Paleoseismological assessment of the Siting Report and the Site License with respect to fault capability
NPP PAKS II

Paleoseismological assessment of the Siting Report and the Site License with respect to fault capability

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ÖSSZFEGYLALÁS


A Telephely Földtani Jelentés Paks II telephely környezetében szerkezetileg összefüggő, DNY-ÉK irányú, aktív törésvonalakat azonosít, beleértve a németkéri vetőket, a Bonyhádfő-törést, Kapos-vonalat és Dunaszentgyörgy-Harta törésvonalakat. Ez utóbbi törésvona közvetlenül a Paks II tervezett telephelye és a meglévő atomerőmű alatt fut. A fenti törésvonalak mentén bekövetkezett, szeizmotektonikailag aktiv mozgások bizonyítékai közé tartoznak az elmozdult negyedidőszaki üledékek (geofizikai, geológiai és fúrási adatfelvételekben részletesen dokumentálva), a felszíni elmozdulásokat jelző geomorfológiai megfigyelések (morfológiai lépcsők, vetők a szélhordta üledékekben, a vízfolyások morfológiája), valamint a korábbi jelentős földrengések paleoszeizmológiai bizonyítéktől, amelyeket 14 különböző helyszínen írtak le.

A Telephely Földtani Jelentésben felsorolt adatok közül a legjelentősebb a Pa-21-II paleoszeizmológiai feltárás, amely a Dunaszentgyörgy-Harta törésvona egyik oldalalagázását mutatta ki a Paksi Atomerőműtől 0,7 km-re és a Paks II. tervezett telephelyétől 1 km-re. A feltárás során 12 földfelszín elmozdító törést észlelték, amelyek két különböző földrengés során keltek meg, mintegy 20 000 és 19 000 évvel ezelőtt. Az egyik dokumentált földtani szerkezet egy negatív virágszerkezet, amely e tanulmány szerzőinek értelmezése szerint egy M ≥6-os földrengés során kellett, és mintegy 0,3–0,4 m vízszintes felszín elmozdulást jelez. E tanulmány készítői arra a következtetésre jutnak, hogy a Paks II telephelyen áthaladó Dunaszentgyörgy-Harta törésvonádat nemcsak aktív törésvonalnak, hanem olyan törésvonalnak is kell minősíteni, amelynek megan az a képessége ("capable"), hogy földfelszín elmozdulást hozzon létre.

A földfelszín elmozdítani képes törések ("capable faults") okozta veszélyeztetettség a magyar nemzeti előírások szerint is kizáró kritérium az atomerőmű telephely létesítésénél. A 118/2011. sz. kormányrendelet 7.3.1.1100. számú követelménye szerint, ha a telephelyen a felszínre kifutó vető által okozott elvetődés lehetőségét tudományos evidenciák alapján megbizhatóan nem lehet elvetni, és az elmozdulás érintheti a nukleáris létesítményt, a telephelyet alkalmatlannak kell nyilvánítani.

Ugyan a Telephely Biztonsági Jelentés alapvetően leírja a telephely közelében lévő Dunaszentgyörgy-Harta törészóna menti negyedkori elmozdulások bizonyítékait, ám nem tartalmazza a Pa-21-II kutatóárokból származó paleoseizmológiai adatokat. A Telephely Biztonsági Jelentés következtetése, miszerint "[a] komplex vizsgálatok eredményei alapján megállapítható, hogy a kutatási területen századok eves időskálad be is elhaladt a szeizmikus események nem képesek a felszín szignifikáns elvétésére, azaz a törési síkok nem tekintethetők kapabilisnek", nem egyeztetethető össze a Telephely Földtani Jelentés adataival. E tanulmány szerzőinek véleménye szerint a Telephely Biztonsági Jelentés és a Telephely Földtani Jelentés következtetései közti eltérések ellentmondanak a helyes tudományos gyakoriság eléveinek.


A telepengedély-határozattal ellentétben e tanulmány szerzői arra a következtetésre jutnak, hogy a Telephely Földtani Jelentésben és Telephely Biztonsági Jelentésben dokumentált geológiai és geofizikai adatok nem elegendőek ahhoz, hogy telephelyen a földfelszín állandó elmozdulásának lehetőségét a 118/2011. számú kormányrendelet 7.3.1.1100 számú követelménye szerint kizárják. Mivel a Dunaszentgyörgy-Harta törészónában, amely a meglévő atomerőmű és Paks II tervezett telephelye alatt húzódik, a telephely közvetlen közelében három zavarzónát fedeztek fel, egyedül csak a 85 m hosszú Pa-21-II paleoseizmológiai kutatóárokból végzett vizsgálat nem lehet elegendő arra, hogy megbizhatóan és átfogóan fel lehessen mérsi a nyilvánvalóan aktív törészóna összes elágazódásának földfelszíni elmozdulási potenciálját.

E tanulmány szerzői arra a következtetésre jutnak, hogy a Pa-21-II kutatóárokból származó paleoseizmológiai adatok megerősítik olyan töréseket létezését, amelyek Paks II telephely közvetlen közelében találhatók és képesek elmozdítani a földfelszínt. Ezek a bizonyított elmozdulások a Dunaszentgyörgy-Harta törészóna részét képezik, a paksi telephelyen folytatódik, és az elmúlt
mintegy 20 000 évben ismételten és jelentősen elmozdították a földfelszínt. A töréseket ezért a NAU meghatározása szerint kapabilisnek („capable fault”) kell minősíteni.

EXECUTIVE SUMMARY

On 27 October 2016, the company MVM Paks II. Zrt. applied for a site license for the new nuclear power plant (NPP) Paks II that should be constructed on a site next to the existing Hungarian NPP Paks. For this purpose, the license applicant had initiated a comprehensive geological exploration program that resulted in a Geological Site Report, written by a multitudinous group of experts, and a Site Safety Report, compiled by MVM Paks II. Zrt. on the basis of the Geological Site Report.

The Geological Site Report identified a system of structurally related, SW-NE-striking, active fault zones in the near region of the Paks II site including the Németkér-, Bonyhád-, Kapos- and Dunaszentgyörgy-Harta fault zone with the latter directly passing below the Paks II site and the existing NPP. Proofs of active seismogenic faulting at the named faults include faulted and offset Quaternary sediments (extensively shown in geophysical, geological and borehole profiles), geomorphological features indicative for surface displacement (fault scarps, displaced aeolian landforms, stream patterns) and paleoseismological evidence of strong earthquakes from about 14 locations. Out of these data, the results from the paleoseismological trench Pa-21-II, excavated at a fault branch of the Dunaszentgyörgy-Harta fault zone about 0.7 km from to the existing NPP Paks and 1 km from the Paks II site, are most remarkable. The trench uncovered 12 surface-breaking faults that apparently formed during two separate surfacerupturing earthquakes at about 20,000 and 19,000 years before present. Structures include a negative flower structure that, according to authors of this study, is indicative for about 0.3–0.4 m horizontal surface displacement during a M≥6 earthquake. The authors therefore conclude that the Dunaszentgyörgy-Harta fault zone, passing through the Paks II site, is both an active and a capable fault.

According to the IAEA, active faults are tectonic structures that moved in the recent geologic past and that are expected to move within a future time span of concern relevant for the safety of a nuclear installation. A capable fault, in addition, has a significant potential for displacement at or near the ground surface. Notably, fault capability is a site exclusion criterion for the siting of new NPPs according to national Hungarian regulations. The Hungarian Governmental Decree No. 118 of 2011, requirement 7.3.1.1100 states that, If the potential occurrence of a permanent surface displacement on the site cannot be reliably excluded by scientific evidences, and the displacement may affect the nuclear facility, the site shall be qualified as unsuitable.

The evidence of active faulting in the site vicinity of Paks II and the evidence of capable faulting at the Dunaszentgyörgy-Harta fault zone next to the Paks II site is not fully and/or not correctly reflected in the Site Safety Report compiled by MVM Paks II Zrt. The Site Safety Report omits relevant data of the Geological Site Report such as virtually all paleoseismological data obtained from the near region of the site, and shows a location and width of the Dunaszentgyörgy-Harta fault zone at the site that differs from the data in the Geological Site Re-
port. Finally, despite accepting evidence of Quaternary faulting along the Dunaszentgyörgy-Harta fault zone in the area close to the NPP site in general, the Site Safety Report does not include a comprehensive and unbiased presentation of the paleoseismological data obtained from the trench Pa-21-II. The conclusion of the Site Safety Report that “seismic events occurring in the research area on a timescale of one hundred thousand years are not able to significantly displace the surface, i.e. the fault planes cannot be considered capable” is not in line with the geological evidence described in the Geological Site Report. The contradictions between the Site Safety Report on the one hand, and the geological observations and the conclusions in the Geological Site Report, on the other hand, is, in opinion of the authors of this study, contrary to the principles of good scientific practice.

In spite of the evidence of the above-mentioned geological structures and the resulting safety-relevant issues with respect to fault capability, and in spite of the potential conflict with the requirement to reliably exclude the potential of occurrence of a permanent surface displacement by scientific evidence, the Hungarian Atomic Energy Agency (HAEA) granted the site license for the NPP Paks II on 30 June 2017.

Unlike the site license decision, the authors of this study conclude that the geological and geophysical data documented in the Geological Site Report and the Site Safety Report are not sufficient to reliably exclude the potential of a permanent surface displacement at the site as required by the Hungarian Governmental Decree No. 118 of 2011, requirement 7.3.1.1100. Although successfully exposing several branch faults of the Dunaszentgyörgy-Harta fault zone, the 85 m long paleoseismological trench Pa-21-II is regarded insufficient to provide a reliable and comprehensive assessment of the potential of fault capability of all branches of the evidentially active fault zone that extends over a width of about 1 km in the subsurface of the existing NPP as well as large parts of the Paks II site.

The authors conclude that, on the contrary, the paleoseismological data derived from the trench Pa-21-II next to the site confirm the existence of capable faults in the site vicinity of Paks II. These capable faults are part of the Dunaszentgyörgy-Harta fault zone, strike into the site and show evidence of repeated and significant surface displacements that occurred during the last circa 20,000 years.

This study therefore concludes that the Hungarian Governmental Decree No. 118 of 2011 on nuclear safety requirements, requirement 7.3.1.1100, is apparently not met. The potential occurrence of a permanent surface displacement on the site cannot be reliably excluded by scientific evidences. The Paks II site should therefore be deemed unsuitable.


Aktive Störungen sind nach Definition der IAEK tektonische Strukturen, die sich in der jüngsten geologischen Vergangenheit bewegt haben und die sich voraussichtlich innerhalb einer für die Sicherheit einer Kernanlage relevanten zukünftigen Zeitspanne bewegen werden. Eine Capable Fault hat zusätzlich ein erhebliches Potential, Verschiebungen an oder in der Nähe der Erdoberfläche zu verursachen.

Die Gefährdung durch Brüche, die die Oberfläche versetzen können (Capable Faults), ist gemäß den nationalen ungarischen Vorschriften ein Ausschlusskriterium für einen Standort eines KKW. Das ungarische Regierungsdekret Nr. 118 von 2011, Anforderung 7.3.1.1100, besagt, dass ein Standort als ungeeignet qualifiziert werden muss, wenn die Möglichkeit des Auftretens einer dauerhaf-
ten Oberflächenverschiebung auf dem Gelände durch wissenschaftliche Be-
weise nicht zuverlässig ausgeschlossen werden kann und die Verschiebung die
kerntechnische Anlage beeinträchtigen kann.

Der Nachweis aktiver Störungen in der Nähe von Paks II und der Nachweis von
Brüchen der Verwerfungszone Dunaszentgyörgy-Harta, die das Potential haben,
die Erdoberfläche zu versetzen, wird in dem von MVM Paks II Zrt. erstellten
Standortsicherheitsbericht nicht vollständig und/oder nicht korrekt wiedergege-
ben. Der Standortsicherheitsbericht übergeht relevante Ergebnisse des geologi-
schen Standortberichts, wie etwa praktisch alle paläoseismologischen Daten
aus der weiteren Umgebung des Standorts, und zeigt eine, von den Daten des
Geologischen Standortberichts abweichende Lage und Ausdehnung der Dunas-
zentgyörgy-Harta Störungszone am Standort Paks II. Obwohl der Standortsiche-
reheitsbericht den Nachweis quartärer Verwerfungen entlang der Verwer-
fungszone Dunaszentgyörgy-Harta in der Nähe des KKW-Standorts grundsätz-
lich beschreibt, enthält er keine umfassende und unvorgengenommene Darstel-
lung der paläoseismologischen Daten aus der Aufgrabung Pa-21-II. Die Schluss-
folgerung des Standortsicherheitsberichts, dass „seismische Ereignisse im For-
schungsgebiet auf einer Zeitskala von einhunderttausend Jahren die Oberfläche
nicht wesentlich verschieben können, das heißt, dass die Bruchflächen nicht als
„capable“ angesehen werden können“, stimmt nicht mit den im Geologischen
Standortbericht enthaltenen Daten überein. Die Widersprüche zwischen dem
Standortsicherheitsbericht einerseits und den geologischen Beobachtungen
und den Schlussfolgerungen im Geologischen Standortbericht andererseits wi-
dersprechen nach Meinung der Autoren dieser Studie den Grundsätzen guter
wissenschaftlicher Praxis.

Die ungarische Atomenergiebehörde (HAEA) hat am 30. Juni 2017 die Standortli-
zenz für das KKW Paks II erteilt. Dies geschah ungeachtet der Hinweise auf die
oben genannten geologischen Strukturen und der daraus resultierenden sicher-
heitsrelevanten Probleme in Bezug auf Brüche, die das Potential haben, die Erd-
oberfläche zu versetzen (Capable Faults) sowie ungeachtet eines möglichen
Konflikts mit den nationalen ungarischen Vorschriften hinsichtlich der Anforde-
rung, das Auftreten einer dauerhaften Oberflächenverschiebung durch wissen-
schaftliche Beweise zuverlässig auszuschließen.

Im Gegensatz zur Standortlizenzentscheidung kommen die Autoren dieser Stu-
die zu dem Schluss, dass die im geologischen Standortbericht und im Standort-
sicherheitsbericht dokumentierten geologischen und geophysikalischen Daten
nicht ausreichen, um das Potenzial dauerhafter Oberflächenverschiebungen am
Standort gemäß dem ungarischen Regierungssdekret Nr. 118 von 2011, Anforder-
ungen 7.3.1.1100, auszuschließen. Obwohl drei Teilstörungen der Verwerfungs-
zone Dunaszentgyörgy-Harta, die sich im Untergrund des bestehenden KKW so-
wie in großen Teilen des Paks II-Standorts erstrecken, in nächster Nähe zum
Standort aufgedeckt wurden, wird der 85 m lange paläoseismologische Schurf
Pa-21-II als unzureichend angesehen, um eine zuverlässige und umfassende Be-
wertung des Potentials zum Oberflächenversatz für alle Zweigstörungen der of-
fensichtlich aktiven Verwerfungszone zu ermöglichen.

1 TECHNICAL SUMMARY

In 2017, the Environmental Agency of Austria (UBA) became aware of detailed reports on geological and geophysical investigations at the site of the planned Nuclear Power Plant (NPP) Paks II. The investigations were initiated by MVM Paks II. Zrt., who applied for a site license to establish a new nuclear plant, Paks II, next to the existing NPP. The reports were compiled by the attorney for MVM Paks II. Zrt. and completed in 2016. They include extensive documentation of the geological characteristics of the site itself and the surrounding region. In 2017, all of the documents, archived on six DVDs and written in Hungarian, were freely available on the internet. A first assessment of the geological contents of the documents was addressed in an informal report to the Austrian Ministry of the Environment (now BMK1) by HINTERSBERGER (2017), where it was pointed out that the Paks II site is located very close to or even on an active fault that can be classified as “capable”.

Active faults are tectonic structures that moved in the recent geologic past and that are expected to move within a future time span of concern for the safety of a nuclear installation (IAEA, 2015) 2. A capable fault, in addition, has a significant potential for displacement at or near the ground surface (IAEA, 2010). Both types of tectonic structures pose significant threats to an NPP. Active faults need to be considered in the safety demonstration with respect to seismotectonic hazards including vibratory ground motion, liquefaction, dynamic compaction, and permanent ground displacement (WENRA, 2015; 2016). The hazard of fault capability is defined in terms of the impact on the plant of coseismic fault rupture and surface displacement, including surface rupture at secondary faults.

Both characteristics – the possible existence of an active fault at the site and in the site vicinity, and the possible existence of a “capable” fault at the site – were regarded to be of key importance for the safety of both the existing NPP and the planned NPP Paks II. This preliminary conclusion, however, was based on only a few documents selected from the extensive Hungarian report (of several thousand pages) that had been translated into German.

On 27 October 2016, MVM Paks II. Zrt. applied for a site license for Paks II, which was granted by the Hungarian Atomic Energy Agency (HAEA) on 30 June 2017, in spite of the unambiguous evidence of the above-mentioned geological structures and the resulting safety-relevant issues. UBA and BMK therefore requested a second report to identify the consequences of identifying active or capable faults at an NPP site according to international guidelines and regulations (DECKER & HINTERSBERGER, 2019).

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1 Bundesministerium Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie / Federal Ministry of Austria Climate Action, Environment, Energy, Mobility, Innovation and Technology

2 For the full definitions of the terms “active fault” and “capable fault” we refer to 7.1 of our report.
In light of the IAEA safety standards and WENRA safety objectives for new NPPs, BMK and UBA consequently decided to analyse this issue in more detail with a focus on fault capability and its safety relevance for the site, noting that the reliable evidence for a capable fault with the potential to affect the safety of a new NPP at a site might be a site exclusion criterion. UBA consequently tasked Kurt Decker and Esther Hintersberger with:

- organizing translations of the relevant chapters of the Geological Site Report produced by the attorney for MVM Paks II. Zrt;
- organizing translations of the relevant chapters of the Site Safety Report compiled by MVM Paks II. Zrt. and submitted to HAEA;
- organizing the translation of the Site License granted by HAEA;
- compiling expert assessments of the Geological Site Report and the Site Safety Report with respect to fault capability;
- assessing the Site License with respect to national and international requirements and guidance documents (including IAEA and WENRA) and the safety objectives of 2014/87/EURATOM, para. 20;
- compiling a catalogue of questions to be forwarded to the Hungarian nuclear regulator for discussion in the context of bilateral meetings between Hungary and Austria;
- compiling a conclusive report on critical issues that have been identified.

The draft version of the report “NPP Paks II: Paleoseismological assessment of the Siting Report and the Site License with respect to fault capability” by K. Decker and E. Hintersberger was handed to UBA in August 2020. UBA subjected this draft to a rigorous and repeated review by recognized Hungarian and German experts. The current final version takes full account of these reviews.
2 OBJECTIVES

In order to obtain a site license for a construction site next to the existing Hungarian NPP Paks, the license applicant for Paks II, MVM Paks II. Zrt. had initiated a comprehensive geological exploration program to investigate site conditions. The program comprised geological, geophysical, hydrogeological, geotechnical, seismological, and paleoseismological investigations (see GERSTENKORN et al., 2015; HORVÁTH et al., 2015; TOTH et al., 2015 for descriptions of the contents). The results of these programs are summarized in the Geological Site Report. Four volumes of the Geological Site Report are particularly important and of high relevance for the evaluation of active tectonics and fault capability (ÁCS et al., 2016; HALÁSZ et al., 2016; MAGYARI, 2016; TOTH, T. et al., 2016), while the remainder deals with geotechnical and hydrogeological site characterizations.

The Geological Site Report constitutes the technical basis for the Site Safety Report, which was compiled by MVM Paks II. Zrt. (MVM PAKS II. ZRT., 2016a, b). The Site Safety Report was then submitted to the Hungarian regulator HAEA in order to obtain the site permit for Paks II. Finally, in 2017, HAEA granted the Site License to MVM Paks II. (HAEA (G. FICHTINGER), 2017).

Herein we evaluate the assessment of the siting process and the issuance of the Site License for the planned NPP Paks II. Accordingly, we focus exclusively on the evaluation of the assessment of the hazards of active faulting and fault capability at the site and in the near region of the site.

The motivation for this narrow focus derives from national and international regulations and guidelines (including the Hungarian regulations), which regard hazards induced by fault capability and/or active faulting as site exclusion criteria. These regulations include the Hungarian Government Decree on Nuclear Safety Rules, which, in volume 7, investigation and evaluation of nuclear facilities, states:

“7.3.1.0800. The potential occurrence of a permanent surface displacement on the site shall be analysed and evaluated. The examination must be sufficiently detailed to enable a substantive decision to be taken on the question of the possibility of discarding the site by the occurrence of permanent surface displacement.”

“7.3.1.1100. If the potential of occurrence of a permanent surface displacement on the site cannot be reliably excluded by scientific evidences, and the displacement may affect the nuclear facility, the site shall be qualified as unsuitable.”

According to these regulations, a site license for Paks II should not have been issued for a location for which geological and paleoseismological investigations cannot reliably screen out the possibility of permanent surface displacement by tectonic faulting, i.e., fault capability.

In our assessment of the siting process and the site licensing, we pursue the following workflow:

- Extract all relevant information on active faulting and fault capability from the Geological Site Report.
• Compare this information with the contents of the Site Safety Report provided by the licensee.

• Assess how the data from both documents – the Geological Site Report and the Site Safety Report – are taken into account in the Site License.

• Assess the following relevant data in detail:
  • Data on active faults at the site and in the site vicinity (relevant volumes of the Geological Site Report: ÁCS et al., 2016 and TOTH et al., 2016)
  • Paleoseismological investigations from the site vicinity and the near region (data in Geological Site Report: MAGYARI, 2016)
  • Paleoseismological investigations at the site (data in Geological Site Report: HALÁSZ et al., 2016)

For all steps described above, we first provide an objective summary of the individual documents of the Geological Site Report, which we then compare to the content of the Site Safety Report. Data are further evaluated based on our geological expertise as well as on published information from the relevant area.
3 ASSESSMENT OF THE GEOLOGICAL AND GEOPHYSICAL DATA

3.1 Geological and geophysical data indicative of active faulting in the near region of the site

3.1.1 Data presented in the Geological Site Report (ÁCS et al., 2016; TÓTH et al., 2016; Hálasz et al., 2016)

Quaternary faults in the near region of the site

Assessments of faults mapped in the near region of the Paks site are based on a large number and variety of geophysical (TÓTH et al., 2016) and geological data (ÁCS et al., 2016). Geophysical fault mapping uses an integrated dataset including 2D/3D reflection seismic to image deep-seated structures and high-resolution, near-surface geophysical profiling to assess the upward termination of faults and identify faults that offset Quaternary sediments.

The comprehensive map of neotectonic faults covering an area of 60 x 60 km centred at the site is presented in ÁCS et al. (2016, Fig. 183; see Figure 1 of our report). The most important fault for the Paks site is the SW-NE-striking Dunaszentgyörgy-Harta fault zone which continues from the Bonyhád fault farther SW and crosses the NPP site. Two other major neotectonic faults – the eastern strand of the Kapos fault and the Németkér fault – strike sub-parallel to the Dunaszentgyörgy-Harta fault zone. ÁCS et al. (2016, Fig. 183) discriminate between faults that offset the top of the Pannonian Algyö Fm. (about 6 Ma) and faults that rupture upward to the base of the Quaternary sediments (Figure 1).

Seismic reflection data show that the major faults in the near region of the site – the Kapos fault ("Kapos-Line"), the Dunaszentgyörgy-Harta fault zone, and the fault system of the Bonyhád Basin – are characterized by flower structures with en-échelon branch faults that fan toward the surface. Fault geometries support strike-slip kinematics for these faults (ÁCS et al., 2016, pp. 696–698).

Evidence of Quaternary faulting and seismic activity of the above faults are summarized in the figures 426 and 427 by ÁCS et al. (2016; Figure 2 and Figure 3 in our report). Data that were used to arrive at these conclusions include evidence for faulting from surface outcrops, trench excavations, seismites, and near-surface geophysical data resolving the structure and depositional characteristics of Quaternary sediments, and the spatial distribution of seismicity. A

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3 The detailed geological model covers an area of 60 x 60 km centred at the site. This approximately corresponds to the “near region” as defined by a distance of less than about 25 km from the site (IAEA, 2010).

4 Per definition of the Geological Site Report, neotectonic faults cut the top of the Algyö Fm. (about 6 Ma), which is the youngest regionally mappable stratigraphic horizon in the imaged in the 2D and 3D seismic reflection profiles at depths between about 200 and 800 m (ÁCS et al., 2016, p. 695).
similar map summarizing evidence of Quaternary fault activity and seismicity in the context of regional faults was provided by TÓTH et al. (2016, Fig. 57).

It is worth noting that the studies by TÓTH et al. (2016) and ÁCS et al. (2016) match and their geological assessment/their mapping conclusions are similar.

Figure 1. Neotectonic faults identified in the region around the Paks site (grey shading) superimposed on surface topography.
Figure 2. Overview of data indicative of neotectonic fault activity. Shown earthquakes (red stars) were recorded by microseismic monitoring in the time window January 1, 1995, and May 31, 2016 (ÁCS et al., 2016, p. 708).

DHFZ: Dunaszentgyörgy-Harta fault zone; E Kapos F.: eastern strand of the Kapos fault; F: fault; 1: evidence for M=6 earthquake (from TÓTH et al., Fig. 57); 2: archeic sag ponds (ÁCS et al. 2016, Fig. 244); 3: linear reach of the Danube above the DHFZ (ÁCS et al. 2016, p. 475); 4: linear morphological scarps trending parallel to the DHFZ (ÁCS et al. 2016, Fig. 236); 5: stream profiles indicative of relative vertical displacement (ÁCS et al. 2016, Fig. 243). Yellow polygon denotes the site of Paks II. Figure from ÁCS et al., 2016, Fig. 426, with the following supplements: 1-5 added from other figures referenced above; fault names and translated legend added for convenience.
The neotectonic phenomena mentioned above are corroborated by geomorphological analyses, which identified several linear scarps next to the Dunaszentgyörgy-Harta fault zone (Tengelice, location 4 in Figure 2; ÁCS et al., 2016, pp. 467–468). The scarps trend SW-NE, i.e., parallel to the fault zone. Some of the scarps are described as terminating or offsetting erosive Pleistocene aeolian landforms and dunes. At least some of the scarps are furthermore reported to coincide with faults imaged in seismic reflection data. The identified scarps thus appear to be tectonic landforms that are located about 9 km SW of the site and about 5 km NE of the location of Szedres, where ÁCS et al. (2016, pp. 469–471) report a sequence of Late Pleistocene seismites.

ÁCS et al. (2016, pp. 473–474, Fig. 243) describe morphological analyses and data from stream profiles (thalweg sections) from the area at the SW-NE-striking Bonyhád fault zone 29 km SW of the site which they regarded to be indicative for Late Quaternary fault displacement (location 4 in Figure 2). Changes in sinuosity and channel orientation indicate tectonic control of the current course of the Danube in the approximately 10-km-long linear course of the stream between Ordas and Harta (location 3 in Figure 2). ÁCS et al. (2016, p. 475) state...
that “this section is located exactly above the Dunaszentgyörgy-Harta fault zone, between the main faults bordering the flower structure.” Tectonic activity of the Németkér fault is indicated by arheic sag ponds with historical salt lakes that are located at the fault zone near Dunaföldvár, 25 km NNE of the site (location 2 in Figure 2; ÁCS et al., 2016, p. 475, Fig. 244). Taken together, the morphological features and geophysical data from both the SW and NE continuation of the Dunaszentgyörgy-Harta fault zone and its vicinity corroborate the Late Quaternary tectonic activity.

The recent tectonic stresses determined from drilling-induced structures (borehole breakouts parallel to $S_{\text{min}}$, drilling-induced tensile fractures parallel to $S_{\text{max}}$) and borehole tests characterize a strike-slip regime with the horizontal main principle stresses $\sigma_1$ and $\sigma_3$ and a vertical position of $\sigma_2$ (ÁCS et al., 2016). The stress orientations are in line with the inferred sinistral kinematics of the generally SW-NE-striking faults. The average orientation of $\sigma_1$ is reported to trend NNE (N030°E), although with significant local deviations of $S_{\text{max}}$. The latter are viewed to indicate an inhomogeneous stress field, which “may be related to the weak zones (fault zones) present in the research area” (ÁCS et al., 2016, p. 685).

With respect to active (Quaternary) faulting, ÁCS et al. (2016, p. 714) conclude the following:

“Figure 426 shows, that indirect and direct observations of Quaternary faults, current earthquakes and phenomena indicative for paleoearthquakes correlate fairly well with the structural elements of the geological 3D model. The summary of neotectonic phenomena / events clearly indicates that neotectonic activity has taken place and continues to take place in the area today. One of the marked manifestations of this activity is a regionally significant sinistral shear belt crossing the area of the 3D geological model which formed with the “participation” of several separate shear zones. This shear belt includes the Dunaszentgyörgy-Harta fault zone which passes directly below the planned site.”

Quaternary faults in the site vicinity

Geophysical data including seismic reflection data and results from electric resistivity tomography prove that the Dunaszentgyörgy-Harta fault zone passes through the southern part of the site (Figure 4; ÁCS et al., 2016, Fig. 417, 418; p. 700). Quaternary fault activity in the vicinity of the site is described extensively in chapter 3.4.1.2 of the Final Geological Report (ÁCS et al., 2016, p. 699 ff).
Location, orientation, and extent of the Dunaszentgyörgy-Harta fault zone next to the site is determined from extended geological and geophysical investigations including 2D/3D seismic reflection data, high-resolution S-wave seismic reflection profiles (profiles Pa-21-S-Geomega and Pa-22-S), and information gleaned from shallow boreholes (Pa-21-A to E). Data are reported to prove that faults cut upward through the entire Pannonian (Upper Miocene) succession, “touch” the base of Quaternary formations, and deform the Tengelice Red Clay Fm., for which an Early Pleistocene (Matuyama chron, 1–2 Ma) age has been inferred based on paleomagnetic data (ÁCS et al., 2016, p. 341, Fig. 176). Direct proof for the deformation of the Pleistocene Tengelice Fm. is provided by fault planes with slickensides that were recovered by drill cores of the borehole Pa-21-B about 300 m SW of the site (Hálasz et al., 2016, Fig. 6, p. 12). Sub-horizontal striations unambiguously document strike-slip faulting kinematics.
The high-resolution S-wave reflection seismic profile Pa-21-S-Geomega is shown in Figure 5, where it can be clearly seen that the faults cut Quaternary strata. The section was acquired about 300 m SW of the site (see Figure 4 for location). Importantly, the mapped faults rupture the contact between Pannonian and Quaternary sediments and reach up into Upper Quaternary and Holocene deposits (ÁCS et al., 2016, Fig. 422, p. 704). A geological cross section based on shallow boreholes shows that the Lower Pleistocene Tengelice Fm. is vertically offset by about 15 to 20 m (Figure 6).

Figure 5. S-wave reflection profile Pa-21-S-Geomega across the Dunaszentgyörgy-Harta fault zone (ACS et al., 2016, Fig. 420).

Red lines denote interpreted faults; broken red lines indicate assumed faults. Depth in ms TWT for S-wave velocities. Red triangles indicate locations of shallow boreholes including Pa-21-B, which cored sediments of the Early Pleistocene Tengelice Fm. that displayed slickensides. Translations and black bar indicating the location of the paleoseismological trench Pa-21-II on top of interpreted profile added for convenience. See Figure 4 for location of the profile.
The Quaternary activity of the Dunaszentgyörgy-Harta fault zone is further corroborated by the electrical resistivity section Paks-MUEL-10 (Figure 7). This survey reveals significant thickening of Quaternary sediments from NW to SE, which is interpreted to result from the continuous activity of the fault during the Quaternary that created accommodation space for sediments (ÁCS et al. 2016, p. 705).

Evidence of a fault recorded by the seismic reflection profile Pa-21-S-Geomega led to the decision to excavate a paleoseismological trench to validate the interpretation of Pleistocene-Holocene faulting. ÁCS et al. (2016, p. 702-703) describe the trenching results shortly stating that the excavated structures are part of
the flower structures of the Dunaszentgyörgy-Harta fault zone and that deformation reaches up to the end of the Late Pleistocene ("késő-pleisztocén végi"). The paleoseismological data acquired are summarized and discussed in chapter 3.3 of our report.

Additional evidence for Quaternary activity of the Dunaszentgyörgy-Harta fault zone is based on S-wave seismic reflection and electrical resistivity profiles acquired on the left bank of the Danube at a distance of about 1.5 km NE from the site (ÁCS et al., 2016, Fig. 424 and 425). The geological profile that is based on the electrical resistivity profile shows variations in the thickness of Quaternary sediments of about 16 m across the fault zone, which is interpreted to result from Quaternary fault activity (Figure 8) (ÁCS et al., 2016, p. 705); the thickness variations measured coincide with faults identified with the P- and S-wave reflection seismic profile Pa-22-D acquired along the same profile line (Figure 9). ÁCS et al. (2016, p. 705) therefore conclude that "the Pa-22-S profile clearly confirms that the essential lateral variability of the Quaternary deposits on the said Paks-MUEL-3 profile section is related to the fault system advancing into the Quaternary sediments." The interpretation is said to be further confirmed by Pseudo-3D aquatic seismic (SeistecTM) measurements on the Danube. This data, however, is included neither in the reports by ÁCS et al. (2016) nor in those by TŐTH et al. (2016).

Figure 8. Resistivity profile Paks-MUEL-3 across the Dunaszentgyörgy-Harta fault zone.

![Resistivity profile Paks-MUEL-3 across the Dunaszentgyörgy-Harta fault zone.](image)

The profile shows thickness variations of Quaternary strata that coincide with faults shown in the S-wave reflection seismic profile Pa-22-D. Modified from ÁCS et al., 2016, Fig. 424. Translations added for convenience. See Figure 4 for location of the profile.

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5 Some results of the Pseudo-3D aquatic seismic are shown in MVM PAKS II. ZRT., 2016a, pp. 46–50.
3.1.2 Consideration in the Site Safety Report (TBJ, MVM Paks II. Zrt, 2016a)

Quaternary faults in the near region of the site

MVM PAKS II. ZRT. (2016a) summarizes the results of fault mapping in chapter 5.2.1.2.6. (p. 57–62). The eastern strand of the WSW-ENE-striking Kapos fault and the SW-NE-striking Bonyhád- and Dunaszentgyörgy-Harta fault zones are mentioned as the most important structural elements in the investigated area. The Dunaszentgyörgy-Harta fault zone is described as a sinistral strike-slip fault branching from the Kapos fault and passing below the southern part of the site and the site vicinity to the south of the site. The authors conclude that this fault and the eastern strand of the Kapos fault are the areas with the “most intensive neotectonic activity” in the investigated area (MVM PAKS II. ZRT. 2016a, p. 60).

Unfortunately, the detailed description of data proving Quaternary fault activity as provided in TÓTH et al. (2016) and ÁCS et al. (2016) is not fully represented in the Site Safety Report. Maps comparing the distribution of seismicity and/or evidence for faulted Quaternary sediments in the context of regional fault patterns (e.g., ÁCS et al., 2016, Figs. 425, 427, 243; TÓTH et al. 2016, Fig. 57; compare Figure 2 and Figure 3 in our report) have been omitted from the Site Safety Report.

With respect to the characteristics of the regional neotectonics, MVM PAKS II. ZRT. (2016a) conclude that “2. ... Based on the geological-geomorphological mapping, it can be determined that no traces of recent structural displacements are discernible on the surface” (p. 186, paragraph 2). It is further concluded that “4. ... the neotectonic style is basically a left lateral displacement to which transfer and transpressive elements are sometimes attached. Undoubtedly, it can also be stated that the total displacement along the main fault is not large on the order of 10 to

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6 Faults cutting the top of the Algyő Fm. (about 6 Ma) are referred to as neotectonic.
100 m.” (paragraph 4) and “5. ... Based on high resolution shallow geophysical studies, special drilling (Pa 21 A-G4) and trenches, it is clear that the DH fault should be considered an active structure. Taking into account the size of the shift and the duration of the activity, an average velocity of a maximum of 0.1 mm/year can be expected for the lateral displacement.”(paragraph 5).

Quaternary faults in the site vicinity

MVM PAKS II. ZRT. (2016a) states that seismic P-wave refraction data and near-surface S-wave seismic reflection data prove a SW-NE-striking fault zone crossing the southern part of the site. Based on the S-wave seismic reflection profiles, the Quaternary-Pannonian boundary and Early and Middle Pleistocene sediments are said to be cut by these faults, which belong to the sinistral Dunaszentgyörgy-Harta strike-slip fault system mapped at depth (MVM PAKS II. ZRT., 2016a, p. 57; Fig. 5.2.1.2.6-1, 5.2.1.2.6-2). A corresponding map showing the extent of the mapped fault zone at the site is shown in Fig. 5.2.1.2.6-1.

It must be noted that the site map shown by MVM PAKS II. ZRT., 2016, Fig. 5.2.1.2.6-1 differs from the corresponding map provided in the Geological Site Report (ÁCS et al., 2016, Fig. 418, p. 700) in terms of the reduced width of the Dunaszentgyörgy-Harta fault zone (Figure 10a of our report). The map by ÁCS et al. shows the fault extending into the location of the planned reactors (Figure 10b), while MVM PAKS II. ZRT., 2016, Fig. 5.2.1.2.6-1 shows a reduced width of the fault zone (Figure 10c).

MVM Paks II. states that the fault was imaged in the seismic S-wave section Pa-21-S and that the depicted faults “may have affected the near-surface range of [the Quaternary] formations.” It is further concluded that “based on the S-wave seismic profiles, the structural indications that can be designated in the Quaternary sediments have been detected by special shallow drilling and trenching, and according to this, near-surface, active tectonics should be expected in the wider research area. The possibility of active tectonics is also supported by seismological analysis and seismic source models.” (MVM PAKS II. ZRT., 2016a, p. 60). In spite of the conclusion that “near-surface, active tectonics should be expected in the wider research area”, the relevance of the data for the site is apparently not further discussed by MVM Paks II (2016a).

In this context it is noteworthy that the high-resolution seismic reflection profile from the continuation of the Dunaszentgyörgy-Harta fault zone 1.5 km NE of the site that indicates fault-controlled thickness variations of the Quaternary sediments and show faults cutting up into the Quaternary (ÁCS et al., 2016, Fig. 422; see chapter 3.1.1; Figure 9) is not shown in the Site Safety Report.
Figure 10.
Location of the Dunaszentgyörgy-Harta fault zone (DHFZ) and two accompanying branch faults.
3.1.3 Expert assessment

Quaternary faults in the near region of the site

The geological and geophysical data documented by TÓTH et al. (2016) and ÁCS et al. (2016) prove active faulting in the near region, most importantly for the Bonyhád fault, the Dunaszentgyörgy-Harta fault zone, the Németkér fault, and the eastern strand of the Kapos fault. Active faulting is supported by several independent lines of evidence including outcrop analyses; boreholes; high-resolution, near-surface geophysics; and paleoseismological investigations (Table 1. Summary of evidence for active faulting from Quaternary sediments and geomorphological data compiled from ÁCS et al. (2016), HALÁSZ et al. (2016) and MAGYARI (2016); see chapter 3.2 and 3.3 for descriptions of the latter). A summary of evidence for the past occurrence of strong earthquakes inferred from seismites and paleoseismological data compiled from ÁCS et al. (2016) is shown in Table 1. Such compilation of data is neither presented in the Geological Site report, nor in the Site Safety Report, although the data is of utmost importance for the assessment of the activity of the faults in the near-region and site vicinity of the Paks II site. It should be noted that almost all the activity listed in Table 1. Summary of evidence for active faulting from Quaternary sediments and geomorphological data compiled from ÁCS et al. (2016), HALÁSZ et al. (2016) and MAGYARI (2016). is not only “Quaternary” (in the sense of “Last-Million-Year”), but in fact younger than 30 kyr.

Among the cited data, seismites recorded from Szedres are among the most remarkable features. ÁCS et al. (2016, p. 469) estimate inter-event-times of about 1.5 kyr for strong earthquakes (M>5.5) at the location next to the Bonyhád fault. Their assessment is based on a combination of OSL and 14C age dating of the seismically deformed sediments.

Evidence for faulting as young as <20 kyr derives from the trench Pa-21-II which was excavated in a distance of only 300 m from the NPP site (HALÁSZ et al., 2016). Inter-event-times for the two paleoearthquakes identified in this trench are less than about 4.8 kyr considering the maximum uncertainty of age dating. A detailed summary and discussion of the results of the paleoseismological trench is provided in chapter 3.3.
Table 1. Summary of evidence for active faulting from Quaternary sediments and geomorphological data compiled from ÁCS et al. (2016), HALÁSZ et al. (2016) and MAGYARI (2016).

<table>
<thead>
<tr>
<th>Paleoseismological evidence for surface breaking faulting</th>
<th>Distance from site (km)</th>
<th>Surface displacement</th>
<th>Post quenone (after ky)</th>
<th>Post quenone (after ky)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M6 Gyapa-Cece, point 1</td>
<td>10</td>
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<td>7.7±1.1</td>
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<tr>
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<td>14.3±2.7</td>
<td>13.2±1.9</td>
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<tr>
<td>Trench Pa-21-ll, event 2</td>
<td>&lt; 1</td>
<td>not quantified</td>
<td>20.7±1.9</td>
<td>19.3±1.5</td>
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<tr>
<td>Trench Pa-21-ll, event 1</td>
<td>&lt; 1</td>
<td>not quantified</td>
<td>20.7±1.9</td>
<td>19.3±1.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Paleoseismological evidence for paleo-earthquakes from seismites</th>
<th>Distance from site (km)</th>
<th>Post quenone (after ky)</th>
<th>Post quenone (after ky)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trench Pa-21-ll seismite 1</td>
<td>&lt; 1</td>
<td>20.7±1.9</td>
<td>19.3±1.5</td>
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<tr>
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<td>Dunapataj-Ordas</td>
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<td>23</td>
<td>22.815</td>
<td>22.315</td>
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<td>Recurrence interval for Szedresen seismites: c. 1.5 ky</td>
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<tr>
<td>Dunafüldváros</td>
<td>25</td>
<td>Below younger Paks Loess Fm.</td>
<td>Bada et al., 2005*</td>
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<td>185.5±15.0</td>
<td>11.1±0.4</td>
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<td>Kismórágy</td>
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</tbody>
</table>

* References in Ács et al., 2016

Additional evidence for neotectonic (< 6 Ma) and Quaternary faulting derives from horizon maps compiled for the top of the Pannonian Algyö Fm. (Figure 11) (ÁCS et al., 2016, annex 15-02), the base of Quaternary sediments (Figure 12) (ÁCS et al., 2016, annex 14-01), and the thickness of Quaternary sediments (Figure 13) (ÁCS et al., 2016, annex 22-09). The maps are apparently neither discussed in the Geological Site Report nor addressed in the Site Safety Report. Both surfaces – the top of the Pannonian Algyö Fm. and the base of Quaternary sediments – show strong fault control with a maximum of 550 m vertical offset of the Algyö Fm. at the Bonyhád fault (Figure 11). Additional post-6 Ma strata with several hundred meters of thickness related to the creation of fault-related accommodation space are associated with the Dunaszentgyörgy-Harta fault zone to the E and NE of Paks and south of the east Kapos fault.

The relief map displaying the base of the Quaternary sediments shows a close match between the depth contour lines and the Bonyhád fault and the Dunaszentgyörgy-Harta fault zone (Figure 12). Horizon geometry suggests that the
The topography of the horizons is best explained by Quaternary syn-sedimentary faulting and the deposition of growth strata.

**Figure 11.** Horizon map of the top of the Algyő Fm. (Pannonian, c. 11–6 Ma) in the near region of Paks.

Thickness variations indicative of Quaternary growth strata at the Dunaszentgyőrgy-Harta fault zone are also documented by geophysical data obtained from profiles next to the site (Figure 7, Figure 8). The data indicate Quaternary vertical displacements of up to several tens of meters along the faults, with a maximum of about 90-100 m at the fault branches of the Bonyhád fault (Figure 12). Differential compaction of Neogene sediments below the Quaternary strata cannot explain the topography of the base of the Quaternary. The major depression of the horizon Base Quaternary SE of the Dunaszentgyőrgy-Harta fault zone overlies a local high of the top of the Algyő Fm. This coincidence excludes interpreting the Quaternary depocentre by a mechanism of compaction of the underlying Neogene strata.
Note the depocenter indicated at the Bonyhád fault with a vertical difference of the base of Quaternary sediments of about 90-100 m. Fault control of the topography of the horizon along the Dunaszentgyörgy-Harta fault zone (DHFZ) further NE is indicated by the drop of the elevation of the base of Quaternary sediments across to the fault zone. Modified from ÁCS et al. (2016, annex 14-01). Colour-code denotes elevation of the base of Quaternary sediments. Black lines: location of faults that reach up to surface; red lines: location of geological cross sections; yellow polygon: Paks II site. Fault names and scale bar added for convenience. [Acs_14_01_base_Quaternary_Fm_fault_map.jpg]
Note the thickening of Quaternary sediments across the Dunaszentgyörgy-Harta fault zone (DHFZ) and the greater thickness at the Bonyhád fault (up to about 100 m). White line denotes locations of reflection seismic profiles Duna-208-93 and Pa3b/93 (TÓTH, 2003) shown in Figure 14. Modified from ÁCS et al. (2016, annex 22-09). Colour-code denotes the thickness of Quaternary sediments. Black lines: location of faults that reach up to surface; red lines: location of geological cross sections; red polygon: Paks II site. Fault names and scale bar added for convenience.

Offset Quaternary sediments identified in several 2D seismic reflection lines were previously reported by TÓTH (2003). Figure 14 shows a 2D seismic reflection line crossing the eastern strand of the Kapos fault. The base of Quaternary sediments is offset by about 20–30 ms TWT, confirming the general topography of the base of the Quaternary strata shown in Figure 12. Other descriptions of Quaternary faults imaged by high-resolution reflection seismic were provided by TÓTH & HORVÁTH (1997).
Significant vertical displacements at the Németkér fault and the Dunaszent-györgy-Harta fault zone are further reflected by regional cross sections that were apparently constructed from outcrop data, boreholes, and geophysical data (ÁCS et al., 2016, Fig. 228). The profiles are shown in Figure 15 (next page). Unfortunately, the authors do not discuss the data in detail. Figure 15 shows the profiles together, with the approximate location of faults crossing the sections. The profiles show fault contacts of Quaternary sediments and thick Pleistocene sediments next to Németkér (80–90 m), Szedres (c. 100 m), Medina-Herc (c. 120 Middle-Upper Pleistocene sediments), and Zomba (c. 110 m). The large thickness increase of Pleistocene sediments at the fault zones may result from vertical fault offset, Pleistocene growth faulting, the filling of Pleistocene (tectonic) landforms, or a combinations of these. Pleistocene faults next to Medina and Szedres are discussed in more detail by ÁCS et al. (2016, p. 445). It should be noted that faults next to the site are shown to offset Pleistocene and Holocene sediments (profile 2 in Figure 15 15). ÁCS et al. (2016) furthermore describe the thickening of Danube river sediments between Paks and the village Hajós from
20–30 m to almost 100 m. The fact that Quaternary sedimentary successions cannot be correlated between a series of boreholes (PAET-22 drillings) is taken as an additional indication of Quaternary faulting (ÁCS et al., 2016, p. 447).
Figure 15. Geological profiles based on outcrop, boreholes, and geophysical data.

Profile 1: Bonyhád-Dunaegyháza; Profile 2: Mezőszilas Jánoshalma (ÁCS et al., 2016, Fig. 228). Note that profiles are not straight and include numerous knickpoints. Location of profiles shown in ÁCS et al., 2016, Fig. 223. Fault names, location of the Paks II site and partly translated legend added for convenience.

We conclude from the data shown in Figure 11 to Figure 15 that:

- The Bonyhád fault, the Dunaszentgyörgy-Harta fault zone, the Németkér fault, and the eastern strand of the Kapos fault are correctly classified as active faults (sensu IAEA, 2015). All faults are clearly reflected in Quaternary thickness maps and the topography of the base of the Quaternary strata is indicative for Quaternary growth faulting.

- Pleistocene to Holocene faulting led to significant offsets along the regional fault systems, most importantly at the Németkér fault, the Bonyhád fault, and the Dunaszentgyörgy-Harta fault zone. Maximum vertical offsets of about 90-100 m are shown for the Bonyhád fault. The vertical displacement estimates from Pleistocene-Holocene growth strata must be regarded as minimum values, as all of these faults are sinistral strike-slip faults, whose horizontal offsets are expected to exceed the vertical slip component considerably.

- Paleoseismological data are indicative for surface breaking faulting and paleoearthquakes prove the very young (< 30 kyr) activity of the the Németkér fault, the Bonyhád fault, and the Dunaszentgyörgy-Harta fault zone.

- Based on all available observations, the Dunaszentgyörgy-Harta fault constitutes a fault system of numerous, structurally related faults. It is therefore not appropriate to treat the individual faults of this system as independent structures. That is, if one of the faults of this system is shown to be active, one cannot exclude activity associated with the other structures.

The main conclusions by MVM PAKS II. ZRT. with respect to active faulting in the near region of the site (2016a, p. 186) are assessed as follows:

- Conclusion 4 (MVM PAKS II. ZRT., 2016a, p. 186) “… the neotectonic style is basically a left lateral displacement to which transfer and transpressive elements are sometimes attached. Undoubtedly, it can also be stated that the total displacement along the main fault is not large on the order of 10 to 100 m.”: Sinistral strike-slip faulting is in line with the observations summarized by ÁCS et al. (2016). The estimated slip distances are, however, evidently not in line with the geological observations summarized above. Data indicate significantly larger Quaternary displacements.

- Conclusion 5 (MVM PAKS II. ZRT., 2016a, p. 186) “… Based on high resolution shallow geophysical studies, special drilling (Pa 21 A-G4) and trenches, it is clear that the DH fault [Dunaszentgyörgy-Harta fault zone] should be considered an active structure. Taking into account the size of the shift and the duration of the activity, an average velocity of a maximum of 0.1 mm/year can be expected for the lateral displacement."): The conclusion of active faulting at the Dunaszentgyörgy-Harta fault zone is correct and in line with geological data. However, it remains unclear how the reported slip velocities were actually determined.

- Conclusion 2 (MVM PAKS II. ZRT., 2016a, p. 186) “… Based on the geological-geomorphological mapping, it can be determined that no traces of recent structural displacements are discernible on the surface”: This conclusion clearly contradicts data summarized in Table 1. Summary of evidence for
active faulting from Quaternary sediments and geomorphological data compiled from ÁCS et al. (2016), HALÁSZ et al. (2016) and MAGYARI (2016), and it is not supported by the data of the Geological Site Report (ÁCS et al., 2016) (see also chapters 3.2 and 3.3).

• Conclusion on active faults, chapter 5.8.2 (MVM PAKS II. ZRT., 2016a, p. 186) “... The now extremely detailed data from the Paks area suggest that the Dunaszentgyörgy - Harta fault zone is a young and active tectonic element of the area. At the same time, it should be emphasized that even in this zone, which can be classified as tectonically active, no significant displacement has developed, that is, no impact on quaternary formations on site that are less than 100,000 years old in the form of a significant displacement.”. The assessment of the Dunaszentgyörgy-Harta fault zone as an active fault is in line with the geological data. The statement that “no significant displacement has developed” is factually wrong and contradicts geological data obtained from several independent lines of evidence, most important the increase of the thickness of Quaternary sediments across the fault. Quaternary sediment thickness in the fault-bounded Bonyhád basin and the thickness increase across the Dunaszentgyörgy-Harta fault zone East of Paks suggest vertical fault displacements ranging up to several tens of metres. As fault slip is dominantly strike-slip, these values have to be regarded as a minimum. The arbitrary selection of a 100,000-year interval for the assessment of Quaternary deformation is not in line with active fault definitions by IAEA (2015) and GOSATOMNADZOR OF RUSSIA (2002, 2003). IAEA (2015) states that in intraplate settings with low deformation rates such as the Pannonian Basin much longer periods (Pliocene – Quaternary to present) are appropriate to characterize active deformation. GOSATOMNADZOR OF RUSSIA (2002, 2003) refers to a fault as active if a relative displacement of 0.5 m and more occurred during the last million years. Data shown in the Geological Site Report show that Quaternary displacements of the Dunaszentgyörgy - Harta fault zone in the site vicinity exceed this value of 0.5 m by far (e.g., Figure 9 in HALÁSZ, 2016; ÁCS et al., 2016, Figure 423 and discussion on p. 705).

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7 The corresponding definitions and guidelines are summarized in chapter 7 of our report.
3.2 Paleoseismological data from outcrops along Highway M-6

3.2.1 Documentation in the Geological Site Report (MAGYARI, 2016, MÀ/PA2-16-FT-07)

MAGYARI (2016) describes sedimentological features and tectonic structures from eolian and fluviatile Late Pleistocene and Holocene sediments which are exposed in four outcrops along Highway M-6 North of the NPP Paks. All of these outcrops are located within the near region of the site as defined by IAEA (2010; distance <25 km).

At observation point 1, located about 10 km NNW of the existing NPP Paks, MAGYARI (2016, pp. 8–9, Fig. 5) describes a series of sub-vertical WSW-ENE- to SW-NE-striking faults that offset Pleistocene loess including a paleosol horizon. Fault geometries and variable vertical offsets suggest that the faults are characterized by strike-slip kinematics. Vertical offsets range from a few cm to 60 cm. The former fault scarps are now masked by a sand unit that also contains fragments derived from semi-consolidated loess that was eroded from the fault scarps. The same sand unit covers all of the fault strands. Faulting is therefore assumed to be penecontemporaneous with the sand cover, which has been dated by OSL to ages between 7.7±1.1 and 5.5±1.1 kyr.

At observation point 4, about 8.5 km NNW of the existing NPP, MAGYARI (2016, pp. 12–13, Fig. 14, 15) describes a number of NE-SW to ENE-WSW- and WNW–ESE-striking faults. At the time of his field survey, 18 faults were exposed, with 6 to 7 fault zones having widths of several tens of centimetres and a spacing of 2 to 5 metres. Fractures and gashes associated with the faults are partly filled with sand dated to 14.3±2.7 kyr by OSL. This fill unit is assumed to be of the same age as the faulting event. A post-tectonic sand unit covering the faults is 13.2±1.9 kyr old. One of the WSW-ENE-striking fault planes has sub-horizontal striations indicative of strike-slip kinematics (MAGYARI. 2016, p. 36, Figure 14: Seismic sections (a, b) and Map (c) indicating quaternary faults and fault zones identified from 2D seismic reflection profiles.). Based on fault patterns that are spatially arranged in a way that mimics the geometry of Riedel shears, MAGYARI (2016, p. 17) infers sinistral strike-slip kinematics for the observed fault zone.

In chapter 6, MAGYARI (2016, pp. 18–20, Fig. 17–19) describes outcrops in a construction pit in the Danube harbour of Paks, about 3–3.5 km N of the NPP. The exposed Holocene floodplain sediments of the Danube exhibit liquefaction features such as convolute bedding and water-escape structures that are interpreted to have formed by seismic ground shaking. The age of these deformed units was expected to be between about 200 and a few thousand years old. MAGYARI (2016) infers a minimum magnitude for earthquakes to create this type of soft-sediment deformation of M=5.5. The author, however, states that a magnitude threshold of M=5.5 to 6 exists, which is a basic condition for these

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8 A relationship between earthquake magnitude and liquefaction supporting Magyari’s assessment is shown in Figure 19.
structures to occur with sufficient frequency in a given area around the inferred epicentre.

In his summary and conclusion, MAGYARI (2016) provides a preliminary interpretation of his observations in the regional tectonic context by comparing the faults mapped at observation points 1 and 4 along Highway M-6 to the regionally predominant WSW-ENE-striking sinistral strike-slip faults. However, he states that he could not relate his observations to a fault zone mapped at depth, apparently because he had no access to subcrop data.

3.2.2 Consideration in the Site Safety Report (TBJ, MVM PAKS II. ZRT., 2016a)

The paleoseismological results obtained from outcrops along Highway M-6 and the harbour of Paks are apparently not considered in MVM PAKS II. ZRT. (2016a). With respect to paleoseismological observations, the cited report only refers to results obtained from trenching at the site, in spite of the fact that MAGYARI (2016) provides pivotal data for the assessment of fault capability and earthquake frequency.

3.2.3 Expert assessment

The regional fault model developed for the region around Paks (TÓTH et al., 2016) shows that the outcrops analysed by MAGYARI (2016) are located at the SW-NE-striking Németkér strike-slip fault, which is parallel to the Dunaszentgyörgy-Harta fault zone (Figure 16, Figure 17). Both faults branch from the WSW-ENE-striking Kapos Line. Riedel shears and negative flower structures shown in reflection seismic profiles identified the Dunaszentgyörgy-Harta fault zone as a sinistral strike-slip fault (MVM PAKS II. ZRT. 2016a, p. 60). The available data therefore show a close structural relationship between the Németkér fault and the Dunaszentgyörgy-Harta fault zone.
Figure 16. Location of the paleoseismological outcrops along Highway M-6 analysed by MAGYARI (2016) superimposed on the depth-to-basement map with tectonic lines.

M: location of paleoseismological outcrops; S: site; DH: Dunaszentgyörgy-Harta fault zone. Background map from MVM Paks II Zrt., 2016b, Fig. 5.2.1.2.1-6.
The detailed description by MAGYARI (2016) further suggests a co-seismic origin of the structures. Descriptions of large fragments derived from the faulted loess succession indicate that faulting led to the formation of fault scarps with free faces from where this material was derived. The described vertical displacement values obtained from the younger fault reach up to 0.6 m. As the inferred fault kinematics is strike-slip, this number only indicates a minimum value for the total strike-slip or oblique-slip displacement at the surface. However, the obtained value allows an estimate of the moment magnitude of the surface-breaking earthquake using the empirical relationships developed by WELLS & COPPERSMITH (1994; see Figure 18). Estimates for the described maximum offset of 0.6 m and for an assumed average surface displacement of 0.3 m result in a moment magnitude of circa M=6.5 for the younger event that occurred between 7.7±1.1 and 5.5±1.1 kyr. For the older event, only a minimum of M>6 can be inferred based on the fact that significant, albeit unquantified, surface displacement occurred. The data is also acknowledged by TÓTH et al. (2016, Fig. 57). Figure 15 (p. 37) in MAGYARI (2016) suggests that the vertical offset is on the order of 10 cm. As the interpreted fault kinematics is strike-slip, this estimate is also a minimum value. Furthermore, WELLS & COPPERSMITH (1994) provide an empiric relationship between the maximum earthquake magnitude.
at a fault and its length. Applying this relationship to the Németkér fault shows that the moment magnitude of $M=6.5$ estimated for the paleoearthquake that occurred between $7.7\pm1.1$ and $5.5\pm1.1$ kyr is below the maximum magnitude ($M_{\text{max}}$), which can be inferred from the length of the Németkér fault. The fault length of about 50 km (inferred from MVM PAKS II. ZRT., 2016a, Figure 5.2.1.2.1-6) constrains $M_{\text{max}} \leq 6.9$ (WELLS & COPPERSMITH, 1994: $M=4.33+1.49\times\log(\text{fault length})$). The estimate of $M=6.5$ for the paleoearthquake is also in line with the more conservative length estimate of 30 km for the fault segment that is shown in Figure 17 (fault F_Nemetker_S, MVM PAKS II. ZRT., 2016a, Figure 5.2.1.2.6-3). For 30 km fault length the WELLS & COPPERSMITH (1994) correlation reveals $M_{\text{max}} \leq 6.5$.

Figure 18. Field photograph of a fault scarp buried below fine sand (a) and empirical correlation between the average Displacement and earthquake magnitude (b, c).
The identification of liquefied sediments from a temporary outcrop in the Danube harbour of Paks provides evidence for a third strong earthquake in the Holocene. The deformed sediments postdate the events identified at the Németkér fault. Liquefaction can therefore not have been induced by one of these events. Figure 19 shows magnitude-distance relations for liquefied sediments that support the interpretation by MAGYARI (2016), who inferred a minimum magnitude for the observed structures of M=5, but regards a higher magnitude threshold of M=5.5 to 6 as more likely. A M=5 earthquake that may adequately explain the observed liquefaction features should have occurred within a distance of less than about 4 km. The only fault within this radius discovered by the geological research programme is the Dunaszentgyörgy-Harta fault zone. The assumption of linking liquefaction with the smallest possible magnitude (M=5) therefore leads to the inference of an epicentre next to the Paks II site. Any alternative interpretation that infers a more distant epicentre necessitates an adequately higher magnitude to generate such phenomena. We therefore conclude that the exposure at the Paks harbour locality indicates a rather young M≥5.5 earthquake that occurred in the near region of Paks II.

Figure 19. Field photograph of liquefied Holocene floodplain sediments and empirical correlation between the epicentral distance of liquefied sediments and the surface wave magnitude.
We conclude from our assessment of the paleoseismological data by MAGYARI (2016) that:

- the Németkér fault has a close structural relationship with the Dunaszentgyörgy-Harta fault zone;
- at least two surface-breaking earthquakes occurred at the Németkér fault in the near region of Paks II in the last circa 14,000 years, the older one with M>6 and the younger one with (estimated) M=6.5;
- the Németkér fault is a capable fault as defined by IAEA;
- a third strong earthquake with a probable magnitude of M>5.5 occurred within the near region or site vicinity of Paks II during the last few thousand years;
- the importance of the data for the characterization of the Paks II site is not adequately considered in the Site Safety Report (MVM PAKS II. ZRT. 2016a).

3.3 Paleoseismological data obtained from the site

3.3.1 Documentation in the Geological Site Report (HALÁSZ et al., 2016)

Geological investigations at the site include the analysis of two paleoseismological trenches that were excavated next to the SW corner of the site of the existing NPP Paks (Figure 20). The trench location was selected on the basis of seismic reflection data (3D seismic cube Paks, 2D line MFGI Pa-21-S and 2D shear wave reflection seismic Pa-21-S-Geomega; see TÓTH et al., 2016, Fig. 31) and the results of shallow boreholes.

Inline 540 of the 3D cube Paks shows that the trench is located at one of three major branch faults of the negative flower structure of the Dunaszentgyörgy-Harta fault system (Figure 21). The NW branch fault shown in inline 540 is covered by the high-resolution shear wave seismic Pa-21-S-Geomega. The interpreted section of the shear-wave seismic reflection data reveals that the fault branch visible on inline 540 consists of at least four individual faults that offset the base of the Quaternary succession, which is mapped at a depth corresponding to 350 msTWT. The interpreted faults reach up to a depth corresponding to about 50 msTWT (TÓTH et al., 2016, Fig. 34).

A series of shallow boreholes drilled along the seismic line Pa-21-S-Geomega supports the notion of a vertical offset of the base of the Tengelice Red Clay Formation on the order of 15 m (HALÁSZ et al., 2016, Fig. 9). ÁCS et al. (2016, Fig. 5; pp. 341–342, Fig. 176) state an Early Middle Pleistocene age (between about 2 and 1 Ma BP) of the Tengelice Fm., based on magnetostratigraphic data.

9 See chapter 7 for the full definition of the term “capable fault.”
The 84-meter-long and about 2.8 m deep paleoseismological trench Pa-21-II was excavated along seismic reflection line Pa-21-S-Geomega to cover the fault that offsets the Tengelice Red Clay Formation. The trench revealed the paleoseismological data summarized below. The second, 12-metre-long trench Pa-21-I farther NW did not reveal deformation structures.

Trench Pa-21-II exposes a succession of laminated aeolian sand. The deposits overlie circa 70-metre-thick fluvial strata (sand and gravel from the Danube) and the Tengelice Red Clay Formation, both penetrated in several shallow boreholes (HALÁSZ et al., 2016, Fig. 9). The exposed section is topped by a bioturbated layer with the imprint of roots of inferred Holocene age. OSL dates from the aeolian sand from the trench at depths of 1.06 m and 1.55 m provided ages of 19.3±1.5 kyr and 20.7±1.9 kyr, respectively. The underlying sedimentary deposits of the Danube at a depth of between 18.7 and 19.2 m were dated to 30.4±2.5 kyr.
In the paragraph on seismotectonics, HALÁSZ et al. (2016, p. 28) describe seismites and seismotectonic structures observed in the trench PA-21-II. Seismites are recorded in a layer immediately below the bioturbated top and in a layer about one metre deep. The lower horizon is a 20-cm-thick deformed layer with a series of folds that were apparently exposed in large sections of the outcrop (HALÁSZ et al., 2016, Fig. 19). A detailed interpretation of the significance of the layers, however, is not provided.

In their description of the seismotectonic phenomena, the authors state that “Given the importance of the observations, each seismotectonic element is described item by item. ... A summary of the detected data for seismotectonic elements is shown in Table 4.” (p. 30). In addition, the report provides detailed trench profiles at a scale of 1:200 in the attachments. In total, 13 “phenomena” were logged in
the trench section. The detailed descriptions and photo documentations by HALÁSZ et al. (2016) particularly highlight the following characteristics of the seismotectonic phenomena:

- variable vertical offset along the vertical sections exposed in the trench walls (structure 0.3 m, Fig. 27; 6.4 m, Fig. 26; 0.5 m, Fig. 29; 43.7 m, Fig. 33)\(^{10}\);
- extensional character associated with normal-fault offset (43.7 m) and sediment layers bending downward into the structures (structure 0.3 m, Fig. 27; 0.5 m, Fig. 29; 2 m, Fig. 30; 5.7 m, Fig. 31;) or filling gashes (43.7 m, Fig. 35);
- features indicative of sinistral shearing (structure 37.0 m, Fig. 32) and strike-slip faulting (structure 43.7 m, Fig. 33: “The structure observed at 43.7 m is a characteristic negative flower structure associated with lateral displacement.” p. 40);
- multiple slip events (structure 43.7 m, Fig. 36: “Based on its geometry and displacements, it is a transtensive negative flower structure. The fracture system shows a two-phase formation, none of which intersects the layers above 1.3 m.” p. 43);
- strike SW-NE parallel to the Dunaszentgyörgy-Harta fault system (structures 0.5 m, 2.0 m, 40.7 m, 43.7 m, Fig. 36; structures 60.8 m, 68.3 m, 71.9 m, 73.2 m).

In the chapter “Interpretation of the seismotectonic structures”, HALÁSZ et al. (2016) discuss different formation mechanisms for the seismotectonic structures uncovered in the trench. Structures showing sediment layers that are deformed at the contact with the structures and which show both upward and downward drag of bedding are compared to structures formed adjacent to sand dikes\(^{11}\). However, the injection of sand could not be detected at any of the observed structures. On page 50, the authors therefore conclude:

“All morphological marks [of sand injections] can be found in the research trench Pa-21-II, but the injected sand itself, the material penetrated from the more distant layer, could not be detected.” And further, “After considering all these difficulties of interpretation, the conservative approach requires a classification as tectonic fractures. The contradictions detailed above are resolved if the layer deformation phenomena of uncertain origin are interpreted as deformation caused by the displacements of the transtensional flower structures.”

The upward termination and OSL dating constrain the age of most of the deformation structures to about 20 kyr. According to HALÁSZ et al. (2016), sediments of the corresponding age of 20 kyr are only cut by the structure recorded at 0.5 m, which extends further up into younger deposits.

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\(^{10}\) Note that that the listed numbers are “labels” of the structures according to their position in the trench, from NW (0 m) to SE (80 m).

\(^{11}\) Explanatory remark: Such dikes result from the upward injection of water-saturated, liquefied sediment from underlying layers.
Based on this interpretation, HALÁSZ et al. (2016, p. 52) conclude that:

- the seismotectonic structures excavated in trench Pa-21-II are fault planes that are part of a negative flower structure associated with a strike-slip fault system;
- unambiguous evidence for offsets of 1 cm (vertical) and 2 cm (horizontal, sinistral) were measured at the structures at 37 m and 41 m;
- the observed faults are located immediately above a fault branch of the Dunaszentgyörgy-Harta fault zone, which was mapped by high-resolution 2D shear-wave reflection seismic and in 3D seismic reflection profiling (Figure 21);
- the age of the identified seismotectonic structures is 18,000–20,000 years, based on OSL data. Tectonic activity can be divided into two generations based on the different cross-cutting relationships of the structures with overlying younger strata. The “recurrence time” (rather: inter-event time) of the formation of the structures is estimated to be on the order of a thousand years (HALÁSZ et al. 2016, p. 4).

The assessment by HALÁSZ et al. (2016) is repeated and summarized in the report by ÁCS et al. (pp. 699–707), where it is stated that the faults and strike-slip fault zones identified in trench Pa-21 are structures of “seismotectonic origin, including sand injections, fractures / fissures and lateral displacement fault zones (p. 701),” which are exactly located above faults mapped in the high-resolution S-wave seismic. ÁCS et al. (2016, p. 703) further conclude that “it is clear that as a result of the neotectonic structure formation, the young, Quaternary (late Pleistocene) structures were affected by the distinctive deformation taking place in the Pannonian layers with exactly the same structure style, but much less intensity. ... It also seems likely that the deformation of the Quaternary structures is not only linked to a single seismotectonic event, but that deformation occurred in the individual fault zones in several phases ..., as also indicated by the structural observations of the research trench.”

3.3.2 Consideration of the data in the Site Safety Report (TBJ, MVM PAKS II. ZRT., 2016a)

Surprisingly, there are pronounced disparities between the structural and sedimentological data that unambiguously document evidence of Late Quaternary faulting at the investigated sites and the material used in the Site Safety Report. Despite accepting evidence of Quaternary faulting along the Dunaszentgyörgy-Harta fault zone in the area close to the NPP site in general, MVM PAKS II ZRT. (2016a) does not include a comprehensive presentation of the paleoseismological data obtained from trench Pa-21-II. The paleoseismological features observed in the trench are referred to as “anomalous near-surface structures” that include a “funnel-like structure interpreted as a flower structure.” The locations of the “anomalous near-surface structures” are shown in a figure that is based on the compilation of trench observations and S-wave reflection seismic (Figure 22). The compilation shows a perfect match of the locations of faults imaged in
the reflection seismic and the structures validated in the trench. This evidence is not further described. Important information on the trenching results provided by Halasz et al. (2016) – such as the finding that the “seismotectonic structures” excavated in trench Pa-21-II are indeed fault planes, that the age of faulting is young (18–20 kyr), and that the trenching recovered two separate fault generations – is not adequately considered in MVM PAKS II. ZRT. (2016a).

Neglecting and suppressing the main paleoseismological conclusions by Halasz et al. (2016), MVM PAKS II. ZRT. further concludes that: “In addition, based on the results of the trench, it was proved that the flower structures appearing in the Quaternary sediments do not create a significant\textsuperscript{12} surface displacement.” Finally, it is argued that the imaged structures pose no significant seismogenic hazard: “It is common experience that the rupture planes associated with small-medium (Mw <6) earthquakes do not reach the earth’s surface, or the deformation in the direction of the surface disappears. Under Hungarian conditions, the average [hypocentre] depth of earthquakes is 8-10 km.” and “... it can be concluded that seismic events occurring in the research area on a timescale of one hundred thousand years\textsuperscript{13} are not able to significantly displace the surface, i.e. the fracture planes cannot be considered capable.”

The evident contradiction of these statements compared to the geological observations and the conclusions drawn by HALÁSZ et al. (2016) and ÁCS et al. (2016; see previous chapter) are not further discussed in this assessment. That this contradiction remains unaddressed is, in our opinion, contrary to the principles of good scientific practice and verges on negligence.

\textsuperscript{12} This wording acknowledges the existence of surface displacement.

\textsuperscript{13} This timescale is not in line with the definition of active faults and fault capability by IAEA (2019).
3.3.3 Expert assessment

Interpretation of the “seismotectonic phenomena”: In their report, HALÁSZ et al. (2016) conclude that the seismotectonic structures excavated in trench Pa-21-II are fault planes, which are an integral part of a negative flower structure associated with a strike-slip system. They arrive at this conclusion after discussing and excluding the possibility that the structures could result from the injection of liquefied sand.

We regard this interpretation as comprehensible and correct. It is in line with all the structural features documented in the report:

- variable vertical offsets along the vertical sections exposed in the trench walls are typical for strike-slip displacements (Figure 23a-b, e-f);
- as expected in a structural setting with a negative flower structure, most of the structures imaged in the seismic reflection profiles and validated in the trench are associated with normal offsets, and sediment layers have been dragged downward into the hanging walls (Figure 23 c-d);
- the extensional character of the flower structures that widen upward is shown by the normal offset of layers and hanging walls filled with younger sediment (Figure 23);
- a downward drag of partially consolidated sedimentary strata cannot result from the injection of liquefied sand from an underlying sediment
layer; in that case, drag features should be of reverse orientation and the injected material should have been homogenized by the fluidization;

- neither sand dikes nor sand laccoliths nor morphological and stratigraphic indications supporting the existence of former sand volcanoes are documented.

Figure 23. Uninterpreted (a) and (b) interpreted photos of structures excavated in trench Pa-21-II.

(a) Uninterpreted and (b) interpreted photo of structure 0.3 m (left) and 0.5 m (right) from HALÁSZ et al. (2016, Fig. 27). Interpretation by K. Decker and E. Hintersberger. 1 and 2 in (b) point to gashes filled by younger sediment; gashes mark the upper termination of the fault below. 3 and 4 denote opposite vertical displacement at structure 0.5 m, which is typical for strike-slip offset of slightly inclined sediment layers.

(c) Uninterpreted and (d) interpreted photo of structure 43.7 m from HALÁSZ et al. (2016, Fig. 35). Arrows highlight fragments of a whitish layer that collapsed into the flower structure. The arrangement of fragments overlying one another is difficult to reconcile with pure extension and is interpreted to indicate strike-slip faulting.

(e) Uninterpreted and (f) interpreted photo of structure 6.4 m from HALÁSZ et al. (2016, picture detail of Fig. 26). Note the opposite vertical displacement of laminae at downward converging branch faults indicative of strike-slip faulting.
**Estimates of surface displacement and earthquake magnitude:** With respect to the displacement at the excavated structures, HALÁSZ et al. (2016) restrict their interpretation to one structure showing 1 cm reverse offset and the sinistral displacement of an en-échelon structure for which they infer a 2 cm offset. We regard the latter measurement as being incorrect, as it disregards the deformation mechanisms and strain distribution in a sinistral shear zone (see Figure 24 for further explanation). The displacement values listed are regarded as minimum values.

Significantly larger vertical offsets are documented from the structure at 43.7 m, showing two important aspects. First, the depicted normal offset close to the structure at 43.7 m records an offset of 12 cm; when measured from the lowermost layer crossing the flower structure, it reaches 4 cm (shown in HALÁSZ et al. 2016, Fig. 33, Fig. 35; e.g., Figure 23d of our report). Second, and more importantly, the trench only allows assessment of the vertical components of the total displacement along the excavated strike-slip faults. As is often the case in strike-slip settings, horizontal slip parallel to the sediment layers may have exceeded the vertical displacement significantly, but this is not quantifiable due to the lack of displaced markers. The observed vertical offsets of up to 12 cm likely correspond to total displacements ranging from ten to a few tens of centimetres.

For the negative flower structure at 43.7 m of the trench log, HALÁSZ et al. (2016) provide data that is detailed enough to approximate the horizontal slip distance required to form a negative flower structure with the documented geometry and size (Figure 25a). For a negative flower structure with an approximate triangular shape in cross section (Figure 25b), the amount of horizontal displacement ($\Delta L$) can be calculated from the volume of the flower structure prior to the slip event ($V_0$) and the volume of the flower structure after fault displacement ($V_1$) (see DECKER et al., 2005 for further explanation):

1. $$V_1 = V_0 + V_{fill}$$
   $$L_1 \times W \times D/2 = L_0 \times W \times D/2 + V_{fill}$$
   $$L_0 = L_1 - 2V_{fill}/(W \times D)$$

2. $$\Delta L = L_1 - L_0$$
   $$\Delta L = L_1 - (L_1 - 2V_{fill}/(W \times D))$$
   $$\Delta L = 2V_{fill}/(W \times D)$$

3. $$\Delta L = V_{fill}/A_{cross}$$
   $$A_{cross}$$: Cross section area of flower structure
   D: Depth of flower structure
   $L_0$: Length of flower structure prior to fault slip
   $L_1$: Length of flower structure after fault slip
   $\Delta L$: Increase of length of flower structure = (minimum) slip distance
   $V_0$: Volume of flower structure prior to fault slip
   $V_1$: Volume of flower structure after fault slip
   $V_{fill}$: Volume of the sediments that fill up the flower structure after the slip event
   W: Width of flower structure
The cross-section area of the flower structure \((A_{\text{cross}})\) is readily estimated as 0.11 m\(^2\) from the trench logs by HALÁSZ et al. (2016, Figs. 33, 35, 36; trench log in Attachment 2 of the report). \(V_{\text{fill}}\) is estimated from the cross-section area of sediments filling the upper part of the flower structure (about 0.03 to 0.035 m\(^2\)) and the along-strike length of the structure. The structure is exposed at both walls of the 1.3 m wide trench. The along-strike length of the flower is therefore \(\geq 1.3\) m and the minimum volume of \(V_{\text{fill}}\) (0.039 to 0.046 m\(^3\)) is calculated by multiplying the cross-section area (0.03 to 0.035 m\(^2\)) with the minimum length (1.3 m). The numbers stated are indicative of a horizontal slip distance of about 0.3–0.4 m according to equation (3) above. Surface offsets of this order of magnitude are typically related to earthquakes with \(M \geq 6\) (cf. empirical correlations shown in Figure 18).

(a) Sediment filled en-échelon tension gashes interpreted to record sinistral slip and 2.5 cm horizontal displacement (from HALÁSZ et al., 2016, Fig. 32); (b) schematic sketch of a sinistral shear zone with en-échelon tension gashes showing that the measurement in (a) determines the horizontal spacing of the sediment-filled tension gashes. The amount of sinistral displacement remains undetermined.

(a) Negative flower structure at 43.7 m of the trench Pa-21-II (background photo from HALÁSZ et al., 2016, Fig. 35, interpretation by K. Decker & E. Hintersberger). The continuous white line indicates the boundary faults of the flower structure; the broken line delimits sediments of the post-tectonic fill. (b) Schematic shoebox model illustrating the geometry of a negative flower structure. The slip distance is equal to the increase of length \((\Delta L)\) of the structure. See text for further explanation.
Number and timing of seismic events: The detailed 1:200 trench log by HALÁSZ et al. (2016, MÁ/PA2-16-FT-14 V2 Pa-21-II) shows that the mapped seismotectonic structures reach up to different depths below surface. While the majority of structures terminate upward at a depth of -1.5 m (structures 0.3 m, 2 m, 6.4 m, 37 m, 41.2 m, 43.7 m, 60.8 m, 68.3 m), four structures (0.5 m, 40.7 m, 41.2 m and 73.2 m) reach up to a depth of about -1 m. HALÁSZ et al. (2016) therefore conclude that “tectonic activity can be divided into two generations.”

We regard this conclusion as being correct. Indeed, the upward terminations of faults highlight two event horizons (E1 and E2 in Figure 26): the lower one immediately above or at the layer dated to 20.7±1.9 kyr by OSL, and the upper one immediately above the layer dated at 19.3±1.5 kyr. Whether E2 coincides with the lower seismite layer identified at a depth of about -1.0 m or the seismite formed by an independent event cannot be further differentiated. The upper seismite immediately below the bioturbated sand in Figure 26 records a separate earthquake that did not lead to the formation of surface-breaking structures observed in the trench profile.

Paleoseismological data from trench Pa-21-II therefore confirm two surface-breaking faulting events that occurred at about 19 and 20 kyr BP, respectively. The younger event may have been associated with the formation of a seismite layer. The time between the two surface-breaking events is correctly estimated to be on the order of a thousand years (HALÁSZ et al. 2016, p. 4). A third paleoearthquake is confirmed by the younger, yet undated, seismite layer.

Figure 26. Interpreted trench log of the paleoseismological trench Pa-21-II, modified from ÁCS et al., 2016, Fig. 250.

The log shows that the upward terminations of recorded faults cluster at the depth of the upper “well-traceable marker horizon” and at the depth of the seismite layer at -1 m below surface. The corresponding horizons are interpreted as representing two distinct seismogenic event horizons associated with surface-breaking faulting. Location of the younger seismite is not indicated in the original figure. Location and depth of samples used for OSL dating taken from HALÁSZ et al., 2016, Fig. 21. Seismotectonic elements supplemented from the trench log MÁ/PA2-16-FT-14 V2 Pa-21-II. Depth scale according to MÁ/PA2-16-FT-14 V2 Pa-21-II.
Orientation and kinematics of seismotectonic structures: On the trench log at a scale of 1:200, HALÁSZ et al. (2016) provide data on the orientation of all recorded structures. Reliable orientations could be measured with confidence due to the fact that most of the structures were exposed in both trench walls and/or on the cleaned floor of the trench. The Schmidt net diagram shown in MÁ/PA2-16-FT-14 indicates that most structures strike parallel or sub-parallel to the SW-NE-striking sinistral Dunaszentgyörgy-Harta strike-slip fault system.

The observed negative flower structures (faults at 40.7 m and 43.7 m) and other features detected along the faults indicate strike-slip displacement. The array of faults with a left-stepping en-échelon arrangement at 37 m supports the interpretation of sinistral shearing. Both types of evidence are in line with the independently inferred kinematics of the Dunaszentgyörgy-Harta fault system.

Trench location and completeness of information: The location of the 84-meter-long paleoseismological trench Pa-21-II was chosen to expose two of the Quaternary faults shown in the 2D shear-wave seismic reflection profile Pa-21-S-Geomega (Figure 27, Figure 28). In this seismic section, TÓTH et al. (2016) interpreted a series of eight faults that offset the base of the Quaternary strata at a depth corresponding to around 350 msTWT and reach up to a depth equivalent to about 50 msTWT (TÓTH et al., 2016, Fig. 34). Out of the eight interpreted faults, the excavated trench exposed three faults, labelled 1–3 in Fehler! Verweisquelle konnte nicht gefunden werden. Locations indicated in the seismic section correspond closely with the “seismotectonic phenomena” that occur close to the NW and SE end of the trench, respectively.

With respect to Figure 27, it should be noted that no paleoseismological data are available for the faults shown in the seismic section farther SE, including the series of important faults labelled 6 to 8. The latter show larger horizontal offsets than those of the trenched faults. Notably, faults 6 to 8 coincide with an approximately WSW-ENE-trending morphological scarp at surface (see, e.g., DEM shown in Fig. 31, ÁCS et al., 2016) and are associated with thickness variations of the Quaternary strata (ÁCS et al., 2016, 1:100.000 map of Quaternary thickness distribution). We put forward an alternative interpretation of seismic line Pa-21-S (Figure 28c), whereby faults in the SE part of the section can be interpreted to reach upward to layers that are equivalent to approximately 100 ms below surface and which offset young sediments inferred to be of Holocene age (Figure 28a, c).

Unfortunately, paleoseismological data are available neither from other Quaternary faults of the Dunaszentgyörgy-Harta fault system that were identified in the site vicinity on the left bank of the Danube river (seismic reflection profile Pa-22-S, Figure 8, Figure 9), nor from the splay fault of the fault system that extends into the perimeter of the planned new reactors as shown on the maps by MVM Paks II Zrt. (2016a, Fig. 5.2.1.2.6-1.) and ÁCS et al. (2016, Fig. 418) (Figure 4 and Figure 10 in this report).

We conclude that the trench Pa-21-II was sited carefully and successfully to expose the targeted faults. However, no paleoseismological data is available from the other faults imaged on the seismic reflection profiles (faults no. 4, 5, 6, 7 and...
8, Figure 27a), including faults that apparently offset Holocene sediments. All faults imaged in Pa-21-S belong to the NW branch fault of the negative flower structure of the Dunaszentgyörgy-Harta fault system shown in inline 540. The trench-derived paleoseismological data are therefore not sufficient to fully characterize the Quaternary tectonics of the Dunaszentgyörgy-Harta fault system.

We conclude that trench Pa-21-II only provides paleoseismological data that cover a small part of all the branch faults of the Dunaszentgyörgy-Harta fault system that are evident from seismic data. The paleoseismological assessment is thus insufficient for a comprehensive characterization of the more than 1-km-wide fault zone.

Figure 27.
Location of the seismic reflection profiles Pa-21-P, Pa-21-S, and the paleoseismological trench PA-21-II with respect to the location of the existing NPP and the site of Paks II.

The approximate distance of the trench from the existing reactors is 700 m. Red polygon denotes the site of Paks II according to the geographic coordinates listed in HAEA (2017).
Interpreted (a), uninterpreted (b) and alternative interpretation (c) of high-resolution near-surface seismic section Pa-21-Geomega.
Our assessment of the paleoseismological data obtained from the site (HALÁSZ et al., 2016) leads us to draw the following conclusions:

- the paleoseismological trench exposed three branch faults of the negative flower structure of the Dunaszentgyörgy-Harta fault zone;
- paleoseismological trenching confirmed 12 surface-breaking faults that apparently formed during two separate surface-rupturing earthquakes at about 20,000 and 19,000 years BP;
- surface faulting is thus of a recurring nature;
- due to the strike-slip kinematics of the excavated faults, surface displacements have not been quantified; the estimates by HALÁSZ et al., 2016, are only minimum values;
- horizontal offsets along at least one structure are likely to be on the order of a few tens of centimetres as indicated by the geometry and fill of one of the excavated flower structures;
- for this flower structure a typical magnitude, $M \approx 6$, is estimated based on its size and geometry;
- although successfully exposing three branch faults of the Dunaszentgyörgy-Harta fault zone, the 85 m long paleoseismological trench is insufficient to provide a reliable and comprehensive assessment of the youngest slip history of the Dunaszentgyörgy-Harta fault zone, which crosses the NPP site and extends over a width of about 1 km;
- no paleoseismological data is available from fault branches that pass below the site of the new NPP.
4 ASSESSMENT OF THE SITE LICENSE DECISION

In chapter 4.1 we summarize the contents of the Site License with respect to fault capability. In chapter 4.2 we compare the justification of the licensing decision with data provided in the Geological Site Report (Földtani Kutatási Program FKP), the Site Safety Report (TBJ), and our own expert assessment of these data with the aim of evaluating whether the Hungarian regulatory requirements concerning fault capability are met.

4.1 Contents of the Site License with respect to active faulting and fault capability

On March 30, 2017, HAEA granted the Site License for Paks II (HAEA, G. Fichtinger, 2017). In the Site Permit, HAEA imposes the following conditions on the licensee:

Para. 1.1 obliges the licensee to develop a program for additional site investigations to assess a defined list of external hazards.

Para. 1.8 of the site license lists 35 requirements from the Governmental Decree No. 118 of 2011 (VII.11.) for which the licensee has to demonstrate compliance in his application for a construction license.\(^\text{14}\)

Para. 1.12. states the regulatory conclusion on the geological site characteristics and the suitability of the site. The regulatory assessment of the site conditions with respect to the subject areas of seismology, tectonics, geotechnics, and hydrogeology was delegated to Baranya Megyei Kormányhivatal Műszaki Engedélyezési és Fogyasztóvédelmi Főosztály Bányaszati Osztálya.\(^\text{15}\) The paragraph includes the regulatory assessment of fault capability according to the requirements 7.3.1.0800 and 7.3.1.1100 of Annex 7 to the 118/2011. (VII. 11.) to the Government Decree.

“The conditions and provisions listed in the statement of the Government Office of Baranya County, Department for Technology Licensing and Consumer Protection, \(^\text{14}\) Annex 7 to the 118/2011. (VII. 11.) to the Government Decree, Nuclear Safety Rules, Volume 7, Investigation and evaluation of nuclear facilities: 7.2.1.0400., 7.2.1.0500., 7.2.1.0600., 7.2.1.0700., 7.2.1.1100., 7.2.1.1300., 7.2.1.1400., 7.2.1.1500., 7.2.1.1600., 7.2.1.1700., 7.2.1.1800., 7.2.1.1900., 7.2.1.2000., 7.2.2.0100., 7.2.2.0200., 7.2.2.0300., 7.2.2.0400., 7.2.2.0500., 7.2.5.0500., 7.2.5.0100., 7.2.5.0300., 7.2.5.0400., 7.3.1.0700., 7.3.2.0800., 7.3.3.0200., 7.3.6.0500., 7.3.6.1000., 7.5.2.0400., 7.5.3.0200., 7.5.3.0400., 7.5.6.0300., 7.5.6.0500., 7.5.7.0300., 7.5.8.0200., 7.5.9.0100.

\(^\text{15}\) Government Office of Baranya County, Department for Technology Licensing and Consumer Protection, Mining Sub-Department / Bergbauabteilung der Hauptabteilung für Technische Genehmigungsverfahren und Verbraucherschutz der Regierungsbehörde des Komitats Baranya.
Mining Sub-Department [referred to as Baranya Mining Authority below] as the competent authority participating in the proceedings:

The [Baranya Mining Authority] declares, on the basis of the documentation sent in the attachment of the site license application, that the requirements for the planned site

7.3.[17].0100.–7.3.1.1100.
7.3.2.0100.–7.3.2.0800.
7.3.6.0900.
7.5.2.0100.–7.5.2.0900.
7.5.3.0100. and the requirements addressed by
7.2.1.0100.–7.2.1.2600.
7.2.5.0100.
7.2.5.0400.
7.3.7.0200. d), e) und j)
7.5.3.0200.–7.5.3.0400.
7.5.6.0100.–7.5.6.0400.

of the Annex 7 to the 118/2011. (VII. 11.) to the Government Decree, Nuclear Safety Rules, Volume 7, Investigation and evaluation of nuclear facilities are fulfilled for the subject areas of seismology, tectonics, geotechnics, and hydrogeology.

The [Baranya Mining Authority], taking into account the expertise of independent experts, confirms that the milestones set out in the program have been met by the allotted site investigation and evaluation program. The [Baranya Mining Authority] accepts the conclusions on the suitability of the site, confirms the adequacy of data and information to be used in the further planning and permitting of the installation.

By accepting the confirmation that geological site characteristics that exclude the suitability of the site are absent, the [Baranya Mining Authority] declares that the site is geologically suitable for the construction of a nuclear installation.

At the same time, evidence of full compliance with the requirements of 7.3.2.080016 of the 7th Annex [of the Atomic law and] the deterministic exclusion of the risk of soil liquefaction must be provided in the course of the construction and approval process of the new nuclear power plant, knowing the foundation plans. [etc.]”

In the “Justification” (“Indokolás”) of its decision, HAEA includes the following statement under the heading “Determined facts of the case” (“A megállapított tényállás”) (p. 9):

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16 “7.3.2.0800. If soil liquefaction may occur as a result of a safety earthquake, the site shall be considered unsuitable unless there are proven technical solutions to eliminate soil liquefaction or it can be demonstrated that the soil liquefaction caused by the safety earthquake is local and does not cause relative safety displacements that have structural consequences that impede its function.”
“Article 1 of the Decree annexes, point 1.2.2.0700 defines the content requirements of the application for the on-site examination and management [?] permit.

In the application for the site license:

a) it must be demonstrated that no site characteristics exist which exclude the construction, as well as...” [etc.]

Under the heading “Decision by HAEA and justification, legal basis of the prescribed conditions” (“Az OAH döntése és előírt feltételeinek indokolása, jogalapja”), HAEA provides justification and explanation for the decisions stated in the Site License.

In the justification for Para. 1.12 (“A rendelkező Rész 1.12 pontjához”, pp. 23–27) the Baranya Mining Authority states the following:

"3. Evidence for the geological suitability of the site and geological data to be considered in further planning:

Faults in the geotectonic vicinity of the planned site (particularly considering the NE-SW-striking Dunaszentgyörgy-Harta Fault Zone, which is proven below a part of the site) can dissect the Pannonian strata and touch the near-surface parts of the Quaternary sediments. However, based on the results of the complex research (drillings, trench, geodesy/space-born geodesy, geomorphological mapping) it can be concluded, that faults, which are associated with 100.000 years earthquakes with magnitude Mw<6 and a focal depth of 8-12 km, do not reach the surface and that these faults cannot lead to tectonic surface deformation. Based on the evaluation of the research the possibility of surface displacement due to a surface breaking fault is excluded for the site. Surface displacement cannot be proved at the site. The conditions to exclude the suitability of the site according to paragraph 7.3.1.1100 of the 7. Annex of the decree do not exist for the investigated site.

The complex investigations confirm, that at the investigated site and within at least 10 km of its surrounding no fault segment exists, which led to surface displacement by faulting in the last 100.000 years. Conditions for denying the suitability of the site according to paragraph 7.3.1.1100 of the 7. Annex of the decree neither exist for the investigated site nor for its surrounding within a distance of at least 10 km.”
4.2 Expert assessment

Para. 1.1 obliges the licensee to develop a program for additional site investigations to assess a defined list of external hazards.

Requirements for additional geological/geophysical investigations are not included.

We propose requesting HAEA to explain why no additional investigations are required with respect to fault capability. This should be justified in particular for the splay fault of the Dunaszentgyörgy-Harta fault zone that was identified within the perimeter of the planned reactors according to the data shown in the Site Safety Report (MVM Paks II Zrt., 2016a, Fig. 5.2.1.2.6-1.). Available high-resolution near-surface geophysics, in particular S-wave seismic reflection profiling and paleoseismological investigations (trenches), are insufficient to provide a reliable and comprehensive assessment of fault-capability hazards for all branch faults of the Dunaszentgyörgy-Harta fault zone. The fault zone crosses the NPP site and extends over a width of about 1 km. Existing investigations, however, only cover a small fraction of this width. Paleoseismological trenching has not been applied in the site area of the new NPP. Additional investigations are therefore considered indispensable and should at the very least include:

- The extension of high-resolution S-wave reflection seismic profiles across the Dunaszentgyörgy-Harta fault zone to cover the entire width of the fault zone;
- Detailed paleoseismological trenching of all faults identified in the existing S-wave reflection seismic profiles Pa-21-S, Pa-22-S, and the extensions of these profiles to prove or disprove fault capability;
- Paleoseismological investigations using trenching techniques and documentation of results in high-resolution logs of all (planned) excavations and construction pits for the new reactor blocks and other infrastructure at the Paks II site;
- Numerical age dating of the faulted Quaternary sedimentary strata using state-of-the-art techniques (14C, OSL, IRSL, pIRIR) to constrain the timing of faulting events.

Para. 1.8 of the Site License lists 35 requirements from the Governmental Decree No. 118 of 2011 (VII.11.) for which the licensee has to demonstrate compliance in their application for a construction license. Among the listed regulations the following topics specifically address geological hazards (the Site License only quotes paragraph numbers; the full text of the regulations is taken from Governmental Decree No. 118 of 2011 (VII.11.));

7.2.1.1400. “The selected site is acceptable if there are proven technical solutions to ensure that the relevant nuclear safety criteria are met under site-specific events and conditions.”

7.5.3.0200. “If there is a geotechnical hazard at the site against which a proven technical solution or measure improving the geotechnical conditions of the site cannot
be implemented, then the probability of the hazard must not exceed 10^-6 / year, taking into account [sic] effect.”

7.5.3.0400. “The parameters belonging to the design basis of the technical solutions and measures for the improvement of the on-site geotechnical conditions shall be chosen in such a way that the measure can meet the requirements of 7.5.3.0200. and in such a way that the danger can be ruled out. For the design of measures to improve geotechnical conditions, the geotechnical characteristics shall be determined in accordance with the requirements for the design of these measures and considerations for the safety of the nuclear power plant, up to a frequency of at least 10^-6 / year.”

The phrasing of the Site License suggests that the fulfilment of the requirements shall be documented for soil liquefaction. The regulations, however, might also be applicable to fault-capability hazards.

We propose requesting HAEA to explain and clarify its position. It should be clarified if HAEA has applied the cited paragraphs to fault-capability hazards and whether HAEA will prescribe technical solutions for mitigating the effects of seismic surface ruptures (fault capability).

Para 1.12 states the regulatory conclusion on the geological site characteristics and the suitability of the site. Among the listed regulations, the two relevant for fault capability are the following:

7.3.1.0800. “The potential occurrence of a permanent surface displacement on the site shall be analysed and evaluated. The examination must be sufficiently detailed to enable a substantive decision to be taken on the question of the possibility of discarding the site by the occurrence of permanent surface displacement.”

7.3.1.1100. “If the potential of occurrence of a permanent surface displacement on the site cannot be reliably excluded by scientific evidences, and the displacement may affect the nuclear facility, the site shall be qualified as unsuitable.”

Fulfilment of all requirements for nuclear facilities, including requirement 7.3.1.1100, is confirmed by the technical authority Baranya Megyei Kormányhivatal Műszaki Engedélyezési és Fogyasztóvédelmi Főosztály Bányaszati Osztálya (Baranya County Mining Authority), which states in Para. 1.12, justification, paragraph 3 (“A rendelkezõ Rész 1.12 pontjához”, pp. 23–27):

- “Faults in the geotectonical vicinity of the planned site (particularly considering the NE-SW-striking Dunaszentgyörgy-Harta fault zone, which is proven below a part of the site), can dissect the Pannonian strata and [1] touch the near-surface parts of the Quaternary sediments. However, based on the results of the complex research (drillings, trench, geodesy-space-borne geodesy, geomorphological mapping) [2] it can be concluded that faults that are associated with 100,000-year earthquakes with magnitude Mw<6 and a focal depth of 8–12 km do not reach the surface and that these faults cannot lead to tectonic surface deformation. Based on the evaluation of the research [3] the possibility of surface displacement due to a surface-breaking fault is excluded for the site. [4] Surface displacement cannot be proved at the
site. The conditions for excluding the suitability of the site according to paragraph 7.3.1.1100 of the 7. Annex of the decree do not exist for the investigated site.

- The complex investigations confirm that [5] at the investigated site and within at least 10 km of its surroundings, no fault segment exists that led to surface displacement by faulting in the last 100,000 years. Conditions for denying the suitability of the site according to paragraph 7.3.1.1100 of the 7. Annex of the decree exist neither for the investigated site nor for its surroundings within a distance of at least 10 km.”

Based on the data included in the Geological Site Report (ÁCS et al., 2016; HALÁSZ et al., 2016; MAGYARI, 2016; TOTH, T. et al., 2016), the Site Safety Report (MVM PAKS II. ZRT., 2016a, b) and our own expertise we assess the statements [1] to [5] of the Baranya Mining Authority as follows:

Ad [1]. High-resolution shear-wave seismic profiles Pa-21-S and Pa-22-S prove that faults cut upward through the base of the Quaternary sediments and are reliably mapped up to a depth that corresponds to about 50 msTWT\(^{17}\). The palaeoseismological trench Pa-21-II furthermore proves that at least two of the eight faults shown in the seismic data reach up to two metres depth below surface. The wording “can … touch the near-surface part of the Quaternary sediments” is therefore not correct and clearly ignores geological facts.

Ad [2]. According to internationally accepted definitions, fault capability is not associated with earthquake probability or recurrence intervals. According to the definition by the IAEA (2003; 2016; 2019) a “fault shall be considered capable if, on the basis of geological, geophysical, geodetic or seismological data (including palaeoseismological [sic] and geomorphological data), one or more of the following conditions applies:

(a) It [The fault] shows evidence of past movement or movements (significant deformations and/or dislocations) of a recurring nature within such a period that it is reasonable to infer that further movements at or near the surface could occur. In highly active areas, where both earthquake data and geological data consistently [and/or exclusively] reveal short earthquake recurrence intervals, periods of the order of tens of thousands of years may be appropriate for the assessment of capable faults. In less active areas, it is likely that much longer periods will be required.

(b) A structural relationship with a known capable fault has been demonstrated such that movement of one could cause movement of the other at or near the surface.

(c) The maximum potential earthquake associated with a seismogenic structure is sufficiently large and at such a depth that it is reasonable to infer that, in the geodynamic setting of the site, movement at or near the surface could occur.”

The Hungarian regulation 7.3.1.0900 apparently adopts this exact wording.

\(^{17}\) TWT: Two-Way-Traveltime in shear wave reflection seismic.
In light of this, statement [2] cannot be asserted because:

(1) The statement refers to only one of three conditions listed by the IAEA (2003; 2016; 2019); conditions (a) and (b) are disregarded.

(2) By definition, the maximum credible earthquake (or maximum potential earthquake) is not related to a recurrence interval and least of all to a recurrence interval of 100,000 years. The assumed value of Mw<6 is not reconcilable with Mmax estimates based on the length of the Dunaszentgyörgy-Harta fault zone, which extends for at least 30 km along strike. This fault length is associated with a maximum credible earthquake with Mw = 6.8 ± 0.3 (WELLS & COPPERSMITH, 1994, Table 2a, regression coefficients for strike-slip faults). Also, the occurrence of earthquakes with magnitudes M>6 in the area of interest has been proven by MAGYARI (2016), who reports data indicative of two M>6 earthquakes associated with the Németkér fault during the last 14,000 years; this fault is comparable to the Dunaszentgyörgy-Harta fault zone in terms of its length and kinematics. At least one paleoearthquake with M>6 is also documented by the data from trench Pa-21-II next to the site. It is therefore extremely unlikely that the recurrence interval of earthquakes with M>6 is as high as 100,000 years. Instead, paleoseismological data in the Geological Site Report suggests much shorter recurrence interval, e.g. in the range of thousands of years. ÁCS et al. (2016), HALÁSZ et al. (2016) and MAGYARI (2016) provide stringent paleoseismological evidence for surface breaking faulting and strong paleoearthquakes that occurred in the last about 30 kyr (see summary in Table 1 of our report) which is not reflected in the Site Safety Report and not acknowledged in the Site License decision.

(3) The arbitrarily selected recurrence interval of 100,000 years is not in line with the IAEA definition of capable faults. For fault capability assessments, IAEA (2009) requires the consideration of much longer timescales, stating that a fault shall be considered capable “if it shows evidence of past movement or movements ... of a recurring nature within such a period that it is reasonable to conclude that further movements at or near the surface may occur. ... In less active areas, it is likely that much longer periods (e.g. Pliocene–Quaternary, i.e. the present) are appropriate.”

Ad [3]. We regard this statement as factually wrong for the following two reasons:

(1) The paleoseismological data obtained from the site in trench Pa-21-II confirm surface-breaking faults that likely formed during two earthquakes at about 20,000 and 19,000 years BP. The obtained data therefore prove that surface faulting is of a recurring nature, which is in line with the definition of a capable fault by IAEA (2003; 2016; 2019);

(2) As outlined in detail in chapter 3.3.3 of our report, seismic reflection data confirm that the flower structure of the approximately 1-km-wide Dunaszentgyörgy-Harta fault zone consists of three major faults. Of this fault array, only the central branch was investigated with appropriate high-resolution seismic reflection methods (line Pa-21-S). This seismic reflection data revealed that
the branches constituting the flower structure consist of at least eight near-surface faults. Out of these, six remained unexplored using appropriate methods. Faults mapped NE of the site in the seismic reflection line Pa-22-S and within the site were not investigated by paleoseismological trenching. Therefore, “the potential of occurrence of a permanent surface displacement on the site cannot be reliably excluded by scientific evidences” as compulsory by requirement 7.3.1.1100. We conclude that the site should therefore be qualified as unsuitable.

Ad [4]. This statement by the Baranya Mining Authority is disproved by the results of the paleoseismological trench Pa-21-II. The trench exposes 12 surface-breaking faults, whose activity was dated to circa 19,000 and 20,000 years.

Ad [5]. In the Geological Site Report, MAGYARI (2016) documents faults displacing Holocene sediments from outcrops along Highway M-6 at the Németkér fault. According to his data, at least two surface-breaking earthquakes occurred in the last circa 14,000 years; the older event with M>6, and the younger one with (estimated) M=6.5. The outcrops from which the data was obtained are located at a distance of 10.7 and 7.5 km from the existing NPP, i.e., in the near region of Paks II. Based on these documented fault offsets, it clearly follows that the Németkér fault is capable of rupturing the ground surface.

In the Site Safety Report, MVM Paks II concludes for the investigations of the Dunaszentgyörgy-Harta fault system that “based on the S-wave seismic profiles, the structural indications that can be designated in the Quaternary sediments have been detected by special shallow drilling and trenching, and according to this, near-surface, active tectonics should be expected in the wider research area. The possibility of active tectonics is also supported by seismological analysis and seismic source models.” (MVM PAKS II. ZRT., 2016a, p. 60)

We conclude that the statement “investigations confirm, that at the investigated site and within at least 10 km of its surrounding no fault segment exists, which led to surface displacement by faulting in the last 100,000 years” is factually wrong. Data in the Geological Site Report prove four surface-breaking earthquakes within a distance of 10 km from the site. Two events with M>6 with ages between 14,000 and 5,000 years were documented in outcrops along Highway M-6. Two other paleoearthquake ruptures with ages between 19,000 and 20,000 years were documented in trench Pa-21-II next to the site.
Summary statement:

We conclude that the geological and geophysical data documented in the Geological Site Report (TBJ) and the Site Safety Report are not sufficient to reliably exclude the potential of a permanent surface displacement at the site that may affect the nuclear facility as required by the HUNGARIAN GOVERNMENTAL DECREE No. 118 of 2011, requirement 7.3.1.1100.

We conclude that, on the contrary, the paleoseismological data derived from trenching next to the site (HALÁSZ et al., 2016) confirm the existence of capable faults in the site vicinity of Paks II. These capable faults strike into the site and show evidence of repeated and significant surface displacements that occurred during the last circa 20,000 years. The documented capable faults belong to the approximately 1-km-wide Dunaszentgyörgy-Harta fault zone, a proven active fault in the subsurface of the existing NPP as well as large parts of the Paks II site.

We further conclude that the HUNGARIAN GOVERNMENTAL DECREE No. 118 of 2011 (VII.11.) on nuclear safety requirements, requirement 7.3.1.1100, is apparently not met. The site should therefore be deemed unsuitable.

Our assessment is based on convincing evidence for active and surface-breaking faulting that is presented in the Geological Site Report. However, this evidence is not correctly reflected in the Site Safety Report (MVM Paks II Zrt. 2016a, b). The omission of relevant data of the Geological Site Report (e.g., all data by MAGYARI, 2016) and contradictions between the Site Safety Report on the one hand, and the geological observations and the conclusions in the Geological Site Report (ÁCS et al., 2016; HALÁSZ et al., 2016) on the other hand, is, in our opinion, contrary to the principles of good scientific practice.
5 ASSESSMENT ACCORDING TO OTHER INTERNATIONAL AND NATIONAL REQUIREMENTS AND GUIDANCE

5.1 IAEA requirements and WENRA safety expectations with respect to the siting of new NPPs

With respect to the siting of new NPPs, IAEA and WENRA require the following:

According to IAEA (2012, SSR-2/1), the safety of a nuclear power plant is ensured by means of proper **site selection**, design, construction and commissioning. It is explained that “the purpose of the first level of defence is to prevent deviations from normal operation and the failure of items important to safety. This leads to requirements that the plant be soundly and conservatively sited, designed, constructed, maintained and operated in accordance with quality management and appropriate and proven engineering practices.” (IAEA, 2012, p.7).

WENRA “expects new nuclear power plants to be designed, sited, constructed, commissioned and operated” to meet the Safety Objectives for New NPPs as stipulated by WENRA (2010) and further explained by RHWG (2013). This includes the expectation of “providing due consideration to siting and design to reduce the impact of external hazards and malevolent acts.” (WENRA, 2010, p. 3).

The Geological Site Report and the Site Safety Report by MVM Paks II Zrt. document the Dunaszentgyörgy-Harta fault zone as an active fault that extends into the site area of Paks II (MVM Paks II Zrt., 2016a, Fig. 5.2.1.2.6-1.; ÁCS et al., 2016, Fig. 418; Figure 4 and Figure 10 in our report). The Dunaszentgyörgy-Harta fault zone is a proven active fault that offsets Quaternary sediments and includes capable faults.

The selection of the Paks II site on top of the Dunaszentgyörgy-Harta fault zone therefore accepts that the external hazard of fault capability (hazard N3; WENRA 2015, p.24) applies to the site. The selected site further admits that near fault effects such as forward directivity and fling-step ground motion (WENRA 2016, p. 6) increase the site-specific vibratory ground motion hazard (hazard N1, WENRA 2015, p.24). Such near fault effects apply to earthquakes with hypocentres below the site and/or in the site vicinity that are caused by slip of the Dunaszentgyörgy-Harta fault zone. The selection of the site therefore seemingly does not conform to the requirement of “sound and conservative siting” (IAEA, 2012). The selection of the site appears also not in line with WENRA’s expectation to “reduce external hazards by providing due consideration to siting” (WENRA, 2010).

Observing the IAEA requirements and WENRA safety expectations requires moving the site to an adequately safe distance from the Dunaszentgyörgy-
Harta fault zone to screen out the hazard of fault capability and mitigate the contribution of near fault effects to vibratory ground motion hazards.

5.2 WENRA safety objectives for new NPPs (H. Hirsch, Cervus nuclear consulting)

The NPP Paks II is a new NPP for which the highest safety standards in accordance with WENRA and IAEA have to be applied. WENRA (2010, p. 3; 2013, p.47) “expects new nuclear power plants to be designed, sited, constructed, commissioned and operated” to meet 7 pre-set safety objectives.

In this context, WENRA stipulates that for new NPP designs “accidents with core melt which would lead to early or large releases have to be practically eliminated” (WENRA, 2010, Safety Objective O3). This conforms to the IAEA Safety Standards stating that “event sequences that would lead to an early radioactive release or a large radioactive release are required to be ‘practically eliminated’” (IAEA, 2016). Principle 1 in the Vienna Declaration on Nuclear Safety (IAEA, 2015) formulates the same objective for new NPPs.

It has to be noted that the accidents referred to in WENRA Safety Objective O3 include accident sequences with core melt resulting from external hazards (RHWG, 2014, p. 33).

Key elements and expectations for demonstrating avoidance of large releases and early releases by using the notion of practical elimination are explained in a recent report by WENRA-RHWG (RHWG, 2019). The notion of practical elimination is applied to accident scenarios; a scenario is understood “as a set of sequences that lead to similar kinds of challenges of the containment function” (RHWG, 2019, p. 9).

Regarding the approach used for the demonstration, the report states: “For scenarios that inevitably lead to a failure of the containment [...] the avoidance of early releases and large releases is adequately achieved by demonstrating practical elimination on a case-by-case basis, by demonstrating either:

- that the scenario is physically impossible, or
- that the occurrence of the scenario can be considered as extremely unlikely with a high degree of confidence.”

(RHWG, 2019, p. 13)

Hence, there are two ways for the demonstration of practical elimination. They are not equivalent; there is a marked priority for the first-mentioned: “Physical impossibility is the preferred way to demonstrate practical elimination of a scenario because it rules out its occurrence.” (RHWG, 2019, p. 14)

Surface displacement due to a surface-breaking fault at the site of an NPP which leads to a significant shift can instigate a severe accident scenario with containment failure as well as other damages, resulting in a release which is both early
and large. A scenario of this kind has to be practically eliminated. Since the early and large release is unavoidable once the initiating event has occurred, this implies that it has to be demonstrated that the initiating event (surface displacement exceeding a certain, minor, extent) is either physically impossible, or extremely unlikely with a high degree of confidence, thus rendering the whole scenario physically impossible or extremely unlikely with a high degree of confidence.

The NPP Paks II Site Licensing Decision does not mention practical elimination or the two ways to achieve its demonstration. But surface displacement due to surface breaking faults is “excluded” for the site, which could, in principle, be regarded as a notion similar to practical elimination. As central argument for the exclusion, it is stated:

“...it can be concluded that faults that are associate with 100,000-year earthquakes [...] do not reach the surface and that these faults cannot lead to tectonic surface deformation. [...] the possibility of surface displacement due to a surface-breaking fault is excluded for the site.”

(HAEA, G. Fichtinger, 2017, Justification for Para. 1.12 “A rendelkező Rész 1.12 pontjához”, pp. 23–27; see chapter 4.1)

However, the similarity does not go very far – this reasoning does not fulfil the expectations for the demonstration of practical elimination.

In the Site Licensing Decision, there appears to be no discussion of the preferred way for practical elimination, the demonstration of physical impossibility. Yet it would be appropriate to thoroughly investigate the prospects of using this way and, should it prove unfeasible, to present the reason why this is so.

Furthermore, the argument presented for the exclusion cannot be accepted as even roughly equivalent to the demonstration of extreme unlikeliness with a high degree of confidence. A frequency of 1:100,000/year does not constitute an appropriate probabilistic target for practical elimination.

The report by RHWG states that probabilistic targets for scenarios for practical elimination should be set (RHWG, 2019, p. 18). It does not specify a numerical value for this target. However, it is obvious that a target of 10⁻⁵/year is not acceptable as extremely unlikely. As an overall target for the frequency of early releases and large releases, a value of 10⁻⁶/year or less is generally assumed, e.g. in various national regulations of WENRA countries. Since the overall frequency of early releases and large releases is the sum of the frequencies of the individual scenarios which lead to such releases, this implies that the target value for an individual scenario has to be in the order of 10⁻⁷/year or less.

Also, it has to be kept in mind that extreme unlikeliness has to be demonstrated with a high degree of confidence. In this context, the RHWG report states the following expectations: “Uncertainty analyses should be performed in a manner sufficient to permit the demonstration of a high degree of confidence in the practical elimination of a scenario...”. “The documented results should show the uncertainties
by including high fractiles of the frequencies involved, not only median and mean, whenever practicable.” (RHWG, 2019, p. 19).

No discussion or analysis of the uncertainties involved is presented in the Site License. Also, there is no discussion of the practicability of determining high fractiles of the frequency provided for the earthquake under consideration, and no discussion of the practicability of providing other numerical measures of the uncertainty.

We conclude that surface displacement due to a surface-breaking fault at the site of the Paks II NPP has the potential to instigate a severe accident scenario with containment failure as well as other damages, resulting in a release which is both early and large. According to the WENRA Safety Objective O3 (WENRA, 2010) such accidents “have to be practically eliminated”.

For the Paks II site accident scenarios that involve fault capability cannot be practically eliminated by the demonstration of physical impossibility, which is the preferred way to demonstrate practical elimination. Demonstration of physical impossibility is rendered impossible by the paleoseismological data obtained from the active Dunaszentgyörgy-Harta fault zone that extends into the Paks II site (see 3.1.1, Figure 4). Paleoseismological trenching by HALÁSZ et al. (2016) confirmed surface-breaking faulting with a recurring nature and surface displacements that reach up to the order of a few tens of centimetres (see chapters 3.3.1 and 3.3.3).

HAEA’s argument that “…it can be concluded that faults that are associate with 100,000-year earthquakes […] do not reach the surface and that these faults cannot lead to tectonic surface deformation. […] the possibility of surface displacement due to a surface-breaking fault is excluded for the site” cannot be accepted as a probabilistic demonstration of practical elimination. The probabilistic value of $10^{-5}$/year is not even roughly equivalent to extreme unlikeliness for which target values have to be in the order of $10^{-7}$/year or less. The argumentation also fails to demonstrate a high degree of confidence for the chosen (insufficient) probability level.
5.3 **Russian regulations with respect to active faults**

Public information indicates that the nuclear island and the new reactors of Paks II will be supplied by the Russian provider Nizhny Novgorod Engineering Company Atomenergoexport, today ASE Joint Stock Engineering Company (https://www.paks2.hu/web/paks-2/en/background-of-the-project), which is part of the Russian Rosatom (https://ase-ec.ru/en/about/history/). We therefore shortly review existing Russian regulations with respect to active faults and the siting of new reactors.

GOSATOMNADZOR OF RUSSIA (2002, NP-032-01) states the following under paragraph 3, Main criteria and requirements for safe nuclear power plant siting:

“3.1. It is not allowed to locate nuclear power plants:

- on the sites directly situated on active faults;
- on the sites whose seismicity is characterized by the maximum credible earthquake (MCE) intensity of more than 9 on Medvedev-Shponhoyer-Karnika seismic intensity scale (MSK-64)"

In this context the term “active fault” is defined as a “tectonic fault along which relative displacement of the earth crust’s adjacent blocks by 0,5 m and more took place during the last 1 bln. [million] years (quaternary period).” (GOSATOMNADZOR OF RUSSIA, 2002, NP-032-01)

Geological data and the assessments in the Geological Site Report and the Site Safety Report by MVM Paks II Zrt. document the Dunaszentgyörgy-Harta fault zone as an active fault that extends into the site area of Paks II (MVM Paks II Zrt., 2016a, Fig. 5.2.1.2.6-1.; ÁCS et al., 2016, Fig. 418; Figure 4 and Figure 10 in our report). ÁCS et al. (2016) and TÓTH (2003) show vertical fault displacements of Quaternary sediments associated with faults whose strike continues toward the site area and whose offsets exceed 0.5 m by far (see Figure 5 to Figure 9, Figure 14, Figure 15 in our report).

HALÁSZ et al. (2016) provide paleoseismological data indicative for two M>6 earthquakes at the site, indicating that the intensity associated with the MCE is I>9.

In summary, in light of the Russian equipment to be installed and based on the unambiguous geological evidence for Quaternary faulting in the site vicinity and on the site of the planned structure, the Paks II site should be considered unsuitable as requirement 3.1 of GOSATOMNADZOR OF RUSSIA (2002, NP-032-01) is not met.
6  OPEN QUESTIONS TO BE ADDRESSED TO HAEA

We propose submitting the following questions to the Hungarian Atomic Energy Authority (HAEA) for discussion at the next scheduled bilateral meeting between Hungary and Austria. All questions address requests to obtain additional information on the Site License for the planned NPP Paks II that was granted by HAEA in 2017 and, specifically, information on the assessment of fault capability at the site.

Background to all questions is the Hungarian regulation 7.3.1.1100 of the 7th Annex of HUNGARIAN GOVERNMENTAL DECREE (2011), which lists the following disqualifying circumstances for an NPP site: “If the potential of occurrence of a permanent surface displacement on the site cannot be reliably excluded by scientific evidences, and the displacement may affect the nuclear facility, the site shall be qualified as unsuitable.”

1. Question: Did the licensee undertake sufficient efforts to investigate the site and the site vicinity (as defined by IAEA) with respect to fault capability?

What is HAEA’s position with respect to the licensee’s claim that requirement 7.3.1.1100 does not require proof?

Background: In volume 1 of the Site Safety Report MVM Paks II Zrt. identifies the requirements to be examined in order to establish the basis for the permit (MVM Paks II Zrt., 2016c, p. 19-36, “Table 2.2.4-1, Requirements for site inspection and assessment of nuclear installations”). The first column of the table lists the NBSZ requirements, while the second column contains justifications for not considering some of the regulations in the site permit. Regulations not considered are marked by the crossed-out regulation numbers in the first column. For regulation 7.3.1.1100 of the 7th Annex of HUNGARIAN GOVERNMENTAL DECREE (2011), which lists fault capability as a disqualifying hazard, the licensee states the following:

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18 Bilateral Meeting under the Agreement Between the Republic of Hungary and the Republic of Austria for the Exchange of Information in Case of Radiological Emergency and for the Issues of Common Interest from the Field of Nuclear Safety and Radiation Protection
"7.3.1.1100 If the potential of occurrence of a permanent surface displacement on the site cannot be reliably excluded by scientific evidences, and the displacement may affect the nuclear facility, the site shall be qualified as unsuitable."

"Point not requiring proof of fulfilment of a requirement, because in the case of an unfit site, no application for a site permit will be submitted."

This suggests to us that MVM Paks II Zrt. regards the fact that the site permit has been submitted as a proof for the exclusion of fault capability.

2. Question: Did the licensee provide a safety demonstration on how to mitigate the following hazards: fault capability (N3 in WENRA 2015a), vibratory ground motion (N1 in WENRA, 2015 [guidance head]), and vibratory ground motion including near fault effects on long period ground motion with very short duration (0.5–5 s) (forward directivity and fling-step ground motion observed from velocity pulses recorded in time histories) (WENRA, 2016)? If yes: What is the basis for the assessment of hazard severity?

Background: „Die Partei wies nach, dass zur Behandlung von auf den Standort bezogenen und im Zuge der Planung zu berücksichtigenden Gefährdungsfaktoren, verwirklichte und getestete technische Lösungen existieren.” (HAEA, 2017, Punkt 1.1.c)

Even if HAEA regards fault capability as screened out, near-fault effects cannot be screened out in seismic hazard assessment for vibratory ground shaking.

3. Question: Did HAEA fully delegate the assessment of the geological suitability of the site and site suitability with respect to seismotectonic hazards (including fault capability) to the Mining Authority19, or did HAEA also review the geological contents of the Site Safety Report (MVM PAKS II. ZRT., 2017) based on its own expertise?


„Den Nachweis annehmend, dass geologische Standortcharakteristika, die eine Errichtung ausschließen (würden) fehlen, bestimmt die Bergbauaufsicht, dass der

19 Baranya Megyei Kormányhivatal Műszaki Engedélyezési és Fogyasztövédelmi Főosztály Bányasztási Osztálya
It appears that HAEA fully relied on the external decision by the Mining Authority without carrying out its own assessments.

4. **Question:** Did the Mining Authority\(^{19}\) base its assessment of the geological suitability of the site (including fault capability) exclusively on the Site Safety Report (MVM PAKS II. ZRT., 2016), or did the Mining Authority also consult the geological reports that had been prepared for the license applicant, in particular the paleoseismological reports by HALÁSZ, KONRÁD & SEBE (2016) and MAGYARI (2016)?

**Background:** It appears that the summary of the geological data provided in the Site Safety Report compiled by MVM PAKS II. ZRT. (2016) is the exclusive basis for the licensing decision. However, point 1.12. of the justification and legal basis of the administrative statement (“Az OAH döntése és előírt feltételének indolólása, jogalapja, A rndelkezö Réz 1.12. pontjához”) indicates that the Mining Authority\(^{19}\) based its decision on the following:

- copy of the application;
- Site Safety Report (TBJ);
- final report of the geological research program;
- contents of the Site Safety Report belonging to the subject area under the influence of the authority;
- independently reviewed material in the Site Safety Report;
- confirmation of payment of the administrative fee.

5. **Question:** The site application by MVM Paks II. Zrt. is dated 18 October 2016. The final paleoseismological report to MVM Paks II. Zrt., which includes the full documentation and interpretation of the paleoseismological results obtained from the site by HALÁSZ, KONRÁD & SEBE (2016), is dated 27. October 2016. The paleoseismology report contains data and conclusions that, in the view of the cited authors, support the existence of a surface-breaking fault at the site.

How confident are HAEA and the Mining Authority that the licensee included all the paleoseismological results that are relevant for assessing the suitability of the site according to NSC 7.3.1.1100 of the 7th Annex of the decree, considering that the paleoseismology report was not yet completed at the time of the application? Did HAEA and the Mining Authority take into account the complete results of HALÁSZ, KONRÁD & SEBE (2016) in their decision, or only the summary provided by MVM Paks II Zrt., which was completed before the final paleoseismology report was available to the license applicant?
Background: It appears that the Mining Authority based its decision on the Site Safety Report, the final report of the geological research program, and an expert review of the Site Safety Report. In its conclusion the authority states that “based on the geological assessment of the site and its surrounding ... it is evident, that no [site] exclusion factors exist, which could endanger the construction and licensing of the new units” (pp. 24–25 of the translated text).

Auch der Sachkundige sagt in seinem Gutachten, dass „anhand der geologischen Bewertung des Standortes und seiner Umgebung ... erkennbar ist, dass es keinen solch ausschließenden Faktor gibt, welcher die Erbauung und Freigabe der neuen Blöcke gefährden könnte“. ... “Im Falle der Auswahl und Anwendung der entsprechenden „bewährten technischen Lösung“ sind die im Zuge der Untersuchung und Bewertung des Standortes aufgedeckten Gefahren behandelbar.“ (Zu Punkt 1.12. des Bestimmungsteiles, Begründung und Rechtsgrundlage der fachbehördlichen Stellungnahme)

6.

Question: In their report to MVM Paks II. Zrt., HALÁSZ, KONRÁD & SEBE (2016) describe the following paleoseismological results: “The seismotectonic structures excavated in trench Pa-21-II are faults which are parts of a negative flower structure of a strike-slip fault system. Displacements along the faults could be proved in two cases: at 41 meter [of the trench profile] with 1 cm vertical, at 37 meter with 2,5 cm horizontal [displacement] component [etc.].” Do HAEA and the Mining Authority regard this scientific result to reliably exclude permanent surface displacement at the site as required by NSC 7.3.1.1100?

7.

In their explanatory statement to para. 1.12. of the Site License, bullet 3, HAEA and the Mining Authority state the following (p. 26 in the German translation): “Faults in the geotectonic vicinity of the planned site (particularly considering the NE-SW-striking Dunaszentgyörgy-Harta Fault Zone, which is proven below a part of the site) can dissect the Pannonian strata and touch the near-surface parts of the Quaternary sediments. However, based on the results of the complex research (drillings, trench, geodesy/space-born geodesy, geomorphological mapping) it can be concluded, that faults, which are associated with 100.000 years earthquakes with magnitude Mw<6 and a focal depth of 8-12 km, do not reach the surface and that these faults cannot lead to tectonic surface deformation. Based on the evaluation of the research the possibility of surface displacement due to a surface breaking fault is excluded for the site. **Surface displacement cannot be proved at the site**. The conditions to exclude the suitability of the site according to paragraph 7.3.1.1100 of the 7. Annex of the decree do not exist for the investigated site.

The complex investigations confirm, that at the investigated site and **within at least 10 km of its surrounding no fault segment exists, which led to surface displacement by faulting in the last 100.000 years**. Conditions for denying the suitability of the site according to paragraph 7.3.1.1100 of the 7. Annex of the decree
neither exist for the investigated site nor for its surrounding within a distance of at least 10 km.”

**Question:** What is the evidence confirming that “surface displacement cannot be proved at the site” [1], and what is the evidence for statement [2]?

**Background:** Statement [1] seems nonfactual considering the observations of displaced Late Pleistocene sediments described in the paleoseismology report from the site by HALÁSZ, KONRÁD & SEBE (2016).

Statement [2] seems nonfactual considering the paleoseismological report by MAGYARI (2016), who shows faults displacing Holocene sediments from outcrops along Highway M-6. At two locations, at distances of 10.7 km and 7.5 km from the existing NPP Paks, the cited author describes two surface-breaking faults with a displacement of up to 0.6 m. Surface displacements occurred between circa 14,000 and 5,000 years ago.

8.

Recent information indicates that the Hungarian government has granted permission to start earthwork to excavate on the building site20. Has HAEA been involved in granting this permission and has HAEA agreed to this permit? Has HAEA ensured that excavation works are accompanied by adequate paleoseismological documentation?

**Background:** Geological data and the assessments in the Geological Site Report and the Site Safety Report by MVM Paks II Zrt. conformably report the Dunaszentgyörgy-Harta fault zone as an active fault that extends into the site area of Paks II (MVM Paks II Zrt., 2016a, Fig. 5.2.1.2.6-1.; ÁCS et al., 2016, Fig. 418; Figure 4 and Figure 10 in this report). Data further indicate that a splay fault of the fault system extends into the perimeter of the planned new reactors.

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7 NATIONAL AND INTERNATIONAL REGULATIONS AND GUIDELINES ON ACTIVE FAULTS AND CAPABLE FAULTS

7.1 Recognized definitions of the terms “Active fault” and “Capable fault”

**Active fault:** “A tectonic structure that moved in the recent geologic past and that is expected to move within a future time span of concern for the safety of a nuclear installation. In highly active (e.g. interplate) areas with short earthquake recurrence intervals, periods of the order of tens of thousands of years (e.g. Upper Pleistocene to present) may be appropriate for defining a fault as active. In less active areas (e.g. intraplate) much longer periods (e.g. Pliocene – Quaternary to present) may be appropriate. In the conservative perspective of NPP siting, any fault within the Earth's crust might need to be reassessed for potential re-activation. […]”
(IAEA, 2015, Tecdoc 1767, p. 157)

**Active fault:** “Active fault – tectonic fault along which relative displacement of the earth crust's adjacent blocks by 0.5 m and more took place during the last 1 bln. [million] years (quaternary period).”
(GOSATOMNADZOR OF RUSSIA, 2002, NP-032-01)

**Active fault:** “Active break – tectonic break with relative displacement of the Earth’ crust by 0.5 m and more having occurred during the recent one million years (quaternary).”
(GOSATOMNADZOR OF RUSSIA, 2002, NP-050-03)

**Capable fault:** “3.6. A fault shall be considered capable if, on the basis of geological, geophysical, geodetic or seismological data (including palaeoseismological and geomorphological data), one or more of the following conditions applies:

(a) It [The fault] shows evidence of past movement or movements (significant deformations and/or dislocations) of a recurring nature within such a period that it is reasonable to infer that further movements at or near the surface could occur. In highly active areas, where both earthquake data and geological data consistently [and/or exclusively] reveal short earthquake recurrence intervals, periods of the order of tens of thousands of years may be appropriate for the assessment of capable faults. In less active areas, it is likely that much longer periods will be required.

(b) A structural relationship with a known capable fault has been demonstrated such that movement of one could cause movement of the other at or near the surface.

(c) The maximum potential earthquake associated with a seismogenic structure is sufficiently large and at such a depth that it is reasonable to infer that, in the geodynamic setting of the site, movement at or near the surface could occur.
(IAEA, 2003, NS-R-3; IAEA, 2016, NS-R-3 Rev. 1; IAEA, 2019, SSR-1, p. 18; all with identical wording except SSR-1, which includes words quoted in square brackets)
**Capable fault:** “A fault that has a significant potential for displacement at or near the ground surface.”

(IAEA, 2010, SSG 9, p. 51)

**Capable fault:** “8.4. On the basis of geological, geophysical, geodetic or seismological data, a fault should be considered capable if the following conditions apply:

(a) If it shows evidence of past movement or movements (such as significant deformations and/or dislocations) of a recurring nature within such a period that it is reasonable to conclude that further movements at or near the surface may occur. In highly active areas, where both earthquake data and geological data consistently reveal short earthquake recurrence intervals, periods of the order of tens of thousands of years (e.g. Upper Pleistocene–Holocene, i.e. the present) may be appropriate for the assessment of capable faults. In less active areas, it is likely that much longer periods (e.g. Pliocene–Quaternary, i.e. the present) are appropriate.

(b) If a structural relationship with a known capable fault has been demonstrated such that movement of the one fault may cause movement of the other at or near the surface.

(c) If the maximum potential magnitude associated with a seismogenic structure [...] is sufficiently large and at such a depth that it is reasonable to conclude that, in the current tectonic setting of the plant, movement at or near the surface may occur.”

(IAEA, 2010, SSG 9, p. 30)

**Capable fault:** The fault must be acknowledged as dangerous under the aspect of a surface breaking fault if according to geological, geophysical, geodetic and seismological data, one or more of the following conditions applies:

(a) Data indicate a recurring nature of movements, significant deformations or dislocations, or all of the three, within such a period of time that does not allow to exclude that the next displacement of a fault terminates at the surface or close to the surface.

(b) there is a structural connection with a dangerous fault line causing a known surface displacement, the movement of which can cause movement of the fault line in the vicinity of the site.

(c) Based on the seismogenic structure, it can be assumed that the maximum possible earthquake is large enough and has such a focal depth that it is reasonable to infer that, in the geodynamic setting of the site, movement at or near the surface could occur.

(HUNGARIAN GOVERNMENTAL DECREE No. 118 of 2011 (VII.11.), 7.3.1.0900)

**Capable fault:** […] “fault capability”; ground displacement or surface rupture at or near the site surface due to co-seismic movements at a fault.”

(WENRA, 2016, p. 6)
7.2 Consequences of identifying active or capable faults

**Active fault:** “3. MAIN CRITERIA AND REQUIREMENTS TO SAFE NUCLEAR POWER PLANT SITING” 3.1. It is not allowed to locate nuclear power plants:

- on the sites directly situated on active faults;
- on the sites whose seismicity is characterized by the maximum credible earthquake (MCE) intensity of more than 9 on Medvedev-Shponhoyer-Karnika seismic intensity scale (MSK-64);
- on the territory within the limits of which the location of a nuclear power plant is prohibited by the nature conservation-related legislation.”

(GOSATOMNADZOR OF RUSSIA, 2002, NP-032-01)

**Capable fault:** “If the potential of occurrence of a permanent surface displacement on the site cannot be reliably excluded by scientific evidences, and the displacement may affect the nuclear facility, the site shall be qualified as unsuitable.”

(HUNGARIAN GOVERNMENTAL DECREE No. 118 of 2011 (VII.11.), 7.3.1.1100)

**Capable fault:** “Capable fault issues for new sites 8.8. Where reliable evidence shows that there may be a capable fault with the potential to affect the safety of a plant at a site, the feasibility of design, construction and safe operation of a plant at this site should be re-evaluated and, if necessary, an alternative site should be considered.”

(IAEA, 2010, SSG 9, p. 31)

**Capable fault:** “5.4. A proposed new site shall be considered unsuitable when reliable evidence shows the existence of a capable fault that has the potential to affect the safety of the nuclear installation and which cannot be compensated for by means of a combination of measures for site protection and design features of the nuclear installation. If a capable fault is identified in the vicinity of an existing nuclear installation, the site shall be deemed unsuitable if the safety of the nuclear installation cannot be demonstrated.”

(IAEA, 2019, Site Evaluation for Nuclear Installations, SSR-1, p. 18)

**Capable fault:** “3.7. Where reliable evidence shows the existence of a capable fault that has the potential to affect the safety of the nuclear installation, an alternative site shall be considered.”

(IAEA, 2016, NS-R-3 Rev. 1)

**Capable fault:** “3.7. Where reliable evidence shows the existence of a capable fault that has the potential to affect the safety of the nuclear installation, an alternative site shall be considered.”

(IAEA, 2015, SSR-35 citing IAEA, 2016, NS-R-3)

“EXAMPLES OF SCREENING VALUES - Distance from capable fault - 8.0 km [II–3] - Exclusion criterion”

(IAEA, 2015, SSG-35 citing IAEA, 2016, NS-R-3, p. 59)
7.3 Investigations suggested by international standards and guidelines

Detailed descriptions of the necessary database and the assessment of capable faults:

“DATABASE RELATING TO FAULT DISPLACEMENT”

“A.10. A fault displacement hazard arises when an earthquake event on a fault close to or beneath safety related structures of a nuclear installation causes displacement to occur that may directly affect the safety of the installation. This hazard is also referred to as a capable fault hazard. A clear definition of a capable fault is given in SSG-9 together with a listing of recommended site investigations in relation to potential capable faults [6].”

“Site survey stage”

“A.11. Capable faults should be thoroughly investigated by integrating geomorphological, geological, geodetic and geophysical methods to make clear the locations, shapes, activity and characteristics of the capable faults, while also considering their distance from the proposed site. At this stage, the available site specific data may not be sufficient but a literature survey relating to the suspect features would be a reasonable source of information.”

“Site selection stage”

“2A.12. An in-depth investigation should be made of the capable faults within the area of the site vicinity (5 km radius) that combines the survey of existing reference materials, tectonic geomorphological investigation, investigation of surface geological features, and geophysical and other investigations.”

IAEA (2015, SSG-35, p. 35)

Detailed descriptions of the most recent paleoseismological methods for the assessment of capable faults:

“8.5. Sufficient surface and subsurface related data should be obtained from the investigations in the region, near region, site vicinity and site area [...] to show the absence of faulting at or near the site, or, if faults are present, to describe the direction, extent, history and rate of movements on these faults as well as the age of the most recent movement.

8.6. When faulting is known or suspected to be present, site vicinity scale investigations should be made that include very detailed geological and geomorphological mapping, topographical analyses, geophysical surveys (including geodesy, if necessary), trenching, boreholes, age dating of sediments or faulted rock, local seismological investigations and any other appropriate techniques to ascertain the amount and age of previous displacements.
8.7. Consideration should be given to the possibility that faults that have not demonstrated recent near surface movement may be reactivated by reservoir loading, fluid injection, fluid withdrawal or other such phenomena.”

(IAEA, 2010, SSG 9, pp. 30–31)
8 TRANSLATED REPORTS AND DOCUMENTS

8.1 Geological Site Report (Földtani Kutatási Program FKP)


Available translations: pp. 20–31, 43–48, 58–69, 76–77, 103–106 (German)


Available translations: pp. 4–21, 26–39 (German)


Available translations: pp. 4–52 (German; complete)


Available translations: pp. 325-326, 341–342; 422–423; 445–450; 467–475, 492–494; 694–714 (German)

8.2 Site Safety Report (Telephely Biztonsági Jelentés TBJ)


Available translations: pp. 1–2, 33, 49, 51, 58–69 (German)


Available translations: pp. 19, 25 (German)
8.3 Site License


*Available translations: pp. 1–4 (German; complete document)*


*Available translations: pp. 1–32 (German; complete document)*
9 REFERENCES


DECKER, K., & HINTERSBERGER, E. 2019. Definitions of the Terms “Active” and “Capable Fault”. Informal report to BMNT and UBA, Vienna, Spp., 08.10.2019


IAEA, 2019. Site Evaluation for Nuclear Installations, Specific Safety Requirements No. SSR-1, 56pp., Vienna.


MÓNUS, P. et al., 2016. Szeizmotektonikai modell: Paleo/Speleo-szeizmológiai vizsgálatok a Paksi Atomerömü telephely tágabb környezetében (“Standortbericht”, DVD 2)


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