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ScienceDirect

Energy Procedia 59 (2014) 28 – 35

Energy Procedia

European Geosciences Union General Assembly 2014, EGU 2014

New method of active electromagnetic induction and seismic monitoring in oil saturated media

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Abstract

It is provided a comparison of no equilibrium effects by independent hydro dynamical and electromagnetic induction influence on an oil layer and the medium, which it surrounds. It is known, that by drainage and steeps the hysteresis effect on curves of the relative phase permeability in dependence from porous medium water saturation by some cycles of influence: drainage-steep-drainage is observed. In earlier papers the analysis of the seism acoustic monitoring data in regimes of phone radiation, response on the first influence of given frequency and on the second influence is developed. For the analysis of seism acoustic response in time on fixed intervals along the borehole an algorithm of phase diagrams of the state of many phase medium is suggested. On the base of developed algorithm a new algorithm of analyze of space, but integral in time for equal observation periods changing by the method of phase diagram state of many phase medium in the oil layer is developed. The developed method allows on quality level to classify the state of the polyphase medium, which is the oil layer, using data of many cycles influence. In that paper we suggest the algorithm of modeling of 2-d seismic field distribution in the heterogeneous medium with hierarchic inclusions. Using the developed earlier 3-d method of induction electromagnetic frequency geometric monitoring we showed the opportunity of defining of physical and structural features of hierarchic oil layer structure and estimating of water saturating by crack inclusions. That allows managing the process of drainage and steeping by water displacement the oil out of the layer. Thus, the developed methods allow on the quality and quantity levels to make a classification of the many phase medium, which is an oil layer, using data for multiple excitation. For quantitative solution of earlier listed events of no equilibrium and hysteretic interaction of water and oil by out working of the oil layer, it is urgently to add and to further develop the system of seism acoustic and electromagnetic observations.

Peer-review under responsibility of the Austrian Academy of Sciences

Keywords: hierarchic medium; elastic, porous, two phase medium; seismic field; electromagnetic field; algorithms of modeling; method of mapping and monitoring.

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1876-6102
Peer-review under responsibility of the Austrian Academy of Sciences
doi:10.1016/j.egypro.2014.10.345

1. Introduction

The processes of oil gaseous deposits outworking are linked with moving of polyphase multicomponent media, which are characterized by no equilibrium and nonlinear rheological features. The real behavior of layered systems is defined as complicated rheology moving liquids and structural morphology of porous media [1]. It is urgently needed to account those factors for substantial description of the filtration processes. Additionally we must account also the synergetic effects. That allows suggesting new methods of control and managing of complicated natural systems, which can research these effects. Thus our research is directed to the layered system, from which we have to outwork oil and which is a complicated hierarchic dynamical system. By developing a mathematical model of a real object it is needed as a quality a priory information use the active and passive monitoring data, which are obtained during the well operation. The solution on inverse problems has a large significance for oil industry, because the oil layer covers to the set of natural systems, which cannot be straight as a whole investigated. Research of the last years showed that in the evolution of dynamical systems, to which covers the oil objects, significant role play the no stabilities, the nature of which searches the theory of self organization and synergetic. That information about their phenomenon we can only obtain using monitoring data, which are sensitive to the hierarchic structure [1]. Let us consider three sequential appeared processes, which lead to exceeding of ultrasoning processes by vibration influence on the layers [2]. First: transfer the weak harmonic oscillations of the bottom layer to the collector blocks. Second: appearance of blocks mikrooscillations in the fluid flow by a high pressure, which leads to pressure pulsations in the liquid and to the irregularity of the flow in cracks. Third: generation of resonant block elastic oscillations, which produce ultrasonic oscillations. Mechanism of transferring oscillations of the initial low frequency latitude wave consists in exciting the collector layer as a whole. Transfer of transverse oscillations by inclined wave falling on the layer and transfer the shear stresses depends on the material capacity, which supports the cracks between the blocks. Thus if the material is water, then the transverse oscillations do not go through the bottom layer into the oil layer. If the material in the crack is viscous, the shear oscillations will influence on the neighbor blocks and initiate microscopic horizontal displacements and rotations.

2. Algorithm of modeling

Let us consider an algorithm of sound diffraction on 2-D elastic heterogeneity with hierarchic structure, located in the j-th layer of n-layered medium [3,4]. If by transition on the next hierarchic level the axis of two-dimensionality does not change and only the geometry of the section of embedded structures change, then we can write the iteration process of modeling of the seismic field (case generation only longitudinal wave). The iteration process covers to modeling of the response of transition from the previous hierarchic level on the next level. Inside each hierarchic level the integral-differential equation and the integral-differential representation are calculated as it is written in [3-4].

$$\begin{aligned}
&\frac{(k_{1jil}^2 - k_{1j}^2)}{2\pi}\iint_{S_{Cl}} \varphi_l(M) G_{Sp,j}(M,M^0)\,d\tau_M + \frac{\sigma_{ja}}{\sigma_{jil}}\varphi_{l-1}^0(M^0) - \\
&-\frac{(\sigma_{ja}-\sigma_{jil})}{\sigma_{jil}2\pi}\oint_{Cl} G_{Sp,j}\frac{\partial \varphi_l}{\partial n}dc = \varphi_l(M^0) \quad by\, M^0 \in S_{Cl} \\
&\frac{\sigma_{jil}(k_{1jil}^2 - k_{1j}^2)}{\sigma(M^0)2\pi}\iint_{S_{Cl}} \varphi_l(M) G_{Sp,j}(M,M^0)\,d\tau_M + \varphi_{l-1}^0(M^0) - \\
&-\frac{(\sigma_{ja}-\sigma_{jil})}{\sigma(M^0)2\pi}\oint_{Cl} G_{Sp,j}\frac{\partial \varphi_l}{\partial n}dc = \varphi_l(M^0) \quad by\, M^0 \notin S_C
\end{aligned} \tag{1}$$

$G_{Spj}(M,M^0)$ - the source function of seismic field for involved problem, $k_{1jil}^2 = \omega^2(\sigma_{jil}/\lambda_{jil})$; - index ji signs the membership to the features of the medium into the heterogeneity, ja – out of the heterogeneity, λ - is a constant of Lameux, σ -the density of the medium, ω- the round frequency, $\vec{u}_i = grad\varphi_i$; i=1,…j, ji,…n, index l =1,…L-number of hierarchic level. If on a some hierarchic level the structure of the local heterogeneity divides on any heterogeneities, the integrals in the formula (1) are taken with account on all heterogeneities. In our algorithm we consider the case, when the physical features of heterogeneities are the same, only boundaries differ. Similarly to that case we can write the same process for modeling of elastic transversal wave distribution in the n-th layer medium with 2-d hierarchic structure of arbitrary morphology.

$$\frac{(k_{2jil}^2 - k_{2j}^2)}{2\pi}\iint_{S_{Cl}} u_{xl}(M)G_{Ss,j}(M,M^0)d\tau_M + \frac{\mu_{ja}}{\mu_{jil}}u_{x(l-1)}^0(M^0) + $$
$$+\frac{(\mu_{ja} - \mu_{jil})}{\mu_{jil}2\pi}\oint_{Cl} u_{xl}(M)\frac{\partial G_{Ss,j}}{\partial n}dc = u_{xl}(M^0) \quad by\, M^0 \in S_{Cl}$$
$$\frac{\mu_{jil}(k_{2jil}^2 - k_{2j}^2)}{\mu(M^0)2\pi}\iint_{S_{Cl}} u_{xl}M)G_{Ss,j}(M,M^0)d\tau_M + u_{x(l-1)}^0(M^0) + \qquad (2)$$
$$+\frac{(\mu_{ja} - \mu_{jil})}{\mu(M^0)2\pi}\oint_{Cl} u_{xl}(M)\frac{\partial G_{Ss,j}}{\partial n}dc = u_{xl}(M^0) \quad by\, M^0 \notin S_{Cl}$$

$G_{Ss,j}(M,M^0)$ - the source function of seismic field for involved problem, $k_{2jil}^2 = \omega^2(\sigma_{jil} / \mu_{jil})$; μ - is a constant of Lameux.

That algorithm for modeling of two types of seismic waves distribution in the matrix massive of the oil deposit and in the interblock space of the oil deposit can be used as an approximate for interpretation data of borehole seism-acoustic monitoring and it can to formulate the requirements to the system of monitoring data for organization a control influence on the oil layer.

2.1. Electromagnetic method for control the morphology of the disintegration zones in the holes

Now very often we are deal with a situation of solid oil deposits, where they are outworked in mines by mining technologies. Here we would to show the use of electromagnetic method for control the morphology of the zones of disintegration in the holes. By providing mining works in high stressed rock massif the man-made seismicity become evident, therefore the problem of its forecasting and prevention attracts much attention in all countries with developed mining industry. The near-term forecasting plays a significant role, but till now the developing of a method which allows to define quantitative criterions for the warning system is a large problem as in mining and in seismology [5]. Using the idea of physical mesomechanics, which includes the synergetic approach for analyzing the state changing of rock massif of different matter content, that problem can be solved by monitoring methods, which can research a medium with hierarchic structure. [6,7]. The medium changing, which lead to near-term precursors of dynamical events can be explained in a frame of a conception of self organized criticality [8,9], for which the main factors are heterogeneity and nonlinearity. In the frame of the Siberian Mining Institute a new direction of massive state research develops, which is named as nonlinear geomechanics [10]. But in our opinion we can achieve more success using together geomechanical and geophysical methods, which are based on a medium model as a model of a stratified block structure with hierarchic inclusions. More over if we are interested also in the evolution of that structure we are needed to use complex geophysical methods, which have sufficient resolution of revealing of the origin and decay of the self-organized structures [7]. For the first time by using the planshet electromagnetic method, which was elaborated in the Institute of geophysics UD RAS we could in the frame of natural investigations realize the idea of revealing of disintegration zones in the rock massif and organize the monitoring of their morphology [11-12]. That method covers to geophysical methods of non destroying control. It differs from other tomography methods by a system of observation and methods of processing and interpretation, which are based on the conception of three staged interpretation [13].

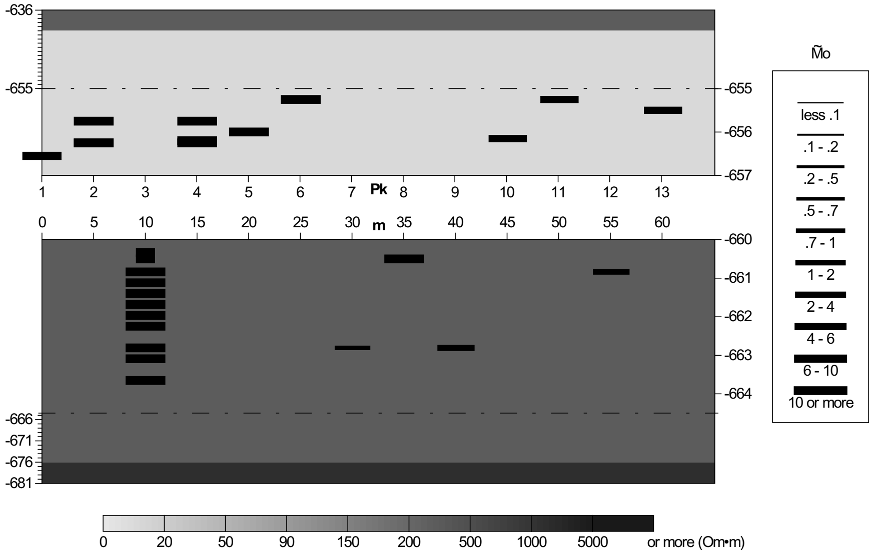

Fig. 1. Geoelectrical section along the profile, horizon -210,ort 3,frequency 5.08 kHz, Tashtagol iron mine, the 7th of August 2007.

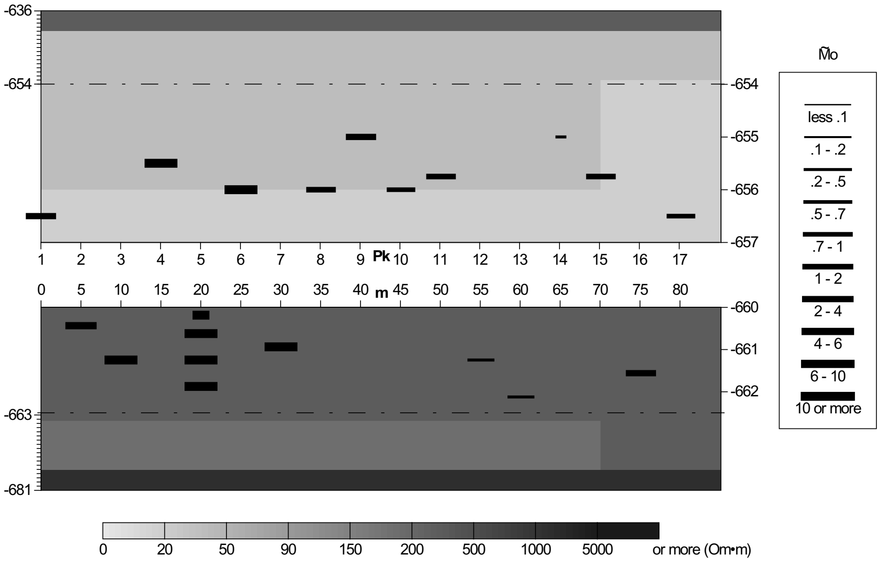

Fig. 2. Geoelectrical section along the profile, horizon -210, ort 4,frequency 10.16 kHz, Tashtagol iron mine, the 6th of August 2007.

In the paper [14] had been described the natural results, which had been achieved by revealing the self organization phenomenon in the rock massive by man-caused influence and the method of defining criterions of stability state on the base of our classification method. Those results had been received during some cycles of electromagnetic monitoring in the Tashtagol mine. The research had been provided on the depths 540-750 m for revealing the morphology of the disintegration zones in the around the hole area of the rock massive, which was influenced by intense natural and man-caused stress field. In the paper [15] we had described the results of using complex seismic and electromagnetic active and passive monitoring for forecasting destroying dynamical events before and after mass explosions. Additionally we shall analyze here the morphology of structure features of the disintegration zones before a powerful dynamical event with energy lg E=6.9. in the Tashtagol mine on the depth 683 m. (Figs. 1, 2) Before 3 days till the rock burst in the holes 3,4 in the geoelectrical sections of the hole ground sub vertical discrete structures occur, which are the combining of the disintegration zones. These structures occur in a resonance regime on different frequencies and only on one frequency for each hole. That phenomenon we observed in different mines. Occurring of such structures are precursors of powerful dynamical events. For defining the place and magnitude of the event we must have an information about the place in the classification table of stability of the massive volume.

2.2. Research of the oil layer by seism-acoustic method, processing and interpretation

In the Institute of geophysics UB RAS the method of active seism acoustic monitoring of the oil layer is developed and improved [16]. That method is used for the estimation of oil saturation and it's possibility to oil recovery. For crack-porous collectors, which are in the process of operation by the method of high liquid head water displacement of oil, the possibility of intensification of ultra sound oscillations can be of large technique importance. Even a very weak ultra sound can destroy during a long time action viscous oil films, which occur in cracks among the blocks, which can be a reason of layers permeability lowering and increasing extraction of oil [17]. For describing of these effects it is needed to consider the wave process in a hierarchic block medium and theoretically research the mechanism of self-oscillations origin by action of relaxation shear stresses [3]. In the papers [2] and [18] the algorithm of phase portrait or diagram construction using data of seismic- acoustic monitoring is considered. As a result of borehole monitoring we have three sets of intensity of seismic-acoustic radiation: phone $I(t,x)_f$, after the first excitation $I(t,x)_{V1}$ and after the second excitation $I(t,x)_{V2}$.

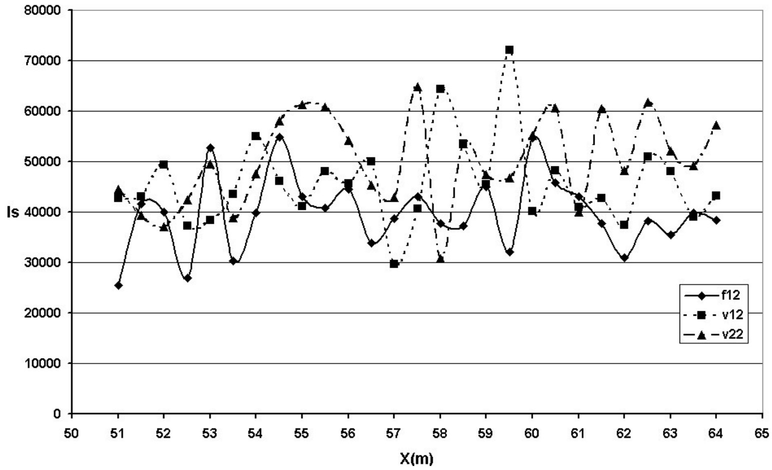

Fig. 3. Distribution of the integral in time intensity of seism acoustic response along the borehole. Symbols: f12-average in time intensity of the massif response of the oil layer before excitation, v12- average in time intensity of the massif response of the oil layer after the first cycle of excitation, v22- average in time intensity of the massif response of the oil layer after the second cycle of excitation. Is corresponds to average intensity (conventional unit), coordinate along the borehole: X=X(m)+2600 m.

These three functions for fixed z are observed on a time interval 14 seconds and with a frequency of discretization 44100Hz with a step along the borehole 0.5 m. The whole time interval we divide on 14 subintervals with a length 1 second. In our paper using the earlier developed algorithm we added a new algorithm of changing space, but integral in time for equal periods of observation. Thus we obtain a new parameter Is (in conventional units), which is calculated as an average in time value for the whole interval of observation along the borehole for all cycles of observation (two for phone data, and two for each observations after first and second excitations) (Fig. 3). Let us think that to the end of corresponding cycles of observation for all points of the oil layer a massif state mainly no equilibrium is formed. It is known that after the Darsi law the filtration velocity is proportional to the pressure gradient. By analogy let us research the distribution of space derivative of Is along the borehole (Fig. 4.). Let us divide for three cycles of observation intervals along the borehole, for which the module of Is is larger than 20000 conventional units.

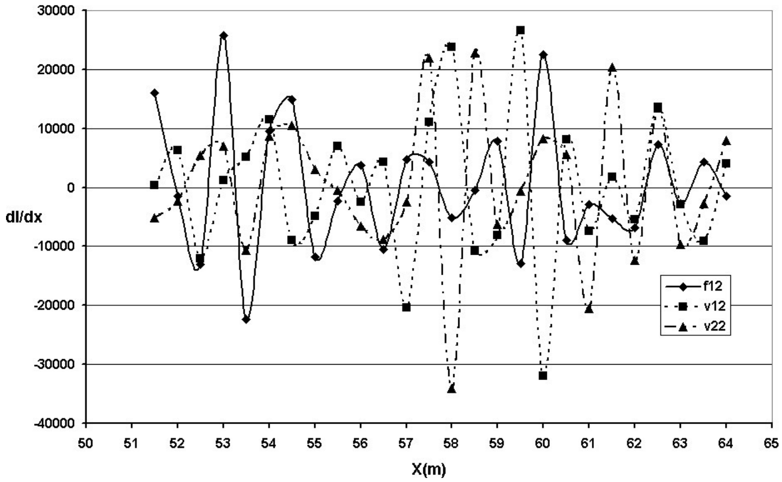

Fig. 4. Changing along the borehole of distribution of integral in time intensity of seism acoustic response. Symbols are the same as on the Fig. 3.

Table1. Intervals for anomaly values of space derivatives for integral in time intensity of the massif response for three cycles of observation along the borehole

X	A	B	C	D
F12	53	53.5	60	
V12	58	59.5	60	
V22	57.5	58	58.5	61

From analyze of the results (Fig. 5) it follows, that the increase of massif activization on a concrete divided interval by the value of the parameter dI/dt occurs if dI/dt >0, when dI/dt<0 the energy acivization decreases. That effect can be linked in the first case with increase of oil mobility and in the second case with the increase with water mobility. The same considered effect we can see on phase diagrams, but on other intervals after the first and second cycles of excitation (Fig. 6).

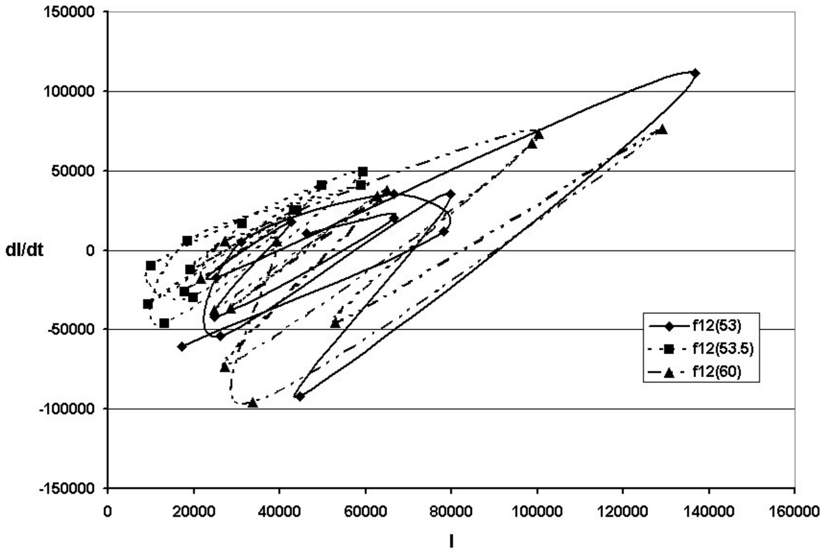

Fig. 5. Phase diagrams of oil layer massive state for the assigned intervals (Table1) of the borehole area before the excitation. Symbols: I-intensity of seism acoustic response as function of time for the period 14 sec. of observation (conventional unit), dI/dt-time derivative, by f12 in brackets are coordinates of the intervals along the borehole X+2600 (m).

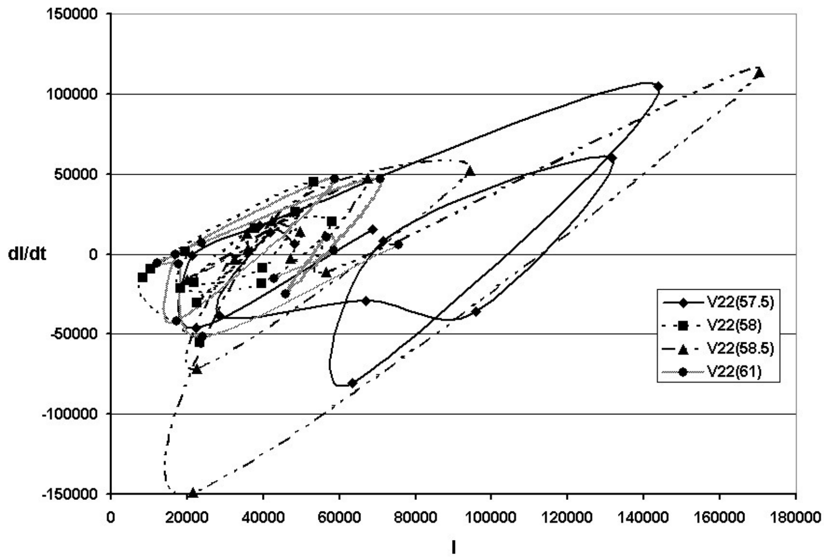

Fig. 6. Phase diagrams of oil layer massive state for the assigned intervals (Table 1) of the borehole area after the second excitation. Symbols are the same, as for the Figs. 3,5.

Thus, the developed methods allow on the quality and quantity levels to make a classification of the many phase medium, which is an oil layer, using data for multiple excitation. For quantitative solution of earlier listed events of no equilibrium and hysteretic interaction of water and oil by out working of the oil layer, it is urgently to add and to further develop the system of seism acoustic and electromagnetic observations.

3. Conclusions

The developed new algorithm for modeling of two types of seismic waves distribution in the matrix massive of the oil deposit and in the interblock space of the oil deposit can be used as an approximate construction for interpretation data of borehole seism-acoustic monitoring and it can to formulate the requirements to the system of monitoring data for organization a control influence on the oil layer. The developed electromagnetic and seismic methods allow on the quality and quantity levels to make a classification of the many phase medium, which is an oil layer, using data for multiple excitation. For quantitative solution of earlier listed events of no equilibrium and hysteretic interaction of water and oil by out working of the oil layer, it is urgently to add and to further develop the joined system of seism acoustic and electromagnetic observations.

Acknowledgements

That work was fulfilled according the Program of Presidium UB RAS 2012–2014.

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