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A Method for an Efficient Fast Track Evaluation and the Assessment of Re-engineering Potential of Mature Fields

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طريقة كفأة سريعة لتقييم إمكانية إعادة هندسة الحقول المعمّرة

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يواجه رفع كفاءة إنتاجية الحقول المعمرة تحديات عديدة منها مشاكل التآكل المتعلقة بالعلوم الجيولوجية وهي ذات أهمية قصوى.

طريقة ولفير التي طورتها شركة توتال لمواجهة الكثير من هذه المشاكل تستهدف توصيف سلوك المكمن والكشف عن مناطق الاستنزاف وتقترح سيناريوهات لإعادة هندسته.

تستخدم هذه الطريقة منظومة برمجة تم تطويرها محليا مبينة على تحليل بيانات إنتاجية أحادية ومتعددة التغير، أساسية، بالإضافة إلى بيانات عددية مكمنية وجيولوجية كما تشمل تكامل، إعادة كمية وكيفية لجميع البيانات الجيولوجية والإنتاجية، مع نتائج الحاسوب الإحصائية. لقد تم تلخيص تاريخ إنتاجية كل بئر على حدة بخصائص مختارة تسمى بمؤشرات الإنتاج، والتي تحسب وتخرط للمساحة الكلية للمكمن. وبهذه الطريقة تبدو إنتاجية أقسام وقطاعات الحقل المختلفة واضحة يمكن تفسيرها بمساعدة بيانات الموائع والمواد الساكنة.

تظهر غالبا معالم غير معروفة مثل انسداد الفجوات المنتجة (انسداد السطوح وتصدع الأروقة واختراقات محاور الماء والغاز... إلخ) وزيادة مساحات اتصالات المكمن العمودية والتوزيع المكاني للانسداد غير المتجانس، أو قطاعات الحقل ذات إنتاجية مختلفة. إن انتظام الإنتاج أو العكس في المدى الكبير لسلوك إنتاجية البئر على طول مساحة المكمن، يدل على درجة استمرارية الإنتاج التي تعكس مميزات المكمن. إن معرفة هذه المعلومات وتفسيرها تقود إلى تشخيص المكمن وإلى التكهن بدرجة كفاءة إنتاجية الآبار مستقبلا. كما تستعمل هذه النتائج فيما بعد لتحديد مواقع المساحات غير المنتجة. يمكن بعد ذلك اختبار فرضيات إعادة هندسة الحقل وحساب الإنتاج المتوقع، وقد تم اختبار عينات منتقاة لتوضيح هذه الأوجه، تتعلق الأولى بمكامن ذات ترسبات نهرية رملية تبين كيف تم تقسيم الحقل إلى مناطق مختلفة الجودة، أما الحقل الآخر المكون من ترسبات الدلتا الرملية متكررة عموديا والتي يمكن تقسيمها إلى مناطق واضحة مميزة بسلوك حركي، وتم على أساس هذه المعرفة اقتراح إعادة هندسة الحقول. وتتعلق الأخرى بطبقة كلسية تكونت فوق حفريات قديمة. أثبتت الحسابات التي أجريت بطريقة ولفير زيادة الاتصالات العمودية بالقرب من الجزء العلوي للمركب المتوافق مع الترسيب والتكوينات الصخرية وقادت هذه إلى اقتراح تطويرات إضافية للحفر أثبتت جدواها.

أظهرت الخبرة المكتسبة من بعض عشرات الحقول أن معظم الحقول يمكن معاملتها بطريقة ولفير ومنظومة البرمجة ويمكن معالجة الحقول ذات التاريخ الإنتاجي الطويل المكونة من عدة آبار (أكثر من 40 عاما ومن 500 بئراً) بالطريقة الموضحة في المثال الأول.

لقد اكتسبنا خبرة من مكامن ذات ترسبات بيئية وأنواع من التكوينات التركيبية وخصائص المواقع المختلفة، يمكن تطبيقها إيجابياً على حقول منتجة لمدة طويلة دون الحاجة إلى بيانات عديدة.

إن طريقة ولفير التي تمكن من الكشف على وجود الهيدروكربونات وبالتالي زيادة الاحتياطي القابل للاستخراج، تعتبر طريقة هامة لزيادة إنتاجية الحقول النفطية.

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Abstract: *Mature-fields production optimisation faces many challenges, among which geoscience-related problems are of paramount importance.*

The Welfare method developed by TOTAL addresses many of these problems, as it is aimed at characterising reservoir behaviour and detecting insufficiently drained areas, as well as proposing and testing of re-engineering scenarios.

The method uses an in-house developed software that is based on mono-variant and multi-variant statistical analyses of mainly production data, as well as geological, reservoir and fluids data. It includes an iterative integration of all, quantitative or qualitative, geoscience and production data with the statistical computation results.

Each well production history is summarised by selected characteristic values, called Production Indicators that are calculated and mapped all over the reservoir area. In this way, field compartments and sectors with different production characteristics clearly appear and are interpreted with the help of static and fluids data.

Previously unknown features often appear, such as production-impacting fractures (sealing surfaces, fracture corridors, axes of water or gas breakthroughs, etc.), areas with increased vertical reservoir connection, spatial distribution of impacting heterogeneity, or field sectors of different value. The uniformity, or to the contrary, a large variation range, of well production behaviours throughout the reservoir area indicates the degree of lateral continuity that characterises reservoir properties. The knowledge of this, and related interpretations, led to a reservoir diagnosis, and to a qualification of the degree of predictability of production behaviour of future infill wells. These results are subsequently used to determine the location of under-produced areas, and a new scenario of future field re-engineering can then be tested and future production calculated.

Selected examples illustrate these aspects. Variable field heterogeneity and linear trends impacting production are presented.

An example of fluvial-deposited silici-clastic reservoirs shows why the field had to be divided into separate areas for water injection. A second field, made up of vertically repeated deltaic sandstone reservoirs, could be split into significant areas with a clearly distinct dynamic behaviour. Re-engineering proposals were based directly on their knowledge.

Another example concerns a platform carbonate reservoir that developed on a paleo-high. Calculations with Welfare proved, in a very fast way, an increased vertical connectivity near the top part of the structure that is fully compatible with the sedimentary and diagenetic settings. This knowledge and the distribution of, for instance, produced water salinity led us to proposing a modification of the water injection pattern and additional development drilling that proved very productive.

The experience acquired over a few tens of fields demonstrates that most of the fields can be processed with the Welfare method and software. Fields with long production history and many wells (say more than 40 years of production and more than 1500 wells) can be easily processed, as demonstrated by one of our examples.

Our experience was gained from reservoirs covering most of the silici-clastic and carbonate depositional environments, and a variety of structural settings and fluids characteristics.

Welfare is a key tool to IOR as it allows spotting un-drained hydrocarbons and thus increasing the quantity of recoverable reserves, and as it facilitates the optimisation of field re-engineering,

INTRODUCTION

Oil and gas field exploitation classically faces many difficulties. Mature fields bring their own lot of additional challenges that need to be thoroughly addressed, in order to extract, in the most economical way, barrels of oil that remain to be produced. Mature fields often started producing long ago, when techniques for extracting information from the reservoir were not as developed as they are nowadays; consequently, the quantity and quality of data may be rather variable throughout the reservoir history. This might drastically impact future field development and economics, if we were not in the position to investigate field behaviour and reservoir characteristics with the necessary accuracy. What we want is clearly to maximise hydrocarbon recovery, optimise economics and exploit natural resources in the best way.

In order to master the recovery of remaining and bypassed hydrocarbons we must maximise the amount and the quality of information that can be extracted from any available data. Therefore, processing all data as thoroughly as possible and integrating them is of great importance. For instance, production rates highly depend on field geological characteristics, reservoir properties and fluids properties; the knowledge of these three allows the understanding of reservoirs for which production history files are available.

In order to obtain the most and the best from the available data, TOTAL has developed an in-house computer-assisted method, called Welfare, dedicated to an efficient fast track processing and interpretation of reservoir-related numerical and qualitative data.

THE WELFARE METHOD

Welfare does not use the classical history matching required by numerical reservoir simulation models, which can last several months or more. Instead, it organises and integrates all dynamic and static data at the same scale, with the spirit of data mining [1,2,3]. It is powerful and fast: a study lasts a few weeks only, sometimes less.

The method includes a data processing and a related, iterative, synthesis that takes into account both static and dynamic results. It can be described as a "computer-assisted brainstorming", in which the software is the tool to answer questions that arise during the study. Nevertheless, there are several steps, ranging from a validation of numerical data and a first synthesis of qualitative data, computations and interpretations that lead to a field diagnosis for each reservoir for which production data are available, breaking the field into sectors, proposing field re-engineering, and testing of scenarios and previsions. Some of the steps may be used in different ways, to further enforce results with other methods.

The numerical data processing primarily uses the production history record, known per completion (one branch of a well equals a completion, in this sense) and, preferably, per reservoir[4]. Numerical geological data (such as hydrocarbon pore volume, net-to-gross, porosity, permeability) and/ or seismic characteristics (such as attributes or interval velocities) can also be included, according to the needs. The numerical processing is based on mono-variant and multi-variant statistical data analyses[5] which can include all numerical data together, at the same scale. The processing options and the necessary control are derived, at every step of the work, from the synthesis of all aspects of reservoir characteristics. Iterations between processing and interpretation improve the results until they are considered satisfactory.

Production history files are numeric tables of varying parameters (such as oil flow rate, water flow rate, cumulative values, water cut, gas-oil ratio) *vs.* time or each other After an adequate preparation (with a homogeneous presentation that will enable a proper use of the tables), the data validation is implemented, through cross-checking and, if necessary, cross-correlation. Production data are smoothed or modelled for each well and each reservoir. Time-related drifts are corrected and readings recorded at different dates, hence at different degrees of reservoir depletion, can then be compared. Key values, called Production Indicators that correspond with singular evolution points (hinge points, maximums, slopes of selected parts of curves) are calculated and filed.

The dedicated software generates histograms, cross-plots and maps all connected by dynamic links[6]. In this way, all production characteristics, including apparent ''anomalies'', can be duly investigated. For each mapped Production Indicator, areas showing a given behaviour are selected and their whole distribution is interpreted. Then, deterministic synthesis maps are built to gather the useful information. They summarise reservoir behaviour, and show ranked areas with high or low production, water inflow, breakthroughs, etc. Classes, obtained from a multivariant statistical clustering of production parameters, are ranked and interpreted, in order to cross-check deterministic results.

All along, syntheses of geological and geophysical data, available at the same scale as dynamic data, are used to calibrate observed dynamic behaviours, and their apparent "anomalies". There is an iterative work to explain dynamic facts from reservoir geology and to evaluate how salient geological features impact production.

Reservoir Diagnosis

The Welfare method is aimed at visualising the salient aspects of a reservoir, evidencing previously unknown features, finding out what heterogeneity impacts production the most, defining compartments and/or sectors with a homogeneous or nearly homogeneous reservoir behaviour, i.e. at highlighting features important to a good understanding of the reservoir area. This field diagnosis is needed to propose adequate solutions for field re-engineering. It must evidence the variable size and location of areas with a given dynamic behaviour and characterise the boundaries between them.

Compartments are defined from different data, which include pressure patterns, Productivity Index maps, Production Indicators distribution and linear features. Sectors are defined as areas with comparable production behaviours. One or several sectors may correspond to a compartment. When compartments cannot be defined, then sectors become predominant. There is a characteristic behaviour pattern for every reservoir in every field.

Evidencing a Degree of Heterogeneity

Some fields are very simple, with a sub-regular pattern of dynamic behaviours: in Figure 1 below, ranked classes 1 (poorest) to 4 (best) follow a nearly radial pattern. Class 1 produces a lot of water and it clearly indicates a water influx from the west, which is related to a stronger aquifer support. Class 4 is located in two central areas and has a lower water cut and a higher oil flow rate Qo; it is located further away from water influx areas and it probably corresponds to higher hydrocarbon pore volume values.

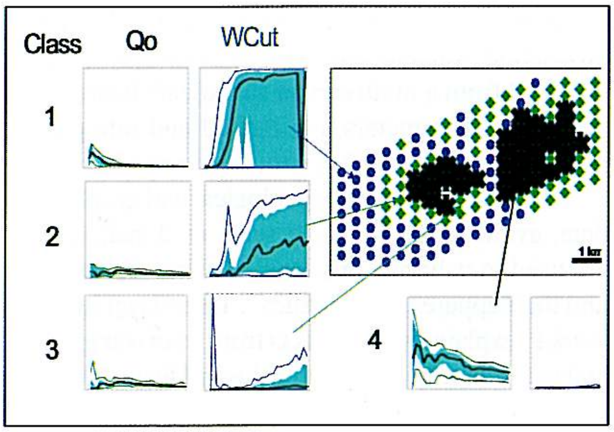

Fig. 1. Reservoir with a simple behaviour pattern.

In this carbonate field, re-engineering is relatively simple to define, and it is based on a choice of the less produced parts or less water-invaded areas.

On the contrary, other fields may show a high degree of variation of dynamic properties. For example, the silici-clastic field of Figures 2 and 3 shows a highly varying pattern, which is clearly visible on Production Indicators maps (as shown in the oil decline rate, Fig. 2) and on classes of production behaviour (Fig. 3).

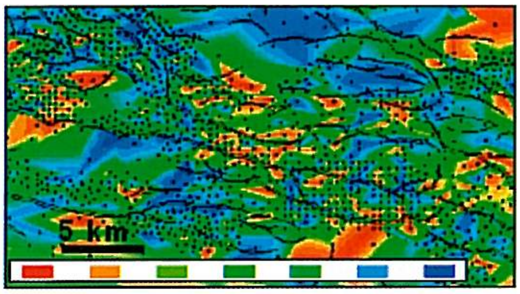

Fig. 2. Reservoir showing a large degree of variation of the Qo decline (larger declines in blue).

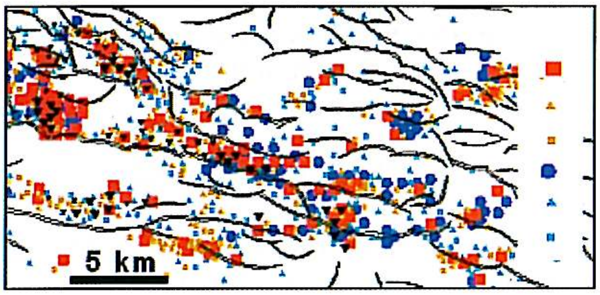

Fig. 3. The same reservoir, seen at the light of a six-class visualisation; it is highly heterogeneous, as some regions are largely different from others, and as large variations occur in every area (best classes in red, worst ones in blue).

Examples of Production-Impacting Linear Features

Previously unknown boundaries are commonly evidenced. This is very important, because it obviously has direct implications on the reservoir behaviour understanding and on re-engineering. Very often, the newly evidenced boundaries are faults at a sub-seismic scale, but they can also correspond to facies variations or diagenetic patterns. Boundaries may be tight, or simply tighter than the surrounding areas, or behave as drains facilitating the propagation of water from the aquifer or from injectors, or gas from the gas cap or from injectors (Figs. 4 and 5).

These cases involve linear axes that can be associated with structural discontinuities. Calibration on seismic and/ or on regional tectonic trends is necessary to finally interpret and refine the patterns.

The impact of evidencing such preferential axes of dynamic behaviour may be very high on a re-engineering project. Not all redevelopment patterns are suitable. The individual injection arrays must be adapted to real constraints that were previously unknown.

Evidencing Compartments Through Dynamic Lineaments Mapping

In a South American silici-clastic field with more than 1500 wells and a production period over 40

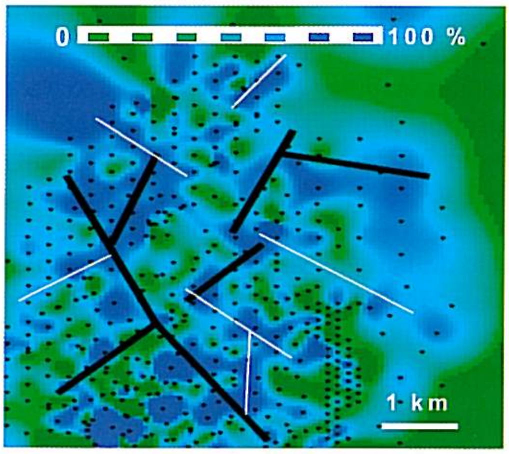

Fig. 4. In this silici-clastic reservoir from South America, the water cut distribution follows trends which can be calibrated on previously mapped faults (in black). Many more faults may be suggested (in white), and their mapping needs to be refined according to the structural knowledge.

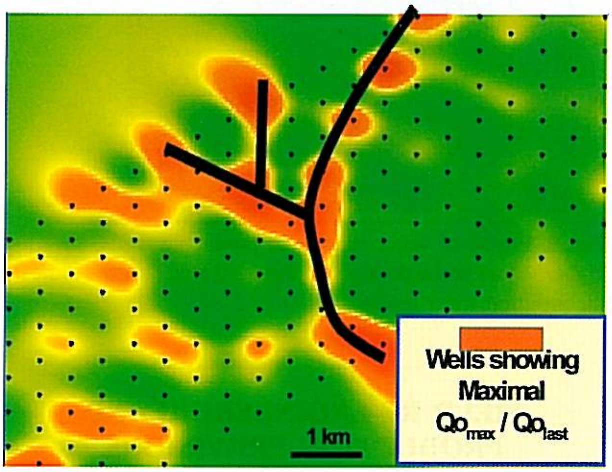

Fig. 5. In this carbonate reservoir from the Middle East, the ratio between the maximum and final oil flow rate indicates trends with a larger decrease, themselves indicating a tighter formation ; the alignments suggest structural patterns.

years, production indicators mapping revealed previously unknown features[7]. These are visible as alignments of wells showing distinct production behaviour from nearby wells (Fig. 6). Overall, well production was poorer in aligned wells, as it could be demonstrated with a mono-variant statistical analysis of several Production Indicators, confirmed by a multi-variant statistical analysis generating ranked classes of well behaviour.

The structural study showed that a first trend of lineaments was parallel to the main trend of normal faults in the field. A second trend was almost perpendicular to it, and was not corresponding with previously mapped faults from 2D seismic. It could be demonstrated that it was the direction of another group of normal faults, present at a sub-seismic scale.

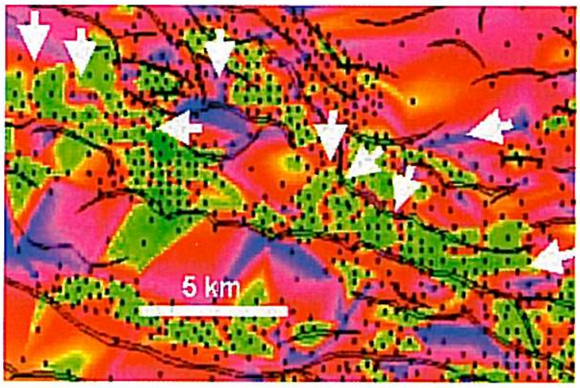

Fig. 6. Dynamic lineaments (shown by arrows) are evidenced from contrasting values of production indicators in aligned wells.

This indicated the need for a seismic reprocessing and the acquisition of 3D seismic, and that (re)processing had to be designed to highlight subtle faults.

The major consequence of the presence of lineaments that behave as trends of much lower permeability is that the field bears many more compartments than those initially thought to exist. Lineaments are partial barriers to water flows and to oil sweep and are potentially detrimental to the efficiency of water injection. Therefore, the design of new injection patterns must be adapted to this new constraint, in order to maximise their efficiency.

Such results are critical for field re-development, as well patterns can be adjusted to heterogeneity.

Evidencing Sectors, Including Natural Water Input Areas

In a West African field (Fig. 7), oil-bearing deltaic to coastal sandstones below a primary gas cap were produced through natural depletion and solution gas drive, with nearly 30 wells. After data validation and

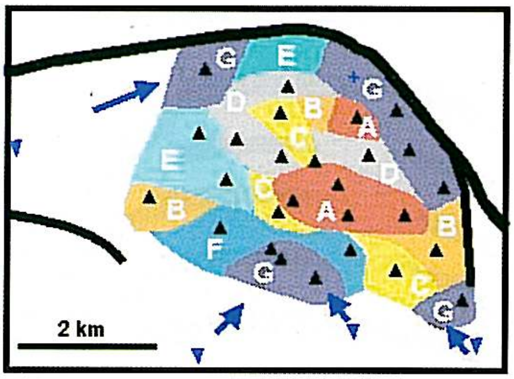

Fig. 7. Sectors definition in deltaic sandstones. A peripheral ring is more water-invaded (areas F and G), while best area A is located atop the structure (blue triangles = water injectors; others= producers).

curve smoothing (water cuts, GOR) or modelling (oil flow rates), Production Indicators were calculated for each well. Around 20 of them were selected and mapped. This led to generate synthesis maps showing the areas with better (A area) and worse (G areas) reservoir behaviour (from larger oil flows and lower water cuts to smaller oil flows and higher water cuts). Several ranked areas with clearly identified characteristics were defined in this way.

This work clearly highlights areas prone to water influx. Based on well density in every area and on the corresponding dynamic and geological characteristics, sectors prone to receive infill wells were selected. This selection can be refined afterwards, through grid reservoir models. It greatly helps in drastically reducing the size and the complexity of these models.

Evidencing an Area with a High Vertical Transmissibility

In a West African carbonate field with nearly 50 producing wells and 7 water injectors, an area with a better vertical transmissibility was evidenced by mapping the "b" value of the 1/b exponent of oil rate decline curves (Arp's Equation). Significantly lower "b" values, below 0.3, are encountered around the structure apex. It was demonstrated that this upper area corresponds with interruptions of three intervening beds of anhydrite and tight dolomite (Fig. 8). This is due to non deposition and dissolution during relative sea level falls that occurred on the salt-related paleo-high where sedimentation took place. Carbonate spread dissolution during the falls, increased porosity and permeability in the same area.

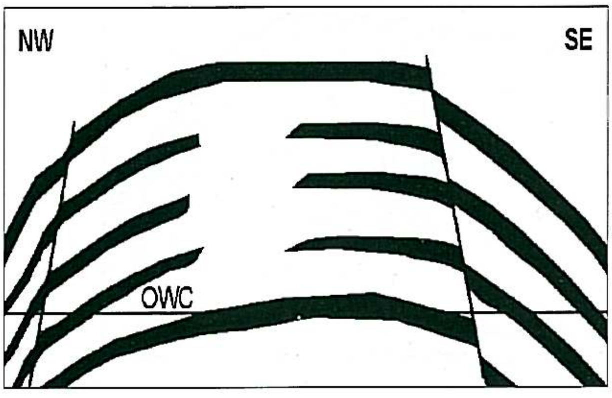

Fig. 8. Simplified reservoir geometry, with a central area of better vertical transmissibility related to interrupted internal barriers and carbonate reservoir dissolution.

These reservoir characteristics indicate that oil is drained differently in different parts of the field. Salinity values mapping (Fig. 9) was used to trace where injection water (at 35 g/l) moved into the oil reservoir, which has a connate water salinity of 250 g/l areas less drained were near the structure apex. An increase of production rate was proposed to drain it and water injection flow rates were adjusted to direct the water front toward the concerned wells. Proposed additional drilling proved very productive.

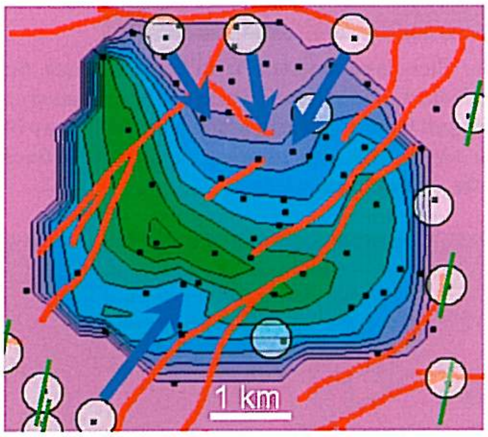

Fig. 9. Produced water salinity in producing wells, showing higher values in the poorly swept central area ; arrows indicate the injection water motion.

FIELD RE-ENGINEERING AND PRODUCTION PREVISIONS

Once the reservoir diagnosis is completed, i.e. once its characteristics and behaviour during production have been duly investigated and understood, and whenever necessary for each production mechanism or EOR/ IOR step, proposals for field re-engineering can be made. They take into account the distribution and density of already existing wells in each of the sectors ranked according to their quality (with reference to oil flow rate, water cut, GOR) and the prevailing production mechanism. Newly acquired knowledge on barriers and drains is largely used to define the re-engineering scheme.

Additional wells may be proposed, or simply redistribute injectors and producers in order to focus the sweeping fluid toward the best producers. Workovers or stimulations can also be proposed. Each scenario can be tested with Welfare, in order to evidence its impact on hydrocarbon recovery.

Production prevision curves can be generated for each sector, compartment or group of wells. They may take into account successive scenarios and production mechanisms (Fig. 10). In this way, the benefits from each scenario can be evaluated and compared, which leads to select the optimum solution.

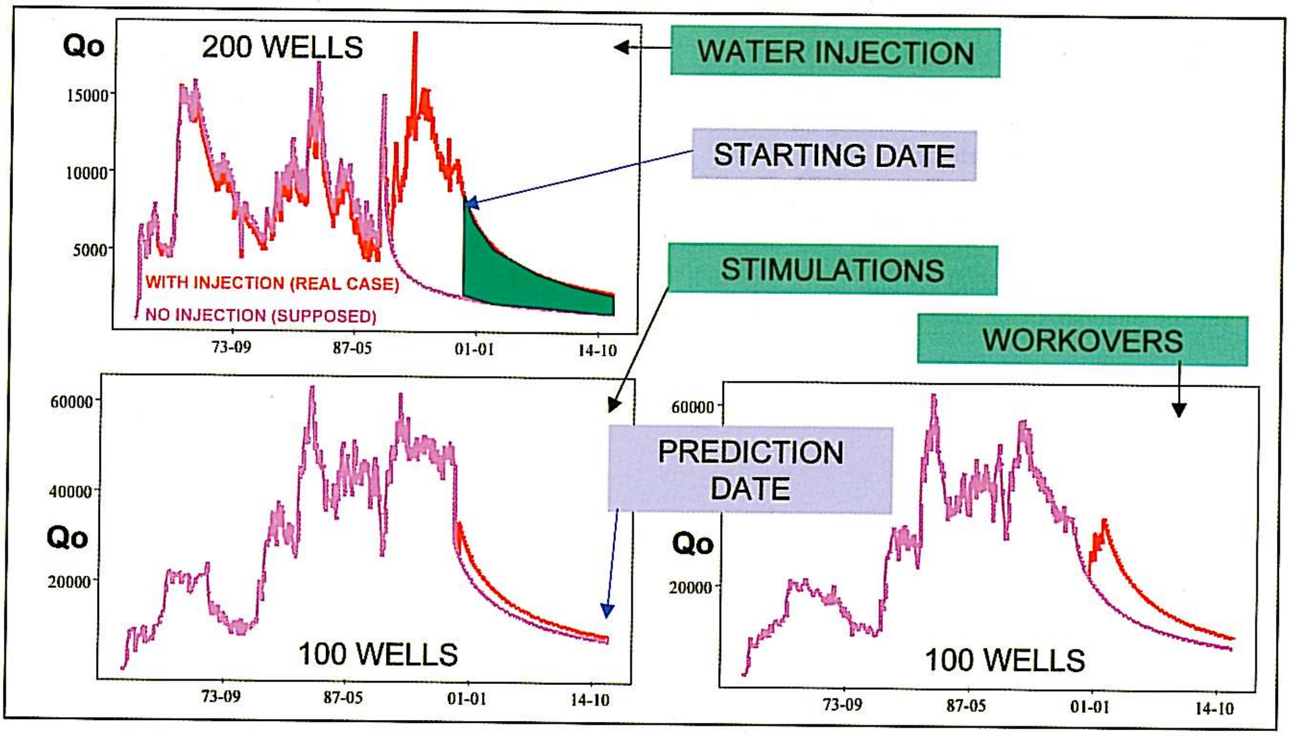

Fig. 10. Examples of curves for different group of wells and re-engineering scenarios. The graphs show the situation at the starting date (Year 2000) and forecasted production.

CONCLUSIONS

The use of production and static data, with the spirit of data mining, and the interpretation of Production Indicators, is an efficient and fast way to map reservoir performance, provided necessary precautions are taken. These precautions noticeably include the consideration of what production mechanism is involved, its degree of continuity through time, the distribution of well activation methods and the distribution of well completions. They also relate to the many uncertainties which usually exist in a mature field.

Production Indicators study is well adapted to find out what major production behaviour patterns occur in the reservoir (inversion approach). After their calibration with geological and geophysical knowledge, and the identification of geological features impacting production, the zones with remaining potential are selected and proposals for reservoir re-engineering are made. Recommended areas or solutions largely take into account the new information provided by the Welfare study. Field re-engineering is, therefore, much more relevant to existing reservoir complexity, and therefore more efficient.

The Welfare method is extremely powerful for both reservoir diagnosis and efficient proposals of re-engineering. By spotting un-produced or bypassed hydrocarbons, and by testing re-engineering scenarios, this method allows large improvements of production. It helps to maximise hydrocarbon recovery, producing natural resources in the most efficient way. It is a key tool to add value to producing fields.

The experience currently acquired by TOTAL concerns a few tens of fields. They correspond to most of the depositional environments, reservoir geometry patterns, and a variety of structural settings and fluid characteristics. Welfare can be applied to most of the fields, but it is particularly efficient for mature fields with long production histories, a large number of wells, with an irregular data array.

The use of Welfare studies may largely contribute to a good field understanding before EOR/ IOR programmes are implemented.

REFERENCES

[1] Berry M.J.A., Linoff, G., 1997. *Data Mining Techniques for Marketing, Sales and Customer Support.* John Wiley and Sons, New York, 378 p.

[2] Coste J.F., Valois J.P., Mouret C., and Guittard M., Baleix J.M., Larrouquet F., Mastin E., Daniel O., 2002. Data mining techniques for optimizing fast track re-engineering of mature fields. *SPE* 78333, Europec

[3] Ehrlich R.E., Dropkin M.J., Broussard N.J., Gay P.S. (2001). Data mining is a key strategy. *Oil and Gas Journal*, Aug. 20, 2001, 40-46.

[4] Coste J.F., Valois J.P., 2000. An innovative approach for the analysis of production history in mature fields: a key stage for field re-engineering. *SPE* 62880, presented at the *SPE ATCE*, Dallas, Oct. 2000

[5] Valois J.P., 2000. *A Robust Approach in Hierarchical Clustering: Application to the Sectorisation of Oil Fields.* Proceedings 7th IFCS, 11-14 Juil. 2000, Namur (Belgique), Springer Verlag ed., 95-100.

[6] Cleveland W.S., 1993. *Visualizing Data.* Hobart Press, 369p.

[7] Mouret C., Coste J.F., Valois J.P., 2003. *Optimized Inversion of Production Data for Reservoir Characterization. EAGE 65th* Conference and Exhibition, Stavanger, Norway, 2-5 June 2003, Paper D44.