Discussion on the applicability of $90^\circ$ phase conversion technique in seismic sedimentology

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Abstract. Since 1998, domestic and foreign scholars have conducted more systematic research on the theory and application technology of seismic sedimentology, and $90^\circ$ phase conversion has been proposed as one of the core technologies of seismic sedimentology. But in actual research and application, the technology has not achieved the expected results. The $90^\circ$ phase conversion intends to give the meaning of the seismic reflection event representing the stratum interface to the lithologic strata by means of phase shift. Due to the complexity and change of the underground strata, there are usually multiple lithology frequent thin interbeds. Therefore, the event axis in the seismic profile is the combined effect of multiple sets of thin interbeds. The seismic data after $90^\circ$ phase conversion cannot convert the original seismic data from interface seismic profile to lithologic stratigraphic profile, and lacks clear geological meaning. Its application ability in seismic structure interpretation and seismic lithology interpretation is very limited. Therefore, it is difficult to become an applied technology of seismic sedimentology. Therefore, it is not appropriate to use the $90^\circ$ phase conversion technology as the core technology of seismic sedimentology. This technology neither improves the seismic data resolution capability nor accurately converts the seismic profile into a lithological profile.

Key words: seismic sedimentology, $90^\circ$ phase transformation, quadrature, seismic forward modelling.

1. Introduction
In 1998, Zeng Hongliu, Stephen C Henry, and John P Riola used the term seismic sedimentology for the first time [1] and proposed the concept of seismic sedimentology. In 2001, he published a paper on The Leading Edge explaining that seismic sedimentology is an interdisciplinary subject that
comprehensively uses seismic data to study sedimentary rocks, sedimentary facies and their formation processes [2]. In 2006, Lin Chengyan, Zhang Xianguo [3] [4] and others summarized seismic sedimentology as: make full use of seismic means, and under the constraints of well data, conduct macroscopic studies of rock formations, sedimentary facies, sedimentary history and sedimentary systems. In 2008, Lu Yongchao, Du Xuebin, Zhu Wenbin (2008) and other scholars pointed out that seismic sedimentology is based on the comprehensive geological interpretation of seismic data, combined with the combined feedback of the sedimentary environment model established by modern sedimentary system research, outcrop and drilling core data. It is a new method system used to identify the three-dimensional geometry, internal structure, lithofacies palaeogeography and sedimentary process of the sedimentary unit [5] [6]. Liu Baoguo, Liu Lihui, Song Yan (2009) and others put forward the concept of practical seismic sedimentology based on practical applications. Practical seismic sedimentology is based on seismic reservoir prediction technology (multi-attribute analysis and seismic wave impedance inversion) and seismic facies analysis methods. Mainly, it is a discipline that studies the sedimentary facies and its formation process in the isochronous stratigraphic framework. It is the product of the combination of sequence stratigraphy, paleomorphology, sedimentology, and seismic reservoir prediction technology. It can be seen that seismic sedimentology has developed to a state where a hundred flowers bloom and a hundred schools of thought are contending, and the development of its research has enriched the new content of sedimentology research.

In the study of seismic sedimentology, scholars such as Dong Chunmei, Zhang Xianguo, Lin Chengyan (2006) proposed three key technologies in seismic sedimentology: 90° phase conversion, stratigraphic slicing and frequency division interpretation. Scholars such as Lin Chengyan and Zhang Xianguo [3] believe that the 90° phase conversion (not limited to 90°) gives the seismic phase a stratigraphic significance and can be used for seismic interpretation of high-frequency sequence stratigraphy. However, the author believes through many years of geophysical exploration practice that the 90° phase conversion does not substantially improve the resolution of the seismic profile, but only rotates the seismic phase by 90° through the Hilbert transformation. The difference in wave impedance is based on the reflection of the stratum interface. In most cases, the stratum is a thin interbedded sediment of sand and mudstone. Simple phase conversion cannot bring the seismic reflection peak (valley) to the center of the stratum. Therefore, the 90° phase Conversion as the key technology of seismic deposition is debatable.

2. Application of 90° Phase Conversion Technology in Seismic Sedimentology
Many scholars often emphasize the application of 90° phase conversion technology when talking about the research technology of seismic sedimentology. It is generally believed that: according to the principle of seismic exploration, the seismic event in the seismic data volume reflects the wave impedance (reflection Coefficient) difference of the stratum interface, that is, the seismic reflection is essentially the reflection of the stratum interface. Seismic sedimentology studies the sedimentary facies and sedimentary evolution systems of each stratigraphic unit under the isochronous stratigraphic framework. Therefore, seismic data is converted into 90° phase in order to make the seismic event axis face the stratum. The amplitude and the event axis have certain lithologic and stratigraphic significance.

Scholars such as Lin Chengyan, Chen Wenxiong, Zeng Hongliu [2] [3] also proposed: 1. The seismic 90° phase conversion technology mainly converts zero-phase seismic data into 90° phase seismic data through Hilbert transform. Make the main lobe of the seismic reflection wave rise to the center of the thin layer (Figure 1); 2. After the conversion, the peak (valley) of the seismic reflection wave's event axis corresponds to the stratum, not to the top and bottom interfaces of the stratum. At this time, the seismic phase is at the thickness range of a wavelength corresponds to the lithology. If the peak (valley) of the original zero-phase seismic data corresponds to the stratum interface R, then after 30°, 60°, and 90° phase conversion, the peak of the event axis corresponds to the sedimentary strata, Figure 1 also
shows the For the thin layer of the double interface, after 90° phase conversion, the valley of the event axis corresponds to the sedimentary strata.

Figure 1. Relationship between formation interface with the phase of seismic events (Hongliu Zeng, 2005)

In the research of the thesis, a single layer of low-resistance sandstone with a thickness of 20m (that is, the wave impedance of sandstone is smaller than that of mudstone) was selected, and corresponding seismic forward modeling was performed. The top of the sandstone is a wave trough and the bottom is a wave peak (Figure 2). After the 90° phase conversion, the wave crest event axis corresponds to the sand layer, and the tracing of the wave crest is the sand tracing (Figure 3).

Figure 2. The right side is 20m isolated low resistance sand layer in the mudstone, and the left is the seismic forward simulation for it

Figure 3. After 90° phase transformation, the peak is corresponding to the sand

The same effect has been achieved in the application of actual seismic data in a research area in the Bohai Basin. The thickness of the sandstone uphole is 23m, and its wave impedance is smaller than that of the mudstone section above and below it. It is calibrated by synthetic seismic records that the top of the sand layer corresponds to the wave trough and the bottom corresponds to the wave peak (Figure 4). After the 90° phase conversion, the uphole sand section corresponds to the phase shifted wave peak,
indicating that for the seismically distinguishable thick sand body, after the 90° phase conversion, the sand layer can be tracked through the wave crest tracking. (Figure 4).

**Figure 4.** The 90° phase transformation technology is feasible for thick sand body

In short, many seismic sedimentology regard 90° phase conversion as one of their key technologies because they hope to use 90° phase conversion to convert the interface type seismic data volume into earthquakes whose seismic amplitude and event axis have a certain lithological significance. Data in order to directly use seismic data for interpretation of sedimentary rocks and sedimentary facies. For isolated formations with a large thickness (greater than 20m), this technique can achieve better results (Figure 4). However, since most of the terrestrial deposits are thin interbeds of sand and mudstone, few single layers are thicker than the 20m sandstone layer is limited by the resolution of seismic data. The seismic event axis is usually a combination effect of multiple sets of thin layers. After 90° phase conversion, it is difficult to make the seismic reflection event axis directly face the lithological strata. It has its geological significance.

### 3. Discussion on the Application of 90° Phase Conversion Technology

In the practical application of seismic exploration, the 90° phase conversion is realized through trace integration, that is, the Hilbert transform is performed on each seismic trace of the seismic data:

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H(t) = \frac{1}{\pi t} \ast f(t) \quad H(t): \text{integral channel}; f(t): \text{original seismic channel}; \ast: \text{convolution.}
\]

Compared with the original seismic trace, the integrated seismic trace has only a 90° phase shift, and no new content has been added (Figure 5). The profile shape and structure are the same. Obviously, it does not improve the resolution of seismic data.

**Figure 5.** The contrast between the quadrature trace and the seismic trace, there is a 90° phase shift.

Since the integration channel and the original seismic channel have a 90° phase shift, will the phase shift be used to convert the seismic event axis representing the stratum interface into a lithological stratum? Due to the thickness and complexity of the underground sedimentary strata, the seismic event axis is often a reflection of the underground stratum, and the event axis is difficult to represent the underground lithological strata. This can be analyzed and studied by the seismic forward modeling of thin sandstone interbedded layers.
Table 1. Parameter table of forward modeling of seismic response of thin sand and mud interbed

|        | Thickness (m) | Layers | Velocity (m/s) | Density (kg/m³) |
|--------|---------------|--------|----------------|-----------------|
| Mudstone | 10            | 17     | 3800           | 2320            |
| sandstone | 20            | 17     | 4800           | 2470            |

Figure 6. The 500m thin sand-shale interbeds seismic response forward simulation.

Heading with Each Initial Letter Ca Through forward modeling, due to the limitation of seismic resolution, for the 500m thick sand and mudstone thin interbedded section designed by the model, no obvious seismic event axis is formed, only strong seismic reflection in-phase is generated on the top and bottom surfaces of the thin interbedded section. Axis, and also formed side lobes. Obviously, in this model, although the sandstone has reached a thickness of 20m, it does not form an independent seismic reflection, but the reflection of the entire thin layer. The top and bottom interfaces of the thin sandstone interbed There is a significant wave impedance difference in the layer, forming a strong seismic reflection event axis. For such seismic data, no matter how phase shift is performed, it is difficult to match the specific lithology.

Since the seismic reflection event axis is the comprehensive response of multiple sets of underground lithologic formations, and the underground lithologic formation is complex and changeable, it is almost impossible to try to achieve the correspondence between the seismic event event axis and the lithologic formation through a simple 90° phase conversion. That is, it is inappropriate to regard it as one of the key technologies of seismic sedimentology.

4. Conclusion
Since the 90° phase shift is simply performed by the Hilbert transformation, the seismic data after 90° phase conversion cannot convert the original seismic data from the interface seismic reflection profile to the lithologic stratigraphic profile and lacks clear geological meaning. Seismic structure interpretation and seismic lithology interpretation have limited application capabilities, so it is difficult to become an application technology of seismic sedimentology.

According to the broad definition of seismic sedimentology: a discipline that uses seismic data to study sedimentary rocks and their formation processes, it can be considered that the core content of seismic sedimentology is the use of seismic technical means and methods to assist in the study of sedimentary facies. For seismic sedimentology research technology, it should include all seismic exploration technologies and methods that can assist in the study of sedimentary rocks and sedimentary facies, such as seismic attribute analysis, wave impedance inversion, stratum slicing, seismic frequency division, seismic facies waveform analysis, etc. .

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