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Application of Artificial Neural Networks on Well Log Data for Lithofacies Mapping of Pliocene, Pleistocene and Holocene

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SUMMARY

Successful artificial neural network analyses of the lithology data – prediction of either sandstones or shale were obtained. These were performed in the youngest (Pliocene, Pleistocene and Holocene) sediments in Sava Depression, Croatian part of the Pannonian Basin, and the input data was based on well log curves (spontaneous potential, shallow and deep resistivity curves). These analyses were successfully preformed in 20 wells of which in two, the training and validation of the networks was made. Such obtained lithology data was used for the construction of lithofacies maps which clearly show the distribution of the overall thickness of sandstone bodies and their number. Palaeotransport directions and areas with thicker sandstone interval for possible gas accumulations can also be observed in the constructed maps. The main influx of sediment was from the NE trough a channel which coincides with recent structural low defined by the absence of Pliocene outcrops while the thickest sandstone intervals can be delimited to the SW part of the mapping area.

Introduction

An area with sufficient number of wells with available well log data was selected within the Croatian part of the Panonnina Basin, Sava Depression for testing the successfulness of preparing the data with artificial neural networks (ANN) for further lithofacies mapping (Figure 1a).

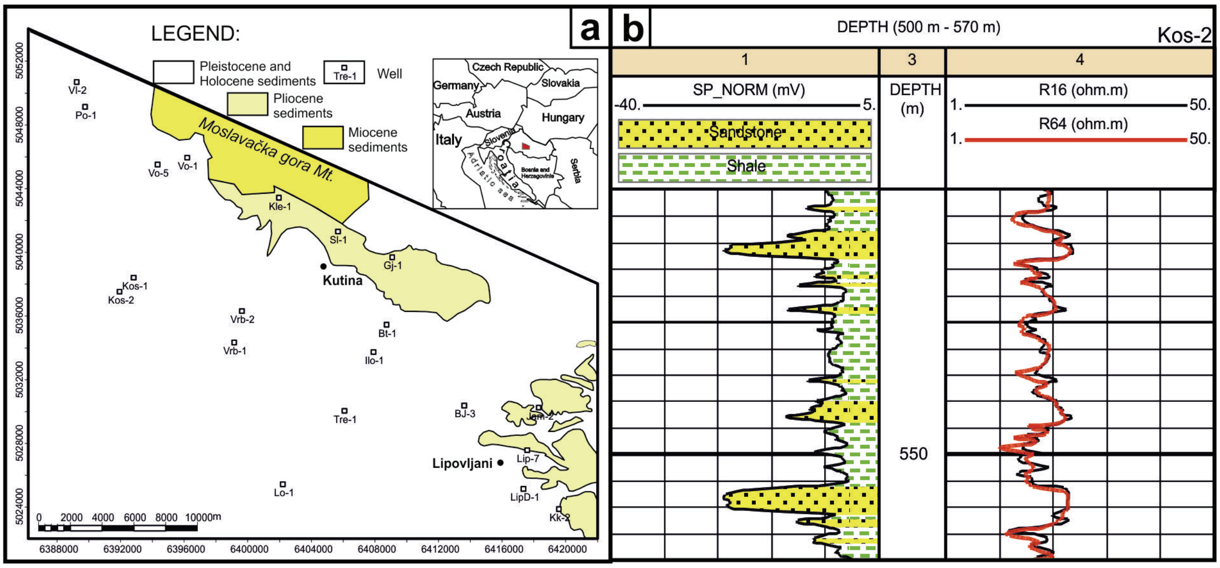

Figure 1 *Location map (**a**) showing the mapping area, position of wells and outcrops along with a well log interval (**b**) showing prediction of the lithology (sandstone/shale) with input curves normalised SP (SP_NORM), R16 and R64*

The youngest sedimentary formation (last 5.332 Ma) has been selected for this analysis because of the large number of available data and the lack of previous exploration which is due to the small number of gas accumulations within in it in contrast to older ones. However, the tectonic events active during Pliocene, Pleistocene and Holocene had a great influence on the formation of traps in older sediments. Regarding this, a detail lithofacies mapping showing the distribution of overall thicknesses, thickness of sand/sandstones, number sandstones layers and sandstone to shale ration in the formation could be helpful in further hydrocarbon explorations in older formations as for locating new plays in the youngest one.

Geological settings

Neogene and Quaternary sediments in Croatian part of the Pannonian Basin can generally be divided into three sedimentary megacycles (Lučić et al., 2001; Velić et al., 2002) the oldest, Lower to Middle Miocene, Upper Miocene and youngest Pliocene and Pleistocene and Holocene one. This division is based on the difference of depositional environments and the nature of tectonics during each megacycle. The youngest megacycle is comprised of a single Formation in the area of Sava Depression – Lonja Formation.

The Lonja Formation comprises of sandstones and shales in older intervals (Pliocene) and poorly consolidated or unconsolidated sands and clay in younger intervals (Pleistocene and Holocene) with sporadic occurrences of peat and lignite. Depositional environment is previously determined as lacustric in older parts with a transition into terestrial environment with marshes at the top of Pleistocene (Lučić et al., 2001; Hernitz et al., 1981). Thicknesses of this formation are variable and range from more than 1400 m in the central part of depression to pinching out on the margins of the depression. Base of the Lonja Formation (i.e. base of Pliocene) is an E-log marker α'.

Preparation of the input data with ANN for lithofacies mapping

Total of 20 wells with available conventional well logs (spontaneous potential (SP), shallow resistivity (R16) and deep resistivity (R64)) as basis for the lithology description of sediments as either sands/sandstone or clays/shale. In further text only sandstone or shale will be used as terms for simplification purposes. Normalisation of the SP curve should precede the ANN analyses. Otherwise, data prediction is limited to the well on which the ANN was trained (Cvetković et al., 2009).

Well	Data interval MD (m)	Well log resolution (m)	Number of cases
Vrb-1	269-1462.5	0.5	2388
LipD-1	220-1000	0.5	1561
			Σ=3949

Table 1 *Representation of data used for training and validation of ANN for further lithology prediction.*

Training and validation of the ANN was made using StatSoft STATISTICA 10. Data was selected from wells Vrb-1 and LipD-1 (Table 1), each located on either side of the selected area (Figure 1a) for minimizing the local influence in data trends. Out of 500 trained ANNs, 10 were selected and were used as an ensemble for lithology prediction on remaining 18 wells. ANN prediction successfulness can be observed in a well log interval shown in Figure 1b.

ANN prediction was successful in 16 of 18 wells, minor discrepancies were recorded in the shallow part of the Jam-2 well as a result of very high values of R16 and R64 curves which are outside the normal range of training data. Also, in the Bt-1 well lithology had to be determined manually. The change in lithology could clearly be observed on R16 and R64 curves but ANN could not distinguish sandstone from shale because of the low amplitude of SP curve values.

Data obtained from ANN analysis was prepared for lithofacies mapping in a way that all layers thinner than 0.5 m were disregarded and two sets of data were constructed. One representing the whole available well log interval and another representing data with 20% of cut off data from kelly bushing. The reason for the construction of 20% cut off data was the problem of some well logs starting far from kelly bushing, e.g., of the Kk-2 well starts at 200 m MD with base Pliocene determined at 1084 m MD which means that only 84.4% of the well log interval was available starting from base Pliocene. Thus, 20% cut off maps were constructed to avoid the influence of the absence of available logs in some wells in the top of the interval.

Lithofacies mapping

Sandstone thicknesses, number of sandstone layers and sandstone to shale ratio derived from ANN analysis were used to construct two component lithofacies maps (Krumbein, 1948). These include:

- total formation thickness map (h),
- sandstone thickness map (he),
- number of sandstone layers map (n) and
- sandstone to shale ratio map (ss/sh).

Maps were constructed in Schlumberger Petrel™ using "isochore interpolation" method and presented in Figure 2. The border between Miocene and Pliocene on the north of the mapping area was outlined with a polygon with a zero value to avoid possible positive values of thicknesses or number of sandstone layers derived from the extrapolation of data trough mapping algorithm.

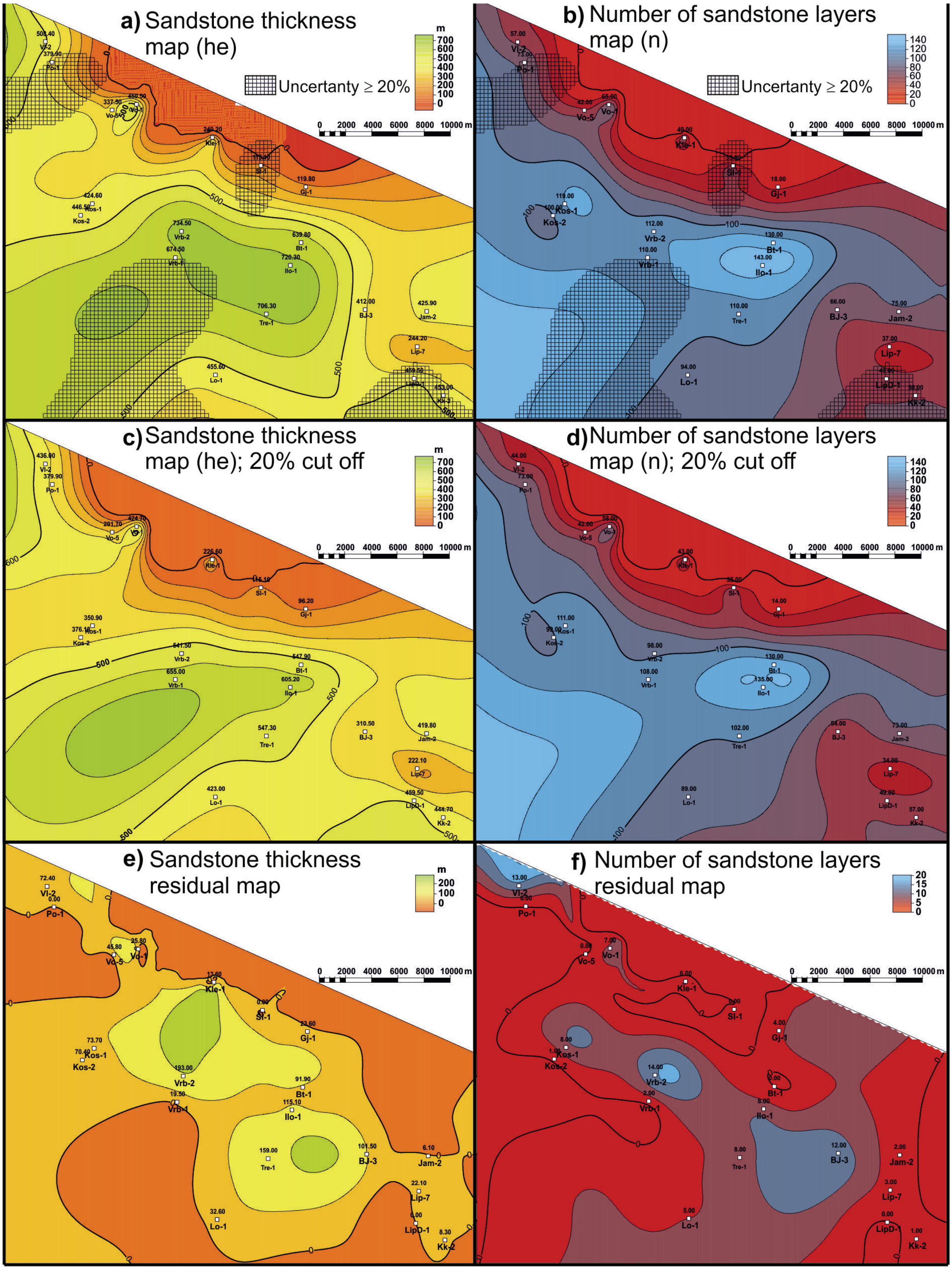

Figure 2 *Sets of lithofacies maps showing sandstone thicknesses maps (total (**a**), with 20% cut off (**c**) and residual map of the previous two (**e**)) and number of sandstone layers maps (total (**b**), with 20% cut off (**d**) and residual map of the previous two (**f**))*

Mayor differences between the whole and 20% cut off maps (Figures 2a and b Vs. Figures 2c and d) can be easily observed on the residual maps (Figures 2e and f) but the major trends in thicknesses and number of sandstone layers are generally the same. Higher uncertainty areas – ones with 80% or less well log available in the Lonja Formation are marked in Figures 2a and b.

Thickening of sandstone interval and trend of the increase of the number of sandstone layers can clearly be observed in lithofacies maps. This is showing the main possible influx of sediments from the NE, between Moslavačka gora Mt. and Slavonian Mts. (Papuk and Psunj) on the far NE (not shown in Figure 1 because of the scale).

Conclusions

The ANN can be used as a quick solution for lithology prediction over a relatively large geographical area in basins with clastic sedimentation, if that the input data are of the adequate quality. Obtained lithology data can later be easily applied for further analyses, like in this case lithofacies mapping.

Such mapping in the analysed area clearly depicted the influx of sediments from NE. The transport occurred in one main paleochanell and possibly several minor ones. The location of the main channels visible in Figures 2c and d coincide with structural low defined by the absence of recent Pliocene outcrops in Figure 1a.

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