How to interpret seismic data for bright spot hydrocarbon indication?

Nishant Kumar, Satyapal Singh Negi, Reliance Industries Ltd, Mumbai, India*
Email:Nishant.kumar@ril.com

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Summary

An organized approach is presented here to test the seismic data bright spots for hydrocarbon indications. The test presents the most basic analysis to be done while inferring bright spots for hydrocarbon presence. The simplicity of the approach doesn't undermine its importance. Application of two simple techniques Polarity and AVO is utilized. The paper also explains what various types of hydrocarbon bright spots are and why we see them the way they are. It also shortens our analysis time and effort window by eliminating cases with absence of hydrocarbon indication or presence upfront. The case marked with certain degree of possibility from here can be further subjected to detailed test. The approach is helpful in mitigating exploration risks and minimizing failures for wells.

Introduction

Amplitude interpretation plays a primal role for hydrocarbon detection. Amplitudes are deceptive but can be much indicative if dealt with certain precautionary measures. Most of the unsuccessful wells are drilled with wrong or insufficient interpretation of basic rudiments.

We describe here a specific direct hydrocarbon indicator named Bright Spot. The presented approach only accounts for a simple but essential general procedure to infer bright spot signatures for hydrocarbon findings. It neither presents a comprehensive overview nor does it go into the intricacies of amplitude analysis. It dispenses a rough view to bright spots so as to avoid exploration failures. The approach shows simple visualization check of seismic data to infer hydrocarbon possibility. If hydrocarbon possibility is found from this test, a detailed study may be implemented afterwards. The simplicity of the approach is the main strength of this hydrocarbon identification routine.

Two techniques 1) Polarity and 2) AVO (Amplitude Variation with Offset) is used to study the direct hydrocarbon signatures of bright spot. This approach lacks any detailed AVO analysis. The study is divided into two parts of the subsurface, one shallow portion and the other deeper portion. The division into shallow and deeper portion of the depth is done because of the differences in compaction trends of the sediment strata that manifests into divergent signs of amplitude information. An example for the interpretation procedure is shown for deeper zone through a case study.

Polarity of the data is inferred from the water bottom in marine cases or from some known reflector in land cases or could be provided by the seismic data processor. For marine cases, seabed interface is a case of positive reflectivity. This positive reflectivity is represented with a peak (Normal SEG convention) signature of the wavelet. In case of reservoir where it is found that the reservoir sands are encased in shales there can be two situations depending on the relative impedance difference between the reservoir sand and encasing shales. If a low impedance reservoir is encased in relatively high impedance shales a trough signature is found at the reservoir top and a peak signature at the reservoir base, this is called as trough over peak signature for the reservoir. If a high impedance reservoir is encased in relatively low impedance shales a peak signature is found at the reservoir top and a trough signature at the reservoir base, this is called as peak over trough signature. Also, the same polarity situations will hold at hydrocarbon sand base whether it is overlain on shale or on water sand.

For AVO signatures, only in low impedance (Class III) or equivalent impedance (Class II, sand impedance equal to that of shales) sands the amplitude increases with offset. High impedance sands (Class I) have amplitudes that decreases with offset.

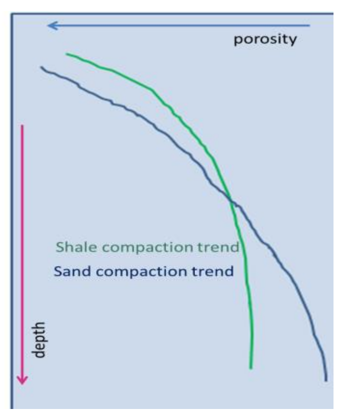

Figure 1: Compaction trends for shale and sand in terms of porosity variation. It can be seen that at certain depth the trends intersect and after that the rate of compaction is more in sands than in shales.The arrows point in the direction of increase in a particular parameter.

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The Figure 1 shows the variation of compaction trends for shale and sands with respect to depth. The compaction trends are inferred in terms of porosity trend. Generally, as shown in the figure, at shallow depths, shales are more compacted than sands. Sands at shallow depths are unconsolidated or have consolidation with high amount of porosity. At deeper levels sands become more compacted than surrounding shales. However there are occasional exceptions when even at deeper depths highly porous uncompacted sand might be encountered.

Fluid sensitivity and Matrix sensitivity

We define our geological situation to be fluid sensitive if changing the fluid from one phase to other (like water to gas) in the rock, the signature of the physical property changes significantly, especially in elastic logs of compressional velocity, modulus and impedance which subsequently affect the seismic responses. It is generally known that shear response doesn't get affected by fluid alterations. Although, in a poroelastic model of the earth fluid alterations may have subtle shear effects but for our purpose of studying seismic signatures at the scale of wavelet sampling the fluids don't have significant impact on shear wave properties. Fluid alterations although manifest their presence through change in Vp/Vs (ratio of compressional to shear wave velocity).

We define our geological situation to be matrix sensitive if changing the mineral framework of the rock from one to other (like quartz matrix to clay matrix) changes the physical property signature significantly especially in elastic logs of compressional and shear velocity, modulus and impedances which subsequently affect the seismic responses.

At shallow depths, sands (water bearing sands) and shales have nearly similar densities and velocities. So the impedance at shallow level for water bearing sands and shales are not much different. This gives rise to low amplitude reflection impressions on seismic data. **The matrix sensitivity at shallow depths is poor.** This means if we replace sand with shale or shale with sand there will be no significant change in reflection behavior.

If in this case, replacement of fluid in sand is made from water to gas phase then the reflection behavior will significantly change. As the impedance of sands and shales are nearly similar, a change from water to gas in sands lowers the impedance since both velocity and density get lowered in gas. This means **fluid sensitivity is significant at shallow level**.

Although a change from water to oil phase would not change impedance that much as the velocity and density of oil is much nearer to water.

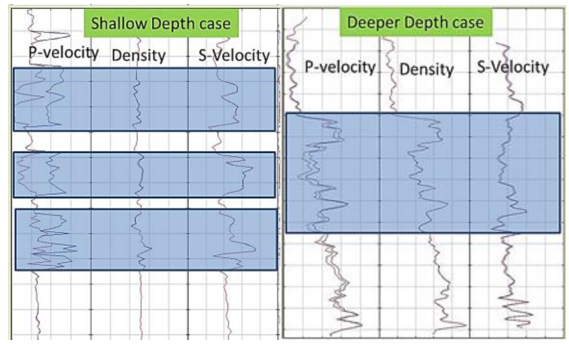

Figure 2: A fluid substitution study showing p-velocity,density and s-velocity logs for 100% water (blue color) and 10% gas(red color) case for shallow depth(left panel) and deeper depth (right panel).The blue enboxed portion shows sand zone.

At deeper levels, sands (water bearing sands) generally have higher densities and velocities as compared to shales. So the impedance of water bearing sands and shales can be significantly different at deeper levels. This gives rise to high amplitude reflection on seismic data. **The matrix sensitivity at deeper depths can be significant.**

If in this case, replacement of fluid in sand is made from water to gas phase then the reflection behavior may not always change significantly. Since sands at these depths are highly compacted and can have less porosity, the fluid in rock has lesser role. In this case change from water to gas in sands does not lower the impedance significantly since both velocity and density don't get affected much. This means that the **fluid sensitivity is less at deeper levels**. But if rock is porous fluid sensitivity can still be seen in that condition and we can have lower impedance hydrocarbon sands at deeper depths also. So the fluid sensitivity at deeper levels is dependent on porosity of the sands.

A fluid substitution study was done as shown in Figure 2 for both shallow and deeper depths. At shallow depths we find significant difference in p-velocity logs as the fluid was changed from water (blue color log) to gas phase (red color log). This behavior was because of high fluid sensitivity at shallow depths. At deeper depths there was no significant change in p-velocity when we change the fluid from water to gas phase. This was because of low fluid sensitivity at deeper depths.

However for density and s-velocity no noticeable differences were observed with fluid substitution from water to gas phase at both shallow as well as deeper depth case.

We introduce here the concept of "soft top" and "hard top". Soft top is an interface between high impedance and low impedance layer, like reservoir top in low impedance sands, while hard top is the interface between low impedance and high impedance layer, like reservoir top in high impedance sands.

Shallow Depth Scenario

At shallow depths, as described earlier low impedance sands are expected for hydrocarbon presence and hence gas sand top is expected to be a trough over peak signature. Because of the temperature and pressure conditions , we are not considering any possibility of oil at shallow region.

Peak over Trough signature

So if a bright spot anomaly with peak over trough signature is encountered then we eliminate the possibility of gas sand occurrence. Since peak signature above represents a hard top and may not be indicator of gas presence. Trough signature below represents a soft base. This possibility is only with a high impedance geobody that is not expected here.

As shown in the Figure 3, seismic data from near, mid and far angles can be seen. The polarity is peak over trough. This indicates high impedance strata that is generally not expected at shallow levels from gas reservoir.

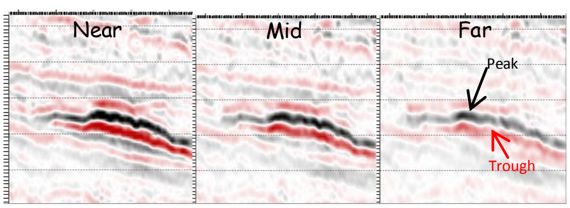

Figure 3: Seismic data from Near,Mid and Far angle stacks.The bright spot is characterised by peak over trough anomaly.

Trough over Peak signature

A trough over peak however corresponds to the low impedance gas sand anticipation. This means that the polarity check is clear. So analysis could proceed to the next step of AVO check. It is to be also observed that from going near to far offsets whether the amplitude increases (or stays the same) or not. If it increases with offset then it is a case of AVO Class III anomaly that indicates low impedance gas sands. So after passing this test we can proceed for detailed analysis.

If a decrease of amplitude with offset is seen in trough over peak situation, it is regarded as not a promising bright spot anomaly in terms of AVO signature. Although it represents AVO Class IV, since negative reflection decreases with offset. It is still disregarded, as this signature (Class IV) is a general signature, till any other convincing reason is obtained. Since even without the presence of any hydrocarbon, amplitude always decreases with offset because of more energy losses at farther offsets.

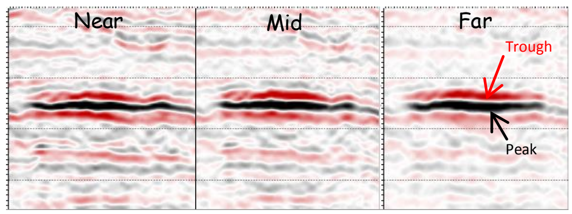

Figure 4: Seismic data from Near, Mid and Far angle stacks.The bright spot is characterised by trough over peak anomaly.

As shown in the Figure 4, seismic data from near, mid and far angles are depicted. It is observed from the data that the polarity is trough over peak. It can be also seen that the amplitude increases as we go from near to far angles. This constitutes the indication of hydrocarbon possibility.

Other case

In Peak over Trough case there can be one other possibility also in exceptional conditions as shown in the Figure 5 because of the presence of shaly sand, sandy shales or laminated sands just above the clean sand and below the encasing shales. This sand-shale composite may have less porosity and slightly higher impedance. It is said to be exceptional because shaly sands have to have higher

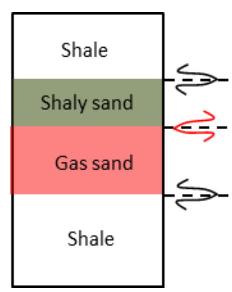

Figure 5: Schematic diagram of a scenario where a peak over trough situation is encountered.The impedance of shaly sand is higher than shales resulting in peak signature at top interface.

impedance than shales. The acoustic impedance contrast between encasing shale above and shaly sands below may be positive reflection or peak and acoustic impedance contrast between shaly sand above and clean sand below may be negative or trough.

This case may occur where bright spots have more than one cycle. In this case a peak over trough over peak over trough sequencing is encountered.

Deeper depth Scenario

At deeper depths if a bright spot is encountered there may be chances that it will be water sand than it would be gas sand unless it is porous or loosely compacted. At deeper depths compacted sands or sandstone have higher velocity and density and thus have higher impedance than the encasing shale so the reflection between shales above and water sands below is positive and is significantly larger.

If water is replaced with gas in this compacted sandstone, whose porosity is sufficient enough to be fluid sensitive, the impedance of the sandstone can come closer to that of shale (slightly higher or slightly lower; AVO Class IIp or Class II anomaly).Distinguishing shale and gas sand in this case is difficult by just looking at stacked section or near stack data. Here AVO comes to the rescue. If an increase in amplitude with offset is seen with negative reflection then there are high chances for it to be signifying hydrocarbon.

If water is replaced with gas phase in some compacted sandstones having low porosity, there may be a situation where fluid replacement doesn’t have much significant role and sufficient lowering in impedance may not be seen with introducing gas. In this case the amplitude is inferred to be of high impedance sands (AVO Class I anomaly) that give positive reflection bright spot. They are hard to interpret since generally by default a high amplitude reflection at near traces diminishes to low impedance reflection at far offset. So to distinguish whether it is a normal case or specific high impedance sand case is difficult from AVO point of view till proper AVO calibration or amplitude balancing is not done.

For oil only saturated sands the condition of reflection behavior would be similar to that of water sands. For partially oil and partially gas saturated sand the reflection behavior is more likely to be similar to gas phase as mentioned above because even a slight presence of gas in pores has a much impact on elastic parameters.

Peak over Trough signature

If the peak over trough signature is seen, there can be three possibilities.

1. Positive amplitude will increase with offset.
2. Positive amplitude will decrease with offset. (Class I)
3. Amplitude will decrease from positive to negative marking a polarity reversal and then increasing in absolute terms.(figure 6&7)

The first case is not favorable in terms of AVO classification. This AVO impression could be because of igneous rocks present. Second case is very difficult to deduce for hydrocarbon presence since as normal positive or negative reflection amplitude at near offset decreases with offset. So it is difficult to deduce whether the reduction in amplitude is because of normal condition or because of gas presence. If this case is encountered the data has to be directed for further analysis. Third case is promising if inferred unambiguously. Polarity reversal is a strong hydrocarbon indicator.

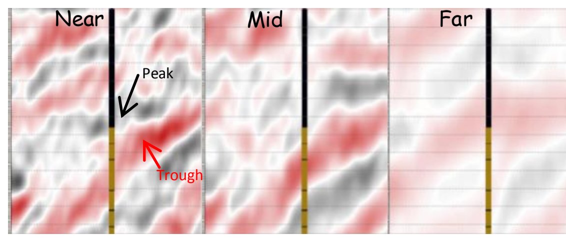

Figure 6: Seismic data from Near,Mid and Far angle stacks overlain by facies log(black represents shale while brown represents gas sand).The bright spot is characterised by peak over trough anomaly in near stack data which changes to trough in far data after polarity reversal of amplitude.

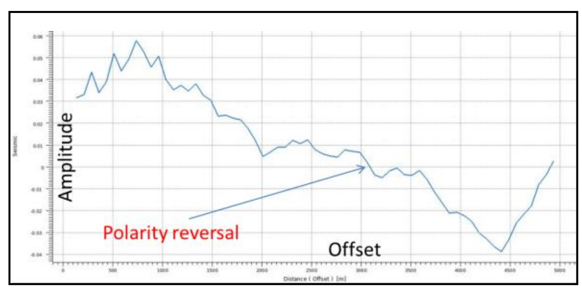

Figure 7: Amplitude Variation with offset curve at the location of peak shown in the section from Figure6. Presence of polarity reversal can be seen as the amplitude changes from positive to negative values.

Figure 6 shows the seismic data with near, mid and far angles. The facies log is overlain which shows shale and gas sand facies. It can be seen that the interface or reservoir top between shale and gas sands fall at peak in near angle stack and in trough at far angle stack data. Figure 7 shows the AVO curve which ascertains the presence of polarity reversal

Trough over Peak signature

At deeper depths gas sands with low impedance or similar impedance to shales may be found if the porosity is retained and is not destroyed, presence of gas in sand can lower the impedance significantly and this lowering can give rise to bright negative reflection. If this amplitude increases with offset then there may be chances for hydrocarbon presence.

Increase of amplitude with offset

Increase of amplitude with offset supported with polarity is a very promising indicator for hydrocarbon detection as shown in the Figure8.

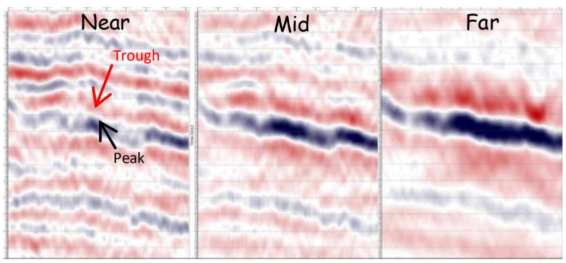

Figure 8: Seismic data from Near, Mid and Far angle stacks.The bright spot is characterised by trough over peak anomaly.The anomaly is not seen at near angle stack but appears at far angle stack.

Algorithm

An algorithm is specified as below to streamline the workflow

Step1: Check the polarity of the data

(Water bottom in marine case, any known reflector in land cases or provided by the seismic data processor)

Step2: Investigate the polarity at the prospect

If soft top (trough over peak reflection)
Go to 3
If hard top (peak over trough reflection)
Go to 4

Step3: Check the AVO

If amplitude doesn't decrease with offset

Low impedance or equivalent impedance (as that of shale) hydrocarbon possibility

If not and the prospect is at deeper depths

Absence of hydrocarbon indication

If not and the prospect is at shallow depth

Low possibility of highly unconsolidated sands
Needs to be correlated with geological models

Step4: Check the AVO

If amplitude increases with offset

Absence of hydrocarbon indication, may be presence of igneous strata

If not and the prospect is at deeper depths

Possibility of high impedance gas sands
Needs further analysis

If not and the prospect is at shallow depths

Absence of hydrocarbon indication

If amplitude decreases with offset, changes polarity and further increases

Possibility of equivalent impedance sands
Needs to be further investigated

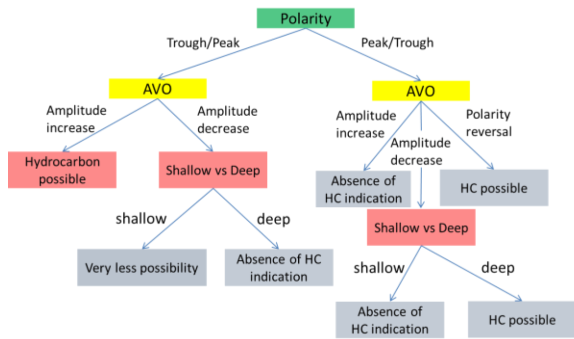

Figure 9: Flowchart of the algorithmic approach

Case study

A case study is presented here from the deeper section of the subsurface. First the polarity signature of the data was examined. It was found that the water bottom reflectivity was represented by peak.

Figure 10 shows the near and far angle stack seismic section from the case study, it is observed that the bright spot anomaly, as shown in encircled area, is characterized with peak over trough signature.

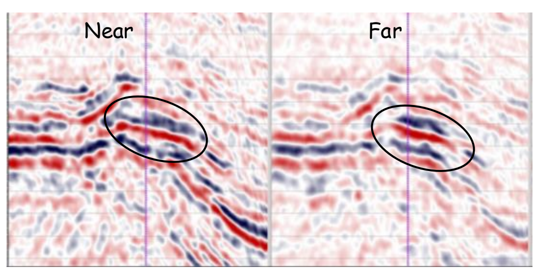

Figure 10: Seismic data from Near and Far angle stacks.

Now let's assume there can be two possibilities
1. Low impedance gas sand having soft top
2. High impedance gas sand having hard top

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The polarity of the data (peak over trough) doesn't support the first condition. Also the anomaly is at deeper depths so high impedance sands are expected here and not low impedance sands. The second condition is met according to the data. The polarity of data supports this case as peak over trough signature is seen.

Next a check for near and far angle seismic data for AVO comparison is made. Since just by visualization it was difficult to assess that whether the amplitude at far offsets increases or not, a single seismic trace from near and far angle stack was extracted (Figure 11).The anomalous bright spots or seismic signatures were marked as position 1, 2, 3 &4.These positions are to be checked. Near trace is represented by blue color and far by pink.

Position1: Far trace exceeds near trace. (not a probable condition).As amplitude of peak signature at high impedance sand top will not increase with offset.

Position2: Far trace exceeds near trace. (not a probable condition as polarity doesn't support trough/peak signature here)

Position3: Near trace exceeds Far trace. (a probable condition as polarity supports and AVO supports)
Position4: Near trace slightly increases far trace. (a probable condition for base of a high impedance sand)

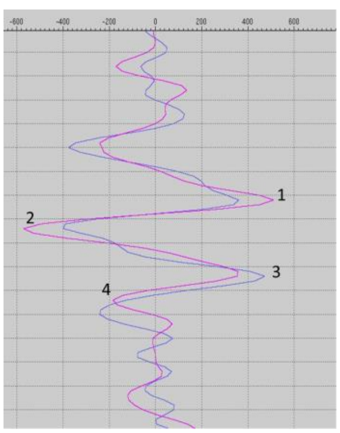

Figure 11: Seismic trace profile from a cdp at a proposed location from case study. Near angle is in blue far angle is in pink color.

A possibility matrix is filled up by the above analyzed anomaly pairs 1&2 and 3&4

	AVO	Polarity
Soft top (low impedance)	✓	X
Hard top (high impedance)	X	✓

Table1: Matrix for bright spot at position1 (peak) and 2(trough)

So it is concluded on basis of AVO and polarity both signatures are not favorable for either low impedance or high impedance gas sands for the first pair of bright spot at position1 and 2.

	AVO	Polarity
Soft top (low impedance)	X	X
Hard top (high impedance)	✓	✓

Table2: Matrix for bright spot at position3 (peak) and 4(trough)

So it is concluded on the basis of AVO and polarity that signatures at position3 and 4 are favorable for high impedance gas sands.

The drilling results confirmed our inferences as position 1 and 2 encountered tight limestone facies while at position 3 and 4 we find high impedance hydrocarbon sand.

Conclusion

The analytical approach presented here brings clarity in analyzing the bright spot and screens the relevant signature for detailed analysis and rejects the irrelevant signatures upfront. This approach presents the coupled usage of polarity with AVO impressions. This paper has tried to fill that gap at primal investigations for hydrocarbon search.

References

Rutherford, StevenR. and Williams, Robert H., 1989,Amplitude–versus-offset variations in gas sands;Geophysics Vol.54,P680-688.

Ostrander, W.J., 1982, Plane-wave reflection coefficients for gas sands at nonnormal angles of incidence: Geophysics**, 49,** 1637-1648.

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