DEVELOPMENT AND APPLICATIONS OF UNIQUE ROLLER CONE BIT TECHNOLOGIES

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ABSTRACT

It is usually a difficult task for drillers to choose a suitable roller cone bit in order to efficiently drill through interbedded formations. When experience and/or drilling log information indicate the interbedded formation is drillable with an insert type roller cone bit, a conical type insert bit is usually chosen because of the durability of its cutting structure. This paper discusses the development and applications of a new type of roller cone bit with chisel inserts that are able to drill very efficiently through interbedded formations. The durability of the new bit is comparable to that of conical insert type bit, but the rate of penetration is significantly improved. The new roller cone bits incorporate new cutting structure with enhanced drillablity, durability, and reduced vibration. Several case studies in western Texas and Oklahoma have been provided in the paper.

INTRODUCTION

The cost of bits used for oil and gas drilling is only about 2% of total well drilling expenditure. However, bit performance is critical to reduce drilling cost and minimize drilling time. Drilling faster and longer footage are almost always objectives in drilling optimization.

There are two kinds of roller cone bits. **A** steel tooth roller cone bit is frequently used for drilling soft formation in the upper section of a well. The insert type bit with tungsten carbide inserts is usually used to reduce the likelihood of having to change the bit due to wear and is often used for drilling medium and hard formation. There are three basic shapes of the tungsten carbide insert: conical, hemi-spherical and chisel. Spherical inserts have a very small protrusion and are used for the drilling hardest formations. Conical inserts have a greater protrusion and a natural resistance to breakage and are often used for drilling medium hard formations or soft formations where hard stringers would cause breakage of chisel shaped inserts. Chisel shaped inserts have opposing flats and a broad elongated crest and are used for drilling soft to medium formations.

Many factors determine the drillability of a formation. Today, with the help of advanced computerized drilling analysis programs, the type of formation and its rock strength as a function of drilling depth can be obtained during drilling [1]. Choosing a type of bit to drill a specific formation section becomes much simpler than ever before. However, difficulties of bit choice still exist when drilling into interbedded formations. Hard stringers require bit features that conflict with those required for softer formations [2]. For example, a light setting of cutting structure with higher extension inserts is able to drill softer formation very efficiently, however, when the same bit is used to drill harder stringers, early damage of cutting structure (insert breakage) may occur. On the other hand, a heavy setting of cutting structure is able to drill harder stringers, but it is not efficient to drill softer formations.

Chisel inserts have proved to be very effective for drilling soft formations. However, chisel inserts may be subject to breakage when they are used for drilling hard formations. Early damage of the cutting structure of a bit may lead to a significant loss of time tripping in and out of a deep hole. Therefore, the chisel insert roller cone bit is not considered a good candidate for interbedded formations, especially when the hard stringers are unpredictably scattered throughout the section.

Due to its natural resistance to breakage, conical shape inserts are often used for drilling soft formations interbedded with medium to hard stringers. While conical insert may be durable enough to drill through hard stringers, the rate of penetration in soft formation, however, may be too slow to be attractive.

Therefore, there is a need to increase the rate of penetration in the section of soft formation and improve the durability of cutting structure in the section of hard stringers. This paper describes in detail three recently developed technologies and their implementation for an optimized design of roller cone bits for drilling interbedded formation. Many field runs have proved that roller cone bits implemented with these technologies drill much faster in soft formations and are very durable in hard stringers. This kind of bit is especially suitable for interbedded formations.

THREE UNIQUE TECHNOLOGIES OF ROLLER CONE BITS

Dynamic Balancing

Until recently, no method existed to determine the balanced condition of a roller cone bit. Industry experts knew that roller cone bits were unbalanced, as the cutting structure on each of the three cones is not symmetrical. Asymmetry is due to teeth rows on each cone being located different distances relative to the centre line of the bit. Variable distance for the teeth rows ensures that there is sufficient intermesh to promote self-cleaning cones and that no uncut grooves are left on the hole-bottom.

The development of a computer drilling simulator represents a breakthrough as a simulator identifies actions a bit designer must take to create a balanced cutting structure. **A** trustworthy drilling simulator makes it possible to calculate how much rock each cone removes (volume balance) and how forces acting upon each of the three cones are distributed (force balance), once an initial cutting structure is analyzed [3, 4].

Armed with this knowledge, a bit designer may manipulate various elements of the cutting structure to achieve a bit that is both volume and force balanced. The number of teeth, the tooth extension, the orientation, or the shape of the teeth as well as the cone profile may be altered to achieve this objective. As a result of these modifications, bit imbalance may be reduced by over 70% compared to conventional design. Fig.1 compares the volume balancing condition of a 12-¼-in. steel tooth bit before and after optimization.

There are several advantages associated with a balanced cutting structure. Bearing / seal life will be extended because no individual cone takes more loading than the others. Bit vibration will be significantly reduced. As a consequence of reduced vibration, the risk of fatigue failure of bit components such as cutting elements, cone, and arms is reduced as is the risk of failure of other down-hole tools that might be subject to vibration.

Optimized Tooth Orientation

If a formation is drillable by both PDC bit and roller cone bit, a PDC bit will drill much faster than a roller cone bit in most cases. In order to understand this phenomenon, we need to first know the physical properties of a rock. The shearing strength of a rock is, in most cases, much less than the compressive strength. For example, experimental results show that the shear strength and normal strength for Panguna andesite at confining pressure has following relationship [5]:

$$\tau = 150 + 0.47\sigma_n \qquad (1)$$

where is shear strength (psi) and is normal strength (psi). The shear strength is about half of normal strength for this kind of formation. So it is much simpler to remove a rock by shearing motion than by compressive motion. As shown in Fig.2 and Fig.3, respectively, PDC bit removes formation by shearing motion and a soft to medium roller cone bit removes formation by the combination of compressive fracturing and shearing, where shearing motion is very small compared to the fracturing motion.

In order for a roller cone bit to remove the rock more efficiently, it is obviously necessary to enhance its shearing motion. Computer drilling simulation has shown that the magnitude and direction of shearing (or scraping) motion is a function of cone offset and cone profile and other bit geometric parameters [3]. For example, with the increase of cone offset, the magnitude of shearing motion is increased. The increased shearing motion leads directly to the increase of the rate of penetration of a roller cone bit with large cone offset. However, large cone offset may create significant vibration during drilling. Therefore, the maximum cone offset is limited. Is there any way to enhance the shearing motion without increase the cone offset? The answer is “yes”.

Computer drilling simulator has shown that the direction of shearing motion is different from row to row. Fig.4 shows an example of shearing motion of cone #1 of an insert bit over the hole bottom. Notice that, on a conventional roller cone bit with chisel inserts, the elongated crests of the chisel inserts are always arranged in alignment with axis of the cone rotation regardless of their direction of shearing motion. Consider two extreme cases as shown in Fig.5. In Fig.5a, the elongated crest is perpendicular to its shearing direction. In Fig.5b, the elongated crest is parallel with its shearing direction. Suppose the cutting depth and the magnitude of the shearing motion is respectively the same in both cases. It is obvious that the rock volume removed in Fig.5a is much larger than that in Fig.5b. The rock volume removed by the bit is the sum of all rock volume removed by each individual tooth. Therefore, it is to be expected that the rate of penetration of a bit can be increased significantly without increasing the cone offset and without changing cone profile, if all rows of teeth are oriented with their shearing directions perpendicular to the trend of their crests.

Optimized Anti-Tracking Mechanism

Tracking occurs when the teeth of a bit fall into an impression in a formation formed by other teeth at a preceding moment in time during the revolution of the bit. Many of the inner row teeth fall into the impressions made by these teeth in the preceding revolution (inner tracking). Similarly, many of the gage row teeth of one cone fall into the impressions made by the gage row teeth of another cone (gage tracking).

A bit cutting structure that develops a tracking pattern can negatively impact bit performance in two ways. **A** cutter that falls into an existing crater is not promoting an efficient cutting action and will not achieve the same rate of penetration possible were it removing ridges between craters. Secondly, as teeth are buried deeper into existing craters, the steel surrounding a cone may contact the formation. The steel cone, being softer than the cutting elements, may abrade and lead to tooth loss. In severe cases, a cone may become so eroded that cone cracks, with the potential to leave debris, such as nose cones, in the hole.

Features to prevent tracking are incorporated into most conventional roller cone bit designs. Row tooth counts corresponding to prime numbers are selected to reduce the likelihood of developing a tracking pattern. Pitch angles of teeth on the same row may also be varied to break up this tendency.

The propensity of inner tracking can be further reduced by varying the tooth orientation angles on inner rows within an optimal range of orientations. Fig.6 shows an example of various orientation angles of inner row inserts.

The propensity of gage tracking can further be reduced by varying the orientations of the teeth between the gage row of one cone and the gage row of another cone as shown in Fig.7 for a steel tooth bit.

By reducing tracking, the bottom hole will be much smoother and as a result, the impact damage to teeth and to cone will be reduced and the ROP will also be increased.

Design Optimization of Roller Cone Bit

In order to incorporate the three new features described above into a roller cone bit, the computer drilling simulator and the multi-objective optimization algorithm have been integrated into the roller cone bit design software. The bit design engineers are able to model the bit three dimensionally, simulate the drilling procedure, optimize the bit geometry, and predict the bit performance without manufacturing and testing a bit.

TARGET FORMATION

In West and North Texas and Oklahoma, the demand is very high for a 7-7/8-in. roller cone bit to drill well sections from about 5000 feet to 11000 feet. In these depth intervals, hard and soft formations are interbedded; and the rock compressive strength varies from 9000 psi to 20000 psi. Fig. 8 depicts a typical case showing that rock properties such as lithology, porosity, and rock strength, change with drilling depth. The challenge here is to drill efficiently through the interbedded section. These formations typically require roller cone bits with IADC codes from 517 to 537. In order to drill fast, high level energy is also applied to the bit. In a typical rotary drilling, WOB may be as high as 70000 lbs; and bit rotational speed may be as high as 200 rpm for a 7-7/8-in. roller cone bit. Bit durability becomes very important in such a drilling environment. Historically, a conical insert type bit has been the preferred choice for its drillability in interbedded hard stringers. However, drilling efficiency was reduced in soft formations.

FIELD PERFORMANCE AND CASE STUDIES

Case 1: Energy Balanced Bit and Conical Insert Bit

Two energy balanced bits with chisel inserts were tested to drill two different well sections in Western Texas, from 5100 feet to about 9000 feet, respectively. The interbedded formation includes dolomite and lime stringers and shale. Historically, conical insert bits with IADC 537 were used to drill the sections by rotary drilling with WOB up to 60,000 lbs and bit rotational speed about 70 rpm. Table 1 compares the bit performances with that of the offset bits. It is observed that the energy balanced bits (EBXS26) are able to drill efficiently through the hard dolomite and lime stringers and keep a much higher ROP when drilling into shale. The average ROP is 46.8 % faster than that of offset conical insert bits. The average dull condition of inner cutting structure of energy balanced bits is 2.5, better than that of offset bits, 4.75. These differences mean that the durability of the inner cutting structure of the energy balanced bit is better. However, heavy gage row insert breakage was observed on the energy balanced bit. Breakage may be due to the fact that the orientation of the gage row inserts reduces the contact area of insert against hole wall. Improvement in the design of insert shape of gage rows is necessary. Another improvement should be made in the durability balance of the inner and outer cutting structures.

Case 2: Energy Balanced Bit and Conventional Bit

In order to reduce the likelihood of breakage of the gage row insert of the energy balanced bit, enhancement on the gage row insert was made. First, the shape of the gage row insert was redesigned to increase the contact area with the hole wall. The toughness of the gage row insert was also increased. In order to balance the durability of the inner cutting structure and outer cutting structure, the inner cutting structure was designed a little more aggressively than the bit used in case 1. The new design was named EBXS24. In this case, the bits were used to drill vertical wells in Elk City, Oklahoma; and the formations drilled were mainly Heebner sandstone, Tonkawa sandstone and Cottage Grove. The weight on bit was about 40000 lbs; and bit rotational speed, about 90 rpm. While the average drilled footage is about 4.7% more than that of the average offset bits, the average ROP is still about 9.7 % faster than that of the average offset bits. More importantly, the dull conditions of both inner and outer structures of the EBXS24 are much better than that of the offset bits (2-3 against 4.4-5).

Case 3: Energy Balanced Bit in Directional Well

An energy balanced 8-¾-in. EBXS30 (IADC 537X) was used to drill a directional well in Duncan, Oklahoma. This time the bit was used to build angles. The weight on bit is about 45000 lbs and bit rotational speed is about 190 rpm using a down hole motor (see Table 3). The formation drilled is mainly Upper and Lower Dyer sand. This bit drilled 62.38% more footage and drilled 55.31% faster than the average of the offset bits. However, one of the seals failed.

JRTHER BIT DESIGN IMPROVEMENT

Detailed analysis of the dull conditions of energy balanced bits indicates that the average dull of the cutting structures is much better than that of conventional bits. This difference suggests that the improved performance gained by the oriented inserts and balanced cutting structure could be transferred to either a lighter set bit or else a higher energy level could be applied to the bit to drill the same section more efficiently. Which strategies should be chosen will depend on the formation drilled, experience gained by drilling engineers, and other operational parameters.

Protection of gage row insert is a big concern to maintain the bit diameter during drilling. When the gage insert is oriented, then the contact area with hole wall is reduced. Any lateral vibration of the bit may damage the gage row inserts. In order to avoid breakage of gage row inserts, the shape of the inserts was redesigned based on the specified orientation angle. Fig.9 shows another possible improved design in which the gage row inserts are all conical type.

CONCLUSIONS

Laboratory tests and rig tests of energy balanced roller cone bits have proved that these bits drill faster in uniform, soft formations (shale and sandstones). Many field runs also indicate that these bits are more durable when drilling into hard stringers. These two facts lead to the conclusion that the energy balanced roller cone bits are a favorable choice for interbedded formations. They are a favorable choice because this kind of bit can drill faster in soft formations and can drill more efficiently in hard stringers. Further improvement of bit design should be focused on how to protect the gage and how to balance the durability of inner and outer cutting structures. **A** detail study of energy level applied to the bit is another very interesting subject and will be studied in a further coming article.

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Table1
Performance Comparison of Energy Balanced Chisel Shaped Insert Bit *to* Conical Insert Bit

Location	Bit	IADC	Depth Out	Footage	Hours	ROP	**Dull**
Upton, TX	EBXS26	527X	9309	4189	118.25	35.4	**2-7-BT-A-E-E-E-O-ER-FM**
Upton, TX	EBXS26	527X	8640	3540	85	41.6	**3-7-BT-H-E-E-E-I-LT-PR**
	Average		**8974.5**	**3864.5**	**101.6**	**38.03**	2.5-7-
Offsets:							
Upton, TX	Bit A	537Y	8721	3614	135.25	26.7	**2-3-WT-A-E-E-E-I-ER-HR**
Upton, **TX**	Bit B	537Y	9433	4328	161.	26.9	**6-7-BT-A-E-E-E-O-CT-TQ**
Upton, **TX**	Bit C	537Y	8713	4048	155	26.1	**7-8-BT-A-E-E-E-O-LT-PR**
Upton, TX	Bit D	537Y	7994	3344	140.75	23.8	**4-3-BT-A-E-E-E-1/4-FC-PR**
	Average		**8715.3**	**3833.5**	**148**	**25.9**	4.75-5.25
Gain				0.8 %		46.8%	

Table 2
Performance Comparison of Energy Balanced Bit and Offset Bits

Location	Bit	IADC	Depth out	Footage	Hours	ROP	**Dull**
Elk City, OK	EBXS24	527X	8450	1440	70.5	20.4	**1-3-WT-A-E-E-E-I-BT-TD**
Elk City, OK	EBXS24	527X	8325	1181	59.0	20.0	**3-3-WT-A-E-E-E-I-NO-PR**
	Average		**8387.5**	**1310.5**	**64.75**	**20.24**	2-3-
Offsets:							
Elk City, OK	Bit A	517X					
Elk City, OK	Bit B	527X					
Elk City, OK	Bit C	527X					
Elk City, OK	Bit D	517X	9130	1868	120.5	15.5	**8-8-WT-A-F-F-E-1/16-HR**
Elk City, OK	Bit E	527X	8258	963	43.5	22.1	**3-4-BT-G-E-E-E-I-ER-BHA**
Elk City, OK	Bit F	527X	8322	1147	59.0	19.4	**3-3-FC-A-E-E-E-I-NO-FM**
Elk City, OK	Bit G	517X	8140	670	33.5	20.0	
Elk City, OK	Bit H	537X	8720	1734	92.5	18.7	**3-5-BT-A-E-E-E-?-WT-PR**
Elk City, OK	Bit I	537x	8196	1049	62.8	16.7	**7-8-BT-A-F-E-E-2/16-WT-PR**
	Average						
	Avera e		**8445**	**1251.7**	**67.82**	**18.45**	4.4-5-
Gain				4.7%		9.7%	

Table 3
Performance of Energy Balanced Bit in Directional Drilling

Location	Bit	IADC	Depth Out	Footage	Hours	ROP	**Dull**
Duncan, OK	EBXS30	537X	8845	839	39.5	21.2	**3-5-BT-G-F-E-E-O-CT/FC**
Offsets:							
Duncan ,OK	Bit A	537X	8877	481	37.3	12.9	**4-4-FC-A-E-E-E-I-?-?**
Duncan, OK	Bit B	517X	8795	516	39.0	13.2	**4-4-WT-A-E-E-E-I-FC-?**
Duncan, OK	Bit C	537X	8603	553	37.25	14.8	**2-6-WT-A-E-E-E-I-?-?**
	Average		**8758.3**	**516.7**	**37.85**	**13.65**	3.3-4.7
Gain				62.38%		55.31%	

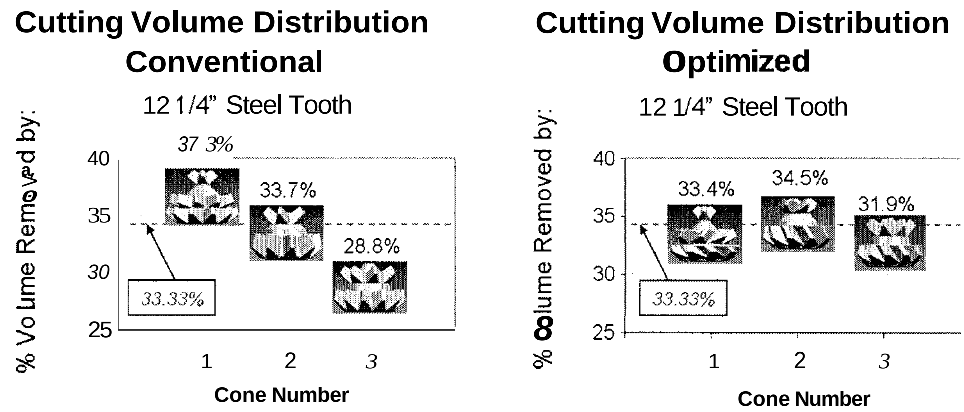

Figure 1 - Percentage Rock Volume Removed by Each Cone Before and After Optimization - For a perfect volume balanced roller cone bit, each cone should remove the same amount of rock during drilling.

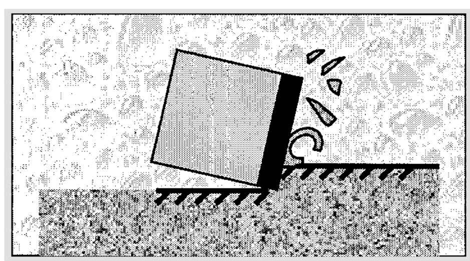

Figure 2 - A PDC cutter removes rock by shearing motion

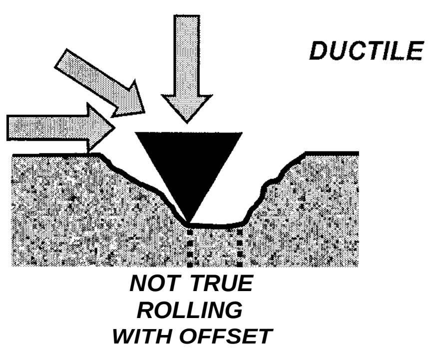

Figure 3 - A tooth on a soft-medium roller cone bit removes the rock by the combination of compressive and shearing action. The shearing action is very small compared to compressive action.

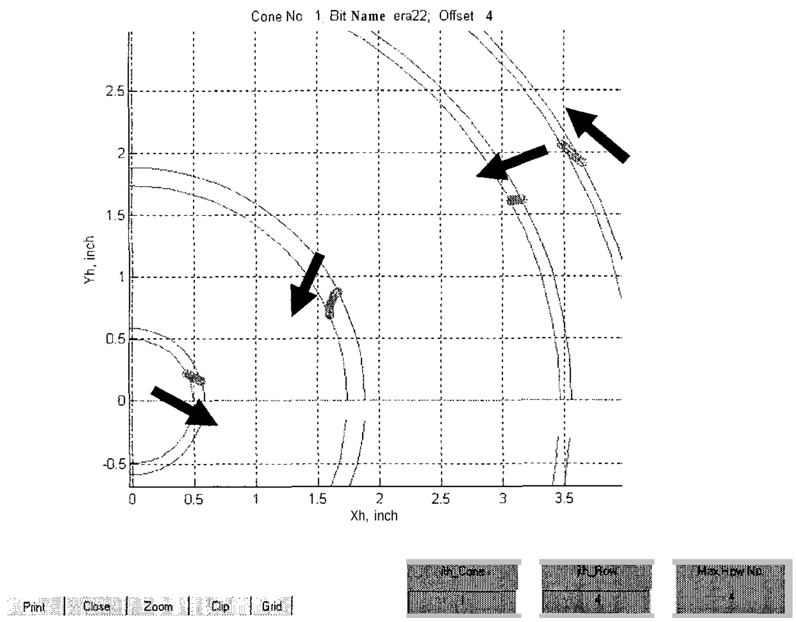

Figure 4 - Scraping Motion of Teeth of Cone No.1 Projected in the Plane Perpendicular to Bit Axis - The magnitude and direction of the scraping motion is different from tooth row to tooth row.

Figure 5 -Amount of Rock Removed By Tooth (a) Elongated tooth crest is perpendicular to scraping direction (b) Elongated tooth crest is parallel with scraping direction.

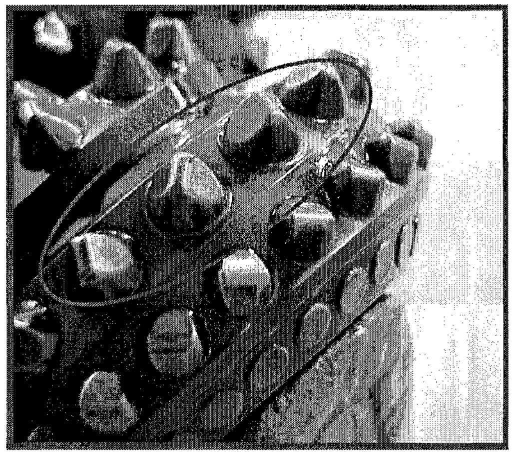

Figure 6 - Optimized Anti-Tracking Mechanism of an Insert Bit- On certain insert bits, adjacent inserts on the same inner rows are offset from one another to prevent them meshing with craters having the same profile.

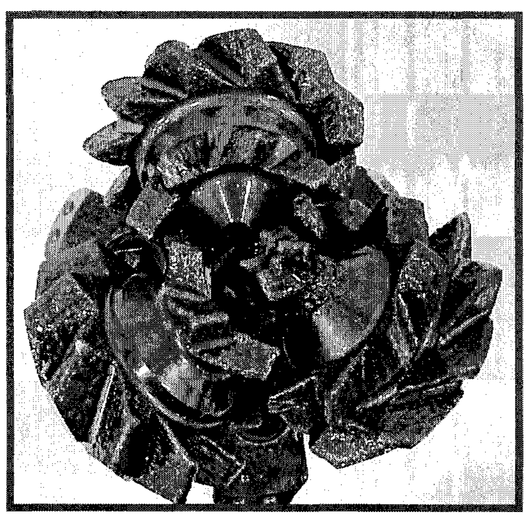

Figure 7 - Optimized Anti-Tracking Mechanism of a Steel Tooth Bit -All steel tooth bits incorporate the anti-tracking feature in the gage row, where orientation angle is different on the gage row on at least one of the three cones.

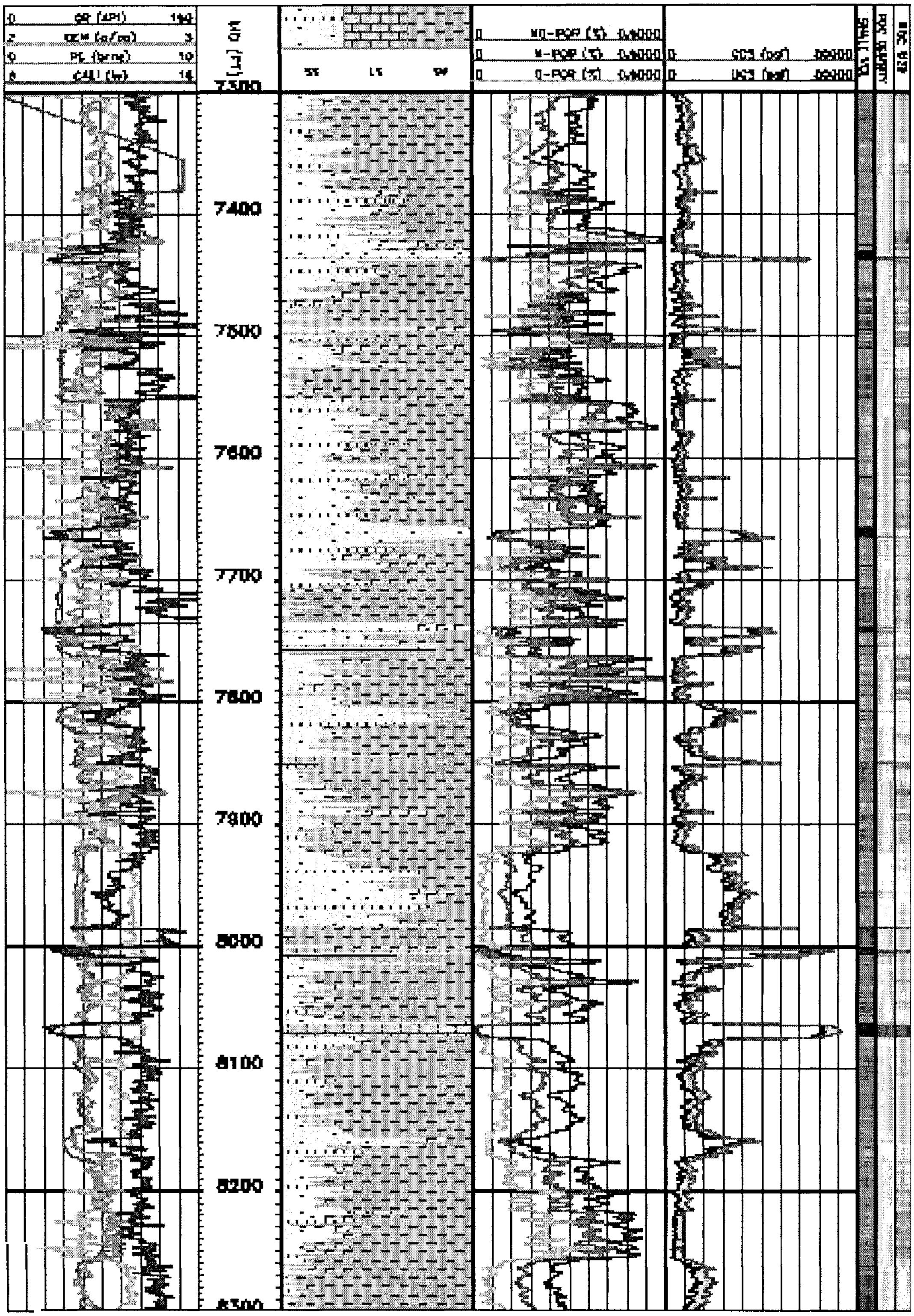

Figure *8* - Formation Properties from *7300* feet to *8300* feet

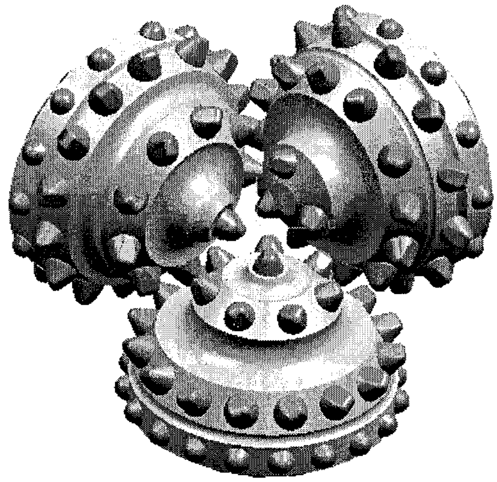

Figure 9 - An Improved Design of EBXS24 with Conical Gage Row Insert