Swiss Bull. angew. Geol. Vol. 18/1, 2013 S. 51-59

Structural geology of Central Switzerland – results of seismic campaign in 2011 in cantons Nid- and Obwalden

Andreas Ebert[1], Oliver Genoni[1], Markus Häring[1]

Key words: Helvetics, seismic, Central Switzerland, tectonics, Drusberg nappe

Abstract

GVM (Gas Verbund Mittelland AG) commissioned in 2011 the acquisition of 113 km of 2D reflection seismic as a first step of an integrated exploration campaign for geothermal and hydrocarbon resources in the cantons Nid- and Obwalden (Switzerland). One of the aims of the seismic campaign was to define the structure of the Helvetic nappes and its base, the internal build-up of the underlying Tertiary sediments and the autochthonous Mesozoic cover.

The new data allow defining the internal tectonics of the Drusberg nappe and its base. The deformation style of the Drusberg nappe is characterized by imbrication and ramp anticlines. The base of the Helvetic nappe forms a relatively flat, wide and gently structured synform south of a line Schwendi – Alpnach – Stans. The base of the Helvetic nappes reaches a max. depth of approximately 1.8–2.0 km below the Sarner Aa valley.

It is not possible to distinguish between south dipping Molasse and supposed North Helvetic Flysch. The autochthonous Mesozoic cover is less deformed. Few faults and folds may correlate with underlying Permo-Carboniferous troughs. The latter can be identified on the seismic sections by unconformities.

Zusammenfassung

Als erster Schritt einer integralen Explorationskampagne für geothermische Ressourcen und Kohlenwasserstoffe erteilte GVM (Gasverbund Mittelland AG) 2011 den Auftrag zur Aufnahme von 113 km Reflexionsseismik in den Kantonen Nid- und Obwalden (Schweiz). Die Kampagne hatte unter anderem zum Ziel, den Aufbau der Helvetischen Decken, der unterlagernden tertiären Sedimente (Molasse, Flysch) und der autochthonen Einheiten (mesozoische Bedeckung und Grundgebirge) zu bestimmen.

Die neuen Daten bestätigen weitgehend bestehende strukturelle Modelle. Der interne Aufbau der Drusberg Decke ist gekennzeichnet durch Verschuppung und Rampenantiklinalen. Die Basis der Helvetischen Decken ist wenig strukturiert und bildet eine weite und flache Synform südlich einer Linie Schwendi – Alpnach – Stans. Die Basis erreicht an ihrer tiefsten Stelle Tiefen von ca. 1.8–2.0 km unter dem Sarner Aatal.

In den darunter liegenden tertiären Sedimenten ist es nicht möglich, einzelne Einheiten zu unterscheiden. Die Grenze Molasse – Nord Helvetischer Flysch konnte nicht erkannt werden. In der autochthonen mesozoischen Bedeckung können nur wenige Falten und Brüche ausgeschieden werden, welche häufig mit unterlagernden Permokarbon-Vorkommen korrelieren. Das Permokarbon kann auf einigen Linien an Hand von Diskordanzen gut identifiziert werden.

[1] Geo Explorers Ltd, Wasserturmplatz 1, 4410 Liestal, [andreas.ebert@geo-ex.ch]

1 Introduction

In the cantons Nidwalden and Obwalden (Central Switzerland), the surface geology is well exposed and allows to construct the complex nappe and fold structures of the Helvetic and Penninic nappes. As a result of this, numerous studies were performed in the past. The first published cross sections across the Pilatus are given in Kaufmann (1867). A selection of more recent and important regional studies about the structural geology of the Central Alpine nappes are the PhD thesis of Menkveld (1995), the recent compilation of the Helvetic nappes of Pfiffner (2011), and the extensive work of Hantke (1961).

However, all the presented information about the deeper subsurface rely on extrapolations from the visible geology at the surface. Deep wells are missing. The closest exploration well that penetrated the Molasse and Mesozoic sediments is Entlebuch-1 north of the Alpine front (Fig. 1). This 5,144 m deep well bottomed in the Upper Carboniferous. Wells at Wellenberg relating to the surveying of the impermeable Palfris Formation by Nagra only reached the base of the Helvetic nappes. The 2,302 m deep geothermal well of Weggis only intersected the USM and UMM of the Molasse sediments.

In the course of the exploration for hydrocarbons in Switzerland during the sixties to eighties several tens of kilometres of seismic were acquired in Nid- and Obwalden. During the seventies and early nineties LEAG (AG für Luzernisches Erdöl), respectively TGK (Tiefengaskonsortium) shot 270 km of 2D reflection seismic (Fig. 1). While the LEAG seismic is accessible, the TGK seismic is not available. When the LEAG seismic were acquired, vibrators were less powerful and were not able to provide the same energy as nowadays. The data quality is only sufficient to sketch the autochthonous Mesozoic cover. It is not possible to define the internal structures and the base of the Helvetic

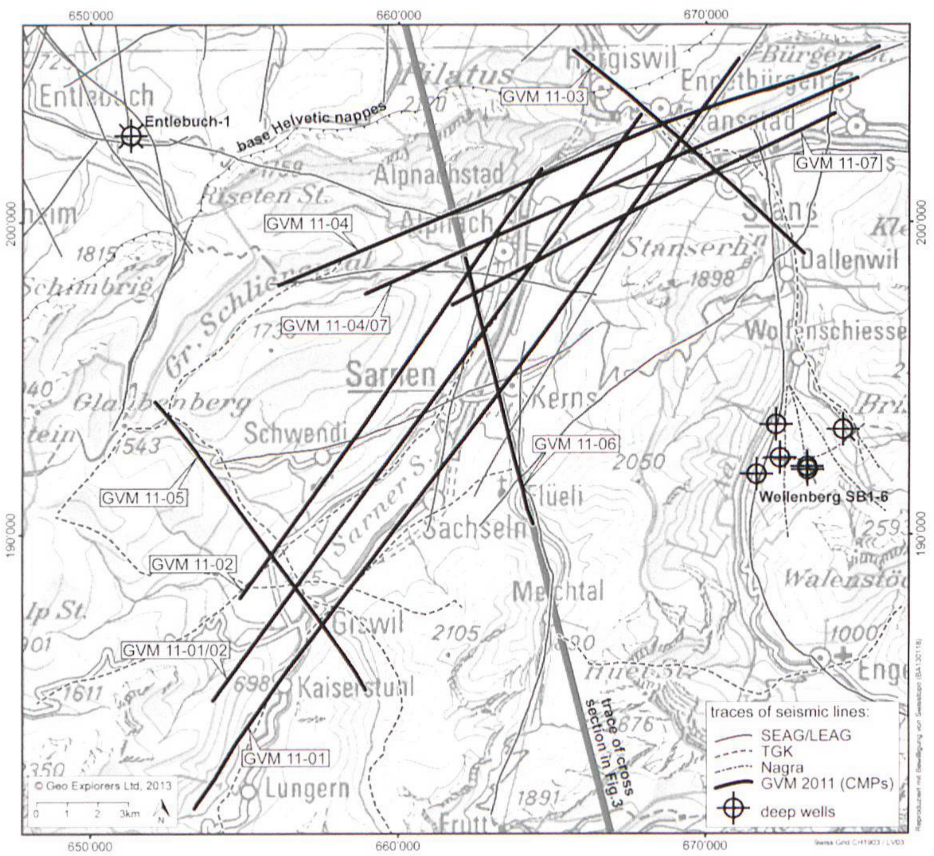

Fig. 1: Outline map of the exploration status in Nid- and Obwalden. Thick black lines represent the new seismic lines of this study.

nappes, the Flysch - Molasse contact, the internal structures of the autochthonous cover and the existence and extend of Permo-Carboniferous troughs below the autochthonous Mesozoic cover.

2 Seismic survey

Motivation for a new survey

Currently, Switzerland depends 100% on imports in case of gas. Only one well, the Entlebuch-1 well, produced a small gas volume of around 74 Mio. m³ within the years 1984–1994. Comparing to neighboring countries the exploration status in Switzerland is low. Most of the underground data from seismic observations or drilling are old and in many locations of dissatisfying quality.

Several indications for potential gas accumulations in the subsurface make the area of the Central Alps attractive for an exploration. Such indications are e. g. the gas finding in the well Entlebuch-1 (Lahusen & Wyss 1995), numerous gas seeps from Lungern to Alpnach (e. g. Greber et al. 1995), gas blowouts in the wells EWS Wilen (Wyss 2001) and Wellenberg SB1 (e. g. Nagra 1997).

Based on these conditions, seismic surveys were acquired in the past in Nid- and Obwalden. However, as described above, the data quality is insufficient to describe the subsurface in detail. To close gaps and to improve the geological model, a new seismic survey was required.

Organisation

GVM (Gasverbund Mittelland AG) holds the exploration licenses for hydrocarbons in Nid- and Obwalden. The initial exploration targets were to estimate the potential for energy resources (gas and hot water) and for gas storage. Geo Explorers Ltd was responsible for the project development, seismic planning, management and the interpretation of the seismic data. DMT GmbH & Co. KG carried out the seismic data acquisition. Permitting was performed by IPS. Gasser Felstechnik AG made the drilling and blasting where source points were not accessible by vibrotrucks.

Execution

Permitting started end of June 2011. Acquisition took place during September 2011. Along seven lines a total length of 112.55 km were acquired (Fig. 1). Additionally, two pseudo lines were recorded (GVM 11-01/02 and 11-04/07) by simultaneous recording along both parallel lines GVM 11-01 and 11-02, respectively GVM 11-04 and 11-07, while shooting took place along one line. Despite the difficult topography and owing to the good and dense road network in Nid- and Obwalden, even in the wooded mountain areas, it was possible to achieve fairly straight lines. 97% of shot points were sourced by vibrotrucks.

The deployed vibrators of type HEMI Mertz M 12 achieve a peak force of 47,700 lbf. Operation took place with four trucks wherever possible. However due to limited space and/or environmental conditions vibrator count had occasionally to be reduced. For blasting 2–2.5 kg of explosives (supergel 30) were used in drill holes up to 15 m deep. The distance between the source points was 50 m and 25 m between the receiver points. Hydrophones were used from Stansstad to Hergiswil across the «Vierwaldstättersee» (line GVM 11-03).

3 Geological overview

The geology of the exploration area is characterized by the Helvetic nappe stack thrusted onto the Tertiary sediments (Subalpine Molasse and North Heveltic Flysch). Internal deformation (folding, imbrication, faulting) occurred in Oligocene and Miocene time. This period correlates with the Kiental and Grindelwald deformation phase. The resulting Alpine nappe stack and the internal folds are clearly visible in the area, e. g. the landmark mountain Pilatus.

Stanserhorn, Buochserhorn, Schlierental and Glaubenberg are built up of Penninic units (Schlierenflysch and Klippendecke) overlying Ultrahelvetic and Helvetic units. The Helvetic nappe stack is divided into two nappes, the Drusberg and Axen nappe. The structural higher nappe, the Drusberg nappe covers the area north a line Lungern – Oberrickenbach – Isenthal. It consists of Cretaceous carbonates and Tertiary sediments. The Cretaceous of the Drusberg nappe was detached from the Jurassic sequence of the Axen nappe within the Palfris shales. The front of the Drusberg nappe forms the cliffs of Bürgenstock, Pilatus as far as Schrattenflue. The strongly folded and imbricated Axen nappe outcrops south of the Drusberg nappe and north of a line Meiringen – Jochpass – Surenenpass.

4 Purpose of new seismic campaign

To date, the existing geological model of the Helvetics relies on surface data and balanced cross sections. Only the wells at Wellenberg intersect the Helvetic nappe stack. Existing seismic data only allow a schematic outline of the autochthonous Mesozoic cover. Apart from that a lot of open questions persist:

- The depth and shape of the base of the Helvetic nappes is unknown.
- The extent of folding, imbrication or the coupling of both within the Drusberg nappe can only be assumed.
- The interfingering of Molasse and North-Helvetic Flysch is unknown.
- Existing seismic provides hardly any information about the internal deformation (e. g. traps, faults) of the autochthonous Mesozoic cover. The gas in nearby well Entlebuch-1 and numerous gas seeps let suppose that Permocarboniferous sediments are enclosed within crystalline basement. Its presence has to be proven on seismic profiles.
- The location and extent of displacement of Aar massif onto autochthonous is vague.

Fig. 2: Convoy of vibrotrucks recording in Nidwalden.

5 New findings from seismic interpretation

Internal deformation Drusberg nappe

Due to uncertainties in predicting the subsurface, several interpretations of the build-up of the Drusberg nappe exist (Figs. 4, 5; Hantke 1961, Menkveld 1995; Pfiffner 2011). Based on surface geology only, it is difficult to define the internal deformation style of the Drusberg nappe south of Pilatus. Depending of the authors, internal shortening is either characterized by folding or imbricating or a combination of both. Based on surface geology, folding is evident, e. g. at Bürgenstock and Mueterschwanderberg (Hantke 1961). Balanced cross sections show that besides folding additional thrusting is mandatory (Menkveld 1995). However, so far it was unclear whether folding or imbrication is the dominant deformation mechanism and how the internal structural build-up looks like.

The new seismic data (Fig. 6) indicate that imbrication is a predominant deformation style within the Drusberg nappe. Displacements seem to be significant and range in an order of up to few kilometers. Folding is concomitant of ramp anticlines.

Along the Sarner Aa valley a large sinistral strike slip fault (e. g. Schindler 1980, Schindler et al. 1996) is assumed. Arguments for this fault are the non-fitting geology on opposite valley slopes, earthquakes below the Sarner Aa valley (e. g. Sarnen earthquake in 1964) with focal mechanisms consistent with the strike slip fault, a lot of gas seeps striking along the valley and numerous sinistral faults in the valley slopes parallel to the valley axis. Unfortunately, this assumed large fault is not visible on seismic. However, this does not mean that the fault does not exist. Reasons for this invisibility can be geological and technical: thick quaternary sediments may cause static problems and filter seismic energy.

Base Helvetic nappes

The base of the Helvetic nappes, in particular the Drusberg nappe, is highly reflective on all sections. It can also be distinguished from the underlying units by a more transparent character. The Cretaceous layering of marls and limestones of the Drusberg nappe shows a good seismic reflectivity compared

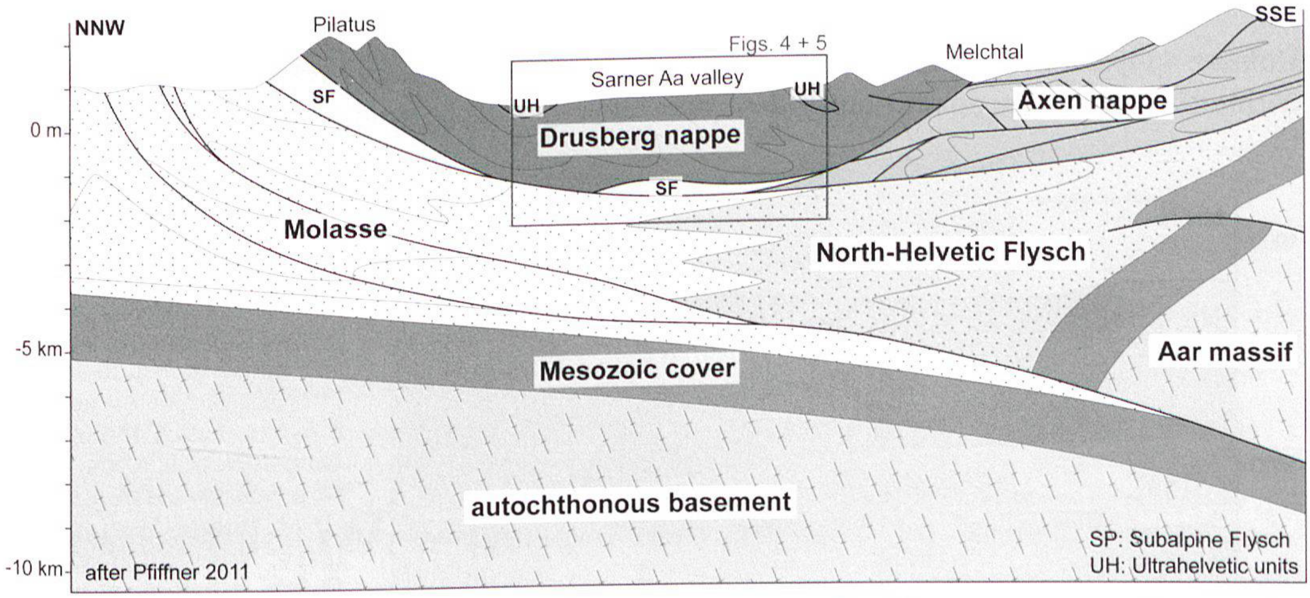

Fig. 3: Cross section from Pilatus to Melchtal (see trace on map in Fig. 1). It shows the prevailing compilation of knowledge after Pfiffner 2011. State of knowledge predates the described seismic survey.

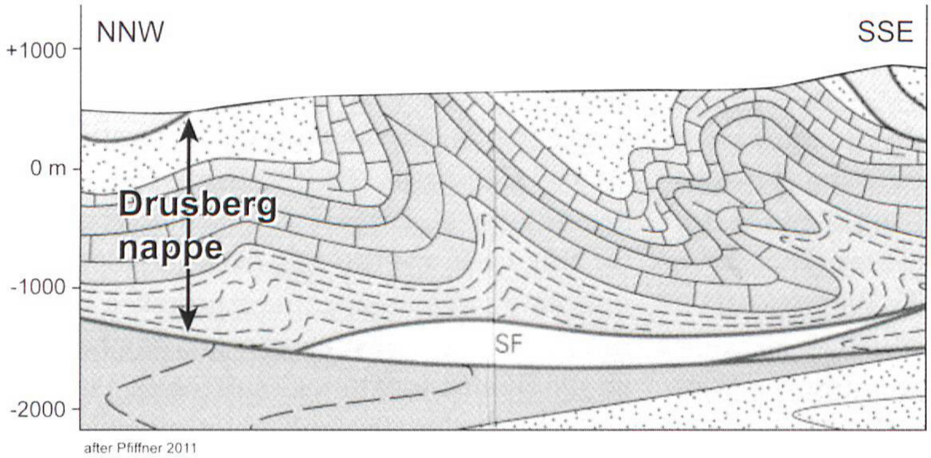

Fig. 4: Cross section from Pfiffner (2011) across the Sarner Aatal, see detail of Fig. 3. Trace of cross section similar to those in Figs. 5 and 6.

to the underlying Tertiary sediments (see Figs. 6, 7). Since the Drusberg nappe outcrops in the Northern part of the investigation area, its base can be easily assigned.

The base of the Helvetic nappes dips steeply from the surface at Pilatus to SE (see Figs. 7, 8) and forms a relatively flat and wide synform in the central part of the investigation area. This synform strikes from NE to SW and covers a flat base of approximately 15 km in width south of a line Schwendi – Alpnach – Stans. This synform is internally weakly structured. Only few faults and low-amplitude folds are present. The deepest parts of the base of the Helvetic nappes reach a two-way-time depth of around 0.9-0.95 sec. (datum 700 m = 0 sec.), corresponding to a depth of approximately 1.8-2.0 km below the Sarner Aa valley.

Molasse – Flysch transition

Within the Tertiary sediment unit (Molasse and Flysch) a south dipping layering is recognisable (e. g. see Figs. 7, 8). However, on the seismic sections it is not possible to trace reflections for long distances within the Tertiary sediments. No clear reflection bands or patterns exist. The seismic contrast within the Tertiary layering is too weak. Additionally, the contact Molasse – North Helvetic Flysch cannot be distinguished.

Sometimes unconformities, onlap, pinch out and swallow structures are identifiable within the Molasse unit. The size of these structures ranges in an order of 1 to 3 km in width. They can be correlated with channels and/or fans, smaller structures cannot be resolved.

Autochthonous Mesozoic cover

The autochthonous Mesozoic sediment sequence can easily be traced (Figs. 7, 8). Similar to the Drusberg nappe the alternat-

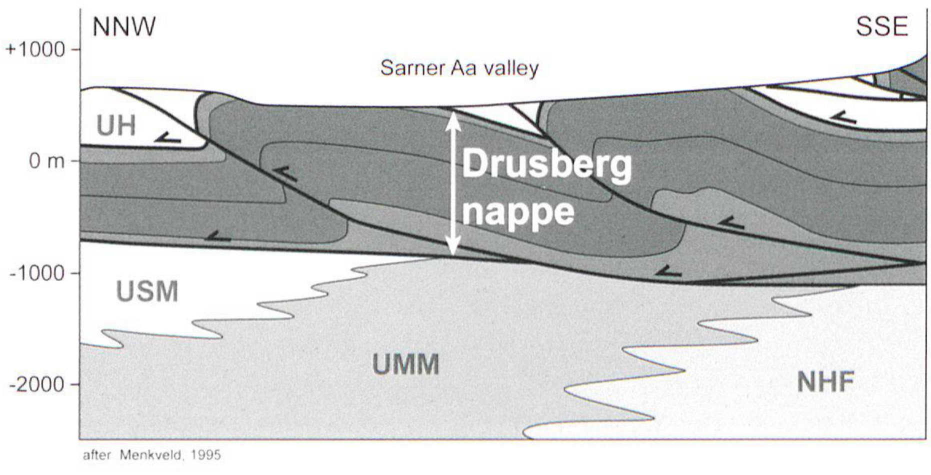

Fig. 5: Balanced cross section from Menkveld (1995) across the Sarner Aatal, see detail of Fig. 3. Trace of cross section similar to those in Figs. 4 and 6. UH: Ultrahelvetics, USM: Untere Süsswassermolasse, UMM: Untere Meeresmolasse, NHF: North Helvtic Flysch, hypothetical boundary between USM/UMM and UMM/NFH.

ing layering of limestones, marls, evaporates and siliciclastic rocks show a good reflectivity. The continuous reflection pattern of the Mesozoic unit allows a good correlation of all seismic sections.

Although affected by the Alpine thrusting – a stack of nappes is overlying the Mesozoic cover – the Mesozoic unit is only weakly folded, imbricated or intersected by significant faults. This implies a decoupling of Alpine deformation in the overlaying Alpine nappes from the autochthonous units. As mentioned above, the assumed Sarner Aa valley fault is likewise not visible in the Mesozoic unit.

Major inversion of Permo-Carboniferous troughs and a correlated folding and imbrications of overlaying Mesozoic cover, as it is evident in the Entlebuch area (e. g. prospect Finsterwald), cannot be observed (Figs. 7, 8). However, the few existing thrusts within the Mesozoic cover correlate with underlaying presumed Permo-Carboniferous troughs.

Permo-Carboniferous sediments

As learned from several seismic interpretations in the Swiss Molasse Basin, a distinction between Permo-Carboniferous sediments and surrounding crystalline basement is ambiguous. Reflections below the Mesozoic unit can either be multiple reflections of prominent Mesozoic reflectors or real reflections within the Permo-Carboniferous troughs. Distinct criteria for Permo-Carboniferous reflections are unconformities, oblique reflection patterns in comparison to the Mesozoic ones, discontinuous and systematically alternating but complex reflection bands.

Such criteria can be observed on the seismic sections in figures 7 and 8. The discordant reflections below the Mesozoic unit can

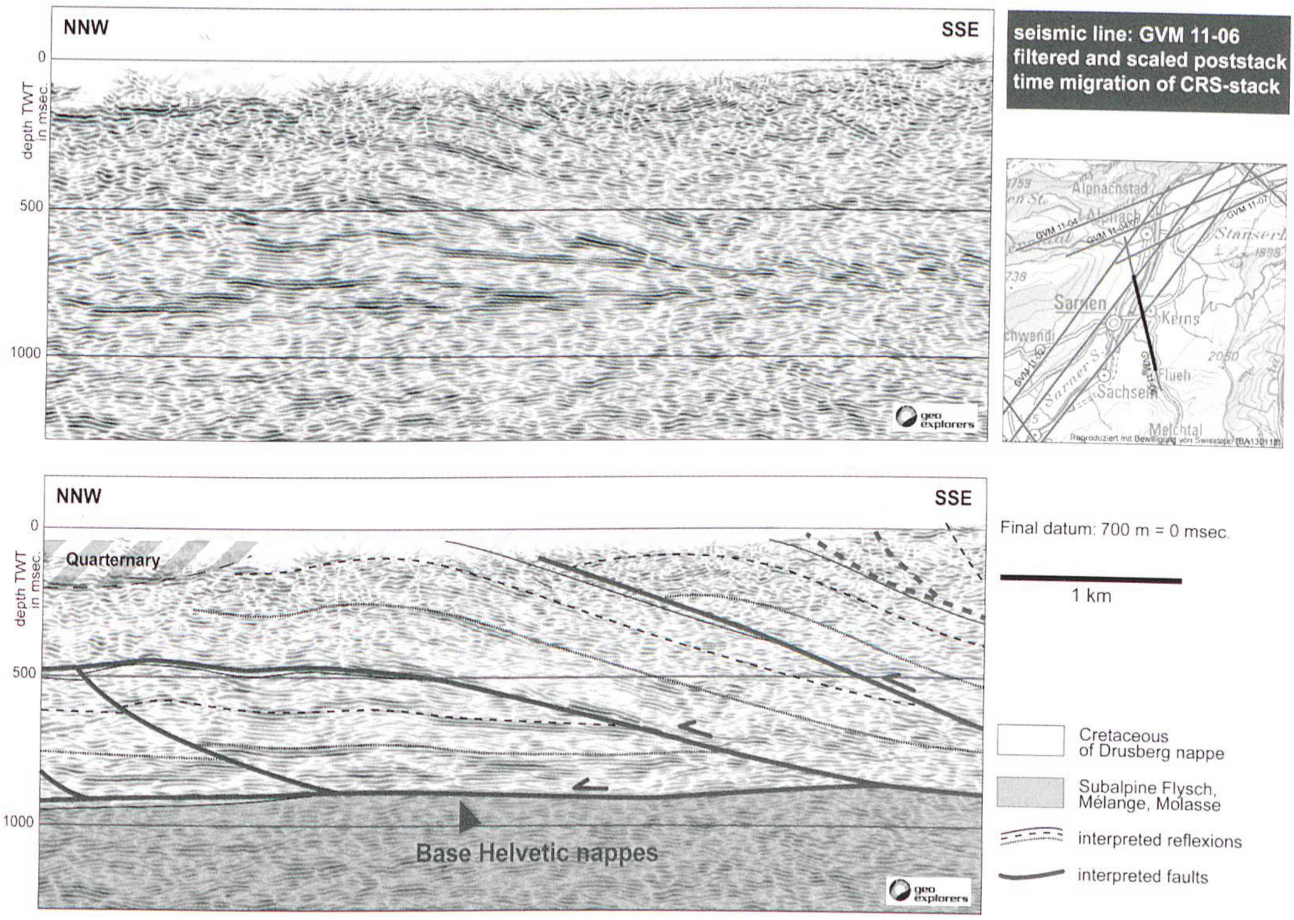

Fig. 6: Imbrication of Drusberg nappe along section of seismic profile GVM 11-06. The cross section is inclined to structural strike of folding and thrusting. Therefore dip of thrusts appears gentle and displacement is exaggerated. Interpretation on the upper right hand part of profile is based on surface geology.

only be attributed to Permo-Carboniferous reflectors. The gas seeps suggest the presence of coal bearing Permo-Carboniferous.

6 Conclusions

The latest seismic data provide significant new findings and confirm structural models. The data confirm imbrication and ramp folding within the Drusberg nappe. Moreover, they show the presence of Permo-Carboniferous sediments. They are likely to contain the source rock providing the gas of the local gas seeps. Attractive leads for gas were identified below the Helvetic nappes and in the autochthonous Mesozoic cover. Prospects for further exploration are given.

Acknowledgements

We thank GVM for the permission to publish parts of their data.

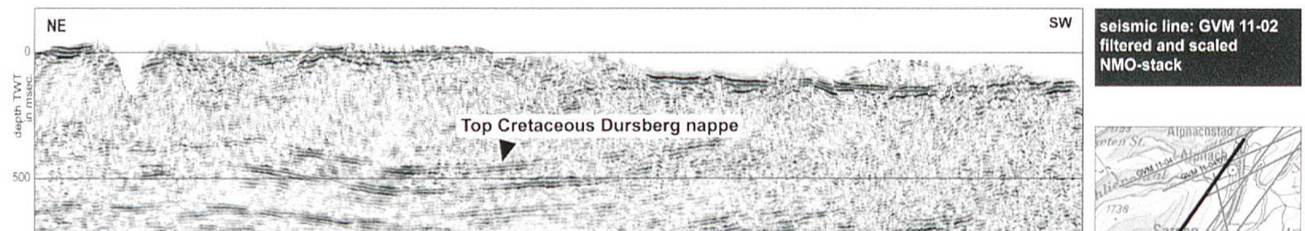

Fig. 7: Section of seismic line 11-02 (NMO stack). The reflections of Cretaceous sediments of the Drusberg nappe and the Mesozoic cover of the autochthonous are visible. Reflections below the Mesozoic cover can presumably be attributed to Permo-Carboniferous sediments. Trace of presented section is given as a black line on the map.

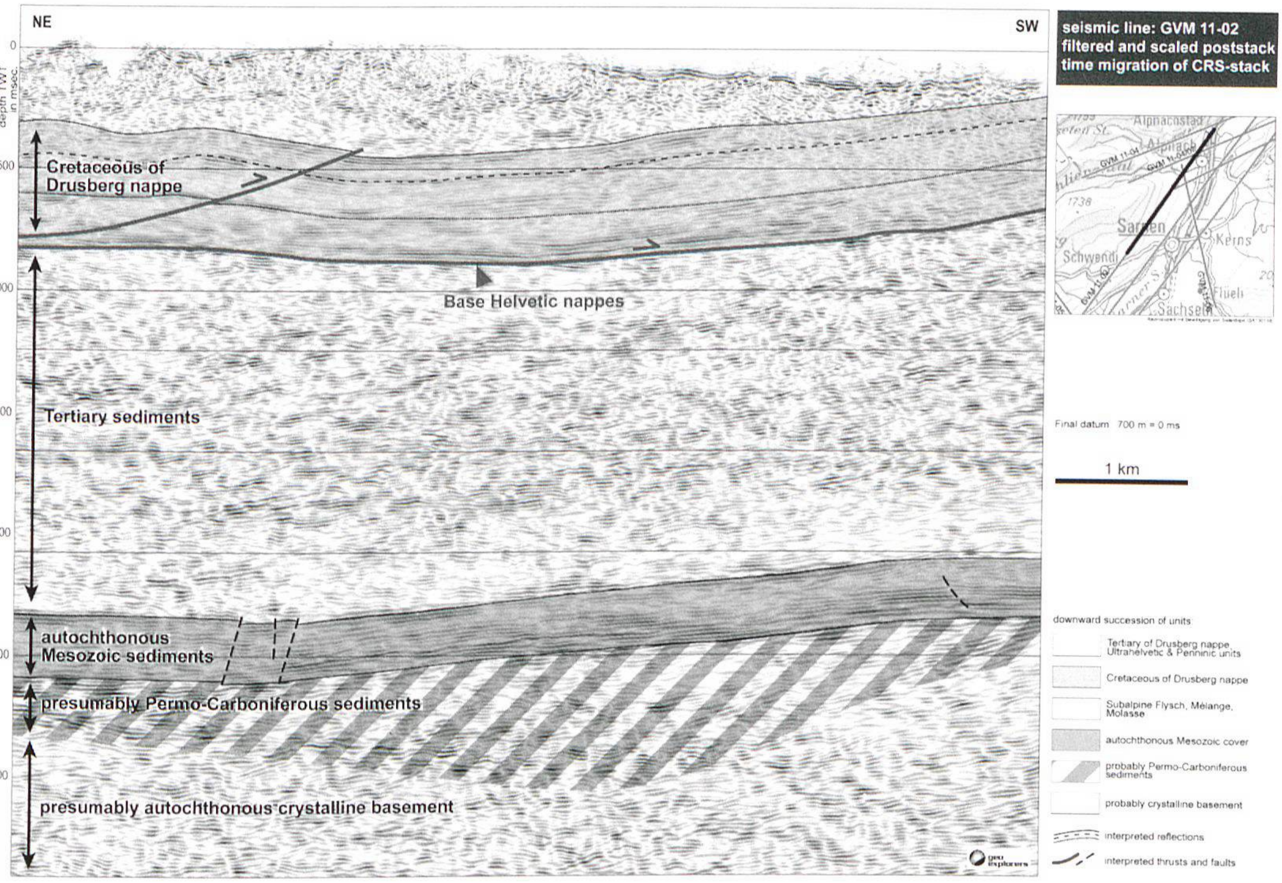

Fig. 8: Sections of seismic line 11-02 (interpreted migrated CRS stack), same detail as in Fig. 7. Similar to Fig. 7, the reflections of Cretaceous sediments of the Drusberg nappe and the Mesozoic cover of the autochthonous can be traced. Reflections below the Mesozoic cover can be attributed to a Permo-Carboniferous trough. Trace of presented section is given as a black line on the map.

References

Greber, E., Leu, W. & Wyss, R. 1995: Erdgasindikationen in der Schweiz. Grundlagen zur Charakterisierung des Gasgefahrenpotentials im Untergrund. Bull. Schweizer Ingenieur und Architekt., 24, 8. Juni 1995, 567–572.

Hantke, R. 1961: Tektonik der helvetischen Kalkalpen zwischen Obwalden und dem St. Galler Rheintal. Vierteljahrsschrift der Naturforschenden Gesellschaft Zürich, 106, p. 211.

Lahusen, H. L. & Wyss, R. 1995: Erdöl- und Erdgasexploration in der Schweiz: Ein Rückblick. Bulletin der Vereinigung schweizerischer Petroleum-Geologen und -Ingenieure, 62/141, 43–72.

Kaufmann, F. J. 1867: Der Pilatus. - Beitr. Geol. Karte Schweiz 5.

Menkveld, J. W. 1995: Der geologische Bau des Helvetikums der Innerschweiz. PhD thesis, Universität Bern, p. 165.

Nagra 1997: Geosynthese Wellenberg 1996. Ergebnisse der Untersuchungsphasen I und 11. Nagra Technischer Bericht NTB 96-01, p. 511.

Pfiffner, O. A., 2011: Structural Map of the Helvetic Zone of the Swiss Alps including Vorarlberg (Austria) and Haute Savoie (France). Geological Special Map 1:100'000, Swiss Geological Survey, 128, Federal Office of Topography swisstopo, Wabern.

Schindler, C. 1980: Geologisch-geotechnische Voruntersuchung der N8 zwischen Sarnen und dem Brünig. Strasse und Verkehr, 66/5, 157–163

Schindler, C., Beer, C., Mayer-Rosa, D., Rüttener, E., Wagner, J.-J., Jaquet, J.-M., Frischknecht, C. 1996: Integrierte Auswertung von seismischen und bodenspezifischen Parametern: Gefährdungskarten im Kanton Obwalden. Geologische Berichte Landeshydrologie und -geologie, 19, p. 61.

Wyss, R. 2001: Der Gasausbruch aus einer Erdsondenbohrung in Wilen (OW). Bulletin für Angewandte Geologie, 6/1, 25–40.