Iluminacija dubinskog kartiranja

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Pregledni rad / Review paper

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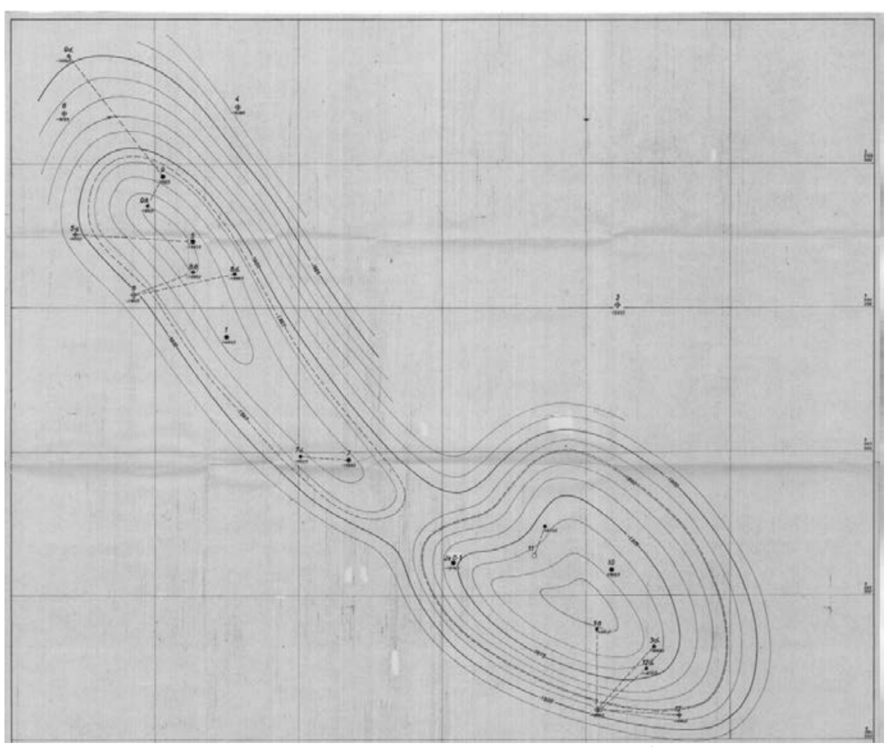
Ključne riječi : dubinsko kartiranje, dubinske strukturne karte, spektralna dekompozicija, Wheelerovi dijagrami.

Prošireni sažetak

Kako najbolje prikazati geološki razvoj i geološku građu podzemlja? Dubinske strukturne karte su svakako najbolje rješenje. Dubinske strukturne karte prikazuju geometriju geoloških jedinica u podzemlju. Izrađuju se na temelju bušotinskih i/ili seizmičkih podataka ili bilo koji drugih podataka koji svojom distribucijom na nekom području mogu prikazati geološku jedinicu. Strukturne karte su dvodimenzionalne dok se treća dimenzija predočava izolinijama čije vrijednosti ukazuju na dubinu zalijeganja geološke jedinice. Prema tome, autor ili korisnik takvih karata mora vizualizirati kartu. Sadržaj karata nekada je bio prilično siromašan i također se prikazivao izolinijama ili šrafurama. Kombinacija izolinija ili šrafura ponekad je unosila konfuziju čime se gubio dio sadržaja.



Slika 1: *Strukturna dubinska karta ležišta naftnog polja Ježevo iz 1984. godine (Naftno-plinsko polje Ježevo: Elaborat o rezervama nafte i plina (stanje 31. 12. 1984.))*

Samo za ilustraciju, geometrija jednog ležišta na polju Ježevo iz 1986. godine (**Slika 1**) prikazane dubinskom strukturnom kartom izrađenom na temelju bušotinskih podataka i nešto 2D seizmičkih profila je samo na izgled slična u odnosu na onu iz 2014 (**Slika 2**). godine. Tehnologija 3D seizmike olakšala je interpretaciju i definiranje strukturnih odnosa u podzemlju. Preciznost geometrije i dubine zalijeganja je element promijene

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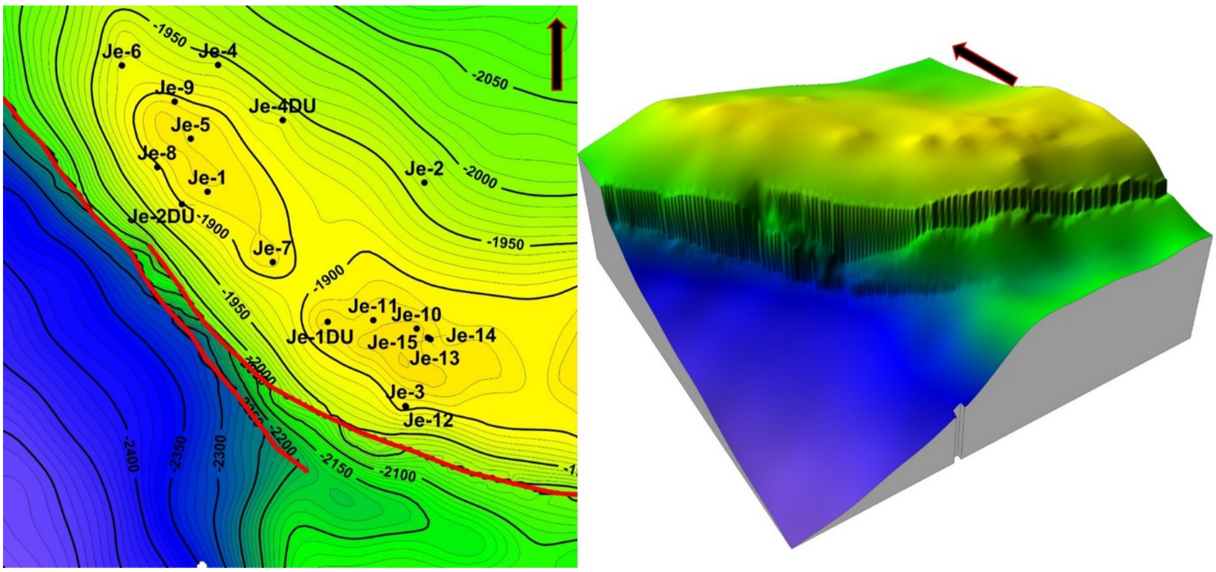
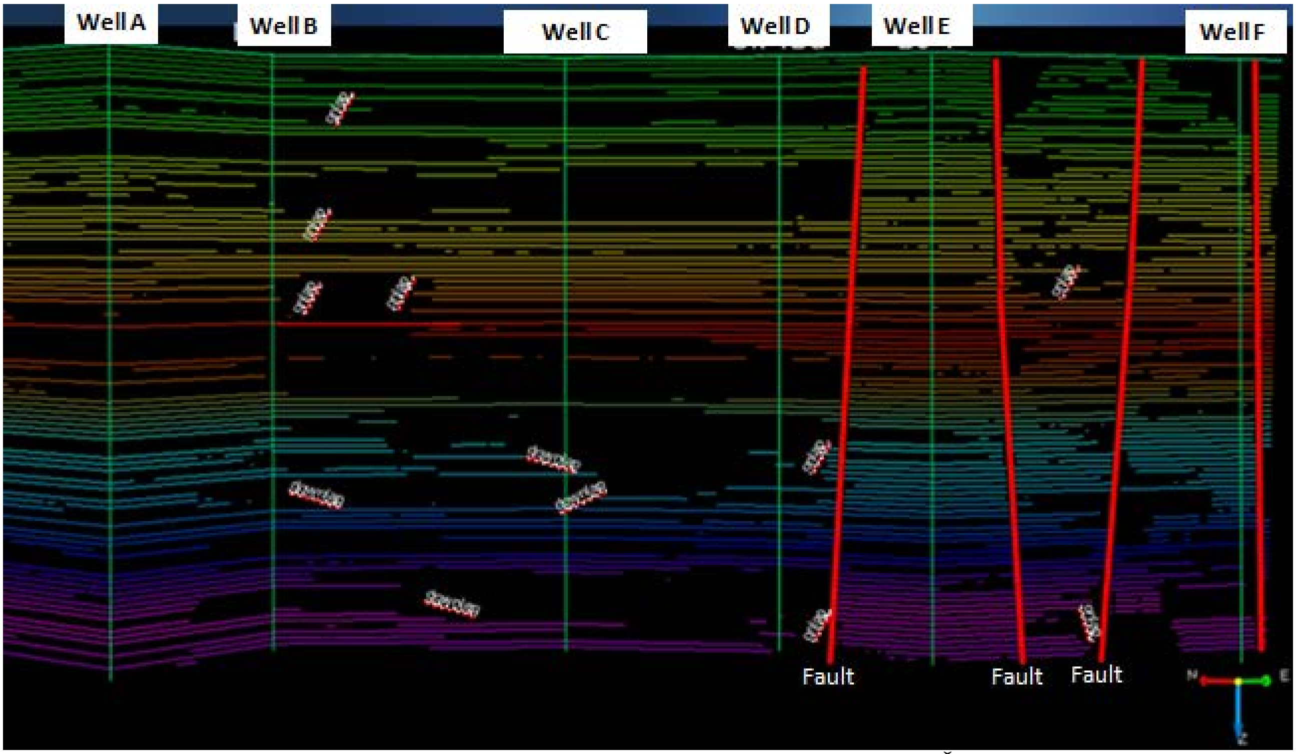
koju donosi tehnološki razvoj. Sadržaj geološke jedinice pokušao se prikazivati različitim tipovima karata: kartama ukupnih debljina, kartama efektivnih debljina, litofacijesnim kartama koje prikazuju odnose pješčenjak/lapor koje su načelno govorile o distribuciji pješčenjaka u prostoru i to samo na temelju bušotinskih podataka.



Slika 2: *Strukturna dubinska karta i trodimenzionalni prikaz ležišta naftnog polja Ježevo iz 2014. godine*

No, razvoj računalne tehnologije omogućio je vizualno prikazivanje treće dimenzije. 3D tehnologija je omogućila da se preko analize seizmičkih atributa, preko 3 osnovna parametra (amplituda, faza, frekvencija) analiziraju detaljnije geološki događaji, formacije, razlikujući taložne događaje (pijesak-lapor) pa čak i posredno, petrofizikalna svojstva. Analitika seizmičkih podataka u frekvencijskom spektru ili domeni donosi potpuno novo svijetlo na geološke teksture u podzemlju. Razbijajući seizmički signal u frekvencijskoj domeni na tri dijela pridružujući im odgovarajuću boju (niske frekvencije-crvena, srednje frekvencije-zelena, visoke frekvencije-plava) dolazi se do spektralne dekompozicije kao posebnog seizmičkog atributa koji u detaljnije prikazuje arhitekturu taložnog sustava. A kako stijene u podzemlju reagiraju na zvučne valove i proizvode određene valne duljine, ona prikazuje i odnose debljina različitih facijesa. Osim toga, odzivi reflektora visokih frekvencija mogu se smanjiti zbog prisutnosti kompresibilnih tekućina te tako spektralna dekompozicija može pomoći i u izravnom otkrivanju ugljikovodika (Castagna et al., 2003; Welsh et al., 2008). Analiza spektralne dekompozicije omogućuje istraživaču kvantificiranje varijacije amplituda i frekvencija, a samim time i uvid u sedimentološke procese, sustave rasjeda i pukotina te ugljikovodike (Hall, M. et al., 2004; de Groot, P., 2012). Primjenjuje se pomoću algoritma brze Fourier-ove transformacije. Fourier-ova analiza pretvara signal iz svoje izvorne domene na prikaz u frekvencijskoj domeni i obrnuto (Van Loan, 1992).

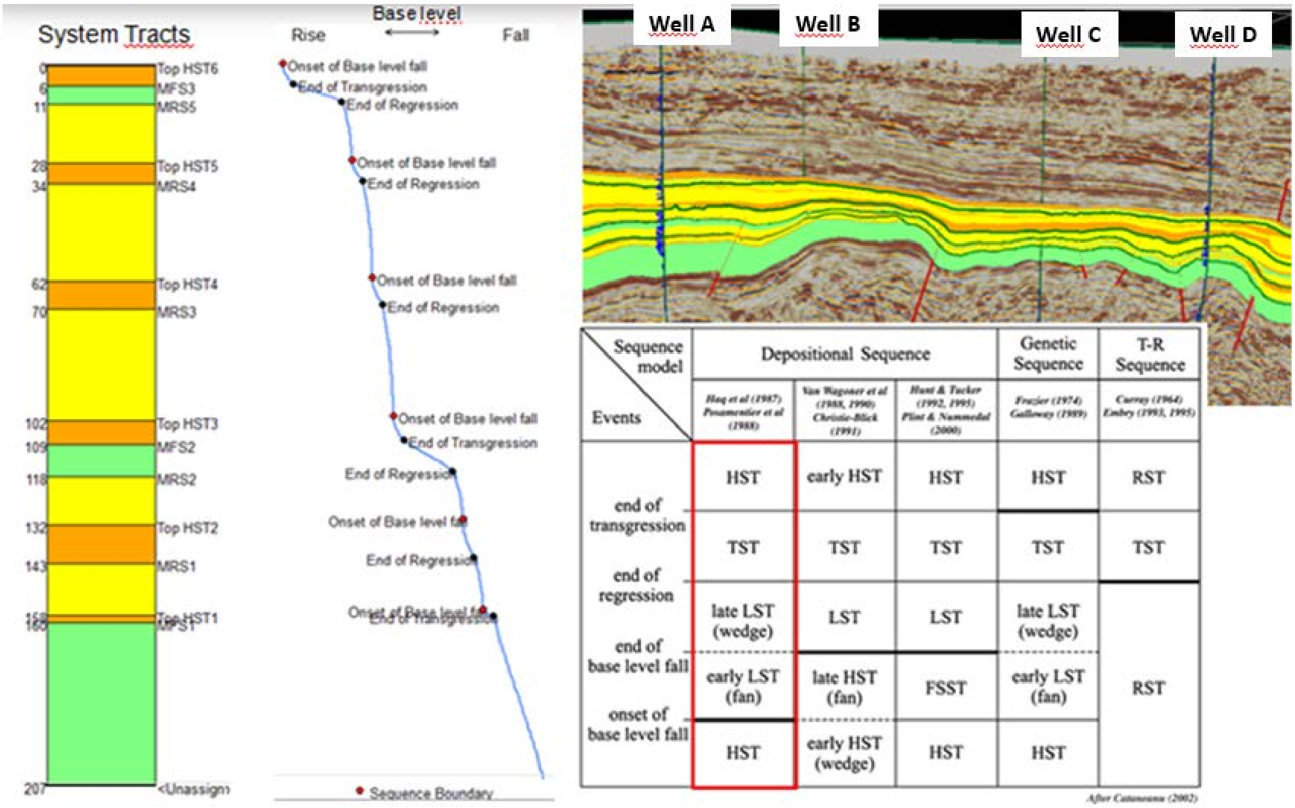
Preko spektralne dekompozicije uočavaju se kompletni taložni sustavi sa svim svojim elementima kao što su hranidbeni kanali, distribucijski kanali, lobovi, poplavna područja te kanalski nasipi. U kombinaciji s Wheeler-ovim dijagramima (**Slika 3**) otkrivaju se i sistemski traktovi koji tvore taložne cikluse na nekom području u određenom vremenu (Qayyum, F., 2015).



Slika 3: *1D Wheelerov dijagram preko područja naftno-plinskih polja Ježevo, Ivanić, Žutica i Okoli do Stružeca*

Metodom izrade Wheeler-ovih dijagrama prema izračunatom matematičkom seizmičkom atributu *Dip Steered Median Filter* (Qayyum, F., 2012) odnosno prema seizmičkim profilima, jednako u dvodimenzionalnoj ali i trodimenzionalnoj formi mogu se kartirati i određivati seizmostratigrafske sekvencije i parasekvencije (HST, TST, LST itd.). Wheeler-ovi dijagrami su prostorno-vremenski dijagrami koji prikazuju prostornu raspodjelu sedimentnih facijesa kroz vrijeme u dvodimenzionalnoj shemi (Qayyum, F. et al., 2014). Trodimenzionalni seizmički podatci omogućuju izradu trodimenzionalnih Wheeler-ovih dijagrama, ali su oni rijetki zbog poteškoća u njihovoj izradi (Cheney, E., 1987). Prema Wheelerovim dijagramima mogu se određivati trodimenzionalno seizmički završetci (*onlap*, *downlap*, *toplap*), a naposlijetku i jako dobro stratigrafske zamke isklinjenja. Ovakvim pristupom olakšana je prepoznatljivost postajanja statigrafskih zamki ugljikovodika, njihovog prostornog ograničenja što u konačnici smanjuje geološki rizik. Izrada ovakvih dijagrama dovodi i do facijesne korelacije bušotina, koja za razliku od klasične litostratigrafske korelacije prikazuje prostorni raspored korelativnih sedimentoloških tijela kao što su sustavi distalnih i proksimalnih lobova, zasebni lobovi, turbiditni kanali i slično. Prema Wheelerovim dijagramima i određenim seizmostratigrafskim sekvencijama i parasekvencijama može se odrediti i izraditi krivulja kolebanja razine mora (u ovom slučaju jezera zbog našeg karakterističnog Panonskog bazenskog sustava - **Slika 4**).

Svim ovim procesima te njihovom kalibracijom sa postojećim bušotinskim podatcima iluminacija podzemlja je potpuna te metode dubinskog kartiranja poprimaju sasvim drugačiji karakter i otkrivaju detalje nezamislive i vremenima djelovanja pok. Velimira Kranjeca.



Slika 4: *Sistemski traktovi i krivulja kolebanja razine jezera na području od Ježeva, Ivanića preko Žutice do Okola*

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Illuminations of the subsurface mapping

Keywords: subsurface mapping, structural maps, spectral decomposition, Wheeler diagrams.

Extended abstract

How to show geology and geological structures underground? Depth structural maps are certainly the best solution. Depth structural maps show the geometry of the geological unit in the underground. They are made on the basis of borehole and seismic data and/or any other data that can clearly show the geological unit with its distribution and quantity in some area. Structural maps are two-dimensional, while the third dimension is represented by the contours whose values indicate the depth of the respective geological unit. Therefore, the author or user of such maps must visualize maps. The contents of the maps were quite poor and they were also displayed with contours or shading and hatching. This combination sometimes brought confusion and inevitably loss of the content.

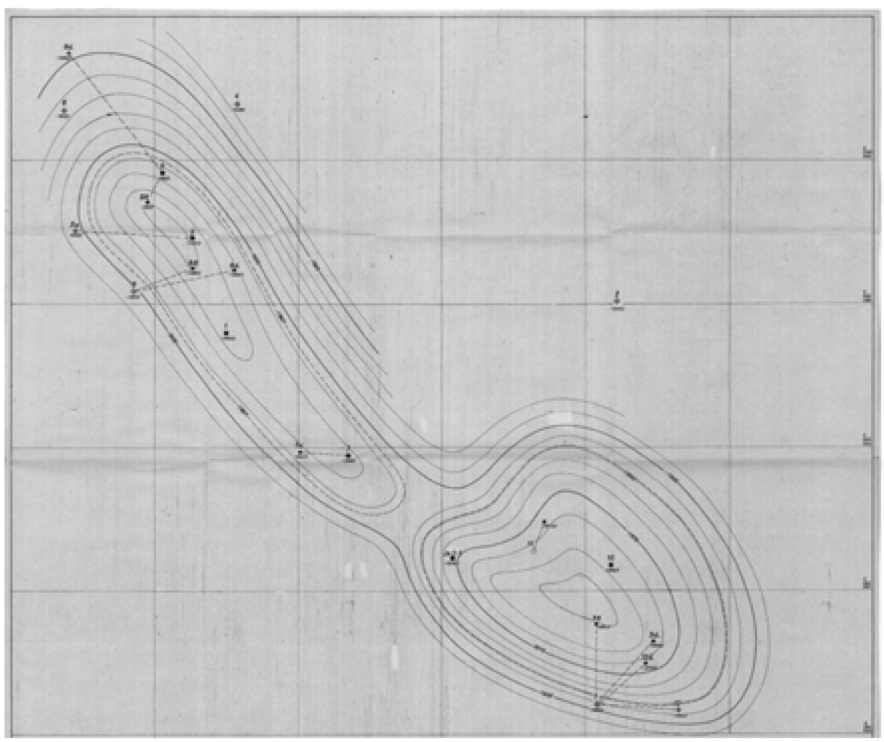

Figure 1: *Depth structural map of oilfield Ježevo from 1984 year (Oil and gas field Ježevo: Elaborate on oil and gas reserves (31. 12. 1984.))*

For illustration purposes only, the geometry of a single reservoir on the 1984 map of Ježevo oilfield (**Figure 1**) on depth structural map made on the basis of the drilling data and some 2D seismic profiles is only similar to that from 2014 (**Figure 2**). 3D seismic technology improved the interpretation and definition of structural relationships in the underworld. The precision of geometry and the depth of burial are elements of the change brought by technological development. The content of the geological units tried to be illustrated by different types of maps: total thickness maps, effective thickness maps, lithofacies maps showing the sandstone/marl relations whose primary task was distribution of sandstones in the area, but only on the basis of the borehole data. Further, in the environment, it was at the level of speculations and assumptions.

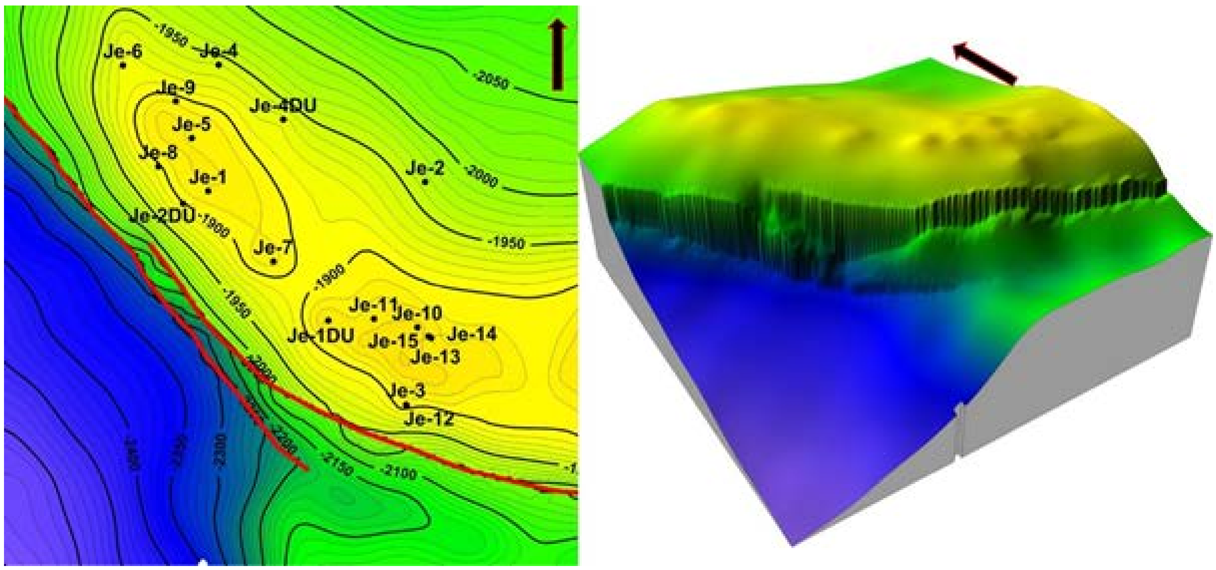

Figure 2: *Depth structural map and three-dimensional display of one of the reservoir from oilfield Ježevo in the 2014*

But the development of technology, has made it possible to visualize the third dimension. At the beginning, 3D technology has enabled the analysis of seismic attributes on all 3 basic attributes (amplitude, phase and frequency) to illustrate various geological events, formations, depositional events (sand-marl) and even indirectly, petrophysical properties. The analysis of seismic data in the frequency spectrum or domain brings a whole new insights to the geological texture in the underground. Spectral decomposition unravels the seismic signal into its constituent frequencies and this allows the interpreter to see amplitude and phase tuned to specific wavelengths (Hall, M. et al.; 2004). And how rocks in the underground react to sound waves and produce certain wavelengths, it also displays relative thickness of different facies. In addition, since the high-frequency response of a reflector can be attenuated by the presence of compressible fluids, spectral decomposition can also assist in the direct detection of hydrocarbons (Castagna et al. 2003; Welsh et al., 2008). Spectral decomposition analysis allows the explorationist to quantify amplitude variation with frequency, and thereby gain insight into the distribution of stratigraphic entities, faults and fractures, and/or hydrocarbons (Hall, M. et al., 2004; de Groot, P., 2012). It is implemented through the algorithm of Fast Fourier Transform. Fourier analysis converts a signal from its original domain (often time or space) to a representation in the frequency domain and vice versa (Van Loan, 1992).

These technological achievements fully expose underground by providing the interpreter with spectacular views of very complex geology. Complete sediment systems can be seen with all its elements such as feeder channels, distribution channels, lobes, floodplains and levees. Combined with Wheeler Diagrams (**Figure 3**) systemic tracts that form sedimentary cycles in some area at a given time can also be detected (Qayyum, F., 2015).

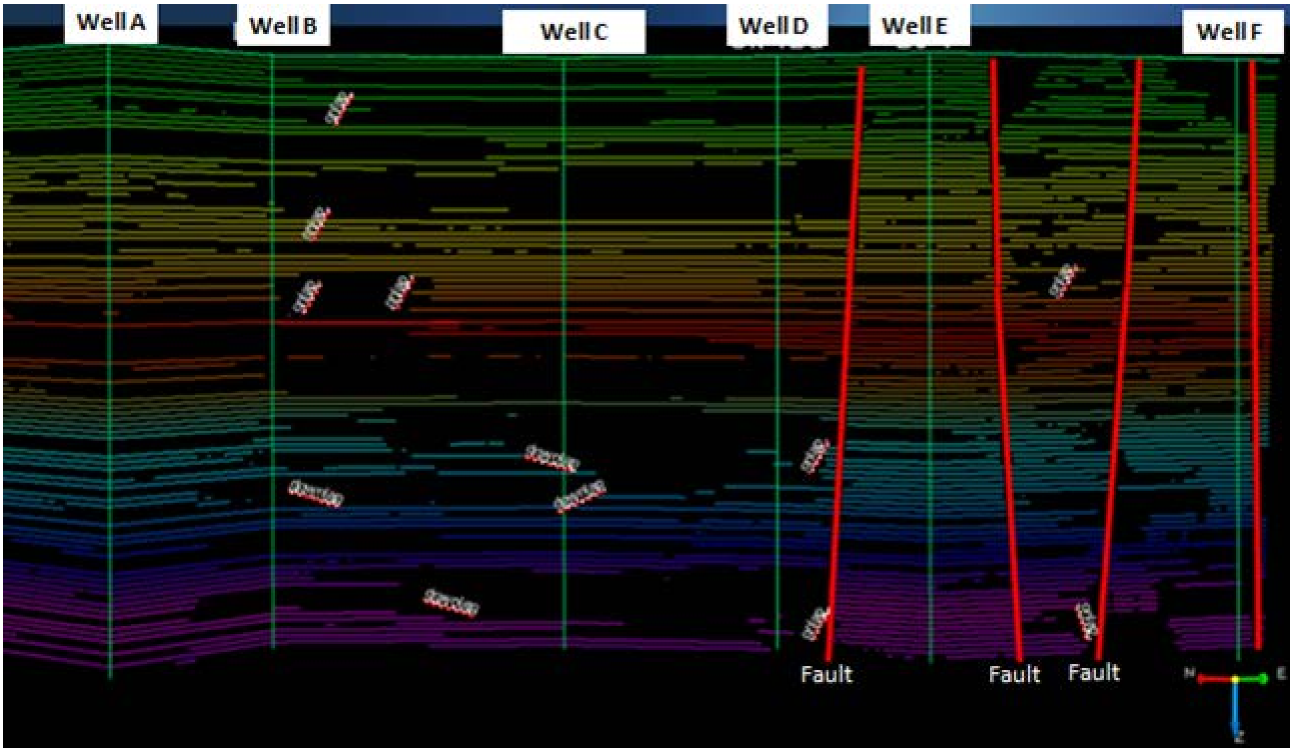

Figure 3: *1D Wheeler diagram across oil and gas fields Ježevo, Ivanič, Žutica, Okoli and Stružec*

By compiling Wheeler's diagrams according to the calculated mathematical seismic attribute Dip Steered Median Filter (Qayyum, F., 2012) on reflection seismic profiles, equally in two-dimensional and three-dimensional form, seismostratigraphic sequences and parasequences can be mapped and determined (HST, TST, LST, etc.). The Wheeler diagram is a spatio-temporal plot, showing the (usually one dimensional) spatial distribution of sedimentary facies through time in a two dimensional chart (Qayyum, F. et al., 2014). Three-dimensional seismic data allows the construction of three-dimensional Wheeler diagrams, but these are rare because of the difficulty of producing them. According to Wheeler's diagrams, three-dimensional seismic terminations such as onlaps, dowlaps, toplaps can be determined which leads to very good mapping and visualization of stratigraphic traps. This approach facilitates the recognition of stratigraphic hydrocarbon traps and their spatial limitation, which ultimately leads to reduction of geological risk. The development of such diagrams leads to the well facies correlation, which, unlike the classical litostratigraphic correlation, shows the spatial distribution of correlative sedimentological features such as distal and proximal lobe systems, separate lobes, turbidic channels and similar. According to Wheeler diagrams and determined seismostratigraphic sequences and parasequences, the sea level fluctuation curve can be determined (in this case, the lake level fluctuation curve due to characteristics of Pannonian basin system - **Figure 4**).

With all these processes and with calibration of existing borehole data underground illumination is more completed. Methods of subsurface mapping today take on a completely different character and they reveal much more details that were probably unimaginable during the working period of the late professor Velimir Kranjec.

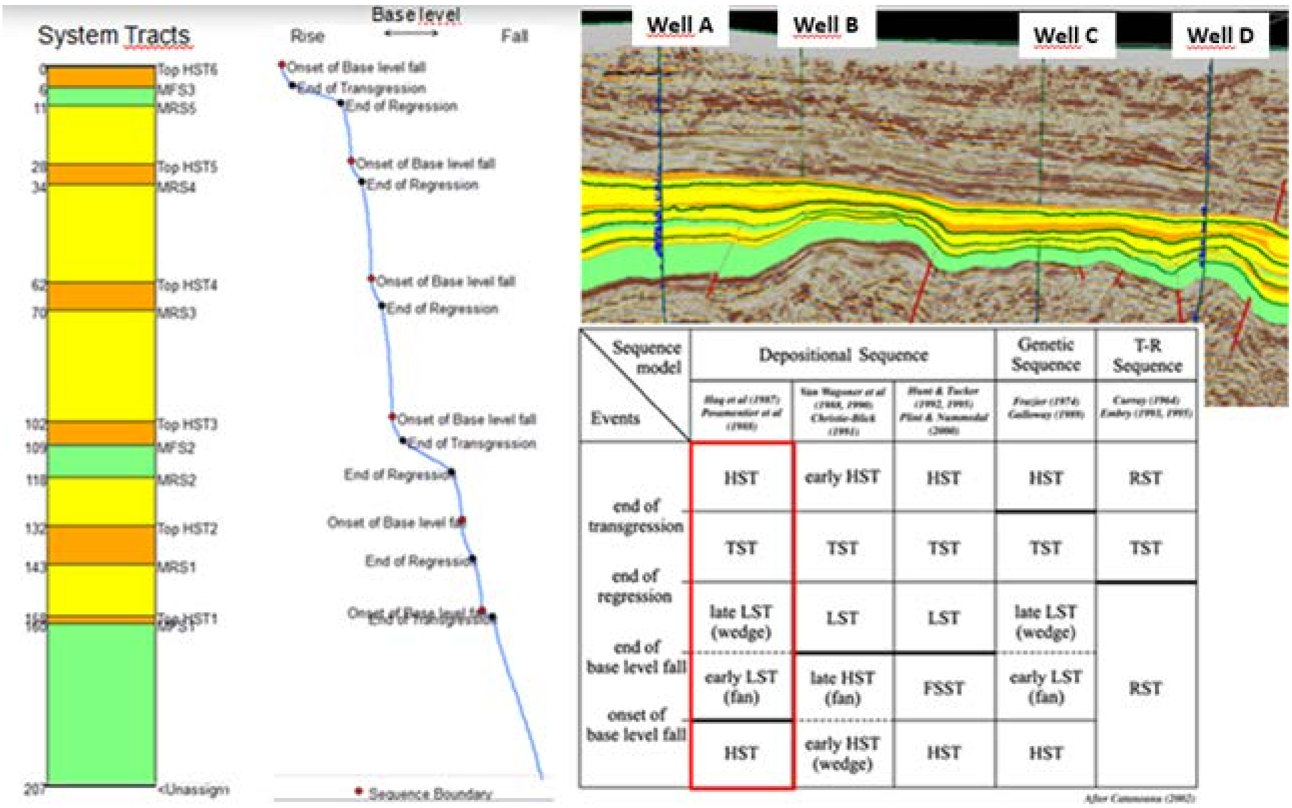

Figure 4: *System tracts i lake level fluctuation curve on area from Ježevo, Ivanić towards Žutica to Okoli*

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