Geothermal energy for the "smart city" Wien, Aspern
Geothermale Energie für die „Stadt in der Stadt" Wien, Aspern

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For a major urban development area in the eastern outskirts of Vienna, Austria, a sustainable supply of renewable energy for district heating and warm water preparation is required. On behalf of the Vienna Business Agency, therefore, a feasibility study was prepared that documents the possibility of extracting a sufficient amount of geothermal energy from a hot water reservoir in the geological substructure of the Vienna Basin. Successful implementation of an appropriate pilot plant could have vast implications for the future development of this type of energy supply in the the CENTROPE Region (Central European Region, i.e. easternmost Austria plus adjacent parts of the Czech and Slowak republics and Hungary), within which the Vienna Basin is the central major geological structure.

Für ein bedeutendes Stadtentwicklungsgebiet im östlichen Randbereich von Wien wird eine möglichst weit gehende Selbstversorgung mit erneuerbarer Energie für die Heizwärme- und Warmwasserversorgung angestrebt. Im Auftrag des Wiener Wirtschaftsförderungsfonds wurde in diesem Zusammenhang eine Machbarkeitsstudie erstellt, die nachweist, dass aus einem Heißwasserreservoir im Untergrund des Wiener Beckens eine ausreichende Menge geothermaler Energie bereit gestellt werden kann. Die erfolgreiche Errichtung einer entsprechenden Pilotanlage könnte entscheindende Impulse für eine Weiterentwicklung dieser Energieform in der gesamten CENTROPE Region (Europa Region Mitte) setzen, in der das Wiener Becken die zentrale geologische Großstruktur darstellt.

1 Introduction: the future "smart city" Wien, Aspern

The former airfield Aspern, in the eastern outskirts of Vienna (22nd district), is presently one of the major urban development areas of the city. Special about this area is the fact that a "smart city", in the Eastern Development Corridor reaching out toward Bratislava, Slovakia, shall be

Fig. 1. On the former airfield Aspern in the eastern outskirts of Vienna, Austria, a new urban center shall be constructed from scratch. Left: present state, viewed from the southeast (aerial photograph: Aspern AG, Vienna); right: final structure according to the masterplan (design: Tovatt Architects & Planners, Drottningholm, Sweden).

Abb. 1. Auf dem Gelände des ehemaligen Flugfeldes Aspern im Osten der Stadt Wien soll eine neues städtisches Zentrum entstehen. Links: derzeitiger Zustand, Blick von Südosten (Luftbild: Aspern AG, Wien); rechts: Strukturierung gemäß dem vorliegenden Masterplan (Entwurf: Tovatt Architects & Planners, Drottningholm, Schweden).

constructed there from scratch (Fig. 1). Finally, within 15 to 25 years time, the area will contain 8.500 accomodation units and up to 50.000 people are expected to live and/or work there. By virtue of this fact, on a total land surface of approx. 240 ha, acquisition of 2,5 million sq.m. floor space for commercial and industrial as well as residential purposes is required. In March 2005, therefore, the "Asperner Flugfeld Süd Entwicklungs und Verwertungs AG" was founded by the Vienna Business Agency (VBA, Wiener Wirtschaftsförderungsfonds, WWFF) and the Federal Enterprise for Real Estate (Bundesimmobiliengesellschaft, BIG) to carry out land reclamation and construction managing. [1]

In order to develop infrastructure and supply facilities according to the most up-to-date techniques, all possibilities to economize on limited resources and lessen the environmental impact as well as the costs had to be considered. Regarding heat supply there is conventional energy available, supplied by the public provider (Fernwärme Wien) on the basis of primary energy from gas, mineral oil and waste incineration, but the availability of renewable and non-conventional energy sources had also to be evaluated. Past hydrocarbon exploration results by the Austrian mineral oil company OMV AG, Vienna, had suggested the presence a hydrothermal energy source in depths beyond approx. 3000 m below the former airfield, therefore on behalf of the Vienna Business Agency a feasibility study was prepared in order to analyse the geothermal potential of this reservoir for supplying the future "city" at Aspern with a sufficient energy flow for district heating and warm water preparation.

The presently planned future urban center in Wien, Aspern, shall attain its individuality as a "smart city" not least by a far-reaching self-supply with energy from renewable sources.

The project was managed in the framework of the Urban Technology Network, Work Package II, activities (UTN II – WP2, cf. [1]). It was divided into two phases: (1) a pre-feasibility study to evaluate primary key-issues on the basis of already accessible data and, by virtue of verification by this study of the prior assumptions that a sufficient geothermal potential is available, (2) a comprehensive feasibility study to assess the total plant equipment and construction procedure as well as the economic resources needed [2]. The final purpose of the work was a master and finance plan for the whole plant and a decision memorandum for appropriate investors. These tasks were performed by a consultant and a project team from Austria, Germany and Switzerland.

The following summary focuses on the findings of the geoscientific investigations mainly carried out by the Geothermal Workgroup at the University of Natural Resources and Applied Life Sciences, Institute of Applied Geology, Vienna (IAG-BOKU Wien).

2 Geological setting: the Vienna Basin and its substructure

The geological frame of the discussed urban development area is given by the Vienna Basin (cf. [3], Fig. 2). This for-

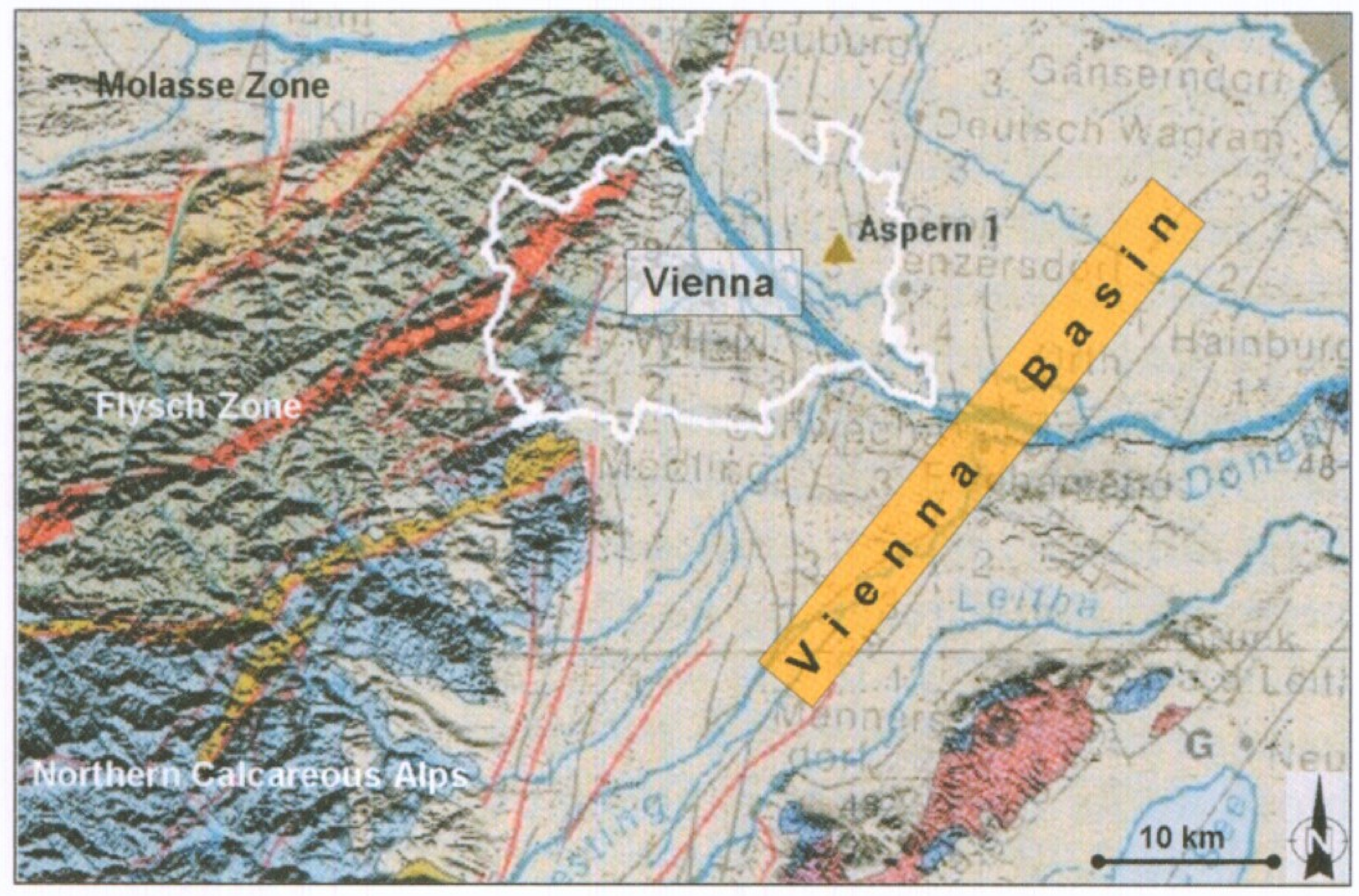

Fig. 2. Geological setting of Vienna (digital elevation model and major tectonic zones, differentiated by colouration). The green triangle in the east of the city denotes the location of the project site ("Aspern 1" was the name of an oil exploration well drilled there in 1974).

Abb. 2. Geologische Situation von Wien (digitales Höhenmodell und tektonische Großeinheiten, differenziert durch Färbelung). Das grüne Dreieck im Osten des Stadtgebietes kennzeichnet die Lage des Projektgebietes („Aspern 1" war der Name einer 1974 am Flugfeld abgeteuften Ölexplorationsbohrung).

merly ocean-filled basin opened in the transition zone between the European Alps and the Carpathians within the last approx. 20 million years and was at last refilled again by erosional products of the rising Alpine mountain chains. The bottom of the basin (buried under a sediment pile up to nearly 6 km thick) is built of the same rock formations as the very eastern part of the Alps to the west and southwest of Vienna (cf. Fig. 3). In the following con-

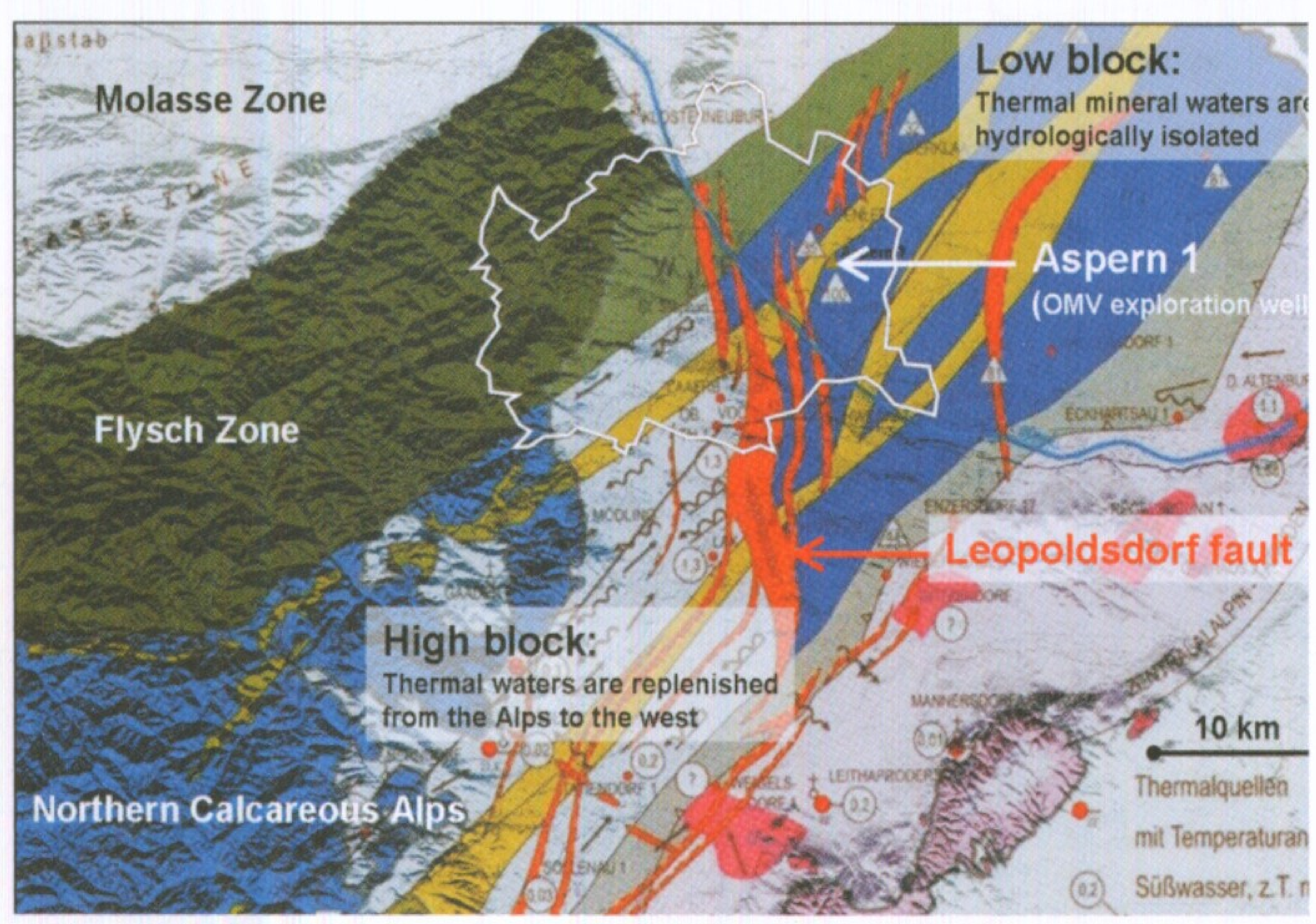

Fig. 3. Geological structure of the bottom of the Vienna Basin (same geographic limits as in fig. 2). The basin sediments are envisaged to be transparent so as to show the tectonic units, particularly the calcareous reservoir rocks (blue), of the easternmost Alps extending to the northeast into the basin bottom.

Abb. 3. Geologische Untergrundstruktur des Wiener Beckens (Bildausschnitt wie Abb. 2). Die Beckensedimente sind transparent zu denken, sodass sichtbar wird, wie die tektonischen Einheiten und insbesondere die kalkalpinen Reservoirgesteine (blau) sich nordostwärts in den Beckenuntergrund fortsetzen.

text the zone of the Northern Calcareous Alps is a matter of particular interest. Like the other formations, it extends in a northeastern direction into the basin floor and in itself is divided into different "nappes" (rock slabs, thrust onto one another and thereby often broken and folded in the course of mountain building processes). In addition, the substructure of the basin as a whole is fractioned into units – separated by "faults" – of, in some cases, very different depth below ground level. So, the Leopoldsdorf Fault, reaching its greatest vertical offset (up to approx. 4000 m) in the southern parts of Vienna, separates an elevated block in the West from a downthrust block in the East. In the calcalpine units of both blocks, limestone and dolomite predominate. Joints and fissures, which are very common within these rocks, contain thermal waters adding up to huge amounts over the total expanse of the calcalpine rock formations. The thermal waters of the western elevated block are replenished by atmospheric waters seeping down to great depths under the morphologic Alps and have been utilized for balneological purposes for a long time (e.g. the spa of Oberlaa in the south of Vienna; cf. [4] to [6]). By contrast, the highly mineralized formation waters within the lowlying block in the east are hydrologically isolated and not being used for any purposes (cf. [3], S. 307–309, and [7] to [9]). Now, by virtue of the present project, a suitable utilization of this hot formation waters is about to be initiated for the first time [10]. Basic informations on this water reservoir were already published on the basis of exploration results by the Austrian mineral oil company OMV AG, Vienna (cf. [11]). But many additional data were needed and so the right to use them was acquired from the company in oder to meaningfully predict the reservoir conditions and formation water characteristics.

3 The hydrothermal reservoir: a lot of hot water waiting to be tapped

The reservoir rock of interest is known to be a dolomite (so-called *Hauptdolomit*, meaning Main Dolomite), a major member of the calcalpine nappes in the bottom of the Vienna Basin. In the investigation area this rock formation is found beyond depths of approx. 3200 m below ground level (cf. Fig. 4). It is intensely jointed and has been recurrently proven to contain thermal mineral water in abundance. The source rock (aquifer) can be further characterized by geohydrological parameters like porosity, ranging from approx. 5 to 13 % by volume, with effective porosity near the lower limit [12], and permeability, varying between 1 and 1000 mD (millidarcy) [13], with a conservative mean value figured out to be about 250 mD. The presumed vertical permeability distribution in the producing section of a future well was evaluated using borehole logging data from several earlier exploration wells. Further rock-specific parameters (heat capacity, thermal diffusivity, ...) had to be estimated, because appropriate data were lacking. The formation pressure is significantly over-hydrostatic ("artesic"), thereby providing the possibility of extracting water just by outflow at the welltop. The static overpressure at surface calculated from the data is in accordance with earlier results from the oil exploration well "Aspern 1", which was drilled on the airfield in 1974 (cf. [8], [11] and Fig. 2 to 4). The geothermal gradient was known to be only slightly above the common mean value (3,0°C/100m), so the formation temperature in the target aquifer could be predicted to range from approx. 110 °C to 150 °C (cf. [14], [15]). But in the east and southeast of Vienna, where the basin bottom plunges to its greatest depths (to more than 8000 m below ground level) and the calcalpine rocks attain their greatest thickness (up to 4000

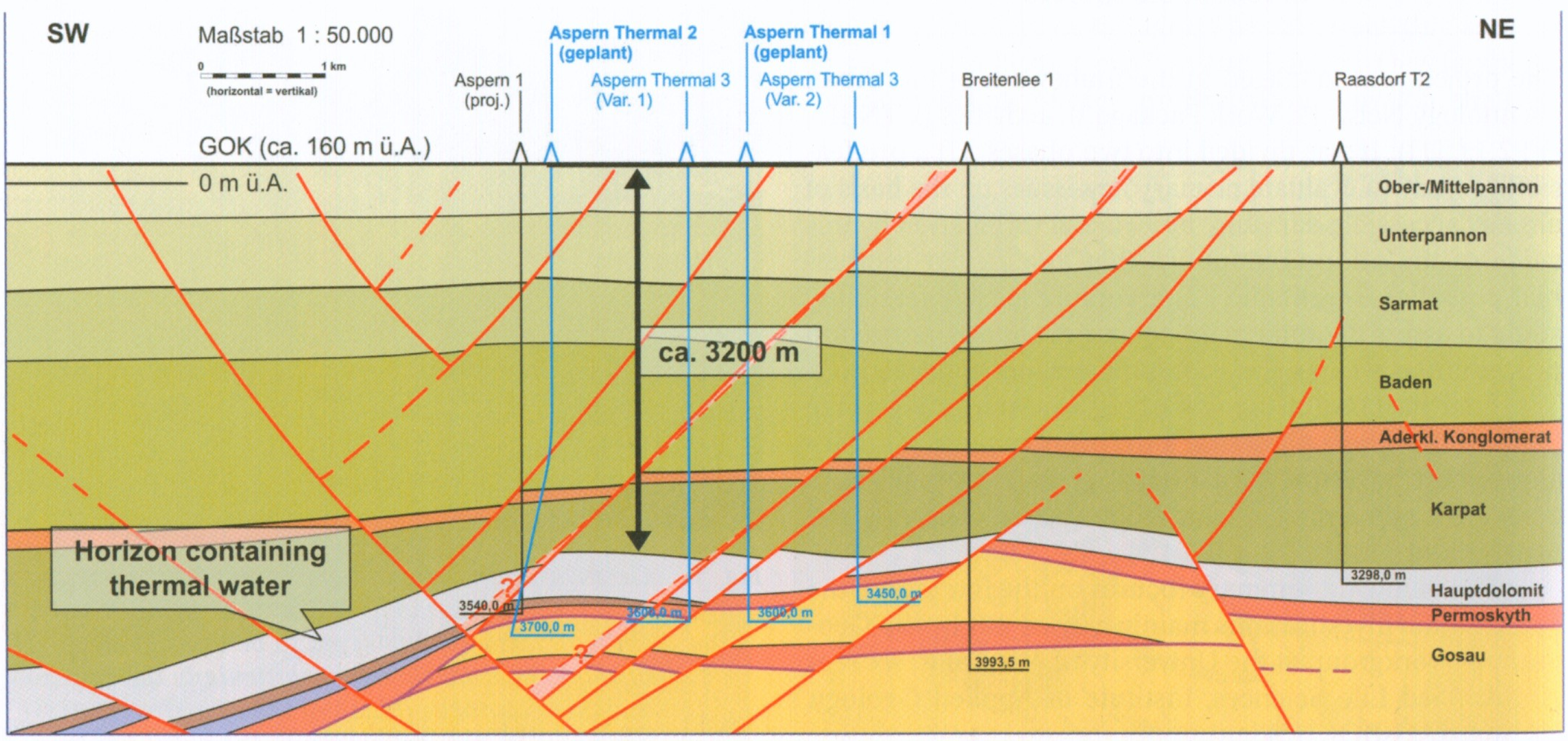

Fig. 4. Geological section parallel to the principal strike direction (cf. cross section, fig. 5) and four possible geothermal wellbores (light blue) intersecting major faults (red lines); the "Hauptdolomit" (light grey) is the main thermal water bearing horizon in the investigation area.

Abb. 4. Geologischer Schnitt parallel zur Hauptstreichrichtung (vgl. Querschnitt, Abb. 5) und vier mögliche Geothermalbohrungen (hellblau), die so angesetzt sind, dass sie größere Störungen (rote Linien) anschneiden; der Hauptdolomit (hellgrau) ist der bedeutendste Thermalwasser führende Horizont im Untersuchungsgebiet.

m), temperatures of much more than 150 °C, suitable even for electricity generation by conventional steam engines, could be expected (cf. [3], S. 308).

The Vienna Basin to the north and east of the Austrian capital and its substructures contain large hydrothermal resources, which shall now be tapped for the first time.

The formation water is highly mineralized, containing salt (mainly NaCl) at a minimum of 150 g/l and some dissolved natural gas (cf. [16]). From a technical point of view, extraction of the brine is expected to pose only minor difficulties. Nonetheless the danger of calcium carbonate and iron oxi-hydroxides being precipitated in the water cycle (especially in the upper parts of the well and the heat exchanger) had to be taken into consideration. Naturally, for legal and environmental reasons, the cooled formation water has to be pumped back (re-injected) into the same horizon, from whence it was produced. The gas chiefly consists of methane, with minor amounts of carbon dioxide and nitrogene. Hydrogene sulfide has not been detected so far, a fact that is very important with regard to drilling practice and choice of suitable materials, and thereby costs. From the calculated gas/water ratio it can be concluded that, in order to keep the gas totally in solution, a minimum pressure of approx. 110 bar will be required (gas saturation pressure). Once the pressure drops below this value in the course of production, an exsolution of gas will set in (i. e. gas bubbles are formed). The exsolved gas will contain methane for the most part and some nitrogen, but also, despite of its much higher solubility, a small amount of carbon dioxide, thereby raising the problem of carbonate precipitation in the upper parts of the well. The gas must be separated before passage of the injection pump (cavitation problem), in fact this should be done as near the welltop as possible. But apart from the gas separation the water cycle shall be designed as a totally closed system. Particularly any incursion of oxygen is to be prohibited (rapid precipitation of iron oxides).

In our study, on the basis of a hydrogeologic and geohydraulic analysis of all available data, the possibility of extrating a sufficient amount of thermal water from the substructure of the Vienna Basin to meet the thermal energy demand of the future Aspern "city" is substantiated by qualitative reasoning as well as documented by calculation. But because no positive temperature anomaly exists in the subsurface of the project area, relatively great drilling depths (min. 3500 m) have to be accepted. With respect to the conditions of operation this implies that among the numerical pressure losses in the water cycle the frictional resistance of the tubings (production/re-injection pipes) may predominate. Because of this, the wellbores can be properly completed only if bottom diameters are set at a minimum of 8 ½ inches (216 mm).

4 Preconditions for a pilot plant: tapping the resource for the first time

The present concept, as a first step, aims at the installation of a geothermal pilot plant. The facility shall utilize a dolomite aquifer that is situated at the northwestern margin of, and largely separated from, the main body of a major calcalpine nappe ("Göller" nappe, cf. Fig. 5). This frontal outlier mainly consisting of *Hauptdolomit* can be found below a strip of land diagonally crossing the former airfield in a SW–NE direction, in depths ranging from approx. 2950 to 3600 m below ground level. In all probability it contains a thermal water reservoir sufficient for extracting geothermal energy at a rate of ca. 18 MW_{th} (suitable for the first implementation phase).

A pilot plant including a geothermal doublet drilled into the bottom of the Vienna Basin (ca. 3500 m deep) was designed to put the regional geothermal prospects to the test.

The formation temperature is supposed to range from a minimum of approx. 108 °C below the airfield to a maximum of approx. 150 °C in the deepest parts of the reservoir, ca. 3,3 km to the southwest. Straight below the airfield an effective mean formation temperature of approx. 116 °C is predicted. However, exploration of the deepest part of the reservoir by means of directional drilling is not recommendable for reasons of cost effectiveness. Instead, the construction of a geothermal doublet, consisting of one production and one re-injection well in the

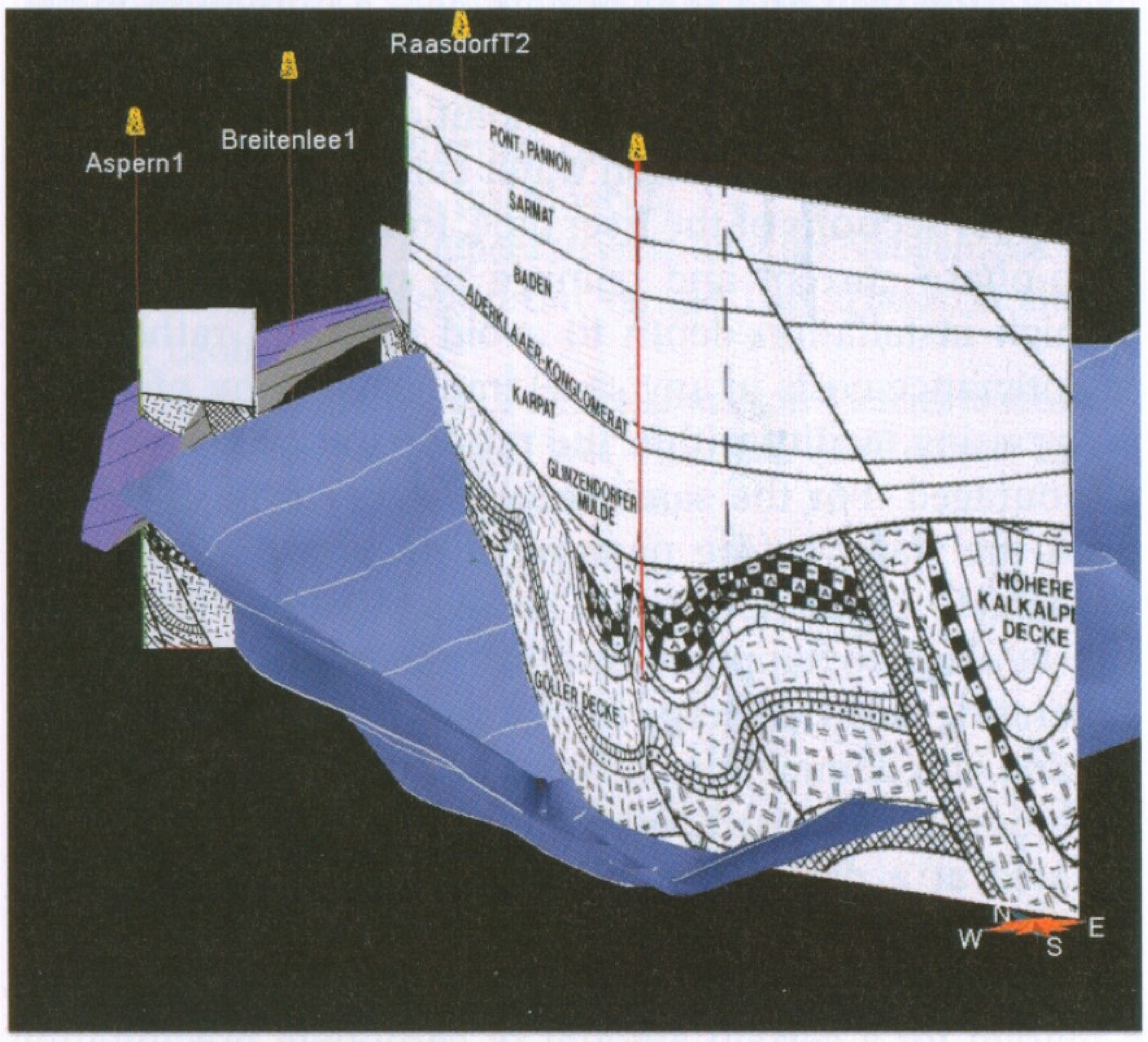

Fig. 5. Geometrical 3D model of the reservoir (intermediate construction stage), viewed from the south, with cross section perpendicular to strike (from [11]). The blue surface depicts the bottom of the water-rich calcalpine Göller nappe system; in the background the frontal outlier that is to be tapped by the planned geothermal pilot facility; yellow derricks and red lines signify earlier oil exploration wells.

Abb. 5. Geometrisches 3D Modell des Reservoirs (Arbeitsstadium), mit einem geologischen Querprofil (aus [11]); Blick von Süden. Die blaue Fläche bildet die Basis des großen wasserhöffigen kalkalpinen Göller-Deckensystems ab; links hinten die Stirnschuppe, die mit der geplanten Pilotanlage angezapft werden soll; gelbe Bohrtürme und rote Linien stellen frühere Ölexplorationsbohrungen dar.

southwestern and northeastern sectors of the airfield, was proposed. The wellbores were planned in such a way as to intersect two major fault zones (normal faults), with an additional fault between the target areas. A special geological section (Fig. 4) was constructed from published [11] as well as unpublished data to properly decide on the drilling locations and predict the geological profiles. A bottom drill diameter of 8 ½ inches (216 mm) is regarded as sufficient for both wells. The surface casing (upper protection pipe) shall be run down to a depth of ca. 900 m, the intermediate casing string however shall be installed as a liner (not to surface), so as to allow for a greater diameter tubing in the uppermost ca. 850 m of the production string (reduction of frictional resistance). It is expected that the source rock does not need to be stabilized by a separate (third) casing string. A riser pipe within the casing, though, will be indispensable to prohibit corrosion. In case that the wellbores will actually intersect the predicted – and highly permeable – fault zones (the southwestern wellbore will have to include a directional section for this purpose), there is a chance of extracting thermal water even at a rate of up to approx. 80 l/s. An exploitable minimum temperature of approx. 110 °C can be safely predicted, because temperature losses in course of production will be restricted to a few degrees, given the high velocity on the way up. Furthermore it is supposed that all this can be achieved without pumping the production well and that nonetheless a minimum installation pressure of 15 bar can be maintained.

Given that a continuing exolution of the natural gas content from the formation water cannot be prohibited in the upper sections of the riser pipe, from technical reasons (two-phase current and damage to pump by cavitation, or high installation depth to avoid this, and rather high maintenance costs in any case) implementation of a pressure raising facility within the production well is strongly discouraged. For the same reasons separation of the gas from the water before passage of the injection pump is thought to be compulsory. The separated gas (methane) can be used to supply additional energy by combustion; generating electric energy for the pumps by means of a gas turbine is recommended. The gas saturation point, where exolution is supposed to set in, will in all probability be situated at a depth of approx. 800 to 900 m below surface. Thus a two-phase current is to be expected only in the larger diameter upper part of the riser pipe, so there is a margin for a certain amount of carbonate precipitation (caused by some exsolution of carbon dioxide in addition to the other gas constituents). But to avoid massive encrustations over time the precipitation reaction shall be impeded by injection of a chemical inhibitor in the appropriate depth.

The re-injection pressure depends on the aquifer's resistance to injection, the static overpressure at the well top (less than at the production well), but mostly on the well completion design and the respective frictional resistance within the injection pipe. For the maximum extraction rate and the recommended well completion a required injection pressure at the welltop of approx. 80 bar has been calculated. The necessary pressure rise at the injection pump can vary between narrow limits around 66 bar, depending on the plant design.

5 Conclusion and future prospects: the Energy Cluster Wien, Aspern

The study – summarized above – was able, on the one hand, to corroborate the prior suppositions that a sufficient geothermal potential is available at Wien, Aspern, to implement an economically feasible heating energy and warm water supply for the future housing and industrial estate there, and on the other hand to define the technical implications by the facts that were discovered. The actual construction of a geothermal cycle and making use of the available high-mineralized formation water is not supposed to be hindered by any major technical problems. It is not advisable, though, to seek complete coverage of the thermal demand of the urban development area (final scheme) from a single geothermal water circulation system or even from the now investigated reservoir (frontal outlier of the Göller nappe) alone. This is because much higher expenditures for drilling large diameter wellbores and the obligation to act according to sustainable reservoir management practices only are not in favour of such an undertaking from an environmental as well as an economical point of view. A separate future exploration of the much larger resource buried within the main calcalpine nappe system (Göller nappe) forming a large part of the substructure of the Vienna Basin seems to be much more promising (cf. Fig. 6). The reservoir can be reached from the eastern outskirts of Vienna, too, and probably will be even suitable for electric energy production. This shall be explored after verification, in the course of construction of the proposed pilot plant, of the predictions given in the present study.

Geothermics is not the whole strategy: the "geothermiccenteraspern" rather is envisaged to be part and parcel of an innovative Energy Cluster promoting all forms of renewable energy utilization.

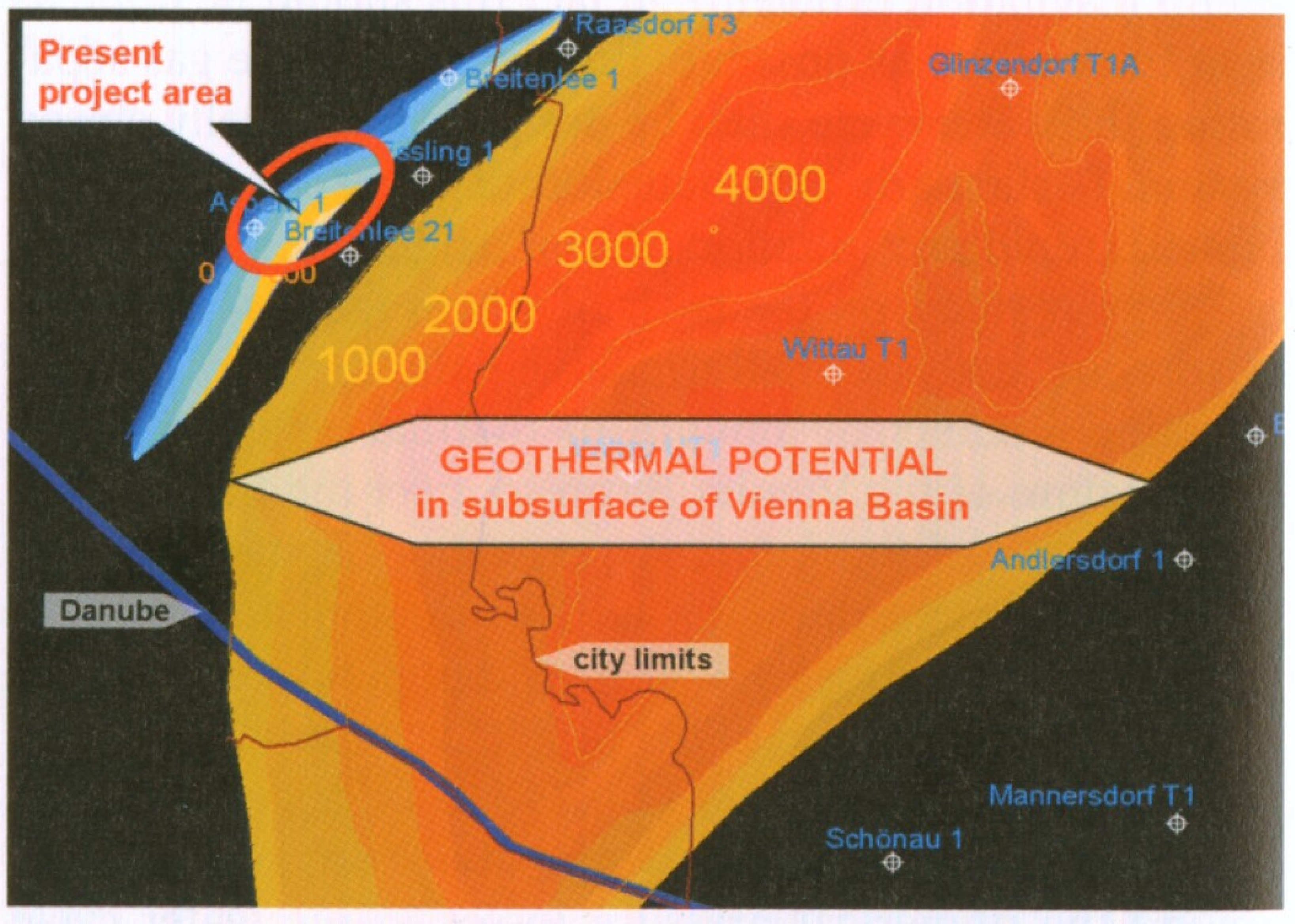

Fig. 6. Plan view of the reservoir depicting the extent and thickness of the calcareous thermal water bearing rocks. It is obvious that a successful pilot plant would utilize nothing more than a minor part of the full geothermal potential that exists.

Abb. 6. Das Reservoir im Grundriss, Ausdehnung und Mächtigkeit der kalkalpinen Thermalwasser führenden Formationen. Es ist offensichtlich, dass eine erfolgreiche Pilotanlage nicht mehr als einen kleinen Teil des gesamten vorhandenen geothermalen Potentials nutzen würde.

A first wellbore now must show its capability to deliver the full amount of water and heat that can be expected from a single installation (geothermal doublet) and to put the cooled water back into the reservoir. The preferred drill site is situated in the northeast of the former airfield Aspern. The investigation program will include geophysical well logging and state-of-the-art borehole imagery (FMS), hydraulic formation testing, sampling (retaining pressure) of formation water and natural gas content for hydrochemical and stable isotope analysis, in-vitro simulation of the water cycle and tracer tests (injection and re-extraction). The results shall be used to set up numerical models of the geothermal reservoir (the geometric input has already been produced) as well as the the chemical system. In addition to that, proposals of supplementary research activities and technical improvements aimed at public agencies supporting the creation of a geothermics competence center at the project site have been put forward by the authors of the study. Strategic partners and investors like energy supply companies have already been successfully approached. In the long run the strategy is to create an innovative Energy Cluster, of which the geothermic facilities, referred to as "geothermiccenteraspern", are an integrated part [1].

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