying Early Miocene growth strata. These fan-shaped growth-strata geometry laterally passes into conformity.

According to the provided well data (see 2.2.3), the flysch layer is composed of alternating sequences of Eocene, Paleocene and Cretaceous strata. An Oligocene stratum, which does not belong to the flysch unit, was encountered in the deepest part (about -5,000 m to -6,000 m) of the deep borehole MAUSTRENK UEBERTIEF 001a (Fig. 30). However, the resolution power decreases with depth (see Fig. 11) making it very hard to determine expected underlying layers (e.g., Waschberg Unit) or to differentiate between the various nappes in the flysch unit.

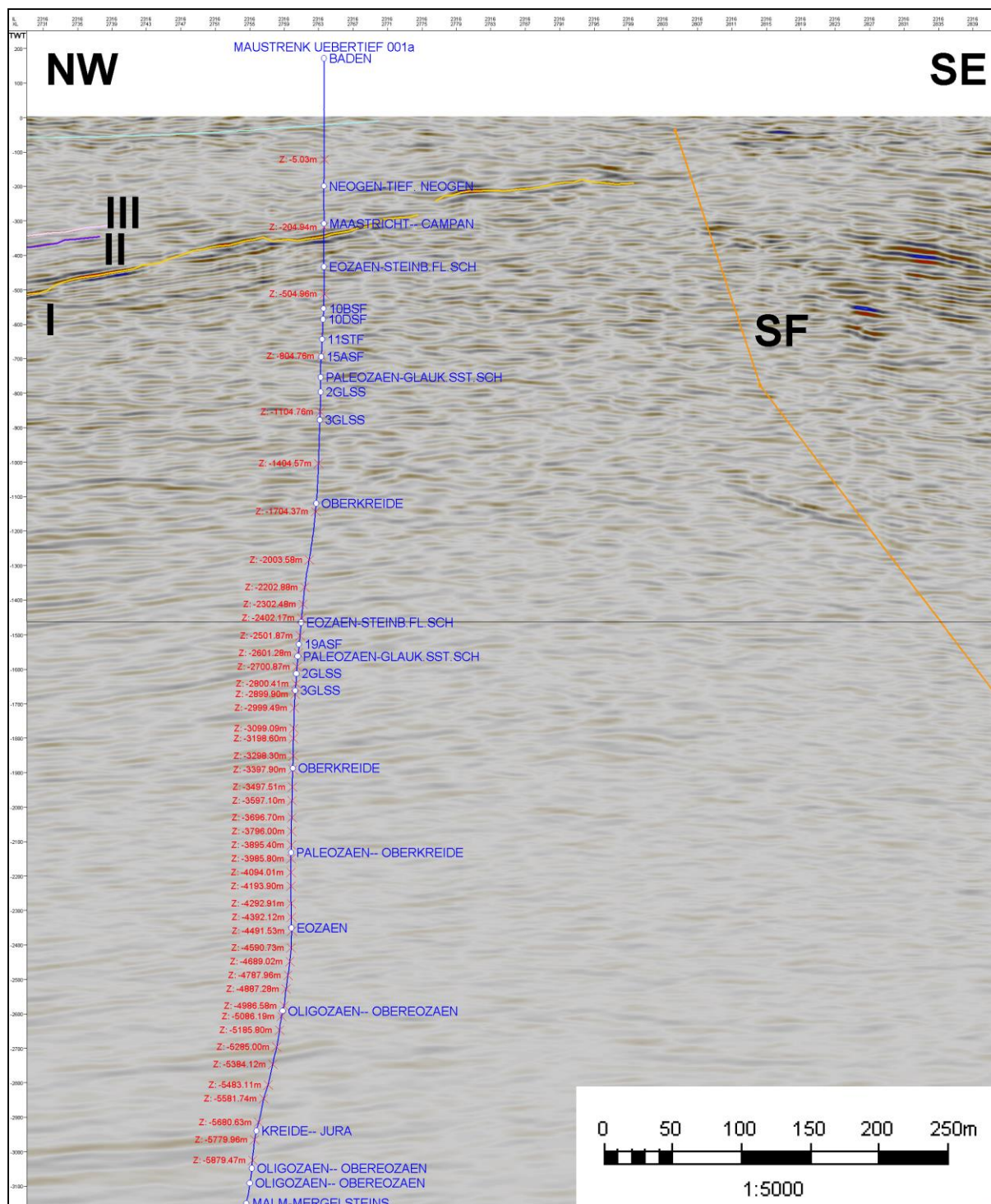


Fig. 30: Inline [2316] with Well Trace of MAUSTRENK UEBERTIEF 001a (Fig. 23) and Well Tops (blue). Depth values (red) from checkshot. I: Top_Flysch; II: Top_Growth_1; III: Channel_1; SF: Steinberg Fault.

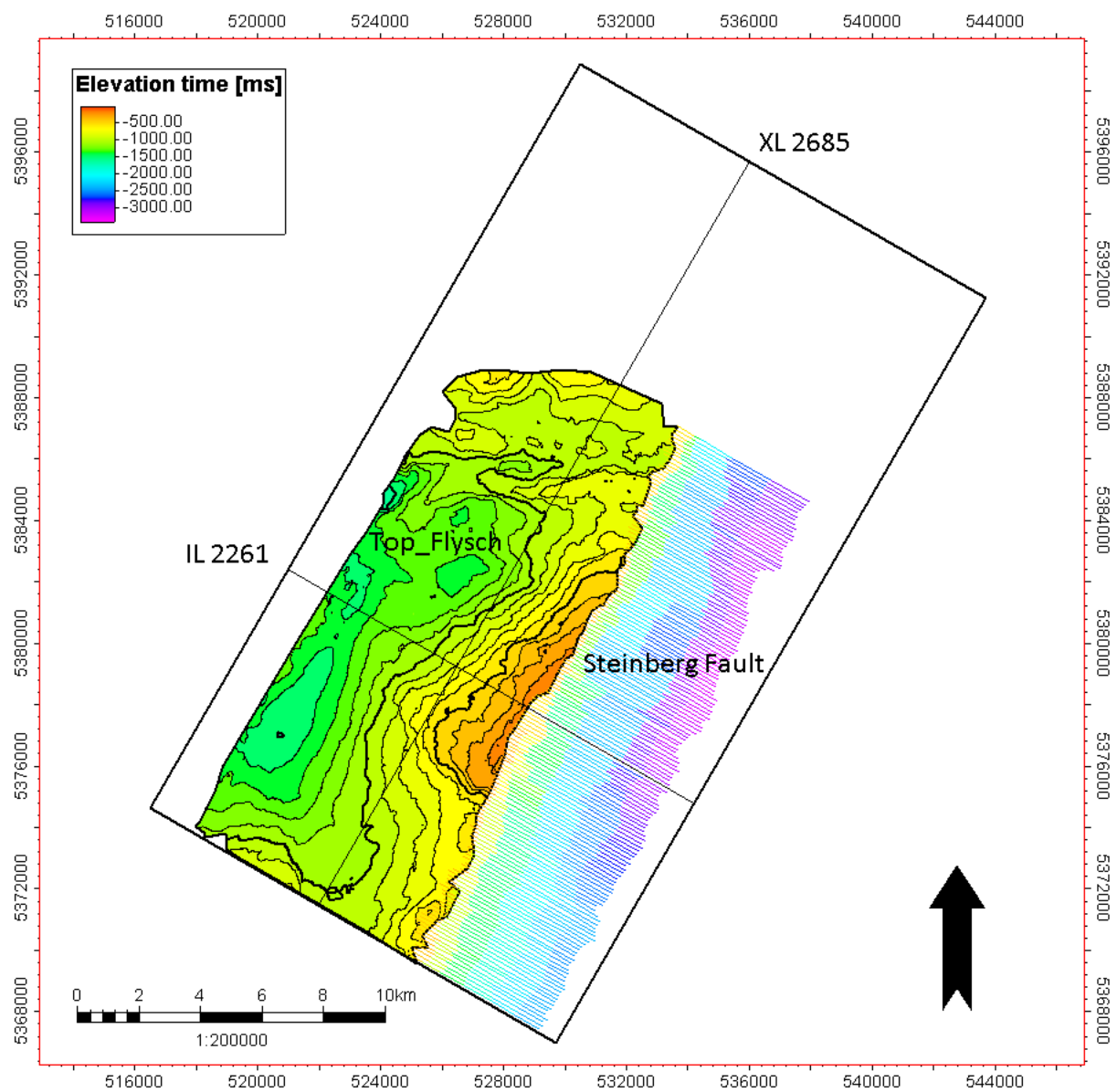


Fig. 31: 2D overview of Top_Flysch horizon. Depth values in ms TWT. See Fig. 1 for geological information.

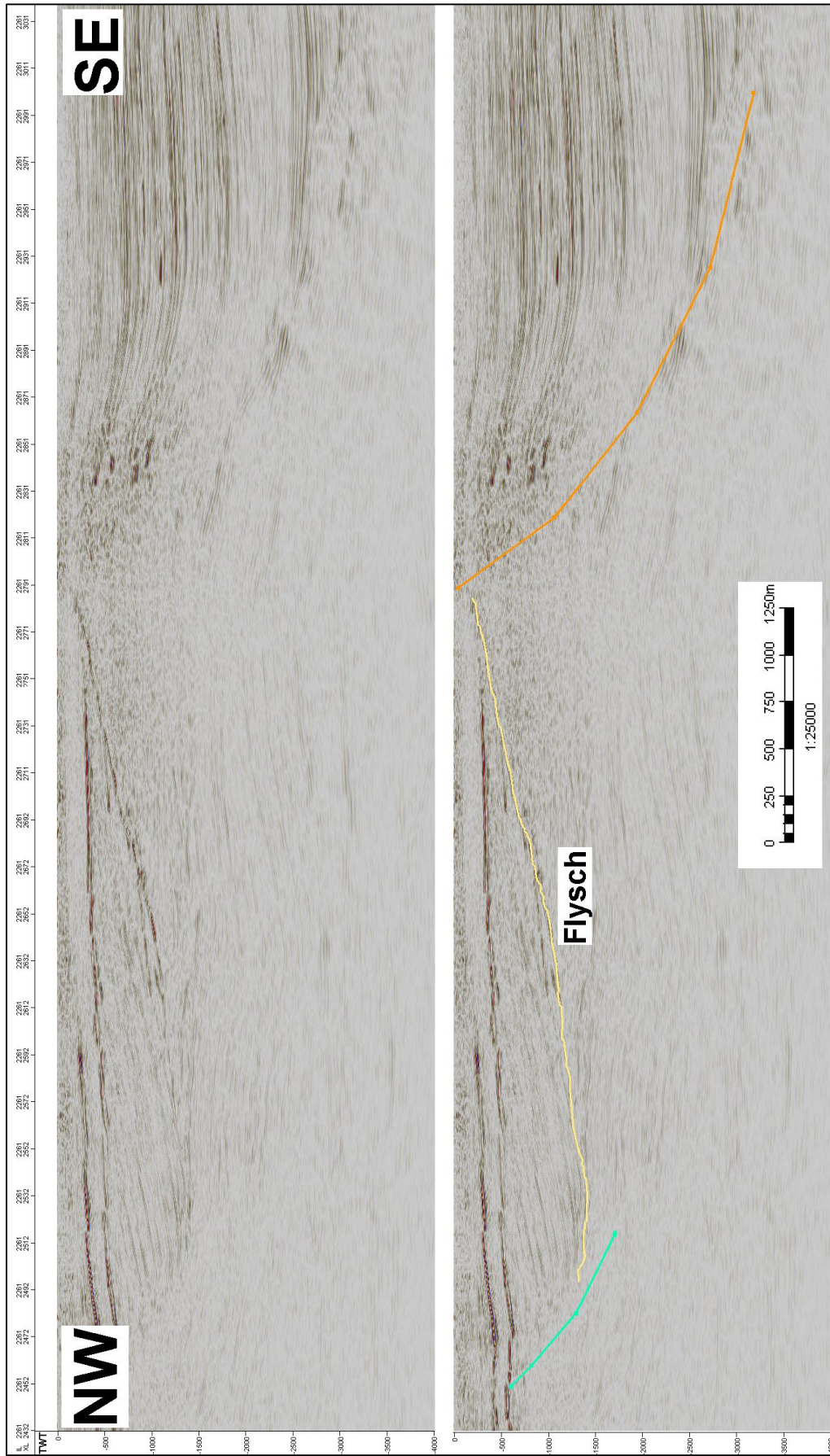


Fig. 32: Inline 2261 with faults and Top_Flysch horizon. Depth values in ms TWT. See Fig. 31 for location.

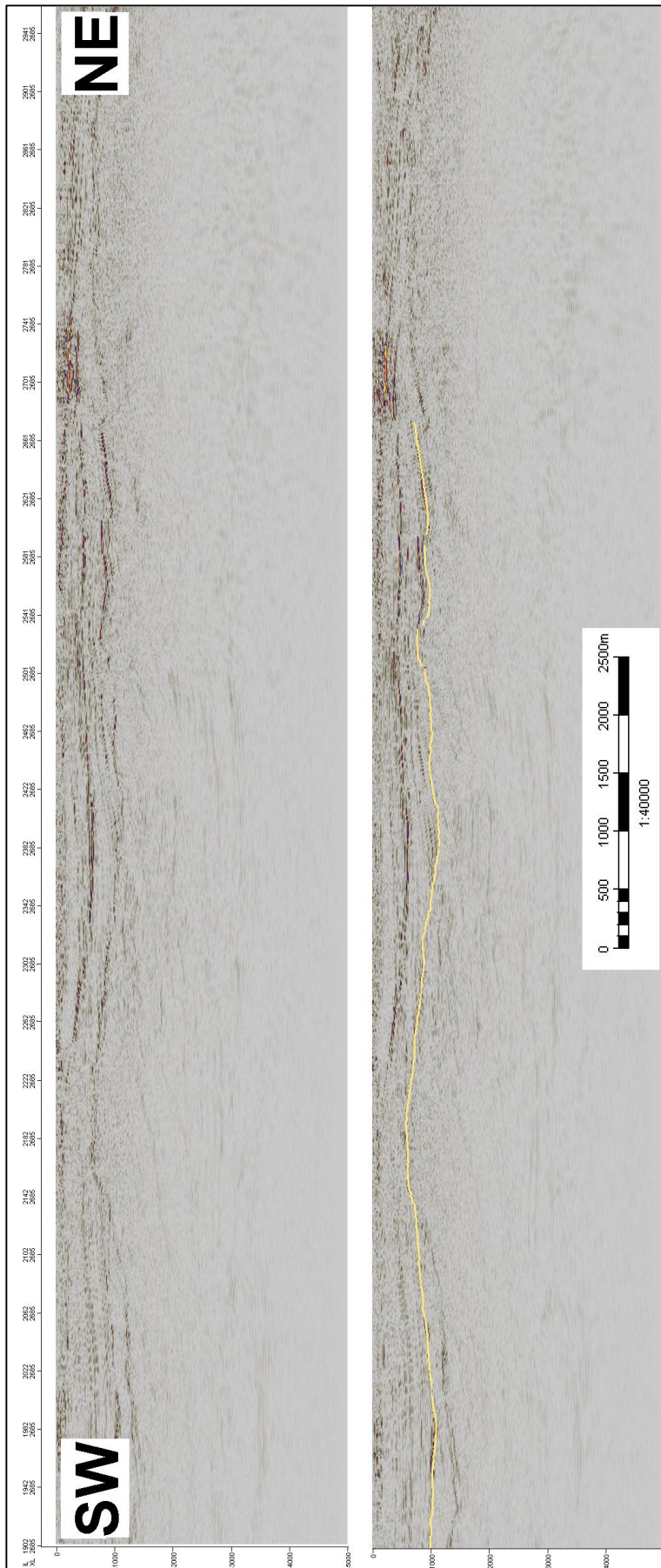


Fig. 33: Xline 2685 with Top_Flysch horizon. Depth values in ms TWT. See Fig. 31 for location.

3.1.2. Growth strata

In the Miocene strata, which overlie the flysch nappes, various unconformities can be distinguished. An angular and erosional unconformity exists between the lowermost Neogene sequence and the pre-Neogene basement (Kreuzer, 1993).

Early Miocene growth-strata were identified at three different locations in the seismic cube that suggest syntectonic sedimentation during the growth of distinct flysch antiforms. The tops of all three layers were mapped serving as an indicator for the ceasing fold growth. These top surfaces represent a border to the overlying, concordant strata and usually also pass laterally into conformity.

Although these three events do not have the same age, they all show tectonic activity during the Ottnangian stage. Two of the events seem to continue into the Lower Karpatian.

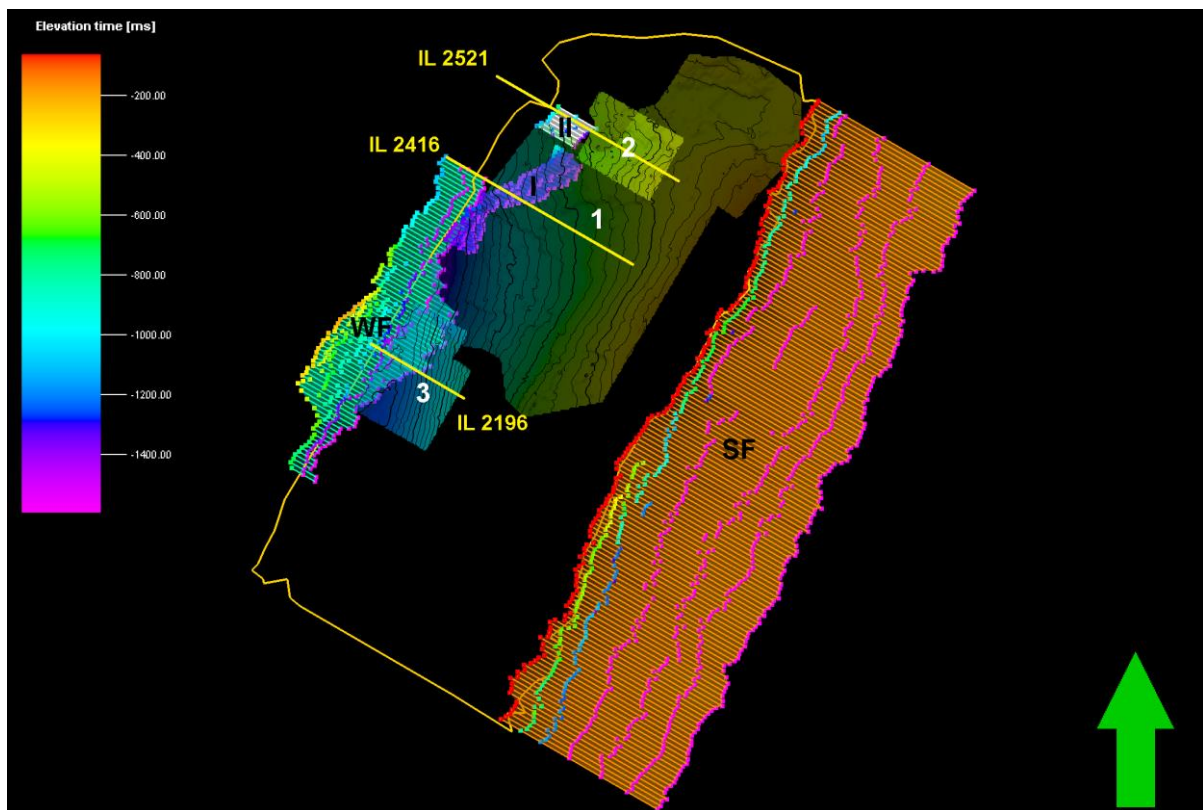


Fig. 34: 2D overview of Top_Growth horizons (1-3) and all mapped faults: Flysch Thrust 1 (I); Flysch Thrust 2 (II); Fault System West (WF); Steinberg Fault (SF). Objects have different transparency. Depth values in ms TWT. The orange polygon represents the border of the Top_Flysch horizon.

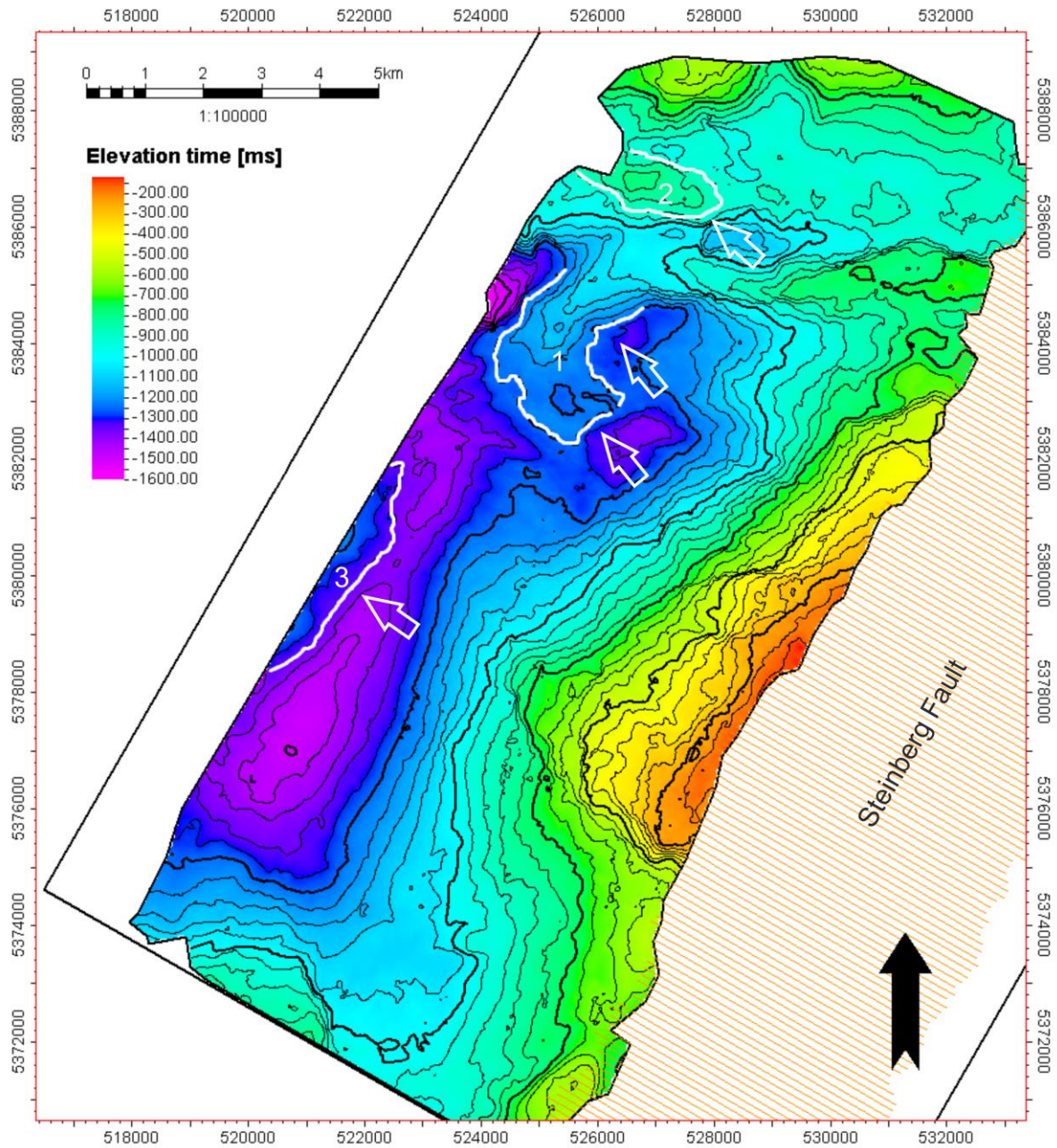


Fig. 35: Location of antiforms (1-3) in Top_Flysch horizon that are responsible for the respective growth strata. White arrows indicate the approx. direction of thrusting.

Thrust faults were mapped within the flysch units below the antiforms. In regard to these flysch antiforms with their respective thrust direction, thrust surfaces range from approximately 1 to 4 km in length. The thrust distances were estimated to a scale of a few hundred meters.

3.1.2.a. Growth strata 1

In the northern region of the Top_Flysch surface an overlying horizon called Top_Growth_1 was mapped (see Fig. 34). Reflectors between these two sequence boundaries show an irregular thickness of strata because the layers decrease in thickness in north-west direction where they overlie the backlimb of a flysch antiform (see Fig. 36). Similar fanning geometries of growth strata can be distinguished only slightly in the forelimb. Therefore, this succession was named Growth strata 1. The Top_Growth_1 surface dips west with a rather constant fall. The calculated dip angle attribute in Petrel shows a maximum of 47°. However, it must be considered that a dip angle in time does not necessarily conform to the actual situation in depth.

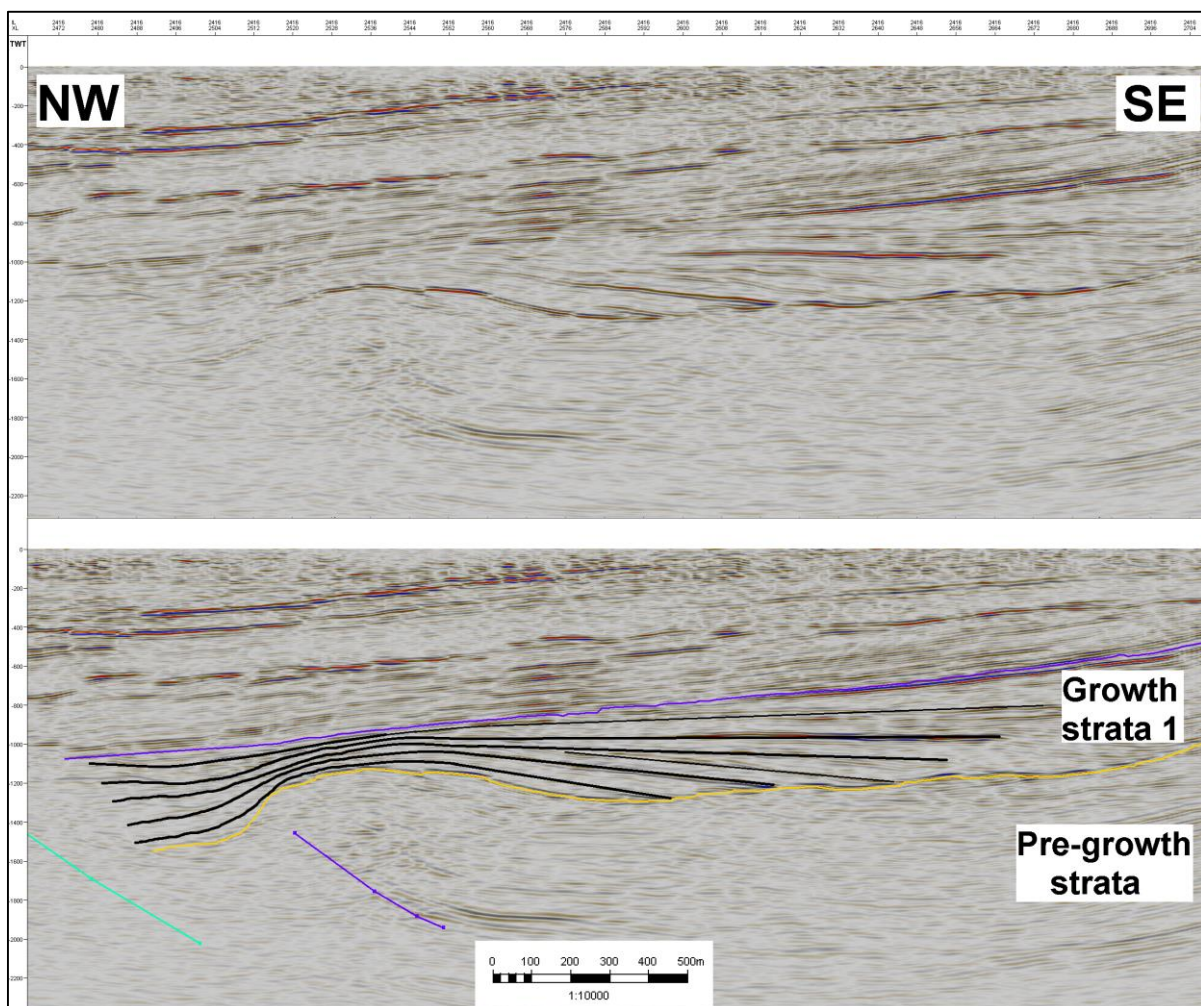


Fig. 36: Petrel Interpretation Window - Inline 2416 with horizons: Top_Growth_1 (purple); Top_Flysch (yellow) and faults: Fault System West (turquoise); Flysch Thrust 1 (purple). Growth strata indicated with black lines. Depth values in ms TWT. See Fig. 34 for location.

The TWT values of the Top_Growth_1 surface range between -127 ms and -1396 ms. The underlying antiform reaches an amplitude maximum of almost 500 ms TWT. The wavelength

lies between 2 and 3 km. The length of the thrust surface, measured parallel to the strike direction, amounts to 2.5 km.

Due to the growth strata phenomena the reflection pattern configuration is rather divergent in areas above the flysch antiform.

The reflector of the Top_Growth_1 horizon is well visible due to relatively high acoustic impedance, as well as an angular unconformity regarding the growth strata below this surface. Compared to the other growth events, the Top_Growth_1 horizon seems to be the stratigraphically oldest one formed.

3.1.2.b. Growth strata 2

A further layer above the Top_Flysch horizon was distinguished by mapping a horizon section called Top_Growth_2 (see Fig. 34). Unconformities and a varying thickness of strata between an antiform of the Top_Flysch horizon and the Top_Growth_2 horizon can be determined (see Fig. 37). Growth strata distinctly pinch-out in the backlimb towards the crest of the antiform. Therefore, this layer was called Growth strata 2. The Top_Growth_2 surface section ranges from Inline 2486 to 2566, as well as from Xline 2560 to 2670. The time values range from -420 ms downwards to -684 ms in TWT where the minimum is reached at the north-west determining the dip direction of the surface. The amplitude of the antiform reaches its maximum at 300 ms. The wavelength amounts to around 3 km while the thrust surface shows a length of about 1 km, measured parallel to the strike direction.

Seismic facies analysis on the Inline planes results in a rather divergent reflection pattern configuration above the flysch antiform. Xline planes show a rather parallel and even configuration of the seismic reflection pattern within the Growth strata 2 layer. The acoustic impedance of the Top_Growth_2 horizon is lower than the one of other horizons in this seismic cube but is clearly visible, especially on the Xlines over long distances. This horizon distinctly overlies the Top_Growth_1 horizon suggesting a relatively younger age.

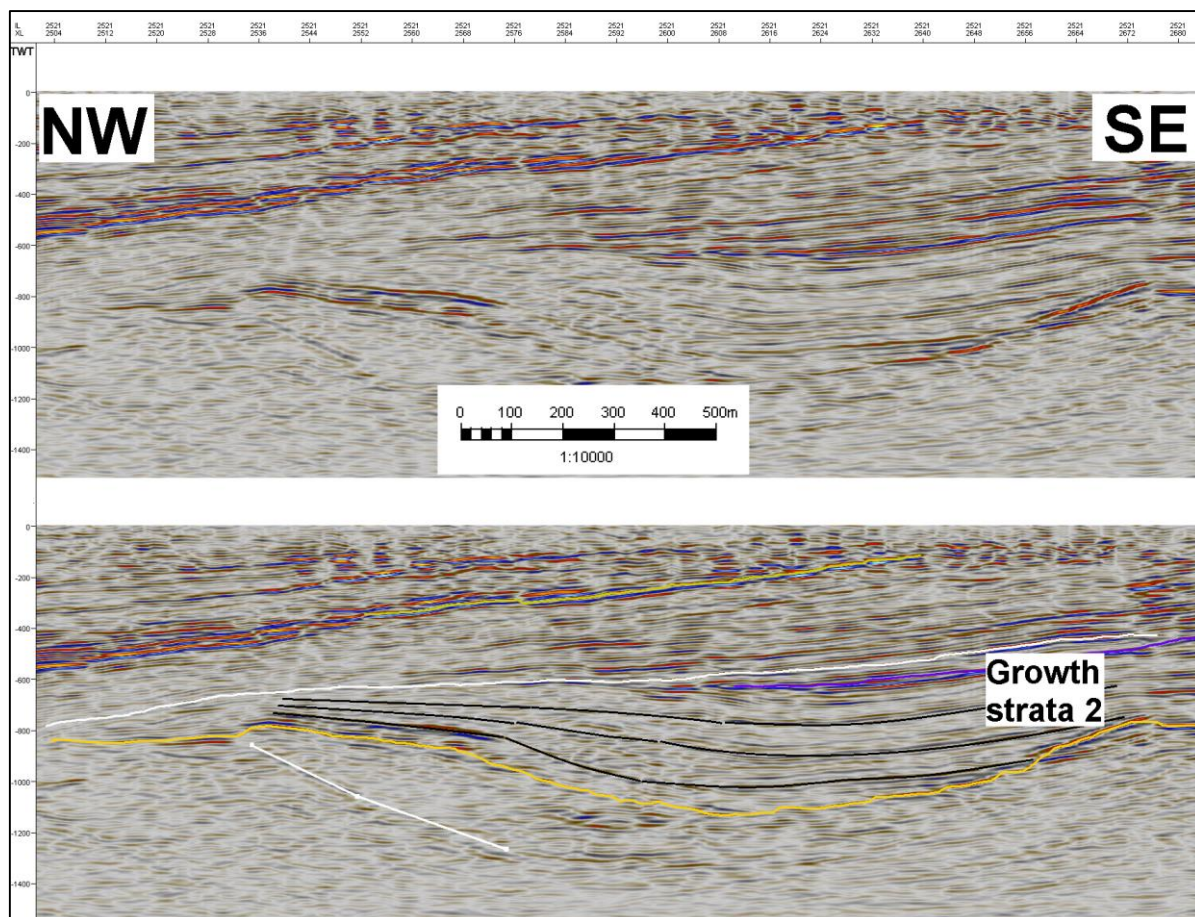


Fig. 37: Petrel Interpretation Window - Inline 2521 with horizons: Top_Growth_2 (white); Top_Growth_1 (purple); Top_Flysch (yellow) and faults: Flysch Thrust 2 (white). Growth strata indicated with black lines. Depth values in ms TWT. See Fig. 34 for location.

3.1.2.c. Growth strata 3

The third growth strata layer was mapped in the western area of the seismic block. Its top surface is defined by the Top_Growth_3 horizon (see Fig. 34). This layer also images fan-shaped strata in the hinterland resulting from north-westwards decreasing in thickness. These strata overlie a kind of monocline in the Top_Flysch horizon that ends up in the Fault System West (see Fig. 38). The layer was named Growth strata 3.

The Top_Growth_3 surface is bordered by Inline 2121 and 2261 as well as Xline 2500 and 2595. It slightly dips westwards with a maximum Z value of -868 ms and a minimum of -1275 ms. The fold seems to have an amplitude of at least 200 ms and the thrust surface reaches a length of more than 4 km in the provided 3D seismic cube.

Its acoustic impedance is not outstanding but the angular unconformities differentiates this layer from the overlying strata.

The configuration of the seismic reflection pattern is very parallel in this layer but divergent in the area adjacent to the basement fold.

Regarding the stratigraphic succession, this top surface is younger than Top_Growth_1 and probably also younger than Top_Growth_2 suggesting this layer to be the relatively youngest out of the three growth strata layers.

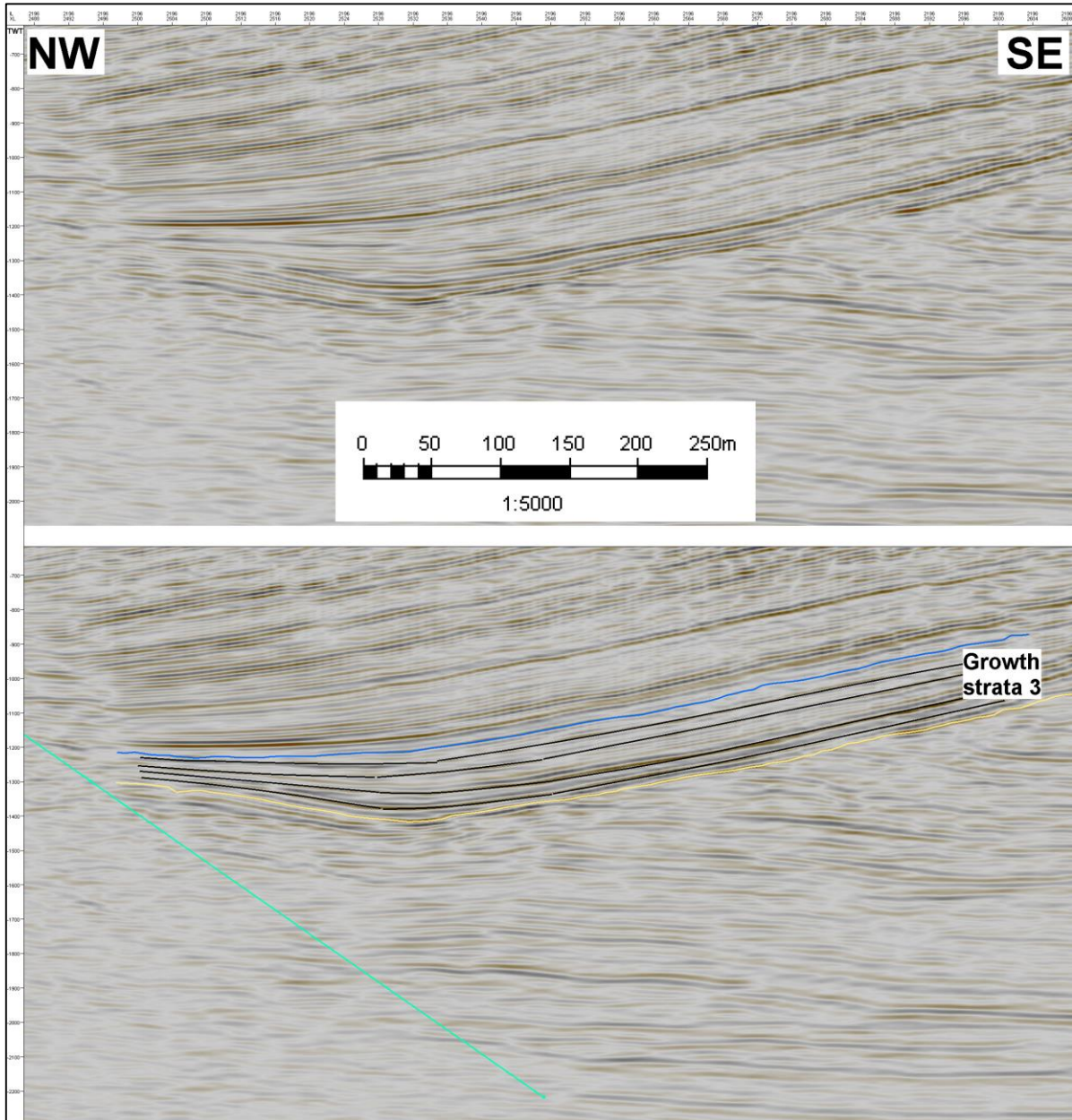


Fig. 38: Petrel Interpretation Window - Inline 2196 with horizons: Top_Growth_3 (blue); Top_Flysch (yellow) and Fault System West (turquoise). Growth strata indicated with black lines. Depth values in ms TWT. See Fig. 34 for location.

3.1.3. Channels

3.1.3.a. Channel 1

In the provided seismic 3D cubes a distinct channel can be distinguished. Its erosive base was mapped as a horizon called Channel_1 (see Fig. 42). It is traceable from the north-western border of the seismic cube until the Steinberg Fault in the south-east. The mapped south-west – north-east extent ranges from Inline 2192 to Inline 2526. Channel 1 reaches a diameter of 7 km to 8 km. It dips north-west with maximum Z values of -49 ms and a minimum of -816 ms resulting in a delta value of 767 ms in total. The dip angle stays reasonably constant. At the deepest point the thickness of the channel fill reaches more than 350 ms.

The channel base is clearly visible in the seismic due to high acoustic impedance of the reflector and the angular unconformities. The sediment fill of Channel 1 shows low-reflectivity or an almost reflection-free pattern configuration in some areas. Reflectors of the channel fill are parallel and even and show onlaps onto the basal unconformity of the channel.

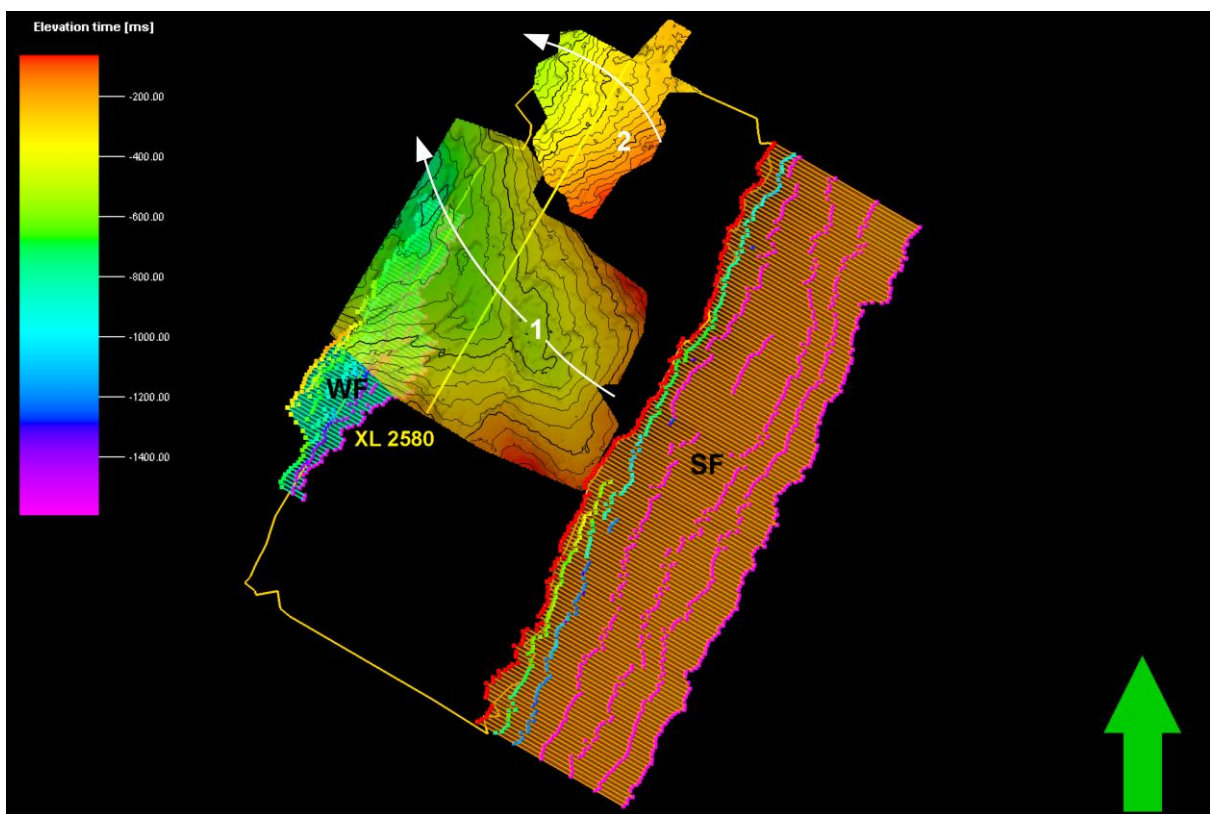


Fig. 39: 2D overview map of horizons: Channel_1 (1); Channel_2 (2) and faults: Fault System West (WF); Steinberg Fault (SF). Objects have different transparency. Depth values in ms TWT. The orange polygon represents the border of the Top_Flysch horizon. White arrows indicate the channel axes.

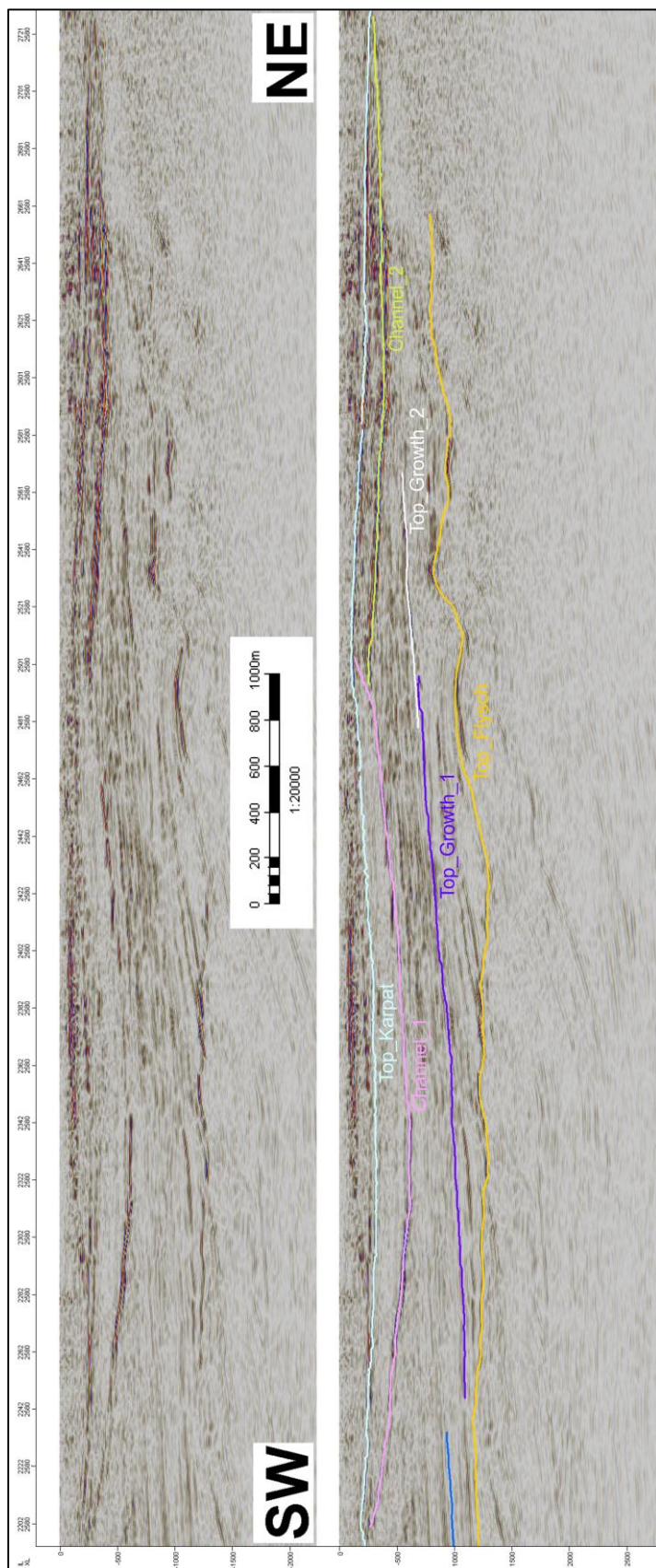


Fig. 40: Xline 2580 with overview of important horizons. Depth values in ms TWT. See Fig. 39 for location.

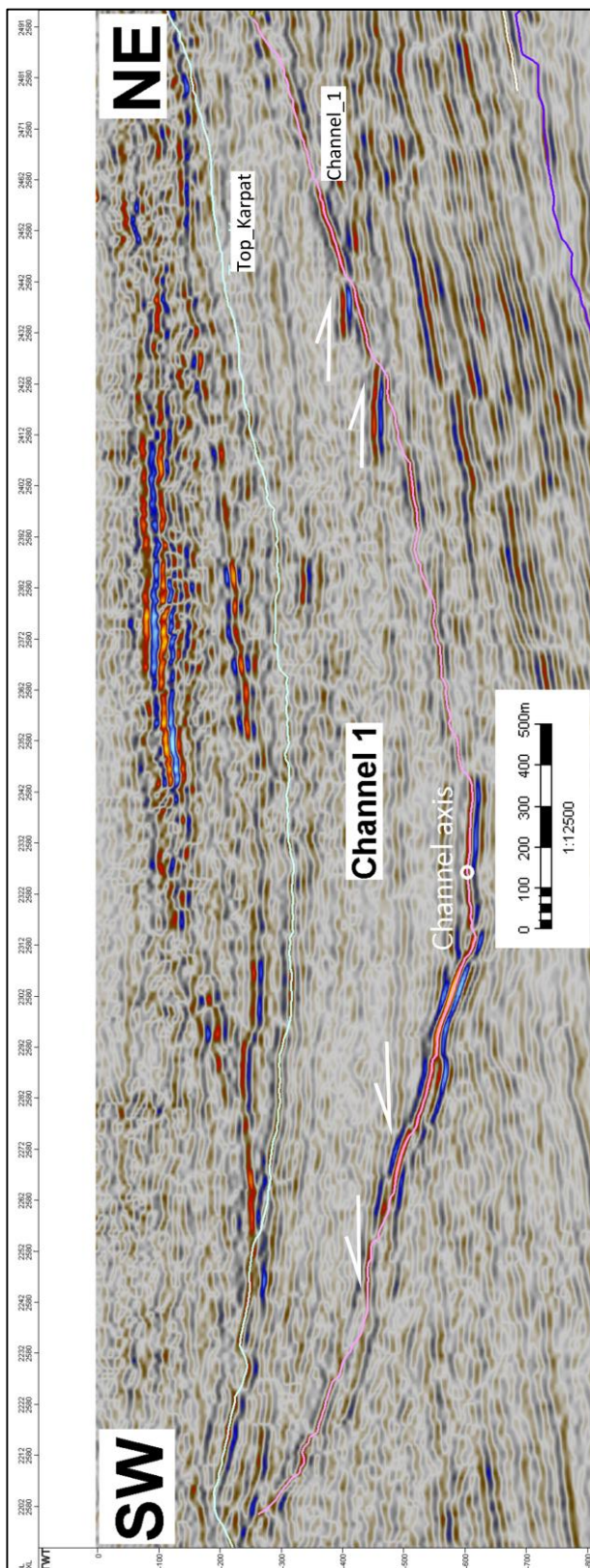


Fig. 42: Xline 2580 focused on Channel 1. Indication of channel axis and onlaps. Depth values in ms TWT. Z scale exaggerated by factor 3. See Fig. 39 for location.

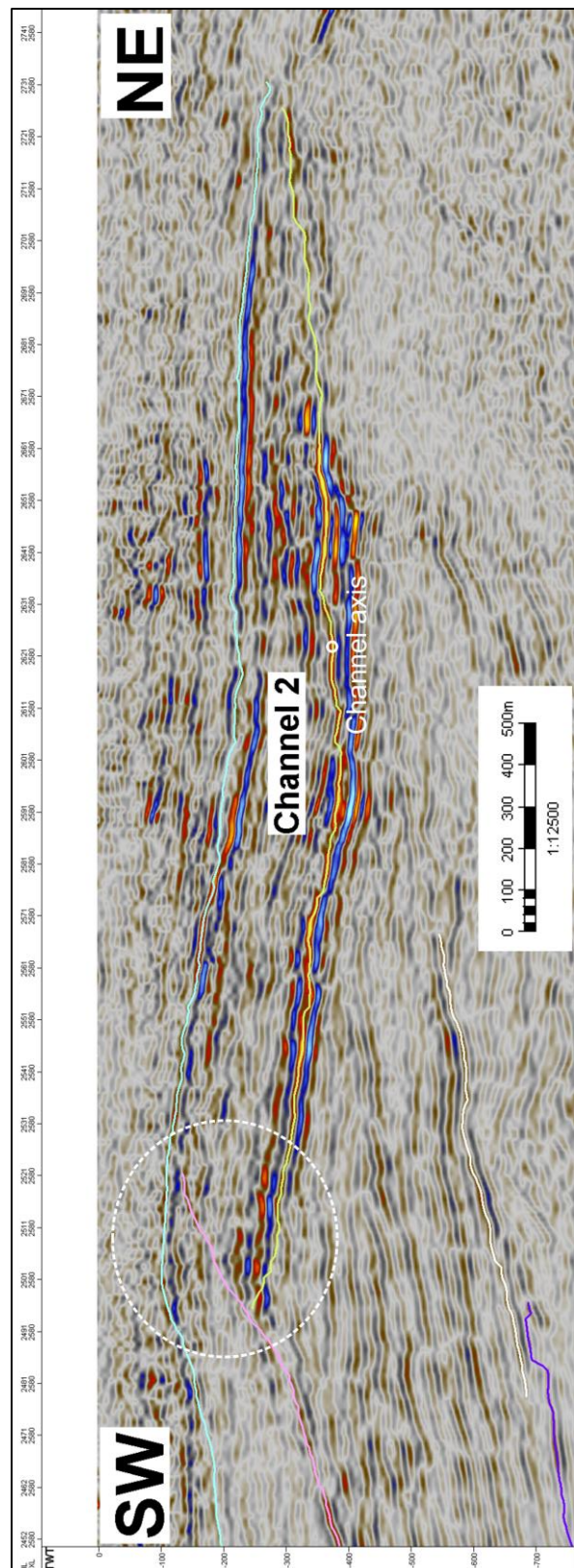


Fig. 41: Xline 2580 focused on Channel 2. Indication of channel axis and cutting by Channel 1. Depth values in ms TWT. Z scale exaggerated by factor 3. See Fig. 39 for location.

3.1.3.b. Channel 2

A smaller channel was mapped with a base horizon named Channel_2 (Fig. 41). It is located in the northern part above the mapped Top_Flysch horizon and bordered at Inline 2486, as well as at Inline 2741 at the northernmost part. The north-west boundary is located at Xline 2490. The south-west boundary lies on Xline 2660. Channel 2 reaches a diameter of 5 km to 6 km in the mapped sector. It seems to dip north-west with a maximum of -113 ms in TWT and a minimum of -587 ms. The difference in time amounts to 473 ms for the base surface Channel_2. The dip angle is relatively constant. At the deepest point the channel fill shows a thickness of about 100 ms.

The sequence boundary at the base, as well as the reflectors of the overlying sediment fill are clearly visible. The configuration of the reflection pattern in the Channel 2 layer can be described as parallel.

The direction of flow, which is represented by the channel axis, appears rather parallel to Channel 1 (see Fig. 39). Some distinct intersection zones between the two channels were mapped imaging the cutting of Channel 2 by Channel 1 (see Fig. 41). This fact determines Channel 2 to be older than Channel 1, which developed after the fill of Channel 2 was completed.

3.1.4. Karpatian

The Karpatian stage was not well-defined in this seismic cube. OMV provided an already mapped Top_Karpat horizon that was imported into the Petrel project. It should define the upper limit of the Karpatian stage. It is the uppermost mapped surface within this Master's thesis (see Fig. 40). This horizon covers the whole seismic cube and even beyond. It is only bound to the east by the Steinberg Fault. However, a new stratigraphic classification of the Miocene units covering the Mistelbach Block was developed by Theobalt, et al. (2015). These results date the provided Top_Karpat horizon to Lower Badenian stage (see 2.2.5).

3.2. Flattened Horizons

A similar dipping of several mapped horizons such as Channel_1 and Channel_2, as well as of the various growth strata layers, can be observed. According to their final geometry, a tilting of these successions is suggested after their deposition.

Petrel 2012.1 provides a feature called "Horizon Flattening" which allows the user to flatten seismic interpretation data, e.g., in the Interpretation Window. This process can help to get a better idea of the original geometries of strata before tectonic deformation took place.

In this case it is possible to virtually remove this postsedimentary event of tilting from the final appearance of strata that is visible in the current 3D seismic cube.

3.2.1. Flattened Top Growth 1

The Top_Growth_1 horizon was flattened in an Interpretation Window for the Inline. The result gives an impression of the situation of underlying growth strata at the end of sedimentation regarding the Growth strata 1 layer (see 3.1.2.a). The underlying Top_Flysch horizon also appears rather parallel to the Earth's surface after the flattening of Top_Growth_1 horizon. The antiform is even more clearly visible than before running this process. Its resulting growth strata dip steeper now. The antiform shows a steeply dipping forelimb and a gently dipping backlimb. It amounts to more than 1 km in horizontal length and indicates north-west directed thrusting as its cause. A subsequent tilting, that might be related to normal faulting in the west, resulted in north-west dipping of the Growth strata 1 layer.

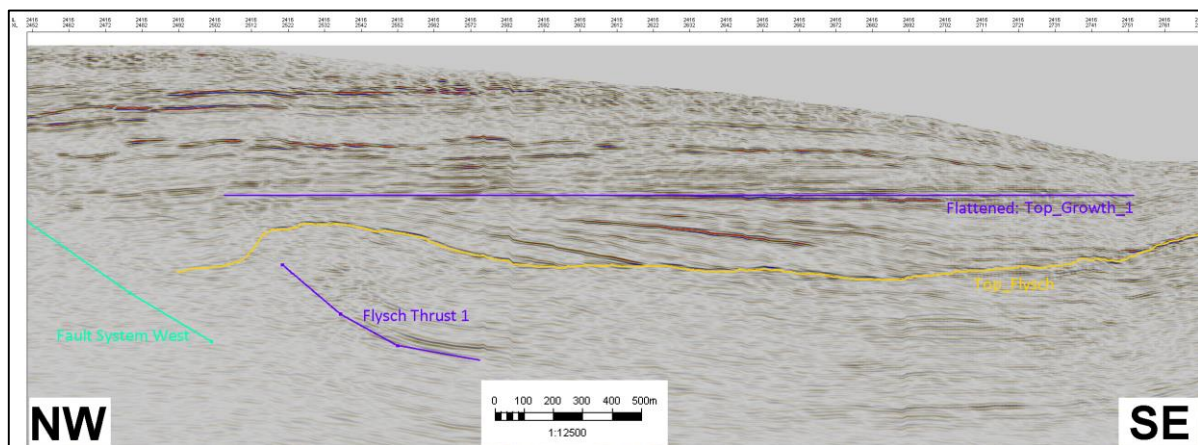


Fig. 43: Inline 2416 with flattened Top_Growth_1 horizons and related faults. See Fig. 36 for comparison.

3.3. Fault Systems

In the processed 3D seismic cube the mapped Top_Flysch surface, as well as most of the mapped, overlying, Miocene horizons are bound by two distinct fault systems. In the north-west the seismic horizons are terminated by a fault system labeled here as Fault System West. In the south-east the so-called Steinberg Fault represents a clear boundary for all mapped horizons.

In the south-west a border results from the end of the provided seismic cube cutting off all objects mapped within this Master's thesis. In the north-eastern region of the cube more noise is imaged and most seismic reflectors become unclear in several sections leading to the decision to stop seismic mapping at Inline 2691. See Fig. 44 and Fig. 45 for overview.

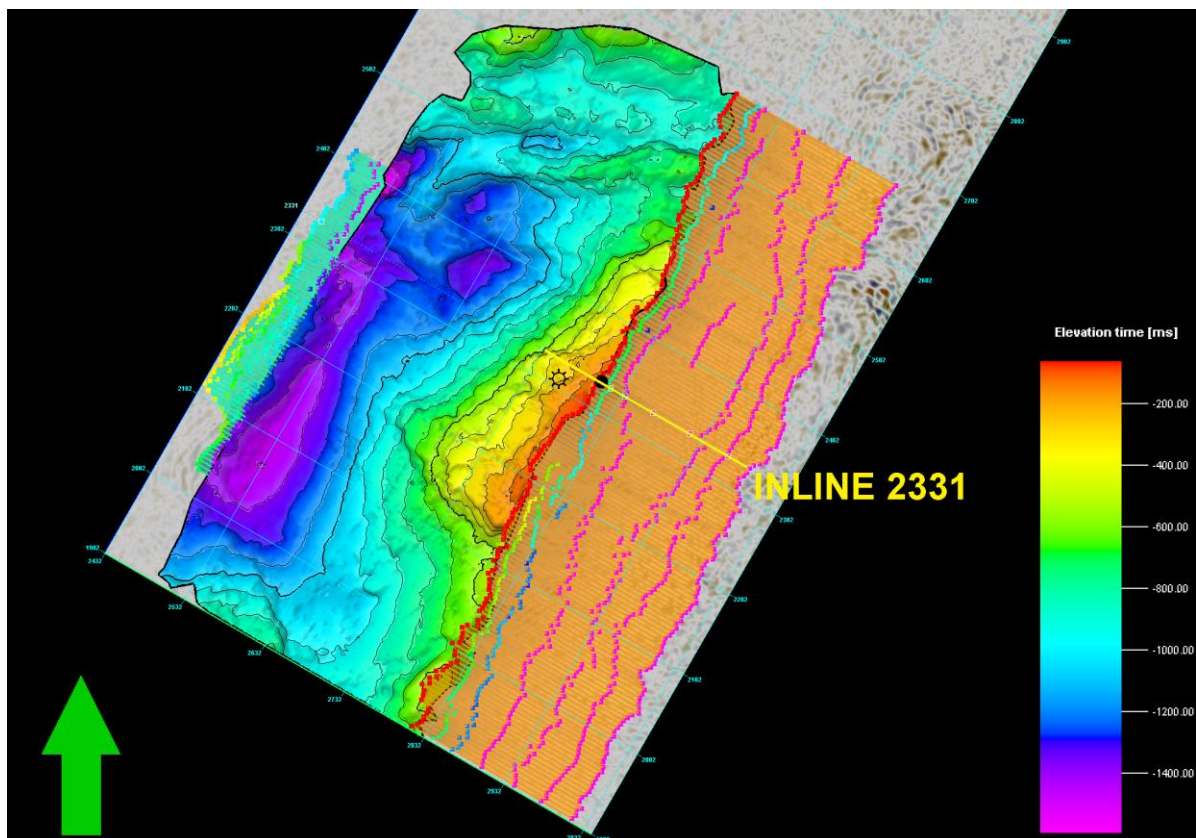


Fig. 44: Petrel 2D overview of Fault System West (turquoise) and Steinberg Fault (orange) bordering the Top_Flysch horizon. Depth values in ms TWT.

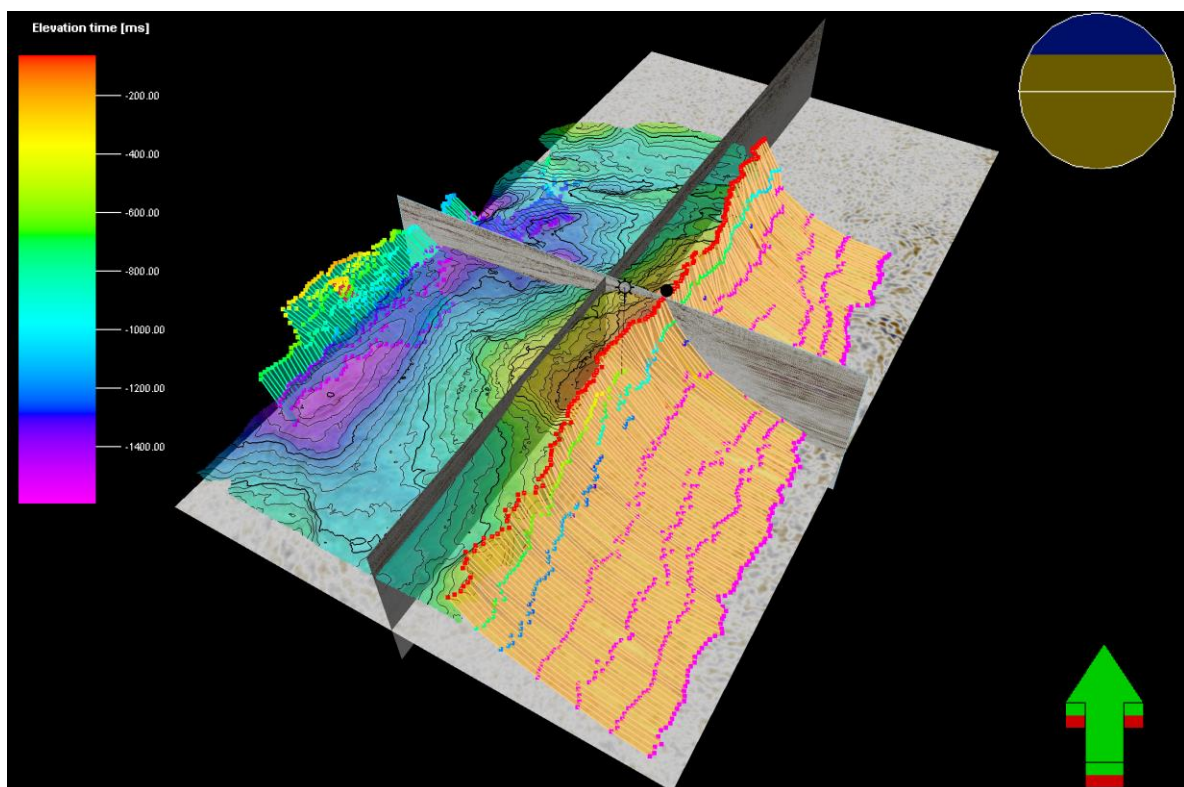


Fig. 45: Petrel 3D overview of Fault System West (turquoise) and Steinberg Fault (orange) bordering the Top_Flysch horizon (Transparency: 50%). Depth values in ms TWT. Inline: 2331.

3.3.1. Steinberg Fault

The so-called Steinberg Fault is clearly visible in this 3D seismic cube due to a huge and distinct offset of the layers. This south-west – north-east striking fault system cuts off all mapped horizons in this area. In the seismic profile, the mapped fault surface dips east-south-east with an inconstant dip angle. Generally, the dip angle decreases with depth in TWT seismic resulting in a listric fault geometry that is visible in all Inline cross sections of the cube (see Fig. 46).

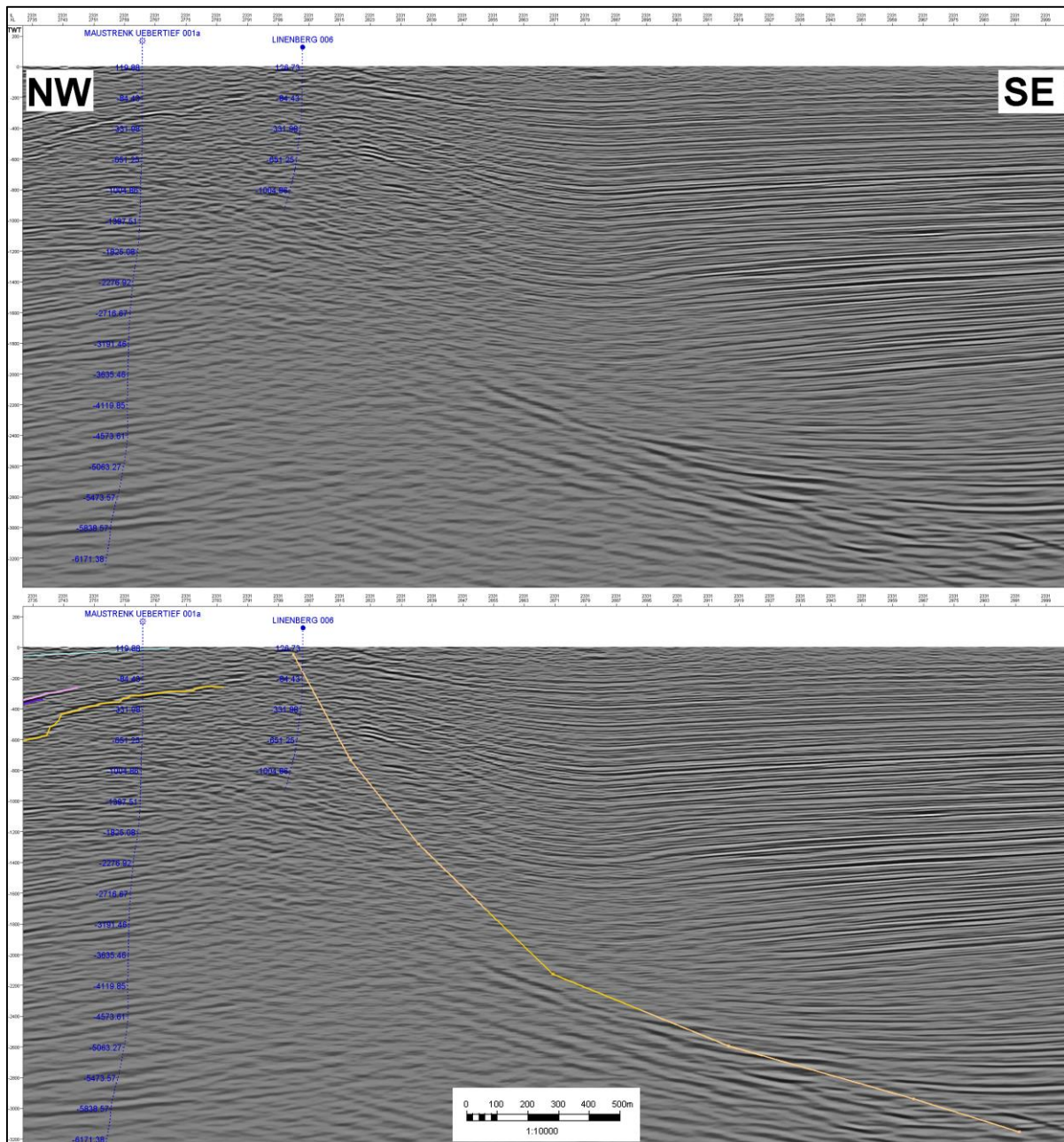


Fig. 46: Inline 2331 with Steinberg Fault (orange) and horizons. Depth values in ms TWT. Wells with depth values in m. Checkshot from MAUSTRENK UEBERTIEF 001a.

Due to the fact that seismic wavelength and velocity increases with depth (see Fig. 11), the dip angle of fault surfaces and their bend in a TWT seismic profile can differ from the actual geometry. Hence, a listric fault geometry might also be the consequence of depth distortion. The supposed flysch sequence in the footwall differs from the overlying Miocene layers because of less and unclear seismic reflectors with lower amplitudes. The hanging wall, in contrast, images the Miocene reflection pattern showing many clear, parallel reflectors with high amplitudes until a much greater depth.

The mapped fault has a maximum Z value in TWT of -13 ms revealing the fact that it reaches the Earth's surface. The minimal TWT value was hit at -3433 ms corresponding to, dependent on the sediment's material composition, to a depth of several kilometers.

The resulting Steinberg Fault surface follows the Top_Flysch horizon from the southernmost section of Inline 1906 northwards until Inline 2676 reaching a strike length of almost 20 km.

The fault system is clearly visible in the whole 3D seismic cube until the northernmost Inline. However, the mapping was halted with Inline 2676 due to the ending horizon objects.

The fault heave, which equals the horizontal offset between the footwall block and the hanging wall block measured perpendicular to the strike direction is up to 5 km (compare to Fig. 2).

The fault continuation into depth was not mapped due to the radical decrease of seismic resolution.

3.3.2. Fault System West

A further fault system was mapped in the western part of the 3D seismic cube that also represents a border for the Top-Flysch and some overlying horizons. Similar to the Steinberg Fault it strikes south-west – north-east and dips east-south-east with a considerably varying dip angle (see Fig. 47).

The Top_Flysch horizon in the footwall of Fault System West was only mapped in few cross-lines showing a vertical displacement of 800 ms at the fault. Other horizons like Channel_1 are also affected by this fault system in some areas. The resulting offset is represented by a lower reflector in the hanging wall (see Fig. 47). In a southwestward direction, the Top_Karpat horizon shows an offset of at most 200 ms and the fault dies out in Lower Badenian. Regarding the difference in offset between the Top_Flysch and the Top_Karpat horizon, a high fault activity during the Karpatian age is suggested. This assumption is confirmed by Karpatian growth strata in the hanging wall of Fault System West visible in the seismic cube (Fig. 47).

The maximum Z value (TWT) of the mapped fault system amounts to -248 ms, while the minimum was hit at -2218 ms. These values result in a difference of 1970 ms. The mapping

starts on Inline 2031 and ends on Inline 2416. That corresponds to a fault track length of almost 10 km. The fault system cannot be spotted along the whole Top_Flysch horizon and seems to die out in a northeastward direction.

Because of the growth strata in the hanging wall, this fault was initially interpreted as a normal fault. Due to Fault System West featuring the same age of activity as adjacent thrusts in the flysch units, a complex of problems arose that needed to be dealt with. Consequently, the mechanism of normal faulting is difficult to imagine during this time (see 4.2.2 for discussion).

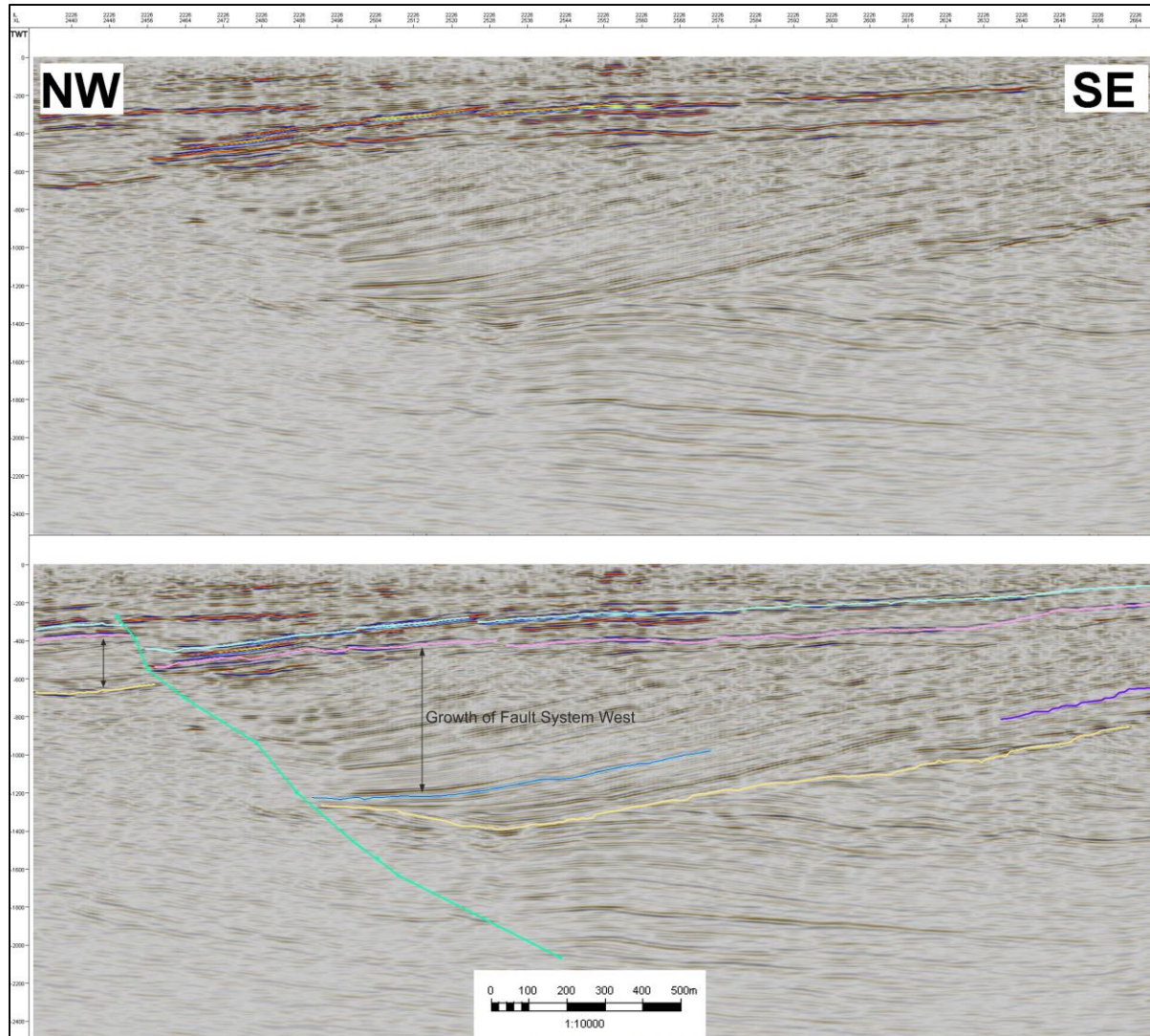


Fig. 47: Inline 2226 with Fault System West (turquoise) and horizons: Top_Karpat (light blue); Channel_1 (pink); Top_Growth_3 (blue); Top_Growth_1 (purple); Top_Flysch (yellow). Indication of Top_Flysch offset between footwall and hanging wall. Depth values in ms TWT.

Aside from the main fault, a smaller, subparallel splay fault was mapped between Inline 2151 and Inline 2191, forming a half-graben system. With a minimum TWT value of -1048 ms and a maximum of -337 ms this approximately 1 km-long splay fault affects the Top_Karpat horizon particularly (see Fig. 48).

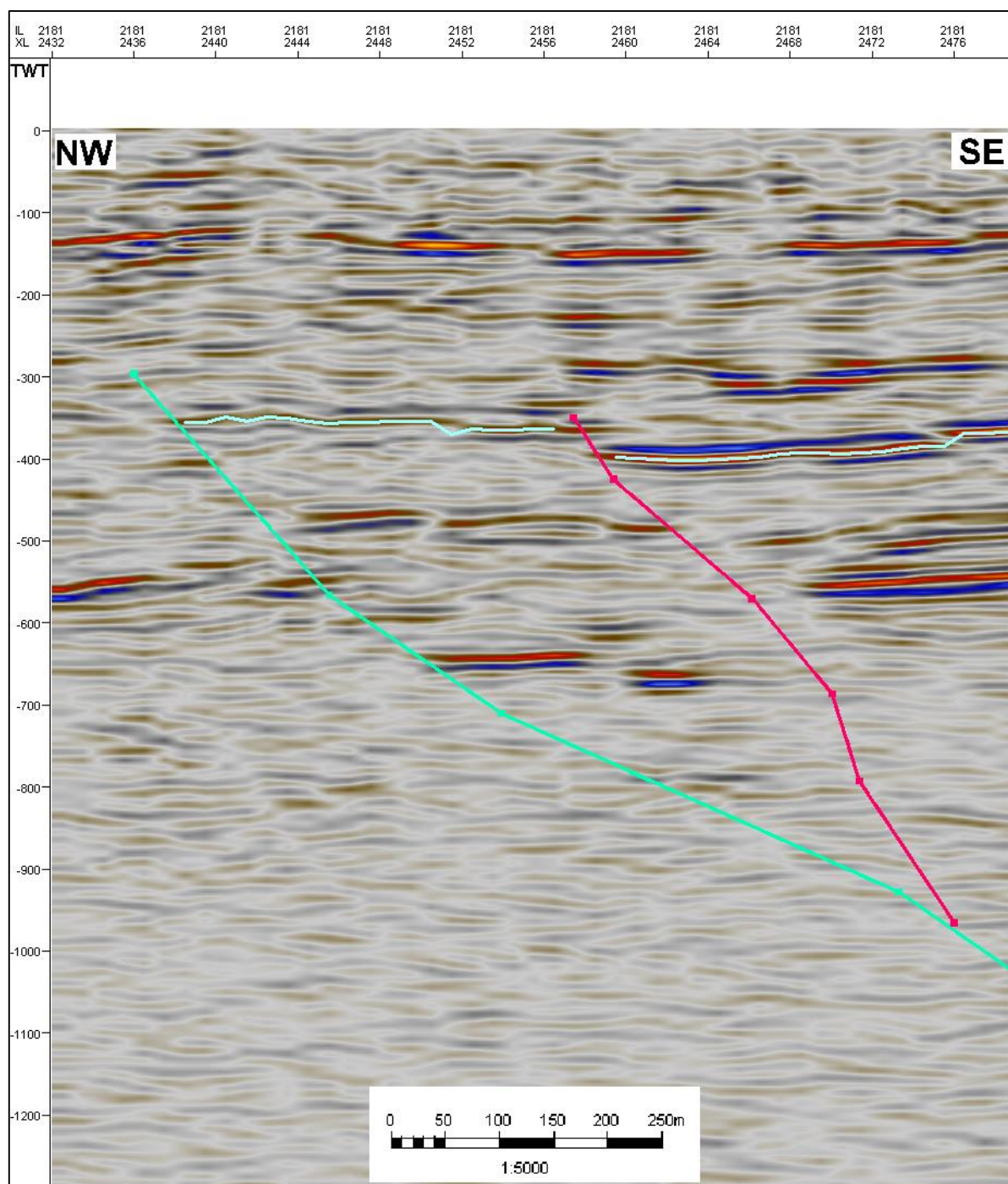


Fig. 48: Petrel Interpretation Window - Inline 2181 with Fault System West: main fault (turquoise); synthetic fault (red). Horizon: Top_Karpat (light blue). Note that there is only a very small offset of the L. Badenian succession (~50 ms). Depth values in ms TWT.

3.3.3. Flysch Thrust 1

A fault was mapped in the northern part of the flysch layer underlying an antiform in the top surface (see Fig. 36) between the Inlines 2336 and 2486 (see Fig. 35 and Fig. 36) and equals a track length of around 3,700 m. It has a similar dip angle and direction to Fault System West (see 3.3.2) which dips south-east. It ends below or at the Top_Flysch surface and does not propagate into the overlying Miocene sediments. The fault was named Flysch Thrust 1 because of further interpretation.

3.3.4. Flysch Thrust 2

Flysch Thrust 2 is a small fault north of Flysch Thrust 1 which is also located below an antiform of the Top_Flysch horizon (see Fig. 35 and Fig. 37). It was mapped between Inline 2496 and Inline 2526 (see Fig. 34). The track length amounts to about 700 m. The dip angle appears shallower than the one of Flysch Thrust 1 but it dips south-east as well. This fault also does not break through the Top_Flysch horizon totally but ends below or at this horizon.

4. DISCUSSION

4.1. Fold kinematics and syntectonic sedimentation

Different tectonic and sedimentological events were observed and mapped in the provided 3D seismic cube (as further discussed in 4.2). This chapter should give an overview of the possibilities to interpret decisive patterns of growth strata imaged in the processed seismic reflection data. This information can be used to determine the timing of deformation and the kinematic history.

4.1.1. Thrust fault-related folding

Regarding the different Miocene growth strata and the blind faults in pre-growth strata, as well as certain folding processes in the flysch layer, a supposed relationship between these tectonic and sedimentary events could be imagined.

The mapped Flysch thrust faults underlie distinct antiformal folds in those areas where growth strata instantaneously cover the pre-Neogene basement. Therefore, the idea of thrust fault-related folding was born.

Kink-band, thrust fault-related fold systems can be subdivided into three principal types of hanging-wall folds: fault-bend folds, fault-propagation folds and detachment folds (McClay, 2011).

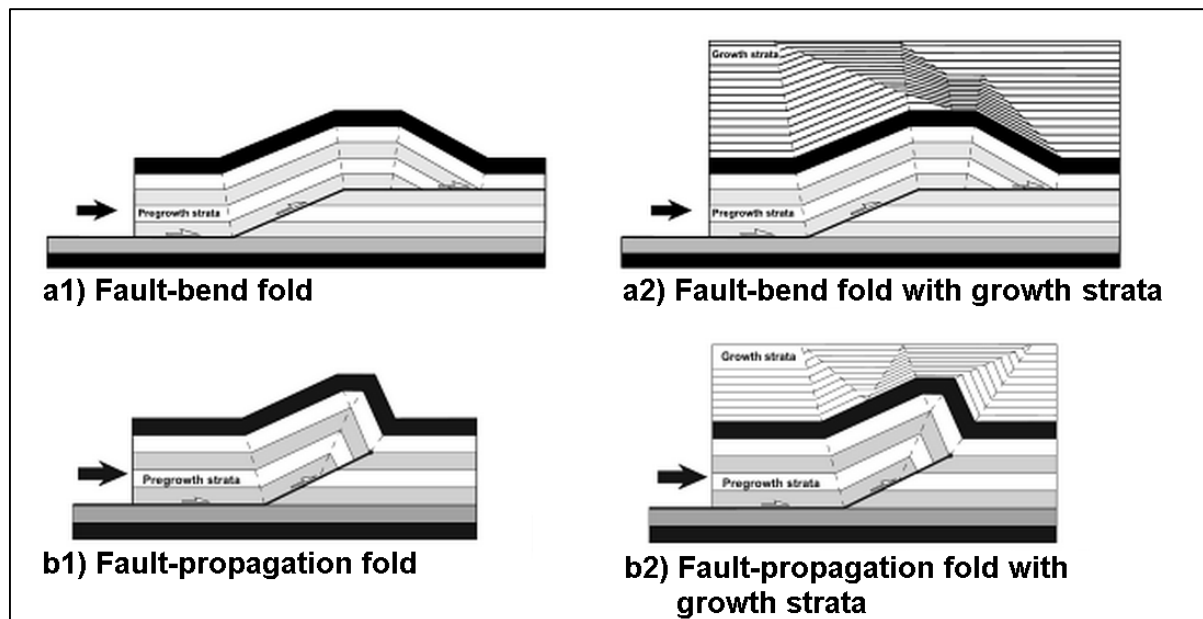


Fig. 49: Comparison of two thrust-related fold-type models; (a) Kink-band fault-bend fold without growth strata (Suppe, 1983) and with growth strata (Suppe, et al., 1992); (b) Fault-propagation fold without and with growth strata. Modified after McClay (2011).

4.1.1.a. Fault-bend folds

Fault-bend folds are hanging-wall-folds that form above footwall ramps in the thrust fault-producing folds below, whereas the footwall section stays undeformed. When such a thrust fault propagates through the whole section (see Fig. 49a1) a subsequent displacement of the hanging wall over the step can be expected (Suppe, 1983). The result is a kink-band fold with constant limb dips. In this model, kink-band migration (see Fig. 55a, Fig. 56a, Fig. 57a) is responsible for the fold amplification by translation of the hanging wall over the stepped footwall thrust surface (McClay, 2011).

Fold uplift, as well as shortening rates of fault-bend folds, can be determined by analyzing the overlying synkinematic growth sequences (see Fig. 49a2; Suppe, et al., 1992). Growth strata is also used to identify the difference between the folding mechanisms of kink-band migration and limb rotation (discussed in 4.1.2).

4.1.1.b. Fault-propagation folds

Fault-propagation folds are formed at the leading edge of gradually propagating thrust fault surfaces as slip accumulates (see Fig. 49b1). During the fault propagation process the slip rate goes to zero repetitive at the tip of the fault. Shortening of strata above the fault tip is compensated by folding. The final kink-band model may show an asymmetric hanging-wall antiform-synform fold pair, tied to the fold tip line, with one steep or overturned limb. This model refers to the mechanism of kink-band migration which means that the limb dips develop simultaneously with the fold and will not change during amplification (see Fig. 55a, Fig. 56a, Fig. 57a). Limb dips always stay constant during kink-band migration. Fault-propagation folds are typically located in fold and thrust belts. Significant growth triangles may develop in simple models with high syntectonic sedimentation rate, representing an important distinctive feature compared to fault-bend fold (see Fig. 57a2; Suppe, 1985; Suppe & Medwedeff, 1990).

Later this model was enhanced by the concept of trishear fault-propagation folding (Erslev, 1991). Different from the original model developed by kink-band migration, this concept supposes the mechanism of progressive limb rotation as responsible for the development of the forelimb (see Fig. 55b, Fig. 56b, Fig. 57b). This process involves differential shear between two tilted axial surfaces (see Fig. 50a). Therefore, downward increasing dips of the antiform forelimb in the direction of the fold tip line can be observed. Fanning growth strata on both limbs could form in a model with triangular shear in the backlimb synclinal hinge region (see Fig. 50b). This model with growth wedges on the fore- and backlimb can often be found in deep water fold belts. A high synkinematic sedimentation rate leads to a better preservation of the structures (McClay, 2011).

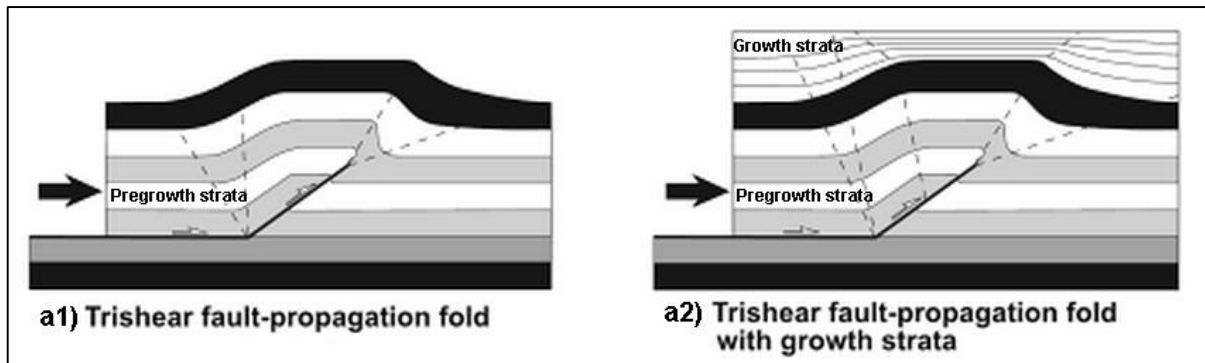


Fig. 50: Trishear fault-propagation fold (a1) without and (a2) with growth strata. Modified after McClay (2011).

While the basic trishear fault-propagation model suggests limb rotation of the forelimb only there are also studies that prove backlimb trishear. The model of Cristallini & Allmendinger (2002) shows trishear fold-propagation folding including symmetric backlimb trishear where the relating growth strata are progressively rotated. Therefore, a pinching out of the strata with a smoothly decreasing thickness is expected on the crest of the antiform (see Fig. 51a).

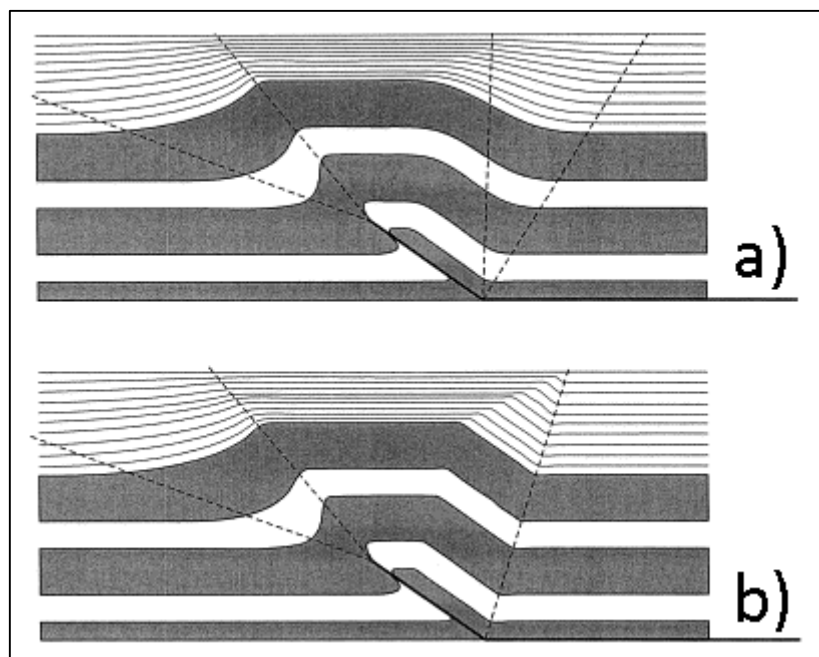


Fig. 51: Trishear fault-propagation fold with growth strata geometries. (a) Fault angle = 35° ; propagation/slip ratio = 1.5; forelimb trishear angle = 30° ; symmetric backlimb trishear angle = 30° ; higher sedimentation rate than uplift rate. (b) Same model as (a) but without backlimb trishear; parallel-kink model. Modified after Cristallini & Allmendinger (2002).

There were also some other subtypes of fault-propagation folds described in the last decades such as transported fault-propagation folds (Jamison, 1987; Shaw, et al., 2005) or basement-involved fault-propagation folds (Narr & Suppe, 1994).

4.1.1.c. Detachment folds

Detachment folds and their three principal models, as well as the syntectonic sedimentation processes, were described by, e.g., Poblet & McClay (1996) and Poblet, et al. (1997) (see Fig. 58). A competent upper layer and an underlying, ductile decollement unit are the distinctive features of these models. The three principal models differ in their fold kinematics (see 14.1.2.b) leading to synkinematic different growth strata architectures. In a very complex process the ductile decollement unit flows into the fold core while shortening and outwards as the fold amplifies (McClay, 2011).

All the three principal models of detachment folds lead to distinct growth strata geometries that are not applicable for the existing results.

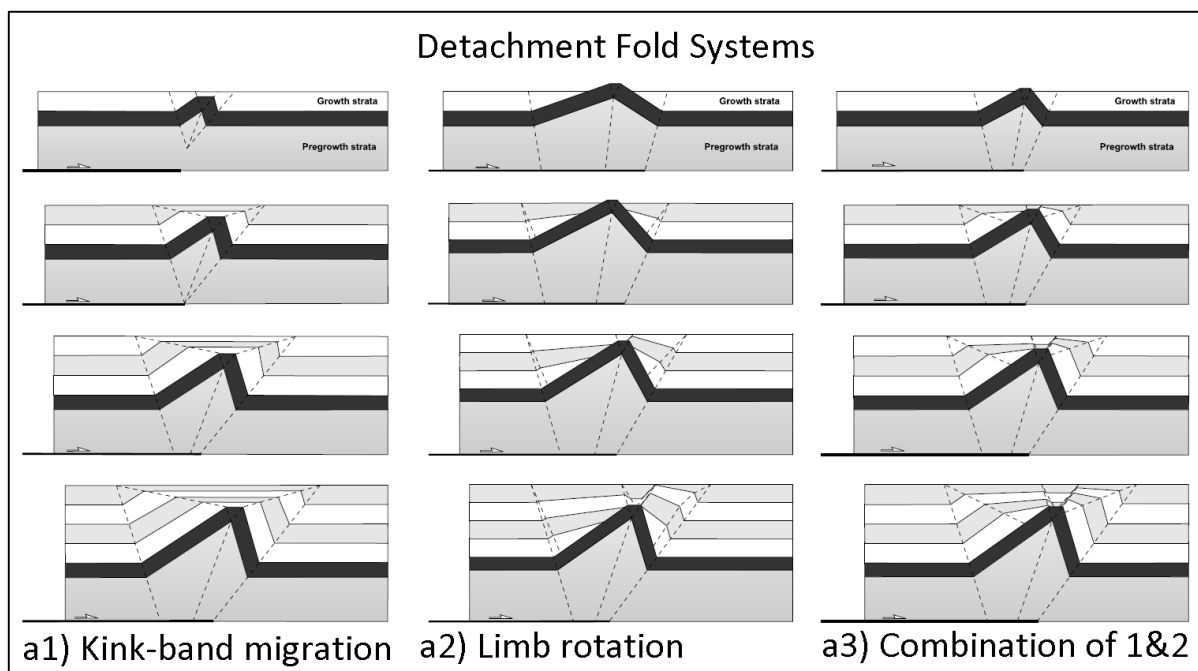


Fig. 52: Models of detachment fold growth by Poblet & McClay (1996) and Poblet, et al. (1997) at high syntectonic sedimentation and continuous shortening. Models (a1-a3) differ in fold kinematics (see 4.1.2.b). (a1) Var. limb length, const. limb dip; (a2) const. limb length, var. limb dip; (a3) var. limb length, var. limb dip. Modified after McClay (2011).

4.1.2. Growth strata

In this Master's thesis the term growth strata is used for a stratigraphic sequence deposited during fault slip and associated fold growth (see 4.1.1), while pre-growth strata describes those strata that existed before deformation (Suppe, et al., 1992). Strata which were deposited after tectonic processes can be called post-growth strata or simply post tectonic strata. Accordingly, the age of growth strata determines the timing of tectonic deformation. Therefore, growth strata geometry is the key to unravelling the kinematics of fault-related folding (Gawthorpe & Hardy, 2002).

Regarding such fault/fold kinematics, it should be considered that for a given fault dip and slip rate, growth strata geometries are strongly influenced by the fault-propagation to slip ratio (p/s), the width of the zone of distributed deformation, and base-level changes (Gawthorpe & Hardy, 2002).

Interpretation of the seismic reflection data of this thesis shows distinct growth strata patterns in the Early Miocene overlying the flysch nappes of their basement (see, e.g., Fig. 36). These sedimentological phenomena seem to coexist with the fold structure in the Top_Flysch horizon observed in the west and north-west of the seismic cube. Underlying blind thrust-faults are thought to be responsible for the development of these antiforms. The geometry of the overlying growth strata suggests that these folds developed as fault-propagation folds (see 4.1.1).

There were three different Top_Growth horizons mapped in the processed seismic cube. These horizons form the top surfaces of distinct growth strata sequences covering the flysch surface with angular unconformities (see 3.1). Each of these sequences was treated as part of a separate tectonic and sedimentological event, possibly originating from the kinematics mentioned before.

For a more precise interpretation of the geological situation in the Early Miocene, the three Top_Growth horizons were flattened in Petrel to simulate strata geometries of the time before tilting of the units occurred (see Fig. 53).

The layer of Growth Event 1 shows fan-shaped growth strata on both the forelimb and the backlimb of the flysch antiform. Such a phenomenon could be described with the model developed by Cristallini & Allmendinger (2002) suggesting backlimb trishear (see Fig. 51a).

In Growth Event 2, the fanning growth strata in the backlimb of the fold is not obviously determinable anymore, after flattening of Top_Growth_2 horizon. The resulting geometries could also be interpreted to be developed by kink-band migration instead of limb rotation of the backlimb (see Fig. 51b). In the forelimb, the strata is not clearly visible.

In Growth Event 3, there is only the backlimb of the antiform visible as the fold is cut by Fault System West. These growth strata distinctly show growth wedges suggesting a fold growth by backlimb rotation (see 4.1.2.b).

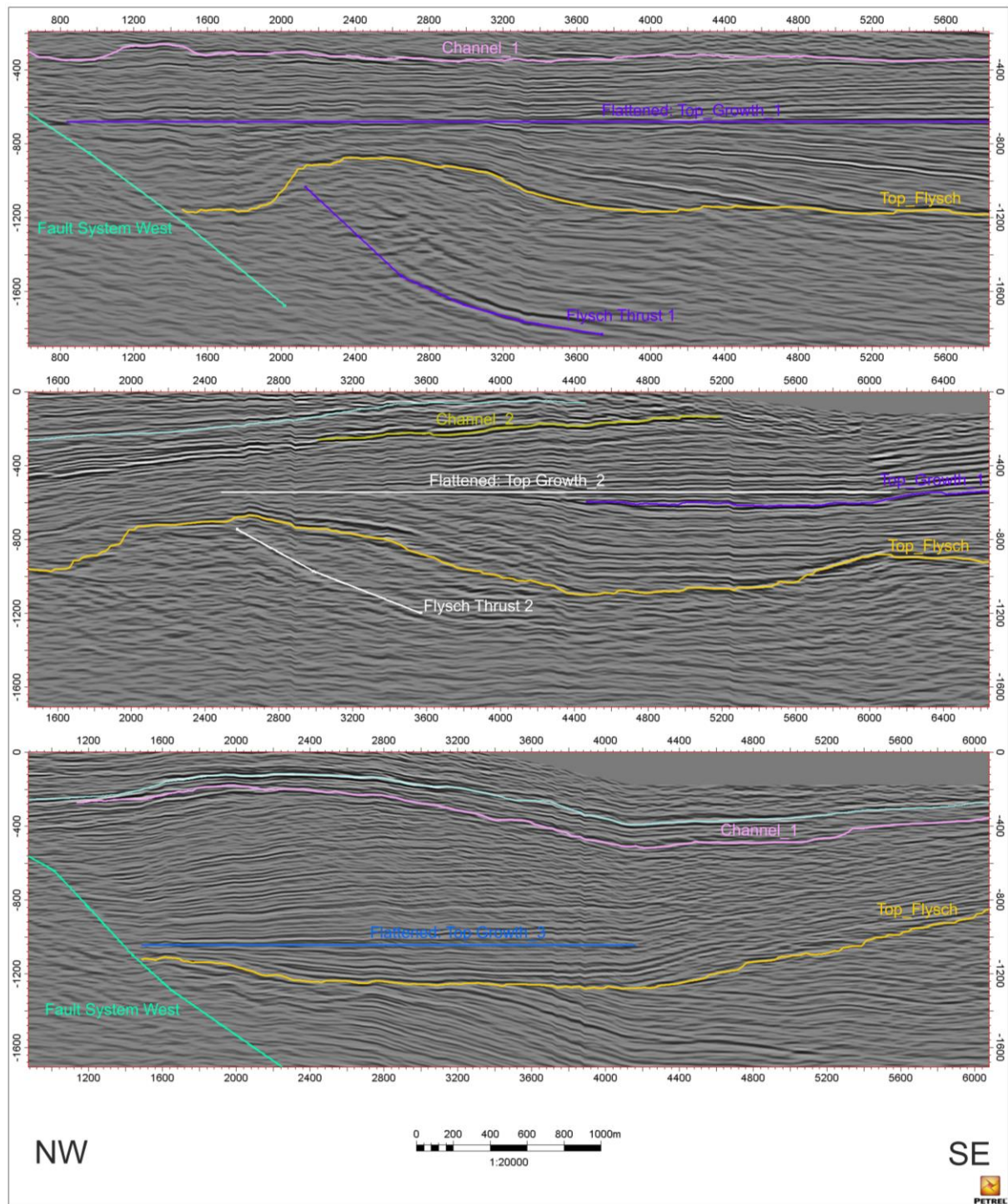


Fig. 53: Flattened Top_Growth horizons (1) on Inline 2416, (2) on Inline 2521 and (3) on Inline 2211. The cross sections (top down) represent the three Growth Events (see 4.2). Growth strata are visible in the backlimbs of the antiforms. Growth event 1 shows growth strata in the forelimb as well. Depth values in ms TWT.

4.1.2.a. Sedimentation rate vs. tectonic uplift

Comparing the level of growth strata with its related fold, it is possible to distinguish between two different kinds of geometries. In one case the tectonic uplift rate is greater than the sedimentation rate, while the other case assumes a greater sedimentation rate than uplift rate (see Fig. 54). In the first model the fold will emerge at the surface. In the second model the

antiform will be covered completely by the growth strata and will not emerge from the basin. These possibilities may apply to every type of fold. The uplift rate is related to the sedimentation rate and both can be expressed with the same unit (e.g., m/Ma). It is dependent on horizontal shortening and therefore on the deformation rate. (Ahmadi, et al., 2013)

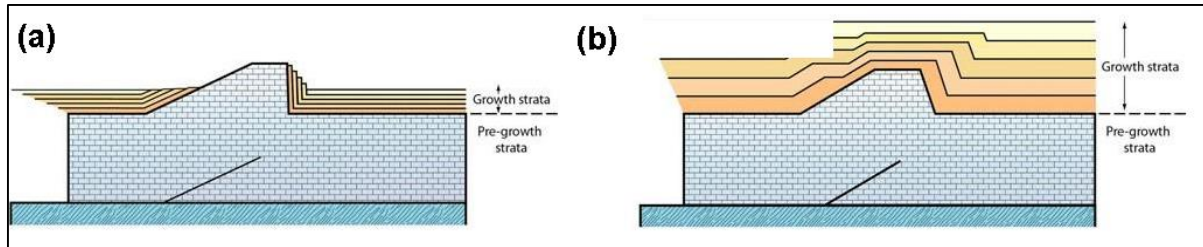


Fig. 54: Two different models of growth strata geometries for the type of a fault-propagation fold. (a) Greater uplift than sedimentary rate; (b) greater sedimentation than uplift. The therefore used modelling software was developed by Rafini & Mercier (2002). Modified after Ahmadi, et al. (2013).

When the sedimentation rate exceeds the uplift rate, growth strata usually appear as sequences, bounded by at least two seismic reflections which thin toward the structural high. In the opposite case syntectonic strata typically thin toward, but also onlap, the structural high. (Shaw, et al., 2005)

4.1.2.b. Fold kinematics

A major reason for the importance of growth strata surveying is the resulting possibility of deciphering the fold kinematic history. Contractional fault-related folds — as we expect them — can most likely be formed by two different folding mechanisms. A distinction is drawn between the mechanisms of kink-band- or hinge migration and limb rotation (see Fig. 55). In all probability, both ways of formation will image different patterns of deformed growth strata in the seismic reflection data but they could have identical final shapes and stratigraphy, as shown in the pre-growth strata (see Fig. 56; Suppe, 1997). The patterns above the fold limbs can help us to determine the responsible folding mechanism. Knowing this mechanism allows us to draw conclusions from the kinematic theory (e.g., fault-propagation folding) that is used for structural interpretation (Shaw, et al., 2005).

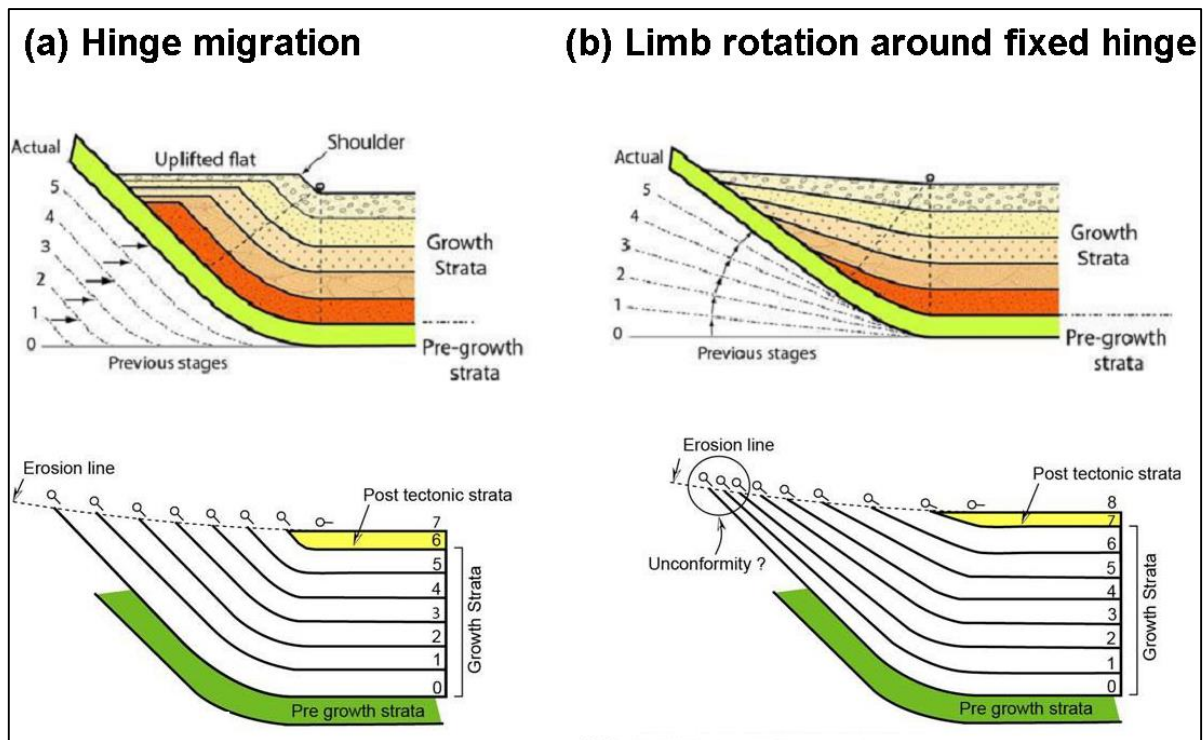


Fig. 55: Expected geometry in growth strata obtained with different hinge kinematics. (a) With hinge migration and (b) with limb rotation around fixed hinges (adapted from Rafini & Mercier, 2002). Lines (1–5) show schematically the evolution of the fold limb in the pre-growth strata (above). Dip trend lines of growth strata layers in deep erosion cases (below). Modified after Ahmadi, et al. (2013).

Kink-band migration: The mechanism of kink-band- or hinge migration (see Fig. 55a) in fault-related folds involves a widening of the fold limbs through time while the dip angle stays fixed (Suppe, et al., 1992).

There are two bordering surfaces in the fold limb in growth strata. An active axial surface which is responsible for the incorporation of material into the limb and which is often pinned to a tip of a fault at depth (Suppe, 1983; Suppe & Medwedeff, 1990) and an inactive axial surface. The latter is also called growth axial surface and represents the original position of deposition along the active axial surface (see Fig. 57a).

When additionally considering the two different models of growth strata geometry based on the sedimentation rate (see 4.1.2.a), folding of strata through the synclinal axis with incorporation into the widening fold limb would be expectable in case of greater sedimentation- than uplift rate (see Fig. 57a2). In this case the dip of growth strata and of the limb in pre-growth strata are equal. Furthermore, the model supposes an upward (in the direction of younger horizons) narrowing of fold limbs forming growth triangles in growth strata.

In the case where the sedimentation rate is less than the uplift rate (see Fig. 57a3), each increment of folding produces a discrete fold scarp located where the active axial surface projects to the Earth's surface (Shaw, et al., 2004). These scarps are onlapped by subsequent depositions forming stratigraphic pinch-outs (Shaw, et al., 2005).

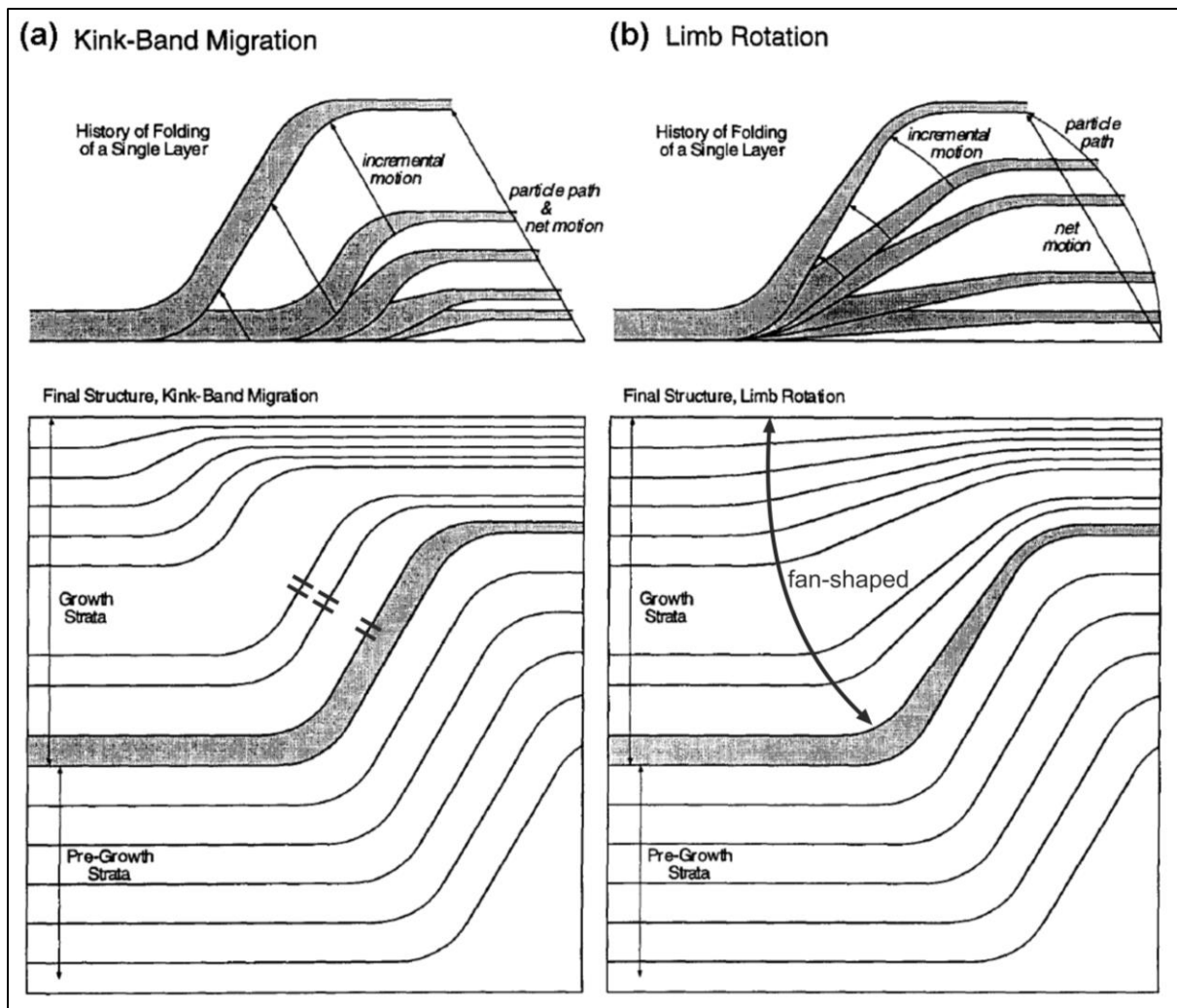


Fig. 56: Balanced forward models of (a) kink-band migration and (b) rigid-limb rotation. The two cross-sections have identical final shapes in the pre-growth strata and identical stratigraphy. They only differ in the shape of growth strata in the fold limb, which shows that they have very different kinematic histories. Modified after Suppe (1997).

Limb rotation: The mechanism of limb rotation with fixed hinges (see Fig. 55b) in fault-related folds involves an increase of the dip angle of the fold limbs during folding (see Fig. 57b1). Only inactive axial surfaces are assumed for this mechanism.

In the model with greater sedimentation- than uplift rate by limb rotation (see Fig. 57b2), progressive rotation of the strata during folding is expected. That leads to an increasing dip with increasing age. Thus, elder horizons dip steeper forming a fan geometry in growth strata. The limb width stays constant during folding/rotating.

In the case where sedimentation rate is lower than the uplift rate (see Fig. 57b3), there is also fanning of limb dips expected in growth strata. Fold limbs are usually onlapped by growth strata. (Shaw, et al., 2005)

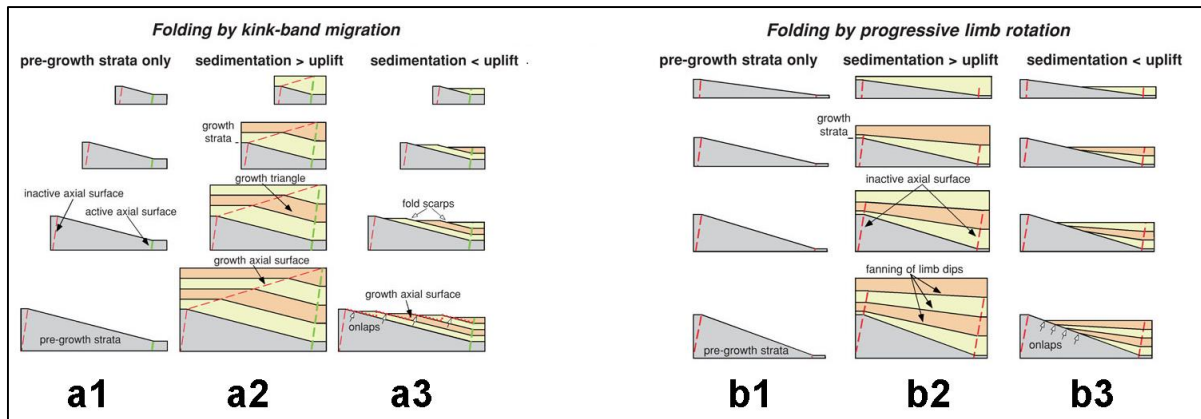


Fig. 57: Different models of growth strata geometry with axis for (a) kink-band migration and (b) limb rotation. Modified after Shaw, et al. (2005).

In nature, both mechanisms of folding can coexist, being involved in one and the same event. A good example for such a case was described in the Almazán Basin in North Spain by Casas-Sainz, et al. (2002), where growth strata geometry indicates two different sequential stages of fold growth. The first one distinguished by limb rotation and the formation of minor kink-band, while the second stage is distinguished by kink-band migration which could be related to fault propagation. Therefore, miscellaneous patterns of growth strata are the result here.

4.1.2.c. Drape sequences

Further models can be used, e.g., to differentiate between drape sequences and growth sequences (see Fig. 58). A drape sequence is a stratigraphic interval deposited above a structure after the end of deformation. They are warped because of primary sedimentary dip or compaction. Dependent on sedimentary environment and facies, their patterns can vary widely. The phenomena of drape sequences is mentioned here because it can exhibit patterns quite similar to growth strata deformed by limb rotation and can therefore be easily confused. A correct interpretation of these patterns is very important to avoid a wrong determination of kinematics. One way to distinguish between these two events is to regard the orientation and the dip of their axial surfaces. While drape sequences usually indicate tension and/or compaction, growth folds show patterns of compression where fold axis dip towards the structural crest (see Fig. 58). From Shaw, et al. (2005).

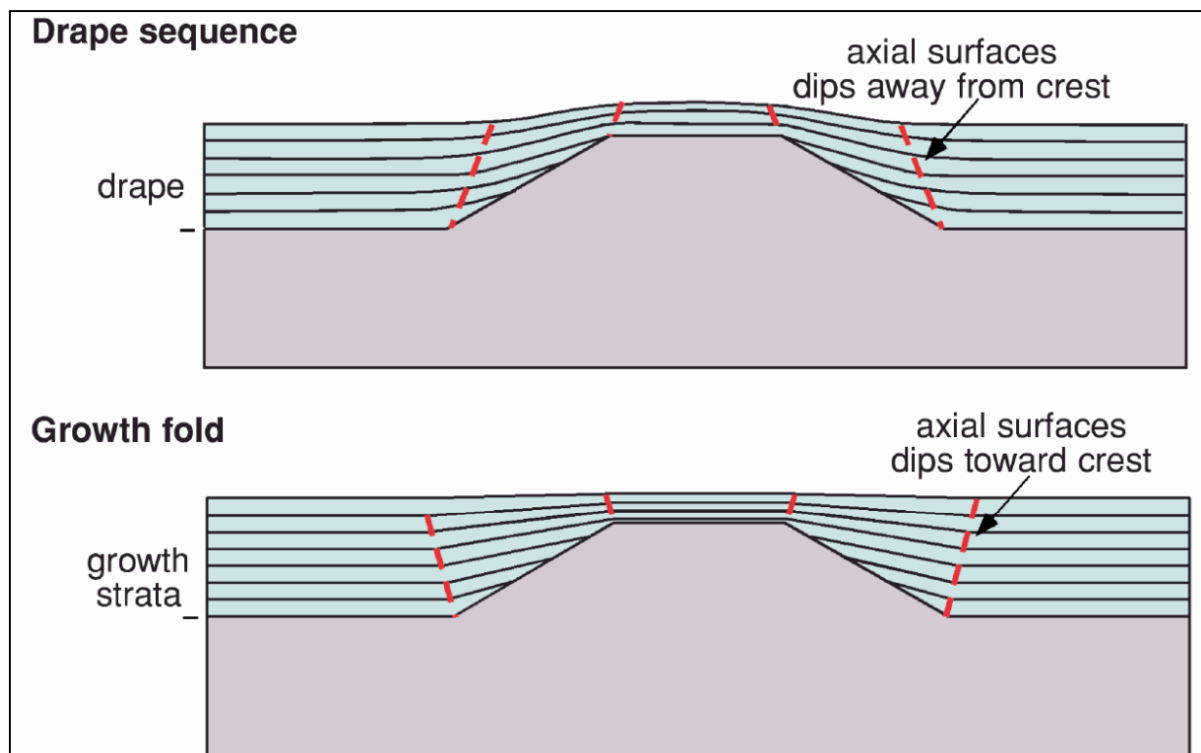


Fig. 58: Demonstration of how to differentiate between a drape sequence and a growth fold by regarding their axial surfaces. From Shaw, et al. (2005).

4.2. Tectonostratigraphic survey of the Mistelbach Block

4.2.1. Syntectonic out-of-sequence thrusting

In the processed seismic volume of this Master's thesis the focus of interpretation lies on three different syntectonic tectonic events concerning the flysch layer and its immediate overlying Early Miocene strata. Information discussed in the previous chapters is used trying to clarify the kinematic history of these events and their relative timings.

Growth Event 1: The Flysch Thrust 1 fault was mapped as a blind fault within the flysch layer. It is assumed to be responsible for the antiform visible above in the Top_Flysch horizon. Therefore, it is expected to be a thrust fault leading to fault-related folding (see Fig. 36). Due to a shallow dipping backlimb and a steep forelimb, the antiform shows an asymmetric geometry. The vertical height of the fold amounts to 200 to 300 ms.

For further analysis the strata deposited above were regarded. They appear as fan-shaped in the overlying sequence since their thickness decreases in the backlimb in the direction of the crest of the antiform. Therefore, syntectonic or synkinematic sedimentation of the succession is expected here and so the sequence was called Growth strata 1. Top_Growth_1 horizon represents the border to the overlying strata showing conformities. Hence it is the marker for the end of tectonic movements along the Flysch Thrust 1 fault. Compared to the two other

investigated events this growth event seems to be the oldest one according to the correlation of the top of the succession (see Fig. 59).

The relation between sedimentation rate and tectonic uplift rate of the antiform was also discussed for this layer. The antiform does not emerge at the top surface of Growth Strata 1 layer but is covered completely by the growth strata. According to the models of Ahmadi, et al. (2013) this geometry indicates a higher sedimentation than uplift rate (see Fig. 54).

Growth strata appear as sequences bounded by seismic reflections which thin towards the structural high. That is also an indication of this model.

Another major point for discussion is the fold kinematics. The prevailing geometric situation with thinning strata and the increasing dip angle with increasing age are typical evidences for the mechanism of limb rotation with a fixed hinge (see 4.1.2.b).

Due to the fact that the inactive axial surfaces dip toward the fold crest, it is not possible to interpret the succession as a drape sequence (4.1.2.c) and the idea of fold growth can be followed up.

Summarizing the idea of a blind thrust fold in the flysch layer, an antiform above and the characteristic pattern of overlying growth strata of the Miocene, a fault-propagation fold is expected which formed during higher synkinematic sedimentation than tectonic uplift rate.

The pattern of growth strata does not match the original model of fault-propagation folds described by Suppe (1985) and Suppe & Medwedeff (1990) which assumes the mechanism of kink-band migration for the fold growth.

Therefore, the enhanced concept of trishear fold-propagation folding was suggested and discussed for the situation of Growth Event 1. This model developed by Erslev (1991) fits the observed pattern of increasing dips of the forelimb strata in the direction of the fold tip line. Aside from poorly visible growth wedges in the forelimb, there is fanning growth strata visible especially in the backlimb of the antiform. Such geometries are comparable with the model by Cristallini & Allmendinger (2002) (see Fig. 51a).

After a comparison of the mapped horizons to the stratigraphic classification by Theobalt, et al. (2015), it is considered that the Top_Growth_1 horizon might represent the top of the Ottnangian as well (see Fig. 24 and Fig. 25). In this case the Growth strata 1 layer could correlate with the Lower and Upper Ottnangian stage.

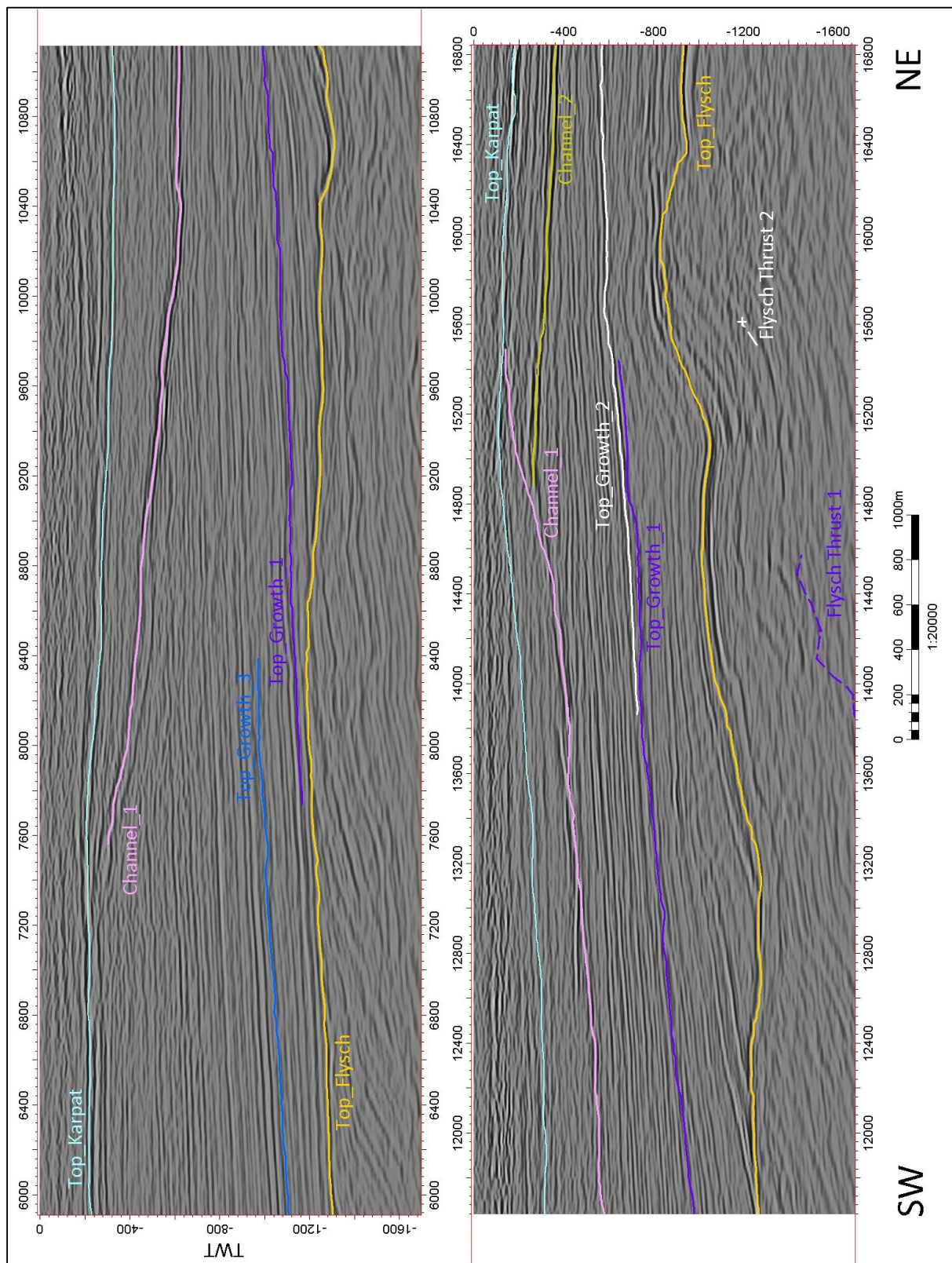


Fig. 59: Intersection of Xline 2575 depicting age references between the Top_Growth horizons as they pass into conformity.

Growth Event 2: The smaller Flysch Thrust 2 fault in the north of Flysch Thrust 1 was also mapped and interpreted as a blind thrust fault leading to folding of rock layers above the fault tip. The fault seems to be propagated further in the north where it reaches to Top_Flysch surface at -800 ms TWT.

Growth strata are identified overlying the developed antiform indicating a syntectonic sedimentation process. The top surface of the so-called Growth Strata 2 layer was named Top_Growth_2 (see Fig. 37). Comparing this event to Growth Event 1, it has to be younger because of a longer lasting fold growth and a consequently longer lasting development of growth strata. This is approved by the fact that Top_Growth_2 horizon was deposited later and therefore lies above Top_Growth_1 horizon in the series of Miocene strata (see Fig. 59). Expecting the Top_Growth_1 reflector to act as the top of the Ottnangian stage the end of Growth Event 2 could be estimated to have occurred in the Lower Karpatian stage (see Fig. 24 and Fig. 25).

Similar to Growth Event 1 the sedimentation rate is higher here than the tectonic uplift rate of the fold. Therefore, the antiform in the Top_Flysch horizon is totally covered by growth strata which thin towards the structural high (see Fig. 54).

The resulting fan-shaped pattern of strata in the backlimb, where the dip angle increases with age, indicates a fold growth by limb rotation (see 4.1.2.b). However, after flattening of the Top_Growth_2 horizon, the geometry of strata becomes ambiguous (see Fig. 53). Potential kinks in the backlimb could prove the mechanism of hinge migration (see, e.g., Fig. 57a). A combination of both kinematic mechanisms, at which limb rotation occurs contemporaneously with hinge migration is not implausible in this case.

The idea of a drape sequence can be excluded due to the dip direction of the fold axis (see Fig. 58).

Assuming the growth of the antiform was caused by a propagating fault tip of the underlying blind thrust fault in the flysch layer, with the assumed kinematics of hinge migration in the backlimb and a syntectonic sedimentation, the result confirms with the basic model of a fault-propagation fault (see Fig. 49b2). Due to the fact that strata is not clearly visible in the forelimb the idea of basic trishear fault-propagation folding cannot be ruled out (see Fig. 51b).

Growth Event 3: The third described growth event happened in the south-west of Growth Event 1. Compared to Growth Event 1 and 2 there was no thrust fault mapped for Growth Event 3 but only expected below a seeming monocline. This monocline might be the result of an antiform developed due to a thrust and divided later by the younger Fault System West (see Fig. 38).

A horizon called Top_Growth_3 was mapped representing the top surface of distinct growth wedges overlying this monocline. Therefore, this sequence was called Growth Strata 3.

Regarding the succession of Miocene strata and the different Top_Growth horizons, it is obvious that Top_Growth_3 horizon was deposited later than Top_Growth_1 horizon and probably also later than Top_Growth_2 horizon (see Fig. 59). According to new stratigraphic correlations of the Mistelbach Block (Fig. 24 and Fig. 25), Growth Event 2 seems to cease in the Lower Karpatian.

The axial surfaces dip towards the fold crest indicating a growth fold mechanism and no drape sequence (see Fig. 58).

The relation between sedimentation and uplift cannot be identified clearly because of the abrupt ceasing at Fault System West. However, it seems as if the sedimentation rate of Growth Event 3 is also higher than the tectonic uplift because strata does not onlap the monocline. It can certainly be said that the fold kinematic history is based on the mechanism of limb rotation around a fixed hinge due to a distinct pattern of fan-shaped growth-strata, at which the dip angle increases with age (see 4.1.2.b).

Summarizing these facts, it could also be imagined to have a thrust fault-related folding in the flysch layer during Growth Event 3.

It is conspicuous that Top_Growth_3 horizon becomes actually younger towards the south-west which means that the real top of the growth strata is located in upper strata. Therefore, the thrust fault is expected to be longer active in the south-west than in the north-east.

In summary, the three thrust events mapped in the flysch units of the Mistelbach Block show different ages. Altogether, their activity is dated from Lower Ottnangian to Lower Karpatian. Regarding a palinspastic map of the Middle Ottnangian, which arises from the studies of Beidinger & Decker (2014), the active in-sequence thrust front is already passed on to the Waschberg Unit in this area leaving the flysch units as inactive piggy-back thrusts (see Fig. 60). Therefore, all three thrust events related to out-of-sequence (OOS) thrusting. Considering already identified OOS thrusts (see Fig. 7), which result from the studies of Zámolyi, et al. (2008) and Hölzel, et al. (2010), the events arising from this Master's thesis belong to that succession of OOS thrusting. However, there is no chronological order determined between all of these diverse events, as well as between the three identified thrusts in the flysch units. The ages of fault activities vary randomly in the Alpine-Carpathian junction showing OOS thrusting in different locations at different times (see Fig. 61). Generally, in-sequence thrust distances increase from west to east resulting in younger OOS activity in the east (see Fig. 8). The thrusting events analyzed for this Master's thesis show thrust surfaces from approximately 1 to 4 km length. Their thrust distances were estimated to a scale of a few hundred meters only.

4.2.2. Strike-slip and normal faulting

Steinberg Fault: The Steinberg Fault accommodates most of the rapid subsidence of the northern part of the pull-apart basin showing a normal offset of up to 5600 m (Hinsch, et al., 2005).

The fault is expected to have been active during nearly the entire evolution of the Vienna pull-apart basin. Growth strata on the downthrown block date the main activity from Badenian to Pannonian. (Golonka & Picha, 2006)

A rooting of the fault in the Alpine-Carpathian floor thrust is expected (Royden, 1985; Royden, 1988).

A big part of the Steinberg Fault is clearly visible in the provided 3D seismic cube (see 3.3.1). In the processed section, the Miocene reflection pattern characterized by clear, parallel reflectors with quite high amplitudes appear until significantly greater depth in the hanging wall than in the footwall and strata seem to be much thicker. This image fits to the well-known idea of synsedimentary normal faulting. The relative young fault activity is also proven with the mapped object in the seismic cube. Due to missing well data, there was no determination of well tops performed on the hanging wall. According to Wessely (1993) there are sediments from Eggenburgian and Ottnangian, Badenian, Samartian and Pannonian/Pont present in the hanging wall, known was “Zistersdorfer Tief”; but no Karpatian. Regarding the respective thickness difference of strata the highest fault activity and/or sedimentation rate is expected in Badenian.

The border to the underlying Alpine-Carpathian nappes are not clearly determinable in the 3D seismic cube due to the decreasing resolution with depth (see Fig. 11).

Regarding the evolutionary history of the Vienna Basin this event basically belongs to the Neo-Vienna Basin (see 1.3) where thrusting continues in the north resulting in extension and an increasing rate of normal faulting (Wessely, 1993).

Fault System West: The south-west – north-east striking fault system named Fault System West (see 3.3.2) appears to have the highest normal activity during Karpatian and dies out in Lower Badenian. The Top_Karpat horizon, which belongs to the Lower Badenian, was offset only in some areas by this fault system and the overlying units usually appear quite intact. Channel_1 horizon was rarely affected by the Fault System West as well.

The reflection pattern of Miocene strata appears much higher in the footwall of Fault System West and the comparatively thicker strata in the hanging wall confirm the here expected synsedimentary normal faulting (see Fig. 47). Growth strata of the fault was dated Karpatian age.

Nevertheless, the adjacent Flysch thrusts show Karpatian activity as well (see 4.2.1) and their resulting growth strata is contemporaneous with growth strata of the Fault System

West. A contrarious tectonic movement featuring normal fault extension at Fault System West and blind thrusting below the flysch antiforms is quite implausible in this area requiring this situation to be rethought. Therefore, the idea of strike-slip faulting was discussed. Perhaps, the growth strata of Fault System West could be the result of a tear fault (Andreas Beidinger, pers. comm.). However, the provided seismic cube does not image the whole fault system and also the footwall is insufficiently visible to make specific statements.

The reflectors between the horizons Channel_1 and Top_Karpat appear quite parallel to the Earth's surface, often with angular unconformities to the underlying strata.

Aside from growth strata in the hanging wall, there is a distinct difference in offset between the Top_Flysch horizon and the Top_Karpat horizon. While Top_Flysch shows an offset of up to 800 ms at Fault System West, there are only 200 ms of displacement noticeable for the Top_Karpat horizon indicating a gradual dying out.

Regarding the assumption that the Steinberg Fault was active between Badenian and Pannonian stage with the greatest tectonic movements in Badenian, the Fault System West is dated distinctly older.

The flysch underground with its overlying Lower Miocene strata is tilted very obviously and the mapped horizons on the Mistelbach Block confirm subsidence by dipping north-west. Tilting of the flysch nappes occurred in a southward direction (Wessely, 1993). At least all horizons between Top_Flysch and Channel_1 show this tilting. Channel_1 and Top_Karpat horizon become more and more parallel to the Earth's surface and angularly unconformable to the underlying layers in the southward direction. In the north, all Miocene horizons have more or less the same dip angle in the north-western direction.

However, Fault System West disappears on this seismic cube in a northward direction and Top_Karpat, as well as Channel_1 and Channel_2, are tilted but only rarely affected or offset by the mapped fault system. This observation leads to the assumption that the Fault System West is part of a bigger system and not solely responsible for the tilting of the units. Possibly there are other, bigger faults that are located outside of this 3D seismic cube.

4.2.3. Paleochannels

Both mapped channel horizons (see 3.1.3) show their upper margins just below the so-called Top_Karpat horizon. According to the stratigraphic classification by Theobalt, et al. (2015) this horizon forms the top of the Iván formation (see Fig. 24). Therefore, these channels are expected to be formed and subsequently filled in the Lower Badenian (see Fig. 25). Even though both structures share a very similar stratigraphic age, Channel 1 seems to be the younger one because it cuts the sediment fill of Channel 2 (see Fig. 41). This problem is not completely clarified as of yet and leaves some questions open.

Channel 1 achieves a diameter of 7 to 8 km at the widest point and shows a depth of about 300 ms TWT at the deepest point. That corresponds to 300 m at a rough estimate. The whole Channel_1 horizon ranges from about -50 ms to more than -800 ms TWT.

Channel 2 is slightly smaller than Channel 1 showing a diameter of 5 to 6 km and a depth of about 100 ms TWT. The horizon was mapped between -100 ms and -600 ms TWT.

Both channels show an onlap fill pattern (see Fig. 28). The seismic reflections are much stronger in Channel 2 than in Channel 1.

Today's flow direction of the channels runs from south-east to north-west. However, it must be considered that tilting of the units occurred from Middle to Upper Miocene caused by strike-slip and normal faults. Therefore, a subsequent reversion of the apparent flow direction could be imagined suggesting an actual sediment input from north-west to south-east during the Lower Badenian stage.

According to sequence stratigraphic analysis from Strauss, et al. (2006), there is a sea-level lowstand expected in the Southern Vienna Basin at the beginning of Badenian stage followed by a transgression and a sea-level highstand in Lower Badenian. Similar results were provided for the Northern Vienna Basin by Theobalt, et al. (2015) suggesting an erosion during the sea-level lowstand in Lower Badenian that might be causal for the formation of these two channels. The subsequent transgression filled all these structures such as Mistelbach and Iváň canyon (see Fig. 25). The latter is responsible for the name of the Iváň formation, which correlates with the supposed channel fill of Channel 1 and Channel 2 (see Fig. 24).

5. CONCLUSION

1. Compressional growth strata: In the provided 3D seismic cube, there was Early Miocene, compressional growth strata identified on the Mistelbach Block, which overlie the flysch nappes of the Alpine-Carpathian thrust units. Three similar events were investigated, at which sediments entirely cover flysch antiforms, which are expected to be responsible for the resulting growth strata geometry. A fan-shaped geometry is visible, at which strata thins out towards the fold crest forming growth wedges. This pattern is particularly visible in the backlimbs of the antiforms. Reflectors in the forelimbs are only poorly visible.

2. Trishear fault-propagation folds: The flysch anticlines on the Mistelbach Block, showing synkinematic sedimentation, are thought to be caused by blind thrust faults in the pre-Neogene, sedimentary basement. For two out of the three antiforms, south-east dipping fault surfaces could be mapped. Therefore, thrust fault-related folding is suggested for the mapped growth events. The resulting growth strata geometry indicates fault-propagation folds with a strong indication for trishear folding. Trishear fault-propagation folds include the mechanism of limb rotation, which is responsible for the pinching out of the growth strata. Due to the fact, that this fan-shaped growth strata pattern is particularly visible in the hinterlands of the respective antiforms, the principle of backlimb trishear is supposed.

3. Early Miocene out-of-sequence thrust succession: The mapped Top_Growth horizons dated the syntectonic thrust activity from the Lower Ottnangian to the Lower Karpatian stage. However, stratigraphic surveying prove different times of ceasing of the respective growth events.

Palinspastic maps by Beidinger & Decker (2014) demonstrate, that the active, in-sequence thrust front of the Alpine-Carpathian units has already propagated further north-west into the foreland during the Middle Ottnangian. Therefore, the determined activity on the Mistelbach Block is interpreted as inactive piggy-back thrusting of the Alpine flysch units in the hinterland. Comparing these events with previous results from Zámolyi, et al. (2008) and Hölzel, et al. (2010), the identified flysch thrusts belong to a succession of Early Miocene, out-of-sequence thrusts at the Alpine-Carpathian junction (see Fig. 61). Previous results revealed two OOS thrust events in the Northern Calcareous Alps dated to Lower Karpatian and Upper Ottnangian to Lower Karpatian. A further Upper Karpatian OOS event was investigated further west on the Spannberg ridge. Following this succession in a north-western direction towards the foreland, the next mapped OOS thrusts arise from this Master's thesis and show fault activity since at least Lower Ottnangian until Lower Karpatian. This OOS succession ceases in the Waschberg Unit during Upper Karpatian stage, when also in-sequence thrusting of the Alpine units ended in this area.

Comparing the respective ages of fault activity within this Early Miocene out-of-sequence thrust succession, no chronological order can be distinguished. The various growth events do not become progressively younger from south-west to north-east but rather show random ages of activity. This fact is also proven by the ages of the three growth events introduced within this thesis.

The studies from Beidinger & Decker (2014) suggest the OOS thrusting to start in the Karpatian stage in the area of the Mistelbach Block (see Fig. 8). Results from this Master's thesis could supplement their studies by proving OOS activity in the flysch units already during the Ottnangian stage. This assumption arises from the determination of distinct syntectonic growth strata of this time.

However, there is only a relatively small amount of shortening expected for the OOS events on the Mistelbach Block. The flysch antiforms show amplitudes between 100 ms and 300 ms. The mapped thrust surfaces result in lengths of 1 km to 4 km. The thrust distances within the Mistelbach Block were estimated to a scale of a few hundred meters.

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8. ATTACHMENTS

8.1. Seismic volumes

Tab. 3: Geometry of the first provided 3D seismic cube. MG I Austria GK M34 coordinate system including a false easting of 500,000.

3D_Mistelbach_cut_UniWien.zgy	Start	End	Step
Inline	2431	3481	1
Xline	5659	6716	1
Lateral geometry	Origin	End first inline	End first crossline
X	516538.46	527981.76	523119.78
Y	5379789.73	5373182.89	5391188.81
Intervals		12,5	12,5
Rotation [degrees]		120	30

Tab. 4: Geometry of the second provided 3D seismic cube. This volume was relevant for the final results. MG I Austria GK M34 coordinate system including a false easting of 500,000.

VBSM_PSTM_noAGC [Crop].zgy	Start	End	Step
Inline	1902	3021	1
Xline	2432	3041	1
Lateral geometry	Origin	End first inline	End first crossline
X	516512.01	529699.63	530500.08
Y	530500.08	5367008.89	5398849.37
Intervals		25	25
Rotation [degrees]		120	30

8.2. Well Data

Tab. 5: Provided well data. Additional information is indicated with x. MG I Austria GK M34 coordinate system including a false easting of 500,000. Coordinate values are rounded to the nearest thousand.

Well Name	Well Head X	Well Head Y	Well Tops	Check-shots	TWT auto
ALT-HOEFLEIN 001	531,000	5,389,000	x		
ALT-HOEFLEIN 002	531,000	5,390,000	x		
GINZERSDORF 001	529,000	5,387,000	x		x
GINZERSDORF 002	530,000	5,386,000	x		x
GINZERSDORF 003	527,000	5,387,000	x		x
GINZERSDORF 004	527,000	5,387,000	x		x
GINZERSDORF 004_updated	527,000	5,387,000			
KETTLASBRUNN 001	523,000	5,379,000			
KETTLASBRUNN 002	523,000	5,379,000			
LINENBERG 001	529,000	5,380,000	x		x
LINENBERG 002	529,000	5,380,000	x	x	
LINENBERG 003	530,000	5,380,000	x		x
LINENBERG 005	529,000	5,380,000	x		x
LINENBERG 006	530,000	5,379,000			
LINENBERG 007	530,000	5,380,000			
MAUSTRENK 001	530,000	5,381,000	x		x
MAUSTRENK 002	530,000	5,381,000	x		x
MAUSTRENK 003	530,000	5,381,000	x		x
MAUSTRENK 003a	530,000	5,381,000	x		x
MAUSTRENK 004	529,000	5,381,000	x		x
MAUSTRENK DF 001	529,000	5,381,000	x		x
MAUSTRENK DF 002	529,000	5,381,000	x		x
MAUSTRENK DF 003	529,000	5,381,000	x		x
MAUSTRENK UEBERTIEF 001	529,000	5,379,000	x	x	x
MAUSTRENK UEBERTIEF 001a	529,000	5,379,000	x		
MAUSTRENK WEST 001	528,000	5,382,000	x		
MISTELBACH 001	519,000	5,382,000	x		
MISTELBACH U 001	524,000	5,382,000	x		
MISTELBACH U 002	517,000	5,372,000	x		
MISTELBACH U 003	521,000	5,374,000	x		
SCHARFENECK 001	528,000	5,379,000	x		
SCHARFENECK 002	527,000	5,380,000	x		
SCHARFENECK 003	527,000	5,379,000	x		
SCHARFENECK 004	525,000	5,378,000	x		
SCHARFENECK 005	525,000	5,378,000	x		
SCHARFENECK 006	525,000	5,377,000	x		
SCHARFENECK 007	525,000	5,378,000	x		
SCHARFENECK 008	525,000	5,378,000	x		
SCHARFENECK 011	525,000	5,377,000			
SCHARFENECK 012	524,000	5,377,000	x		
SCHARFENECK 015	526,000	5,379,000			
SCHARFENECK OST 001	526,000	5,379,000	x	x	
SCHARFENECK U 001	526,000	526,000	x		
ST.ULRICH 290 (checkshot only)	?	?		x	

8.3. Horizons

Tab. 6: Overview of the most important mapped horizons.

Surface Name	Stratigraphy	Dip	X range	Y range	-TWT range [ms]
Top_Karpat (OMV)	L. Badenian	-	516494-543704	5366991-5398866	452-73
Channel_1	L. Badenian	NW	520490-529890	5376770-5387820	815-48
Channel_2	L. Badenian	NW	526497-531497	5384822-5390722	587-119
Top_Growth_3	L. Karpatian	NW	520767-524017	5377372-5381472	1275-868
Top_Growth_2	L. Karpatian	NW	526952-529902	5384309-5387309	684-419
Top_Growth_1	Ottangian	NW	522926-533176	5378305-5388355	1399-245
Top_Flysch	Creta. – Eoc.	NW	518000-533550	5369669-5388919	1600-120

8.4. Faults

Tab. 7: Overview of the most important mapped faults and their timeframe of activity.

Fault Name	Fault Type	Dip	Eggen. / Ott.	Karpatian	M. - U. Mioc.
Steinberg Fault	Normal Fault	SE			x
Fault System West	Normal Fault	SE	?	x	L. Badenian
Flysch Thrust 2	Thrust Fault	SE	x	x	
Flysch Thrust 1	Thrust Fault	SE	x		

8.5. Abstract

This Master's thesis analyses of a 3D seismic cube, provided by OMV, and focuses on Early Miocene growth strata that overlie antiforms on the allochthonous, Alpine flysch nappes of the Mistelbach Block in the Northern Vienna Basin. These folds are expected to be caused by blind out-of-sequence thrusts in the pre-Neogene basement between the Lower Otnangian and the Lower Karpatian stage. Their ages of activity are determined by mapped horizons, using the seismic interpretation software Petrel, which represent the top surfaces of growth strata. Therefore, they give information about the ceasing of the syntectonic sedimentation processes. Thrust fault-related folding is suggested for the investigated events, at which trishear fault-propagation folds, including the mechanism of backlimb rotation during fold growth, might be responsible for the resulting, fan-shaped growth strata geometry that is particularly observed in the hinterlands of some of the flysch antiforms. The thrust distances are estimated to a scale of a few hundred meters and belong to an entire succession of Early Miocene out-of-sequence thrusts between the Northern Calcareous Alps and the Waschberg Unit in the Northern Vienna Basin. Aside from the thrust events, two bigger fault systems are mapped in the provided seismic cube, including the famous Steinberg fault. Furthermore, according to a new stratigraphic classification of this area, two channels are determined and dated to Lower Badenian stage.

8.6. Zusammenfassung

Diese Masterarbeit beinhaltet die Interpretation einer 3D-Seismik der OMV AG, mit dem Schwerpunkt auf frühmiozäne Growth Strata, welche Antiformen auf den alpinen Flyschdecken der Mistelbacher Scholle im Nördlichen Wiener Becken überlagern. Es wird vermutet, dass diese Falten auf blinde Out-of-Sequence-Überschiebungen im präneogenen Beckenuntergrund zurückzuführen sind, welche vom unteren Oligozän bis ins untere Karpat aktiv waren. Deren zeitliche Zuordnung erfolgt mit Hilfe der Seismikinterpretationssoftware Petrel, indem jene Horizonte kartiert werden, die den Oberflächen der Growth Strata entsprechen. Dadurch kann Aufschluss über das Ende der syntektonischen Sedimentationsprozesse gegeben werden. Für die untersuchten Events wird das Prinzip von Thrust Fault-Related Folding angenommen. Trishear Fault-Propagation Folds, die den Mechanismus der Backlimb Rotation während des Faltenwachstums beinhalten, könnten die mögliche Ursache für die fächerförmige Geometrie der Growth Strata sein. Dieses Muster kann man vor allem im Hinterland der jeweiligen Flyschantiformen erkennen. Die Überschiebungsweiten werden auf einen Bereich von einigen hundert Metern geschätzt. Diese Störungen gehören zu einer gesamten Abfolge von Out-of-Sequence-Überschiebungen zwischen den Nördlichen Kalkalpen und der Waschbergzone im Nördlichen Wiener Becken. Abgesehen von den Überschiebungen werden zwei größere Störungssysteme kartiert. Eines davon zeigt den berühmten Steinbergbruch. Außerdem werden zwei Channels ermittelt, welche anhand einer neuen stratigraphischen Gliederung auf das untere Baden datiert werden.