ANOMALOUSLY PRESSURED GAS DISTRIBUTION IN THE WIND RIVER BASIN, WYOMING

Topical Technical Progress Report

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Executive Summary

Anomalously pressured gas (APG) assets, typically called “basin-center” gas accumulations, represent either an underdeveloped or undeveloped energy resource in the Rocky Mountain Laramide Basins (RMLB). Historically, the exploitation of these gas resources has proven to be very difficult and costly. In this topical report, an improved exploration strategy is outlined in conjunction with a more detailed description of new diagnostic techniques that more efficiently detect anomalously pressured, gas-charged domains. The ability to delineate gas-charged domains occurring below a regional velocity inversion surface allows operators to significantly reduce risk in the search for APG resources. The Wind River Basin was chosen for this demonstration because of the convergence of public data availability (i.e., thousands of mud logs and DSTs and 2400 mi of 2-D seismic lines); the evolution of new diagnostic techniques; a 175 digital sonic log suite; a regional stratigraphic framework; and corporate interest.

In the exploration scheme discussed in this topical report, the basinwide gas distribution is determined in the following steps:

1. A detailed velocity model is established from sonic logs, 2-D seismic lines, and, if available, 3-D seismic data. In constructing the seismic interval velocity field, automatic picking technology using continuous, statistically-derived interval velocity selection, as well as conventional graphical interactive methodologies are utilized.

2. Next, the *ideal* regional velocity/depth function is removed from the observed sonic or seismic velocity/depth profile. The constructed *ideal* regional velocity/depth function is the velocity/depth trend resulting from the progressive burial of a rock/fluid system of constant rock/fluid composition, with all other factors remaining constant.

3. The removal of the *ideal* regional velocity/depth function isolates the anomalously slow velocities and allows the evaluation of (1) the regional velocity inversion surface (i.e., pressure surface boundary); (2) detection and delineation of gas-charged domains beneath the velocity inversion surface (i.e., volumes characterized by anomalously slow velocities); and (3) variations within the internal fabric of the velocity anomaly (i.e., variations in gas charge).

Using these procedures, it is possible to construct an anomalous velocity profile for an area, or in the case of the Wind River Basin, an anomalous velocity volume for the whole basin. Such an anomalous velocity volume has been constructed for the Wind River Basin based on 1600 mi of 2-D seismic data and 175 sonic logs, for a total of 132,000 velocity/depth profiles. The technology was tested by constructing six cross sections through the anomalous velocity volume coincident with known gas fields. In each of the cross sections, a strong and intense anomalously slow velocity domain coincided with the gas productive rock/fluid interval; there were no exceptions.

To illustrate the applicability of the technology, six target areas were chosen from a series of cross sections through the anomalous velocity volume. The criteria for selection of these undrilled target areas were (1) they were characterized by anomalous velocity domains comparable to known gas fields; (2) they had structural, stratigraphic, and temporal elements analogous to one of the known fields; and (3) they were located at least six sonic miles from the nearest known gas field. The next step in the exploration evolution would be to determine if the detected gas-charged domains

are intersected by reservoir intervals characterized by enhanced porosity and permeability. If, in any of these targeted areas, the gas-charged domains are penetrated by reservoir intervals with enhanced storage and deliverability, the gas-charged domains could be elevated to drillable prospects.

Hopefully, the work described in this report (the detection and delineation of gas-charged domains) will enable operators in the Wind River Basin and elsewhere to reduce risk significantly and increase the rate and magnitude of converting APG resources to energy reserves.

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Anomalously Pressured Gas Distribution in the Wind River Basin, Wyoming

INTRODUCTION

Basin-center and deep-basin gas assets, or more accurately, anomalously pressured gas accumulations (Figures 1A,B) represent a huge, relatively untapped North American energy. For example, in the Wind River Basin, Wyoming (~8500 mi^2) the USGS estimates that the in-place APG resource is nearly 900 Tcf (Figure 2; Johnson et al., 1998). However, cumulative production, to date, from the anomalously pressured portion of the stratigraphic section in the Wind River Basin is less than 1 Tcf. This type of gas-in-place to production imbalance is typical in most of the RMLB. Obviously, these huge, undeveloped or underdeveloped gas resources, which occur in all the RMLB, need to be more effectively exploited. In the past, the exploitation of APG resources in the RMLB has been difficult and costly, but there are a few notable exceptions, such as the Jonah Field in the western Green River Basin, the Standard Draw-Echo Springs Field in the Washakie Basin, and the Cave Gulch Field in the Wind River Basin, and relatively older successes in the Alberta, Denver-Julesberg, and San Juan basins. These notable successes demonstrate that the task of exploiting the APG assets in the RMLB can be accomplished, and that the financial rewards can be great. To more fully exploit APG assets in the RMLB will require new strategies, technologies, and diagnostic techniques, all with the dedicated objective of substantially *increasing the rate and magnitude* of converting these gas resources to energy reserves.

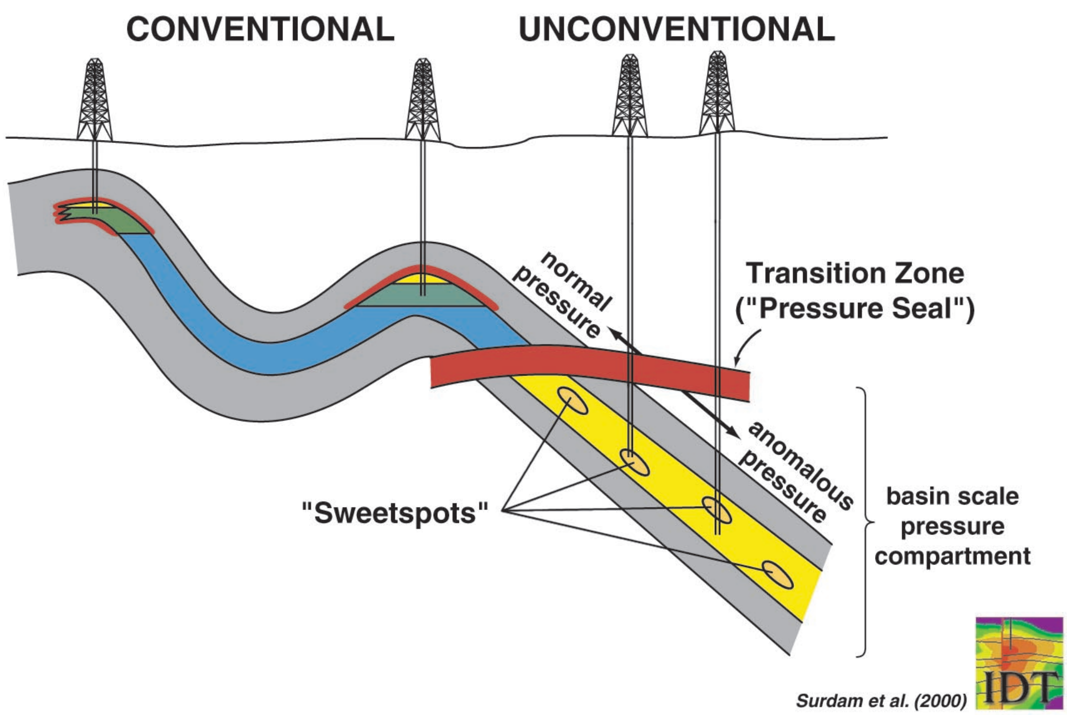


Figure 1. Schematic diagram illustrating the two elements crucial to hydrocarbon exploration in gas-saturated, anomalously pressured rocks: (1) the pressure boundary (i.e., regional velocity inversion surface) and (2) sweet spots.

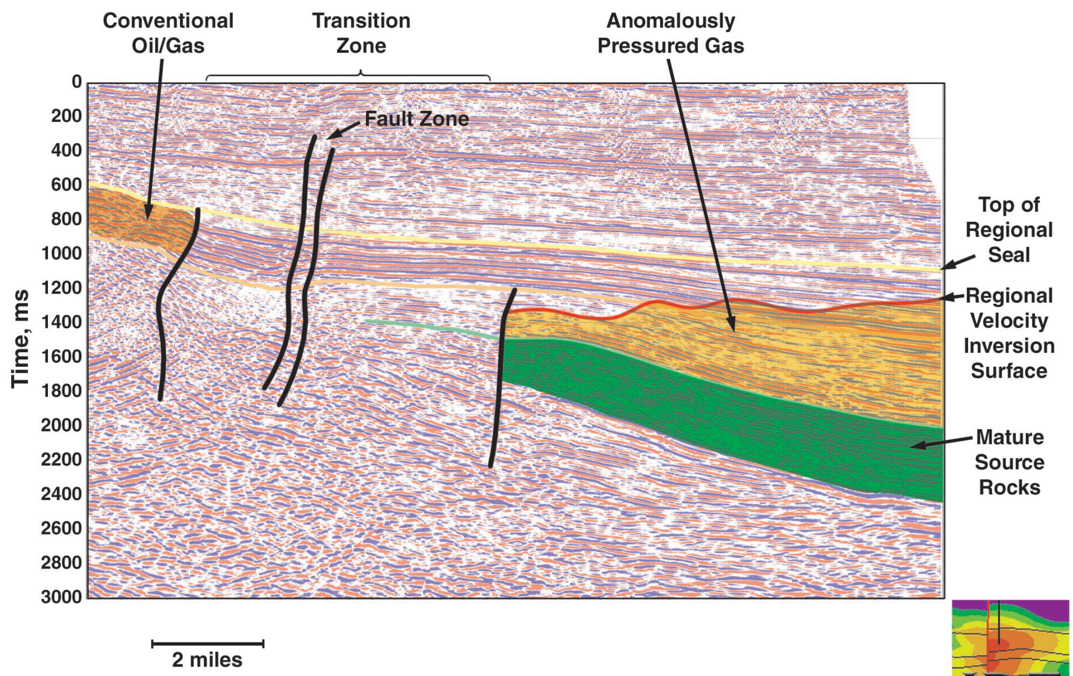


Figure 1B. Seismic stack section that cuts through a petroliferous basin, showing the distribution of conventional oil/gas and anomalously pressured gas fields. The relationship between the regional velocity inversion surface and the APG accumulations is also shown.

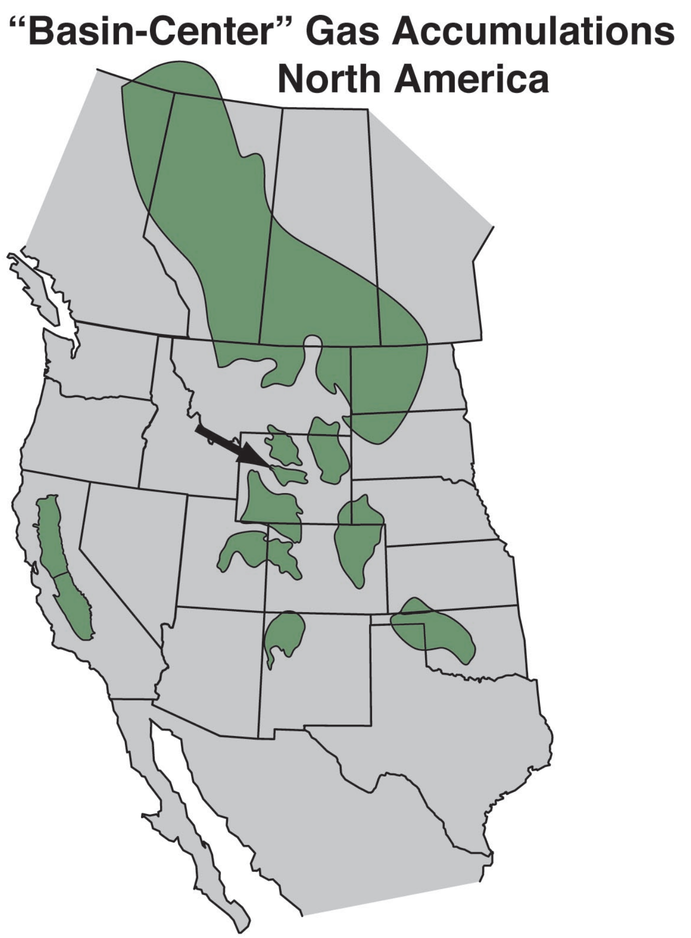


Figure 2. Map showing the Rocky Mountain Laramide Basins and Anadarko and Sacramento Basins, where the new IDT exploration strategy and diagnostic tools for APG accumulations have been applied. The black arrow points to the Wind River Basin, WY.

In the Wind River Basin of Wyoming, like most RMLB, the first step to achieving a substantial increase in the rate and magnitude of converting anomalously pressured gas resources to energy reserves is to gain a vastly improved understanding of the regional distribution of the targeted gas asset. The application of integrated new and improved diagnostic techniques that result in a more effective determination of the regional distribution of APG assets will serve as the centerpiece of this topical report. These diagnostic techniques will be applied to the Wind River Basin of Wyoming, but they are generally applicable to all the RMLB.

NEW EXPLORATION STRATEGY

The research being conducted at Innovative Discovery Technologies (IDT) — which is supported by DOE under Contract DE-FC26-01NT41325 — is dedicated to demonstrating a new and more effective way to explore for and exploit APG assets in the RMLB. The IDT technology is the product of more than 10 years of research in 30 basins from around the world (Table 1). From this experience, several key interpretive exploration elements have been isolated that are critical to the efficient, effective discovery and exploitation of anomalously pressured, "basin-center" gas resources. These key interpretive exploration elements include, but are not limited to, the following petroleum system attributes:

1. Gas distribution;
2. Gas migration conduits;
3. Gas content of the reservoir rock/fluid systems;
4. Fracture swarm distribution;
5. Linear fault orientations; and
6. Reservoir attributes associated with enhanced porosity and permeability in the targeted production intervals.

Explorationists presently have at their disposal the technology and diagnostic techniques to evaluate all of the above critical elements of a petroleum system. The strategy that IDT espouses is based on determining the potential for spatial overlap of the optimum values of as

ROCKY MOUNTAIN BASINS	INTERNATIONAL
Powder River Basin, WY	Mahakam Delta (East Kalimantan), Indonesia
Bighorn Basin, WY	Kiru Trough (Sumatra), Indonesia
Wind River Basin, WY	Waropen Basin, Indonesia
Badger Basin, WY	Offshore Camaroons (West Africa), Cameroons
Washakie Basin, WY	Bohai Bay, China
Green River Basin, WY	South China Sea, China
Hanna Basin, WY	Yellow River Delta, East China
Hoback Basin, WY	Cooper Basin, Australia
Great Divide Basin, WY	San Jorge Basin, Argentina
Sand Wash Basin, WY, CO	Neuquen Basin, Argentina
Denver Basin, CO	Maturin Basin, Venezuela
Piceance Basin, CO	Cauca Valley, Colombia
South Park Basin, CO	
Uinta Basin, UT	
San Juan Basin, NM	
West Canada (Alberta) Basin, Canada	
Other North American Basins	
Western Anadarko Basin, OK	
Sacramento Basin, CA	

Table 1. List of basins in which the IDT exploration strategy and associated technologies have been applied.

many of the key interpretive elements as possible (Figure 3). The degree and quantity of overlap of the optimum values for each of the key interpretive elements determines the uncertainty of defining APG production "sweet spots." Gas production sweet spots are defined spatially as the intersection of a gas-charged fluid domain with a reservoir rock domain characterized by enhanced porosity and permeability (Figure 4). The focus of this report is the techniques used to define gas distribution and gas migration conduits within the Cretaceous-Tertiary stratigraphic interval of the Wind River Basin.

TECHNOLOGY DEMONSTRATION: RESULTS AND DISCUSSION

Wind River Basin

The Wind River Basin is an ideal setting for demonstrating a determination of gas distribution on a basinwide scale in a typical RMLB. This unique demonstration has never yet been attempted in any RMLB because of data limitations, and is only now possible in the Wind River Basin because of the convergence of public availability of thousands of mud logs and DSTs; 2400 mi of 2-D seismic lines (from Echo Geophysical Corp.; see Figure 5); the IDT technology and a digital 175 well log suite compiled by IDT (Figure 6); the availability of a stratigraphic framework compiled by the USGS; and corporate interest. All of the data sets mentioned above have very good basinwide coverage.

Procedure for Evaluating Gas Distribution and Gas Migration Conduits

In the analytic approach advocated in this report, the diagnostic scheme for evaluating gas distribution in an RMLB begins with the construction of detailed velocity profiles, velocity fields, and finally, a velocity volume. In the case of the Wind River Basin, the evaluation began with the analysis of 175 sonic velocity logs, which proceeded as follows:

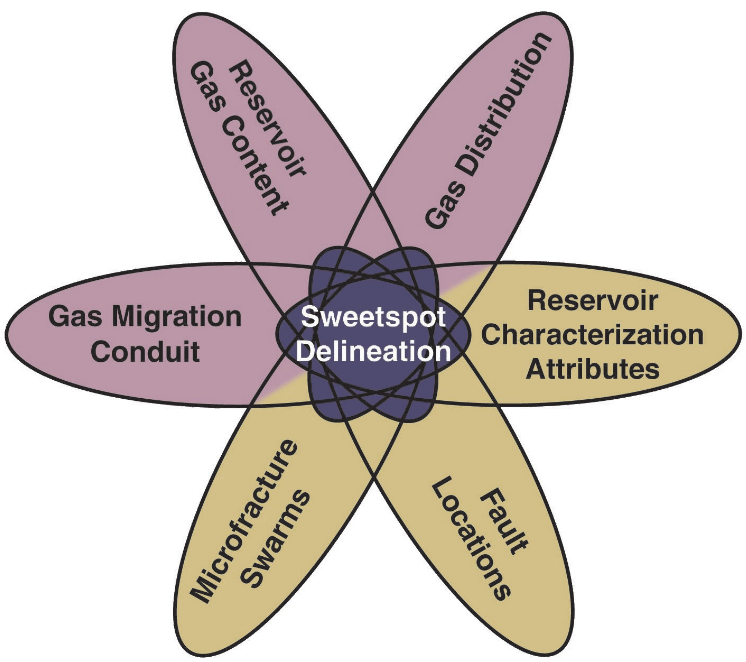


Figure 3. Illustration of an integrated strategy that examines the overlap of critical exploration elements. Exploration risk reduction is a function of the degree to which the optimum values of the critical elements overlap. From Surdam (2001).

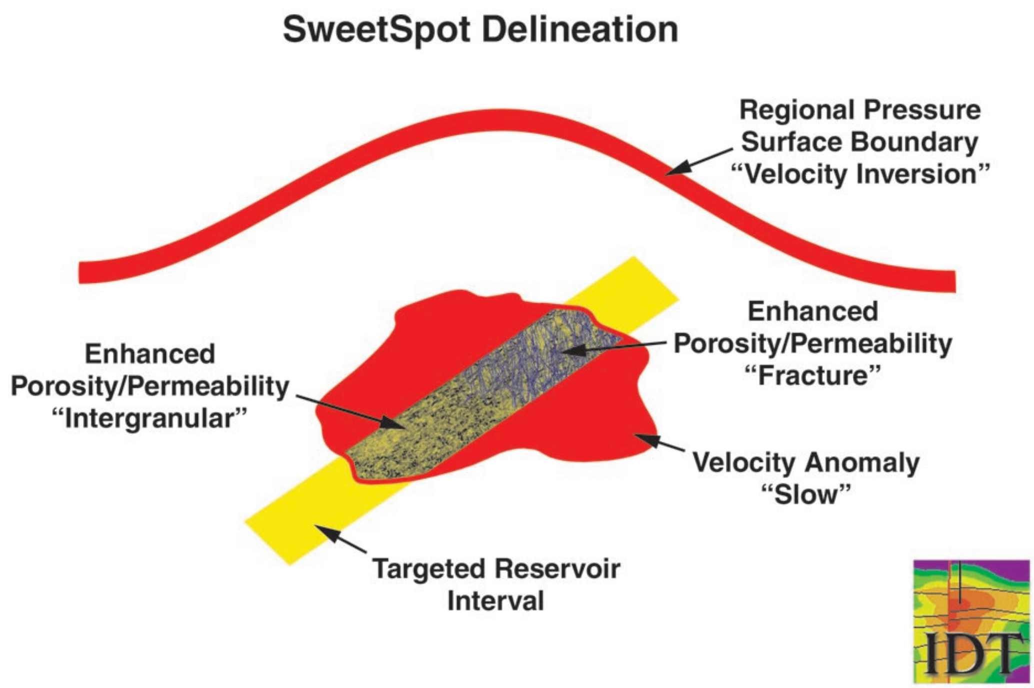


Figure 4. Schematic diagram illustrating that the gas production sweet spots are defined spatially as the intersection of a gas-charged fluid domain with a reservoir rock domain characterized by enhanced porosity and permeability.

Index Map for Echo Geophysical Co. Wind River Basin Seismic Data Base

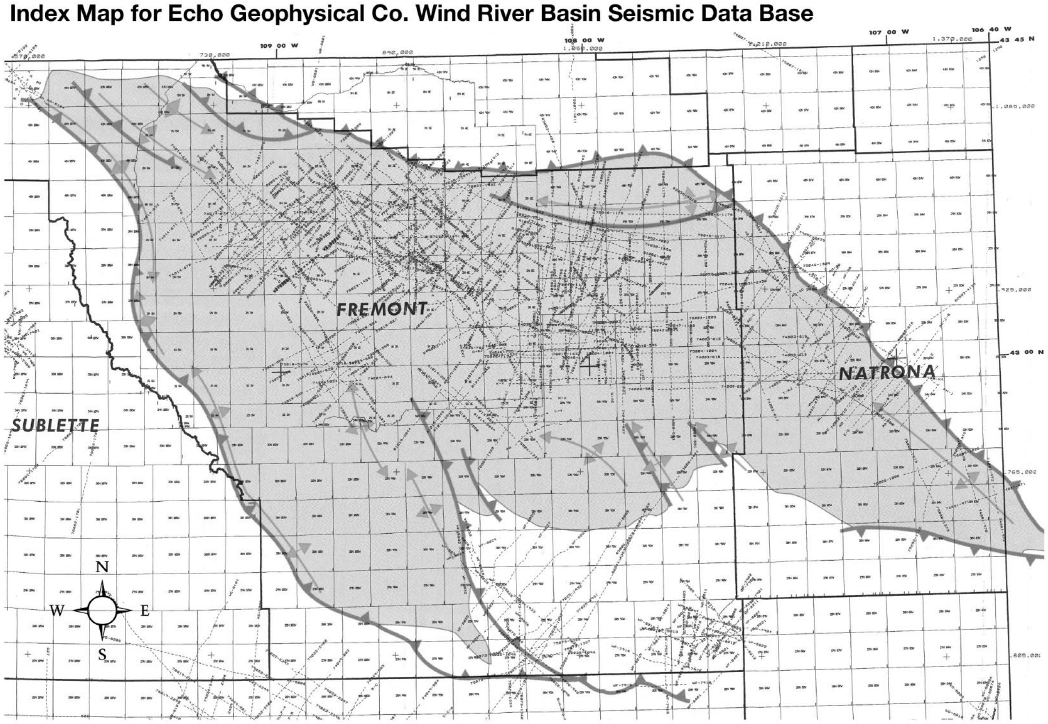


Figure 5. Index map of the 2400 mi of 2-D seismic data that are available for this project.

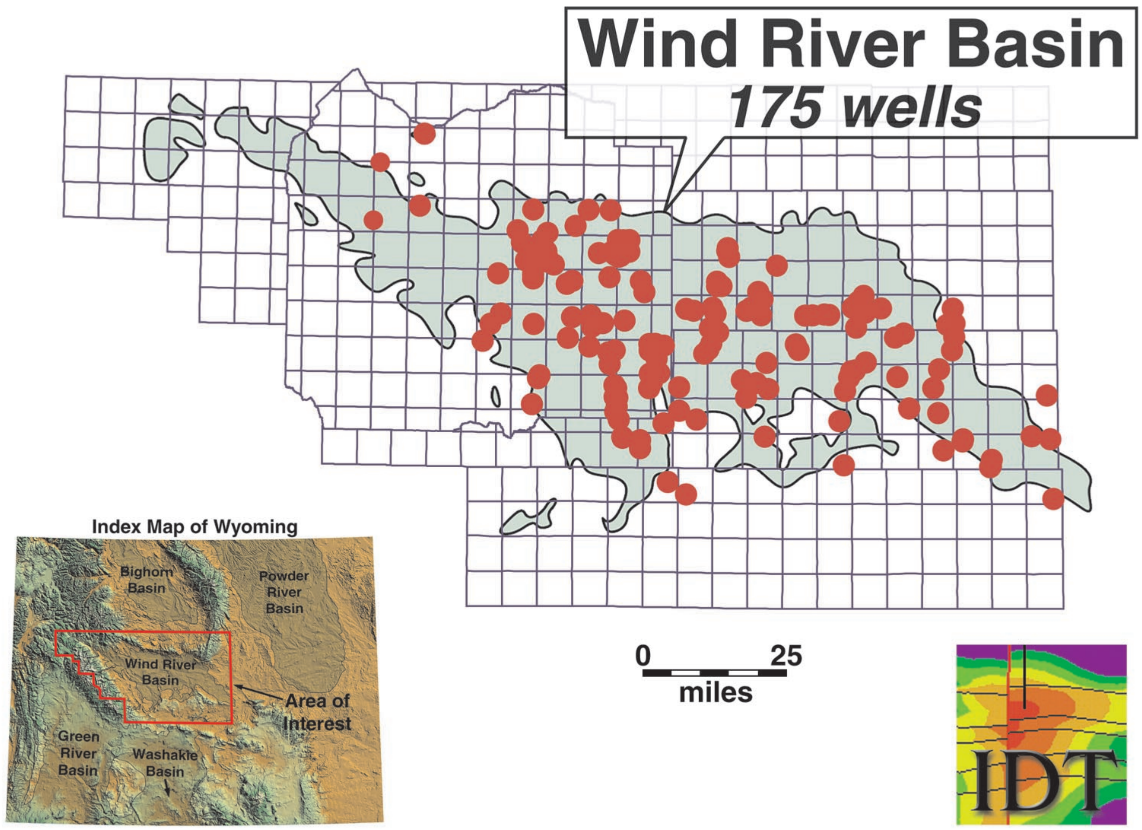


Figure 6. Index map showing the location in the Wind River Basin of the 175 digital well logs used in this project.

1. The sonic velocity/depth profiles were digitized, smoothed, and normalized.

2. Next, the *ideal* regional velocity/depth function was removed from the observed velocity/depth profile, which allowed isolation of anomalously slow velocities (Figure 7).

3. Isolation of the anomalously slow velocities allowed evaluation of (1) the potential for a regional velocity inversion surface (i.e., the boundary between normally pressured rock/fluid systems above and anomalously pressured rock/fluid systems below, which can be either over- or under pressured); (2) gas-charged domains (i.e., volumes characterized by anomalously slow velocities); and (3) variations within the internal fabric of the velocity anomaly.

Sonic Log Smoothing and Normalizing

If a well bore is in good condition and there are no problems with the logging environment, the sonic tool is capable of recording very accurate interval transit time profiles with depth. In practice, this ideal setting is not common. Even with good digitized sonic logs, several additional tasks are required before constructing a velocity/depth profile for the log. First, spike noises must be removed and cyclic skips must be replaced. These tasks are accomplished by programs designed to remove or smooth the spikes and cycle skips. Second, the effects of coal and carbonate-rich lithologies on the velocity/depth profile, which can be significant, must be removed. Third, missing (i.e., unconformity) or repeated (i.e., faults) sections must be replaced or removed from the observed sonic velocity/depth profile. These types of smoothing and normalizing have been used in this study.

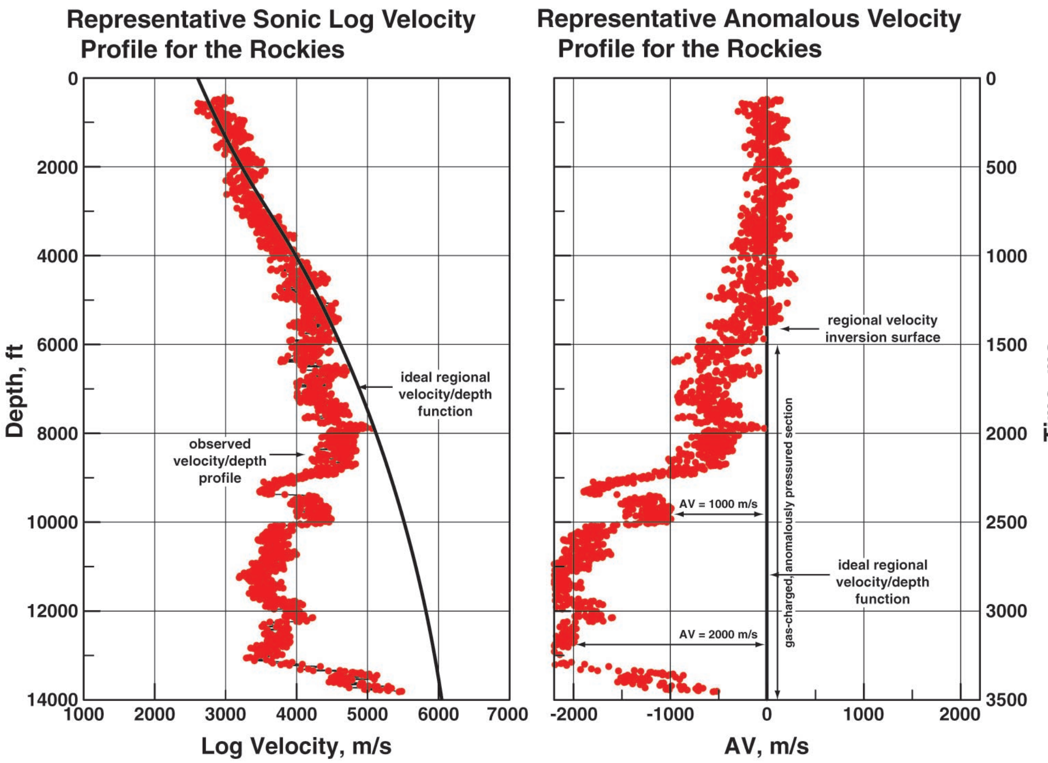


Figure 7. On the left panel are an observed sonic velocity profile (red) and an *ideal* regional velocity/depth trend (black). On the right panel, the *ideal* regional velocity/depth trend has been removed from the sonic velocity profile. The vertical black line is the *ideal* regional velocity/depth trend.

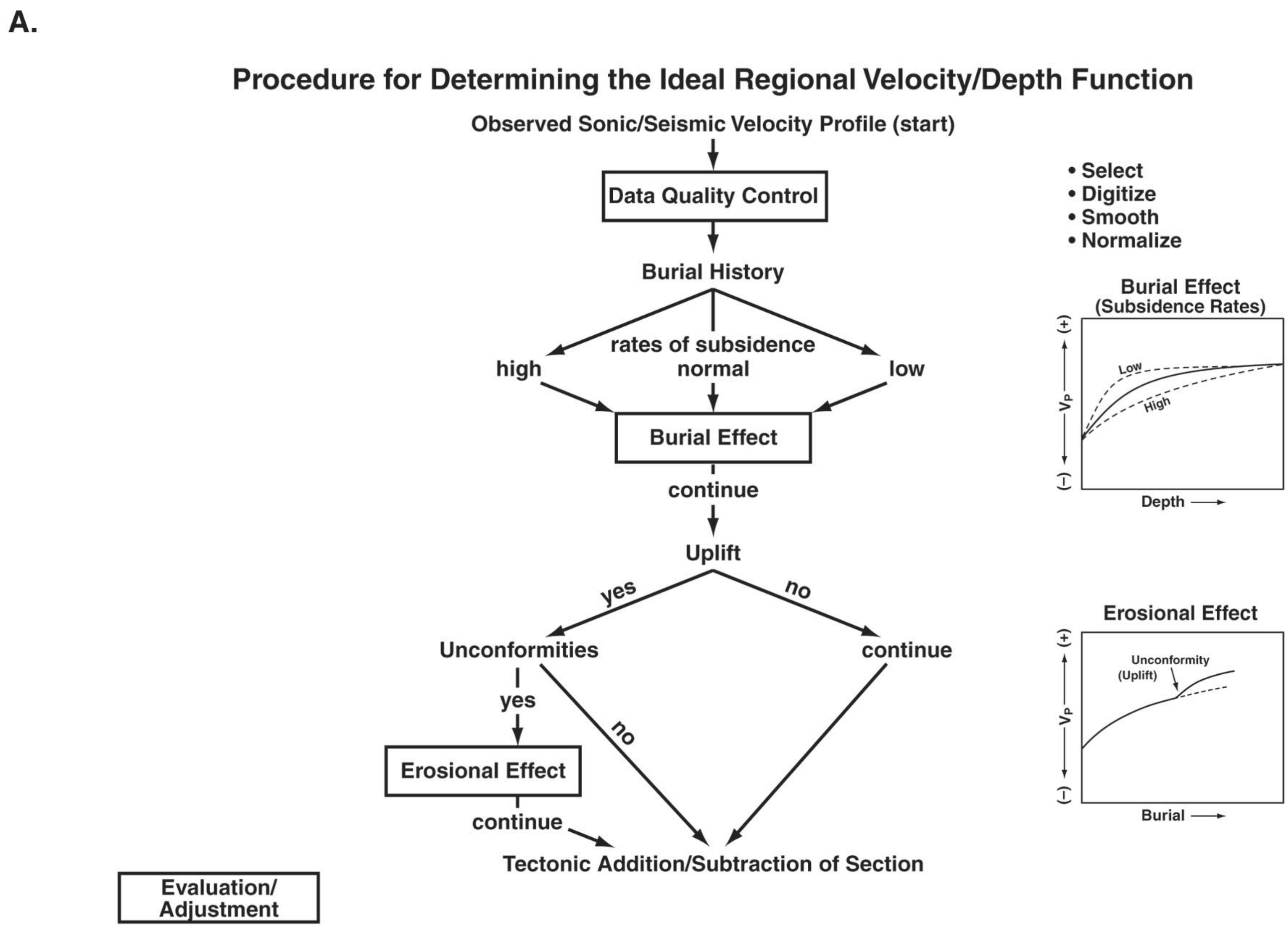
Ideal Regional Velocity Function

The ideal velocity/depth function is determined by integrating the geologic, geophysical, geochemical, and petrochemical characteristics of a specific basin or region including, but not limited to:

- Burial history,
- Stratigraphic/lithographic framework,
- Thermal/maturation systems,
- Hydrodynamic pressure regimes,
- Fluid composition, and
- Petrologic characteristics with petrochemical data (i.e., sonic velocity logs and seismic interval velocity profiles; see Figures 8A-C).

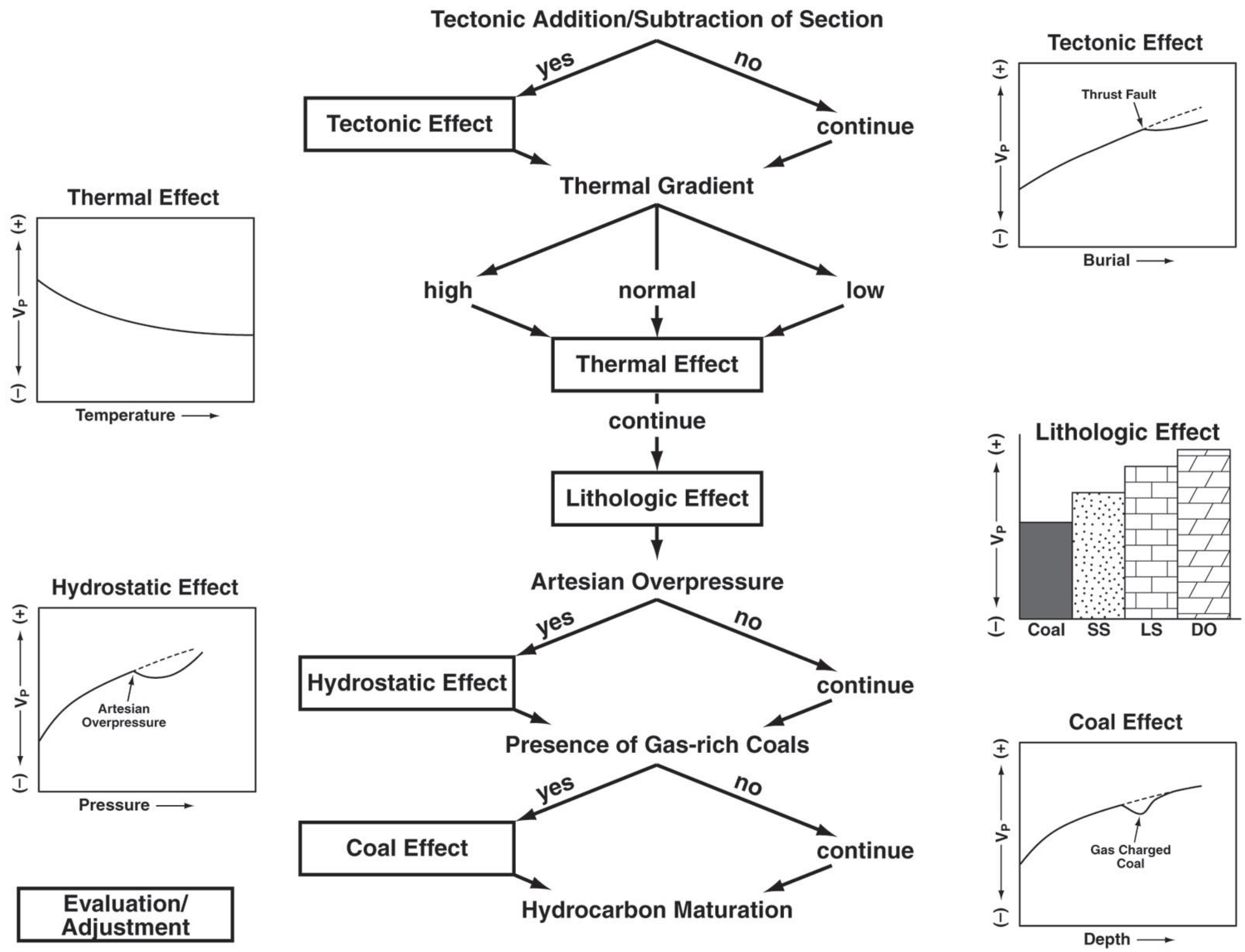
This integration results in a grossly improved understanding of the shape, constraining factors, limitations, and range of uncertainties associated with the velocity/depth function, and, most importantly, the potential for regional variations in the ideal velocity/depth function. Note that the procedure described in Figures 8A through 8C results in the removal of the velocity effect of many factors, not just the gas effect. The constructed ideal regional velocity/depth function is basically the velocity/depth trend resulting from the progressive burial of a rock/fluid system of constant rock/fluid composition, with all other factors remaining constant (Figures 8A-C).

Once the ideal regional velocity/depth trend is determined, a very useful velocity baseline is established that is invaluable in a variety of comparisons and velocity evaluations, particularly because, in the RMLB and in many other

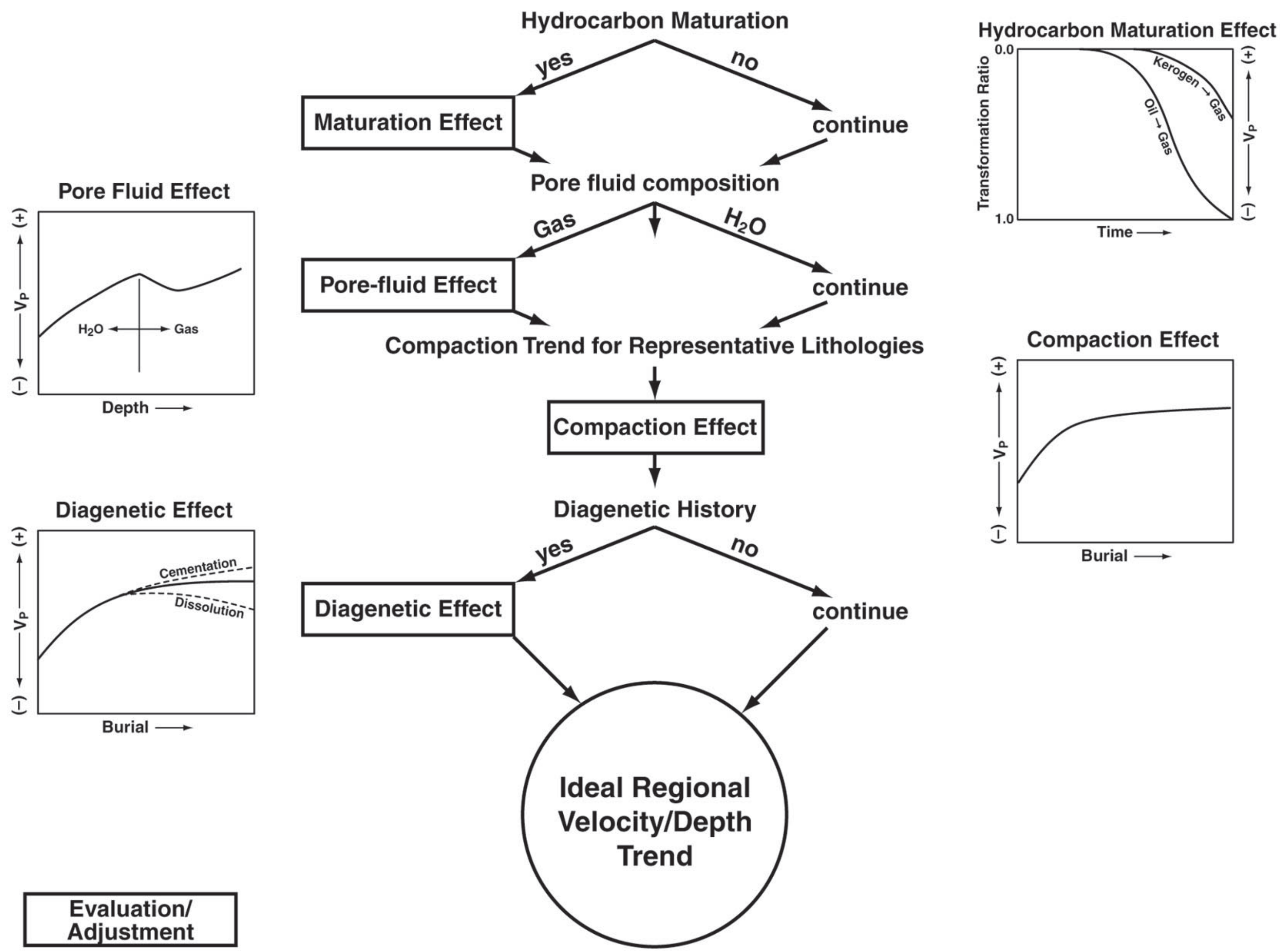


Figures 8A-C. Schematic diagrams of the stepwise procedures IDT utilizes in establishing the regional normal velocity/depth function in an area or basin of interest.

B.


Tectonic Addition/Subtraction of Section
yes
no
Tectonic Effect
continue
Thermal Gradient
high
normal
low
Thermal Effect
continue
Lithologic Effect
Artesian Overpressure
yes
no
Hydrostatic Effect
continue
Presence of Gas-rich Coals
yes
no
Coal Effect
continue
Hydrocarbon Maturation
Thermal Effect
(+)
Vp
(–)
Temperature
Hydrostatic Effect
Artesian Overpressure
Pressure
Evaluation/ Adjustment
Tectonic Effect
Thrust Fault
Burial
Lithologic Effect
Coal
SS
LS
DO
Coal Effect
Gas Charged Coal
Depth

C.



Hydrocarbon Maturation
yes
no
Maturation Effect
continue
Pore fluid composition
Gas
H2O
Pore-fluid Effect
continue
Compaction Trend for Representative Lithologies
Compaction Effect
Diagenetic History
yes
no
Diagenetic Effect
continue
Ideal Regional Velocity/Depth Trend
Pore Fluid Effect
(+) Vp (−)
H2O Gas
Depth
Diagenetic Effect
(+) Vp (−)
Cementation
Dissolution
Burial
Evaluation/ Adjustment
Hydrocarbon Maturation Effect
Transformation Ratio
0.0
1.0
Kerogen → Gas
Oil → Gas
Time
(+) Vp (−)
Compaction Effect
(+) Vp (−)
Burial

parts of the world, rock-fluid systems characterized by velocities significantly slower than would be predicted by the ideal regional velocity/depth function are gas-charged and anomalously pressured — some overpressured and some underpressured (Surdam, 1997). To illustrate this point, note that the background gas, gas shows, and gas flares from the mud logs have a very close correlation with the anomalously slow velocities from all 175 sonic logs (for an example, see Figure 9).

Analysis of the 175 sonic logs using this procedure is an important first step in the construction of velocity and anomalous velocity volumes for the Wind River Basin. However, 175 sonic logs spread over 8500 mi^2 yields a sampling grid too widely spaced to be of use in delineating anything but the gross aspects and configuration of the basin wide velocity field (Figure 10).

Seismic Velocity Field

In order to construct a more detailed and useful velocity field for the Wind River Basin, it is necessary to make the transition from sonic velocity to seismic interval velocity. The velocity field must be constructed from a more closely spaced sampling grid than is provided by the sonic logs, and the velocity construction must accurately portray the present-day velocity characteristics of the rock/fluid system of interest.

In the Wind River Basin, the seismic lines chosen for inclusion in the velocity field construction were constrained by a single criterion. This criterion stipulated that the seismic survey offset must be large enough to resolve anomalous velocity domains at the depth of the Mesaverde Group. At present, 145 or more 2-D seismic lines, which cover 1600+ miles, have

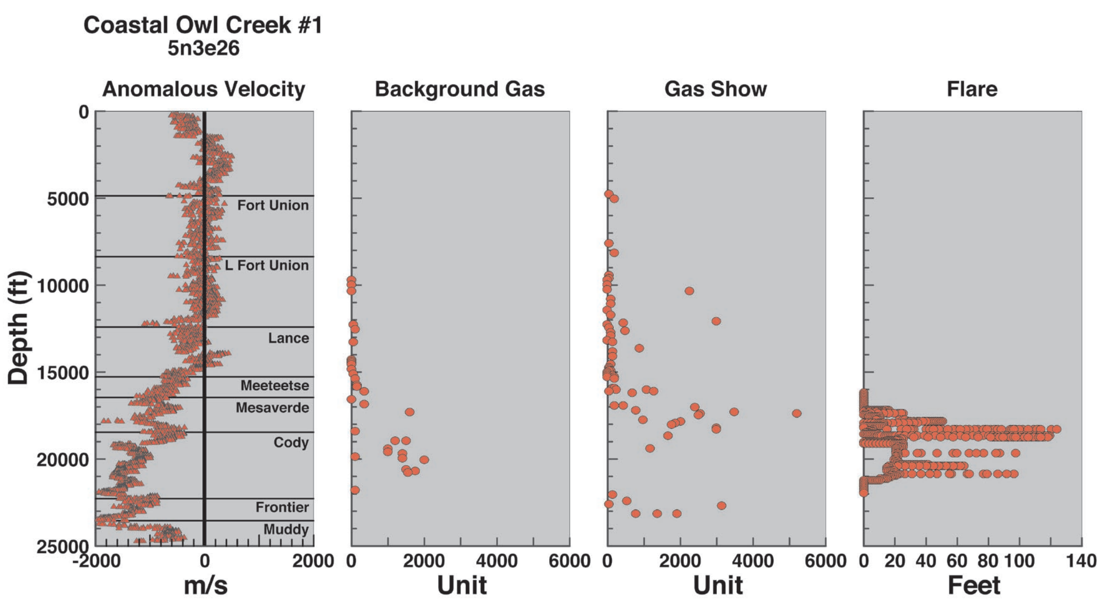


Figure 9. A typical anomalous velocity profile showing that the anomalously slow velocities below 13,000 ft present-day depth have a very close correlation with the background gas, gas shows, and gas flares.

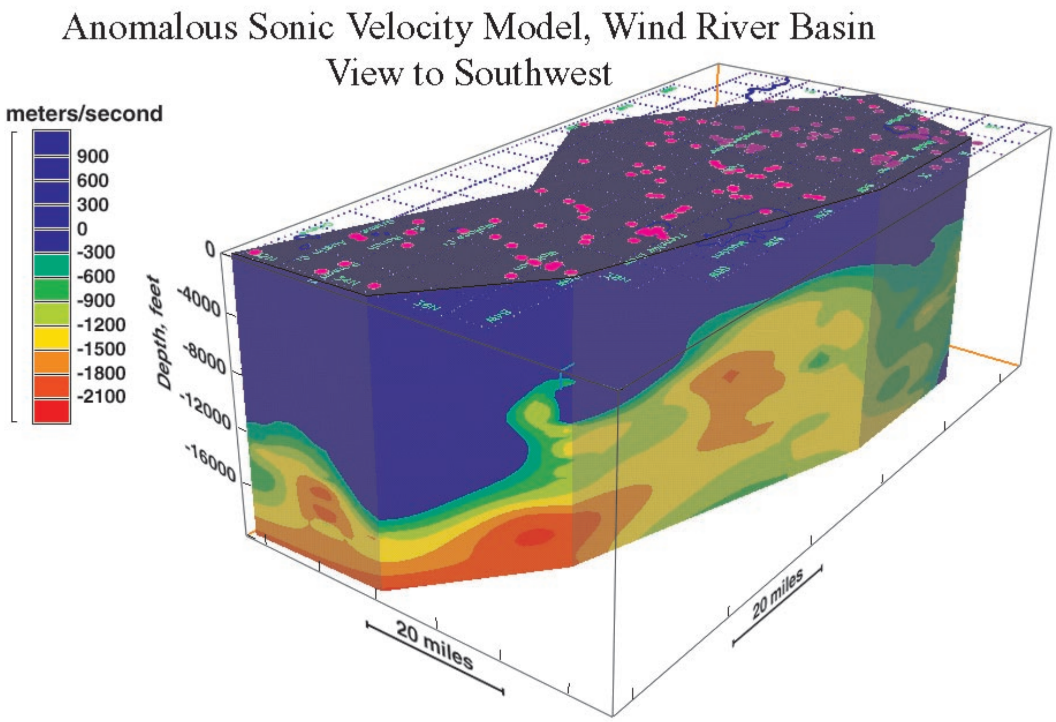


Figure 10. 3-D model of anomalous sonic velocity in the Wind River Basin based on the 175 sonic logs shown in Figure 6.

been analyzed. For each of the seismic lines in the study, a highly detailed seismic interval velocity/time profile has been constructed at every CDP, with vertical velocity picks at 2-4 ms intervals. Approximately 132,000 velocity/depth profiles have been constructed and evaluated for the study. The transition from sonic velocity to seismic interval velocity results in an increase of nearly three orders of magnitude in the available velocity/time of depth profiles in the Wind River Basin. The IDT research team is using a new, automated picking technology designed by Yuri Ganshin that uses continuous, statistically-derived interval velocity selection, as well as conventional graphical-interactive methodologies (Figure 11A). In both cases, standardization with velocity/depth profiles from the sonic logs is important. Figures 11A-C demonstrate the increased velocity resolution and definition using the new automated, continuous, statistically-derived methodology. Using these procedures, a velocity field was constructed for each of the evaluated 2-D seismic lines in the Wind River Basin study (for example, see Figure 12).

Anomalous Velocity Volume

The next step in the evaluation of the gas distribution and migration conduits was to create an anomalous velocity volume. In other words, for the Wind River Basin, volumes containing only rock/fluid systems were characterized by anomalously slow velocities. This task was accomplished by removing the *ideal* regional velocity/depth (or time) function from the observed velocity field for each 2-D seismic line (Figure 13; compare with Figure 12). The result is an anomalous velocity construction, or the isolation of all domains in the seismic velocity field that are slower than would be predicted by the ideal velocity/depth (time) function at a specific depth or time.

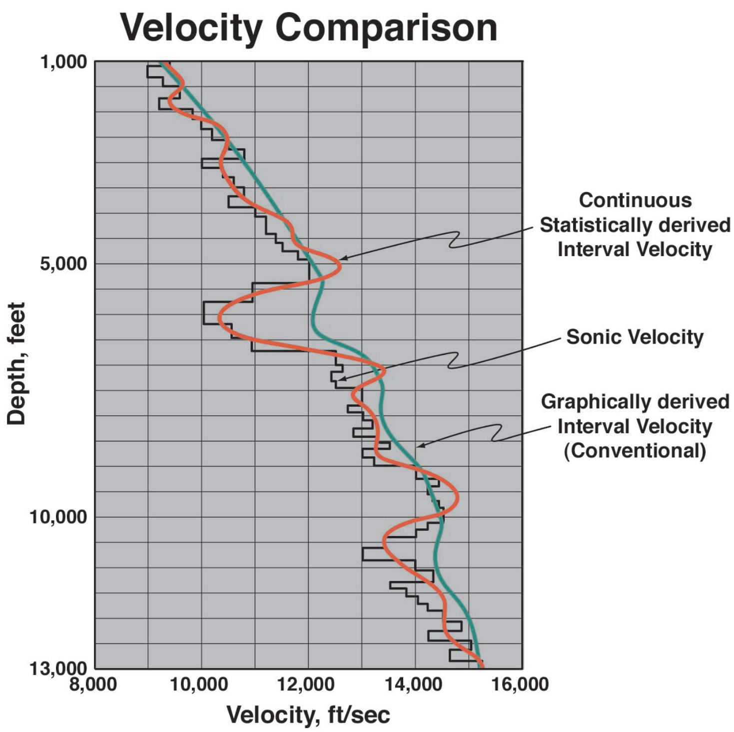


Figure 11A. Plots of interval velocities versus depth. Note the significant differences between velocities obtained from average sonic data and those velocities graphically-derived from seismic data; and the similarities between the sonic velocities and those velocities obtained from continuous statistically-derived seismic data.

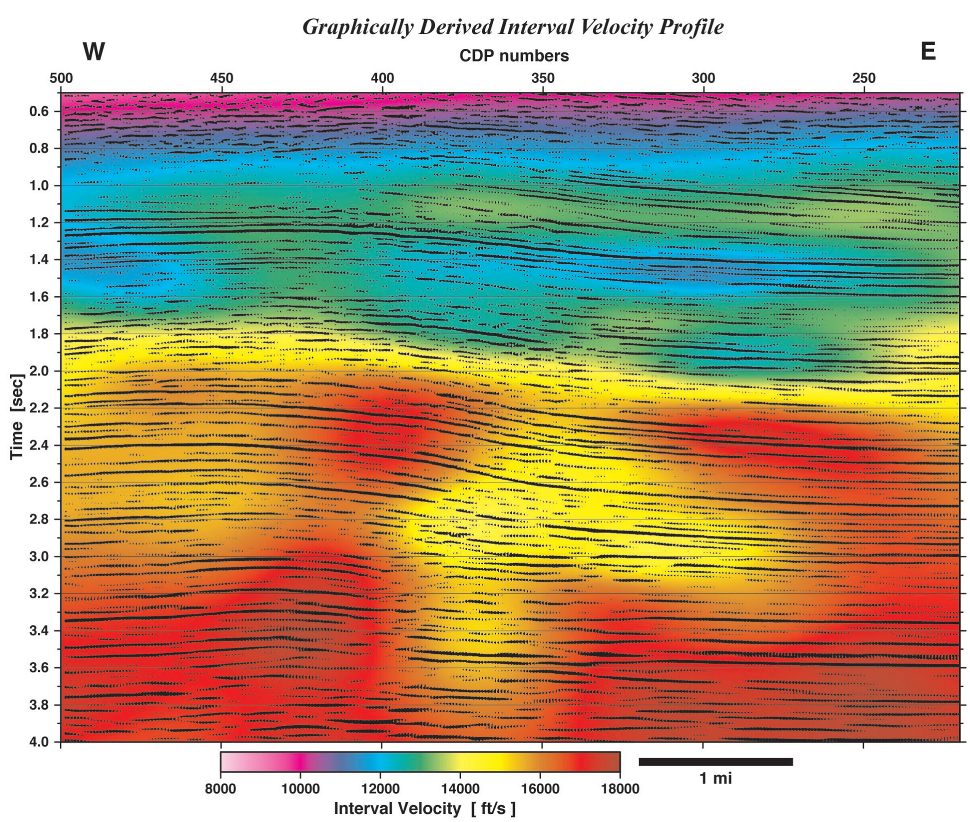


Figure 11B. Seismic interval velocity profile derived from conventional graphically-derived data sampled at every 10th CDP and vertically at 20 ms intervals.

Continuous Statistically Derived Interval Velocity Profile

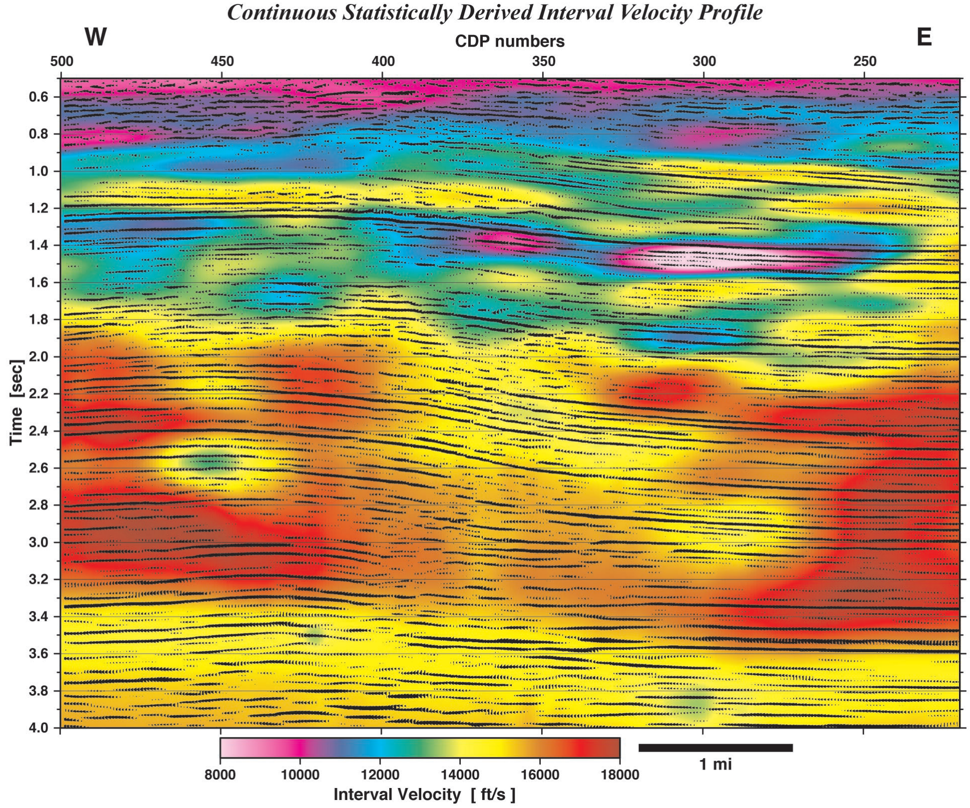


Figure 11C. Seismic interval velocity profile derived from continuous statistically-derived data sampled at every CDP and vertically at 2-4 ms.

Typical Inverval Velocity Profile

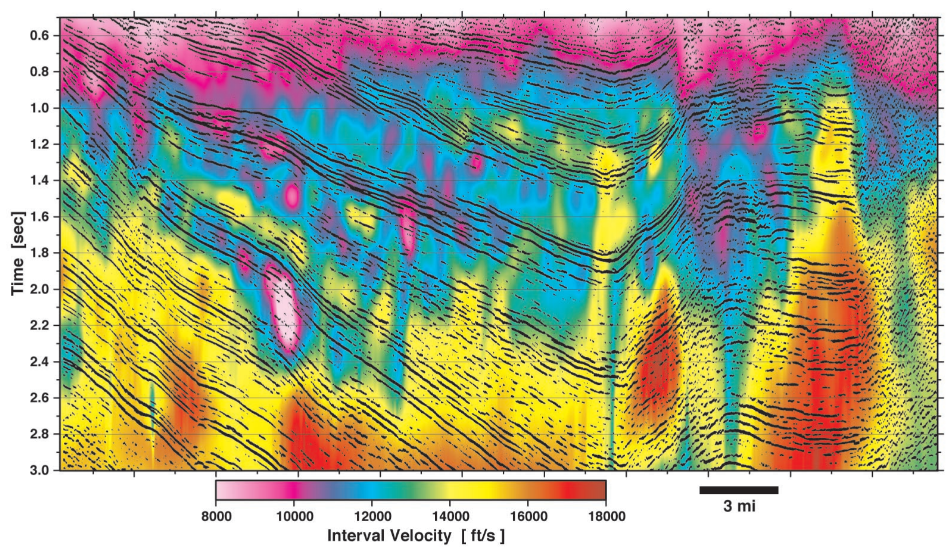


Figure 12. Typical seismic interval velocity profile derived from the IDT technology employing a combination of both conventional graphical and continuous statistical techniques standardized with sonic velocity data.

In order to construct the anomalous velocity volume, the 2-D anomalous velocity data from each seismic line were linked together to form an anomalous velocity 3-D data set. Using Dynamic Graphic's geospatial modeling software, the anomalous velocity data set was gridded and modeled (i.e., facies file) and used to construct a 3-D anomalous velocity volume (Figures 14A-C).

The 3-D anomalous velocity (AV) volume can be used to:

1. Delineate the regional velocity inversion surface, or the depth at which the observed velocity value begins to become significantly slower than would be predicted at that depth by the ideal regional velocity/depth function (i.e., equivalent to the regional pressure surface boundary, which separates normally pressured, water-dominated fluids above from anomalously pressured, gas-charged fluids below; Figure 15).
2. Easily isolate the gas-charged rock-fluid systems (i.e., anomalously slow velocities) (Figures 14B).
3. Quantify the magnitude of the velocity anomaly by comparing it to a standard, or baseline (i.e., ideal velocity/depth function), which allows the internal fabric of the velocity anomaly to be compared both horizontally and vertically (Figure 14A).

The quantification of anomalously slow velocity values (i.e., the removal of the *ideal* velocity/depth function from the observed velocity/depth profile) is critical to delineating gas distribution and to detecting gas migration conduits. The establishment of the anomalous velocity profile, cross section, or volume allows evaluation of gas attributes that can be related to exploration/exploitation success in areas containing APG resources (Surdam, 1997; Surdam, 2001a; Surdam, 2001b; Surdam, 2001c; Surdam et al., 2001).

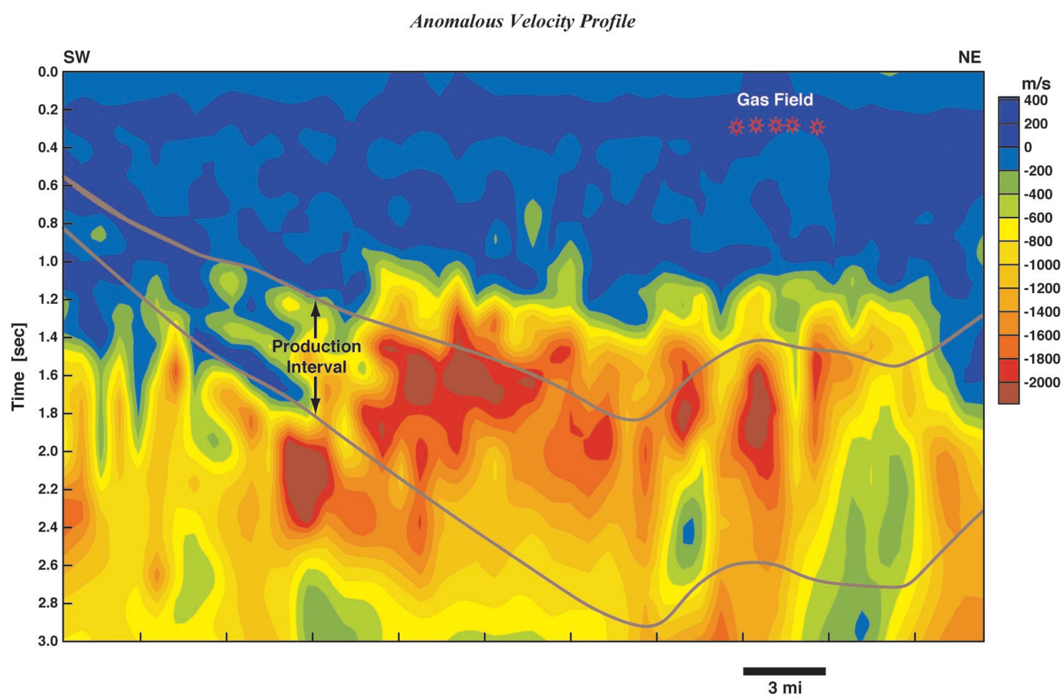


Figure 13. Anomalous velocity profile derived from velocity field illustrated in Figure 12. Removal of the *ideal* regional velocity/depth function neatly isolates the anomalously slow seismic interval velocity domains (i.e., gas-charged domains).

Gas Migration Conduits

Vertical gas migration conduits typically are characterized by positive relief on the regional velocity inversion surface, which is an indicator that gas is moving up higher in the section than in adjacent areas characterized by lower relief on the surface. Many of the significant gas accumulations in the RMLB are characterized in part by positive relief on the regional velocity inversion surface (e.g., Jonah, Standard Draw-Echo Springs, and Elmworth).

In the Wind River Basin, the regional velocity inversion surface (Figure 15) suggests significant vertical migration of gas (see positive relief on Figure 15) has occurred. Many of the topographic highs on the regional velocity inversion surface in the Wind River Basin are 3000 ft higher than the surrounding areas (Figure 15). Each of the highs represents the vertical migration of gas (i.e., gas chimney); thus, these areas represent conduits characterized by enough permeability to allow vertical gas migration.

Regional Gas Distribution

The anomalous velocity volume is a representation of the regional gas distribution in the Wind River Basin. The uncertainty of the representation relates directly to the proximity of analyzed 2-D seismic lines. Even away from the locations of the 2-D lines, this volume yields important information with regard to the shape, trends, and regional variations of the distribution of anomalously slow velocity domains (i.e., gas-charged volumes).

CONCLUSIONS

The anomalous velocity volumes shown in Figures 14A-C and 15 illustrate the distribution of gas-charged domains in the Wind River Basin below the regional velocity inversion surface. Construction of the distribution of gas-charged and water-charged domains significantly reduces exploration uncertainty in Wind River Basin

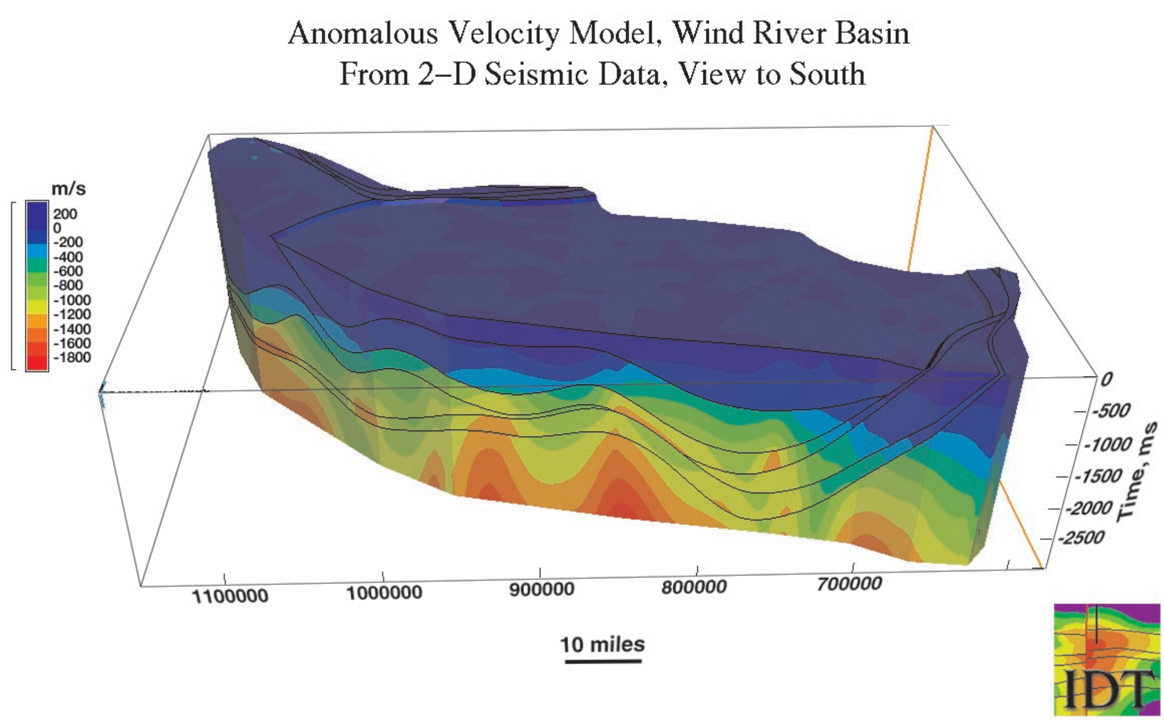


Figure 14A. Anomalous velocity volume for the Wind River Basin based on the 2-D seismic framework outlined in Figure 5.

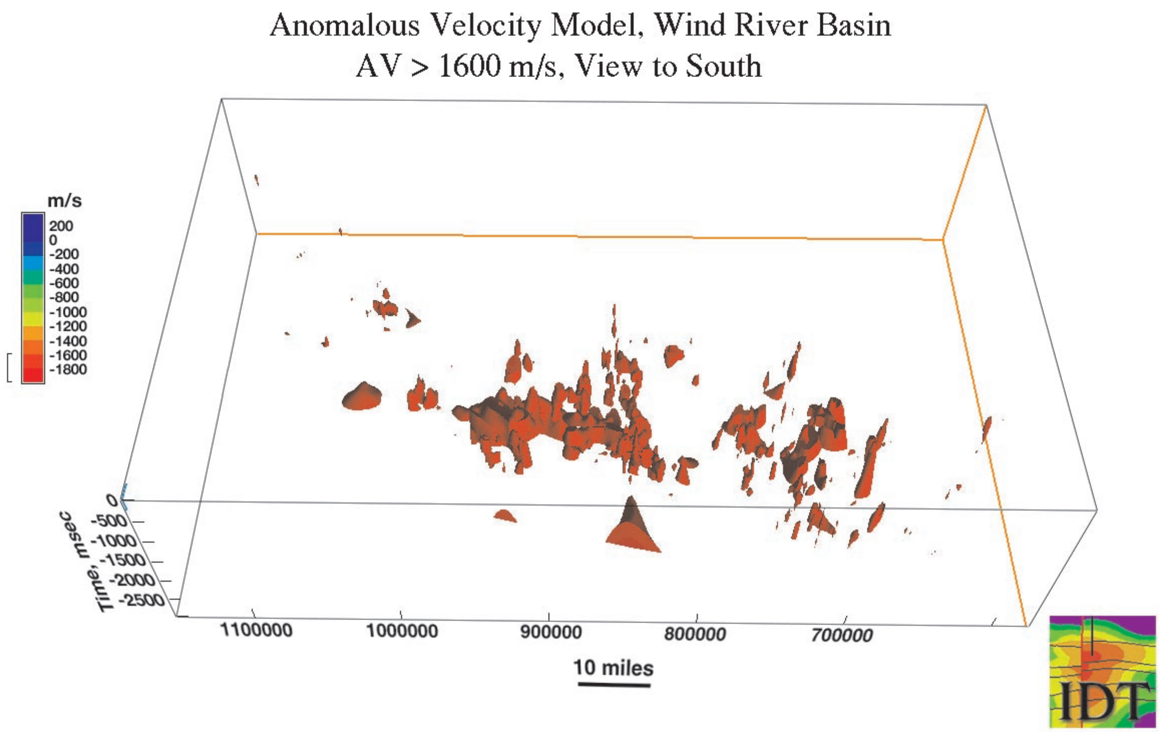


Figure 14B. Anomalous velocity model for the Wind River Basin for anomalous velocity values 1600 m/s slower than the *ideal* regional velocity/depth function.

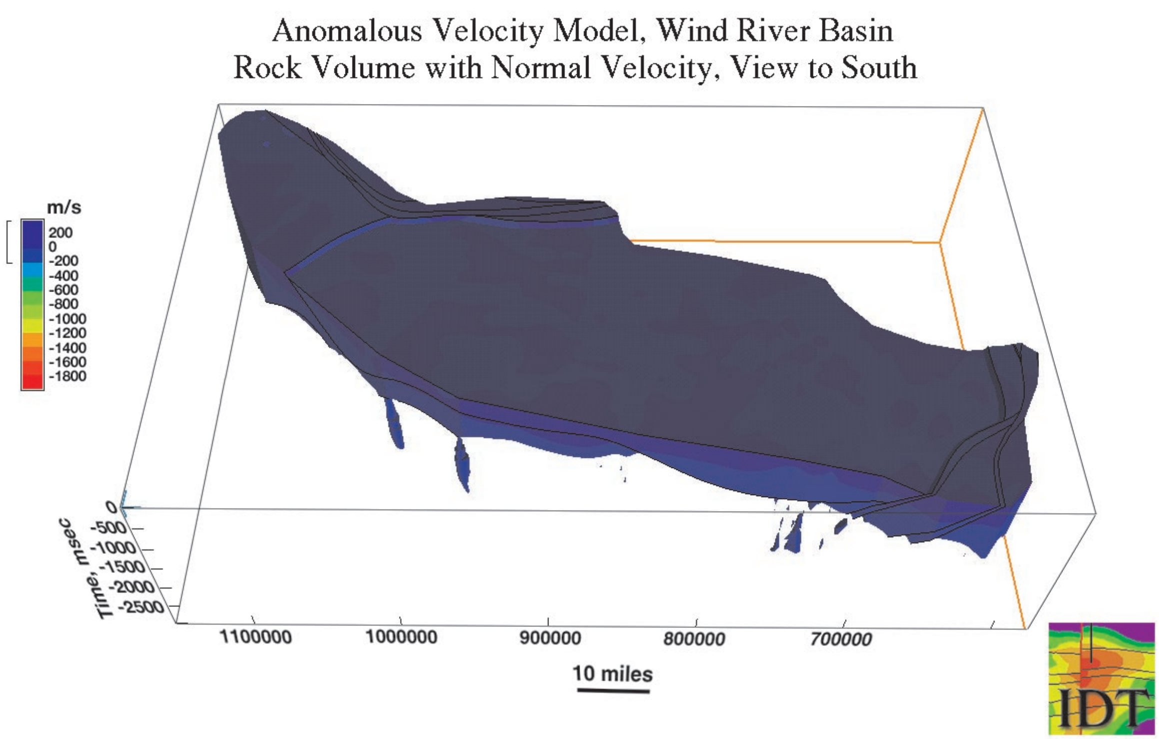


Figure 14C. Anomalous velocity model for the Wind River Basin showing the rock/fluid systems falling on the *ideal* regional velocity/depth trend (i.e., water-dominated fluid-flow system).

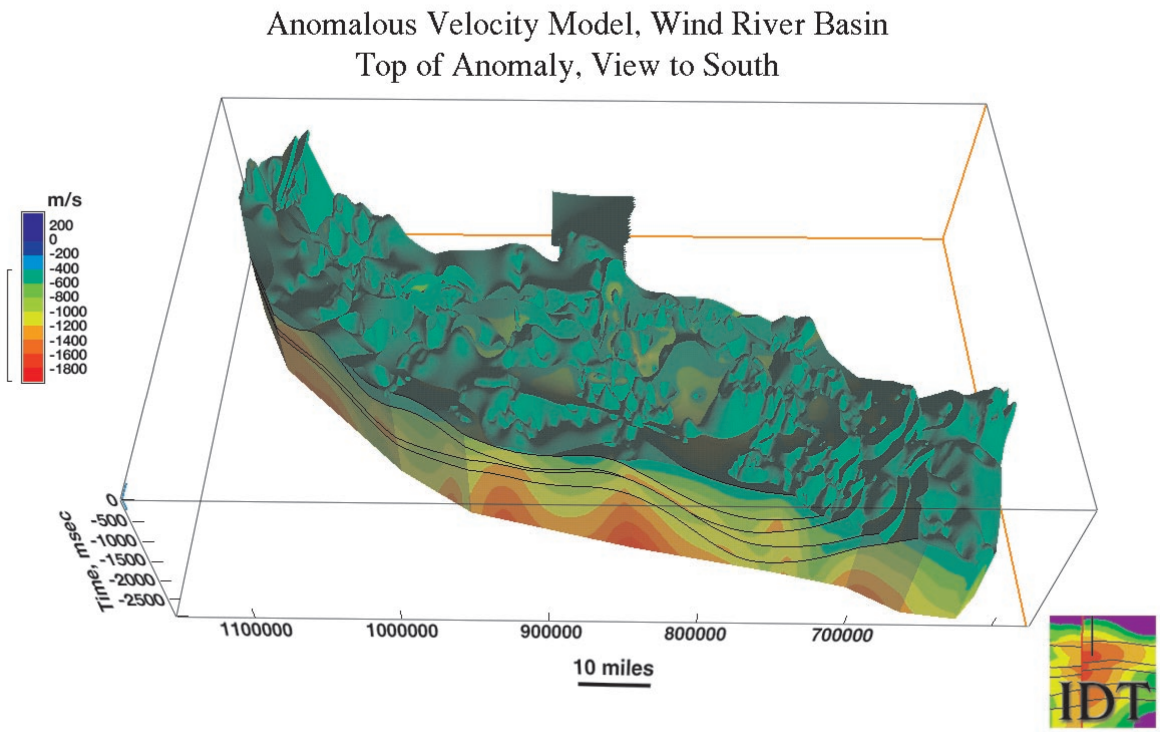


Figure 15. The velocity inversion surface in the Wind River Basin; this surface separates normally pressured, water-rich domains above from anomalously pressured, gas-charged domains below.

(Figures 14A-C). Even more exploration uncertainty (i.e., risk) can be achieved by determining where target reservoir intervals characterized by enhanced porosity and permeability intersect and penetrate the anomalous velocity volume (Figure 4), shown in Figures 14A and 14B for the Wind River Basin, and especially those targeted domains extracted from the volume chosen for special attention (Figures 17A and 17B). The technology demonstrated in this topical report detects and delineates gas-charged domains, but additional work in the form of evaluating the porosity and permeability characteristics of reservoir units penetrating the gas-charged domains is essential to elevating gas-charged domains to the level of a drillable prospect (Figure 4). However, the diagnostic techniques presented in this topical report will greatly aid in the search for and prioritization of gas-charged domains and the selection of exploration targets. The work described in this report will significantly aid operators in the Wind River Basin and elsewhere by providing essential assistance in reducing risk and in increasing the rate and magnitude of the conversion of APG resources to energy reserves. To support these conclusions, the following discussion of the validity and applicability of the technology in the Wind River Basin is presented.

Validation

To test the validity of the strategy and technology outlined in this report, several cross sections through the anomalous velocity volume coincident with producing gas fields were constructed. All the fields chosen for this test are characterized by production from the Lower Tertiary and Upper Cretaceous stratigraphic sections. Three fields were chosen from the eastern Wind River Basin (i.e., Northern Dinty Moore, Boonville Dome, and East Madden fields), and three fields were chosen from the western Wind River Basin (i.e., Muddy Ridge, Pavillion, and Sand Mesa). In each of the six cross sections, a strong and intense anomalously slow velocity

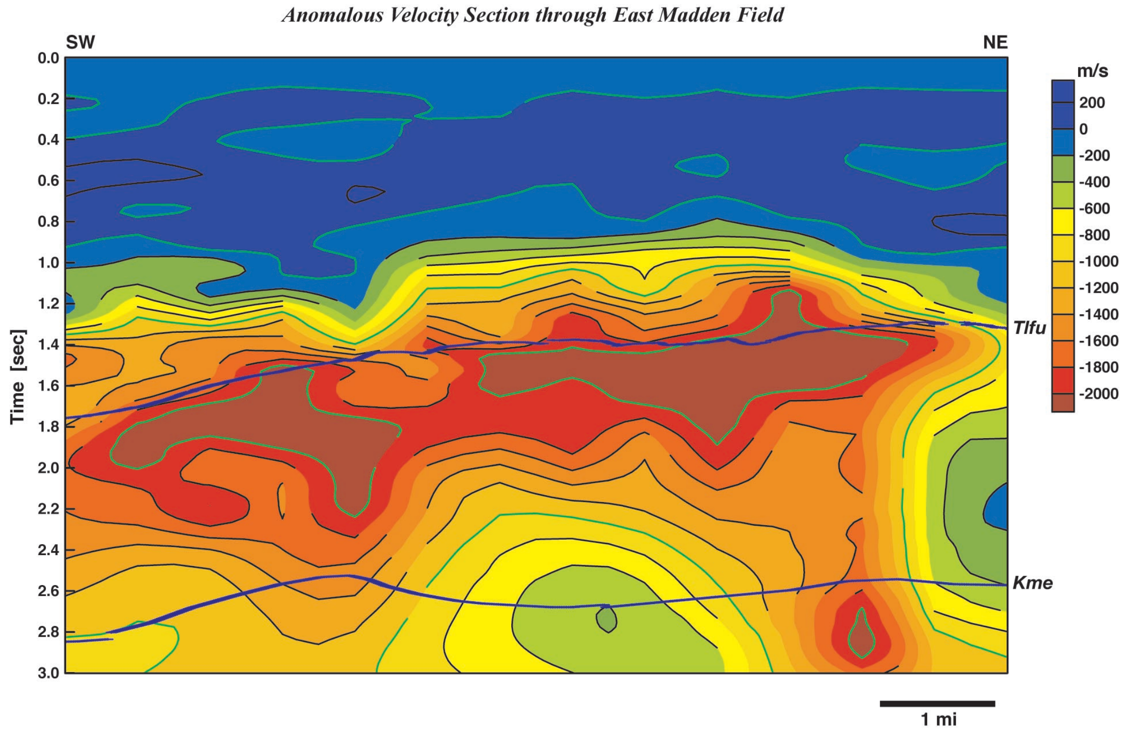


Figure 16A. Cross section through the Wind River Basin anomalous velocity volume (Figure 14A) at the location of the East Madden field. The productive section of interest is the Lower Tertiary-Upper Cretaceous interval (i.e., Tlfu-Kme). Note the significant anomalously slow velocity domain characterizing the anomalously pressured gas production in the East Madden field.

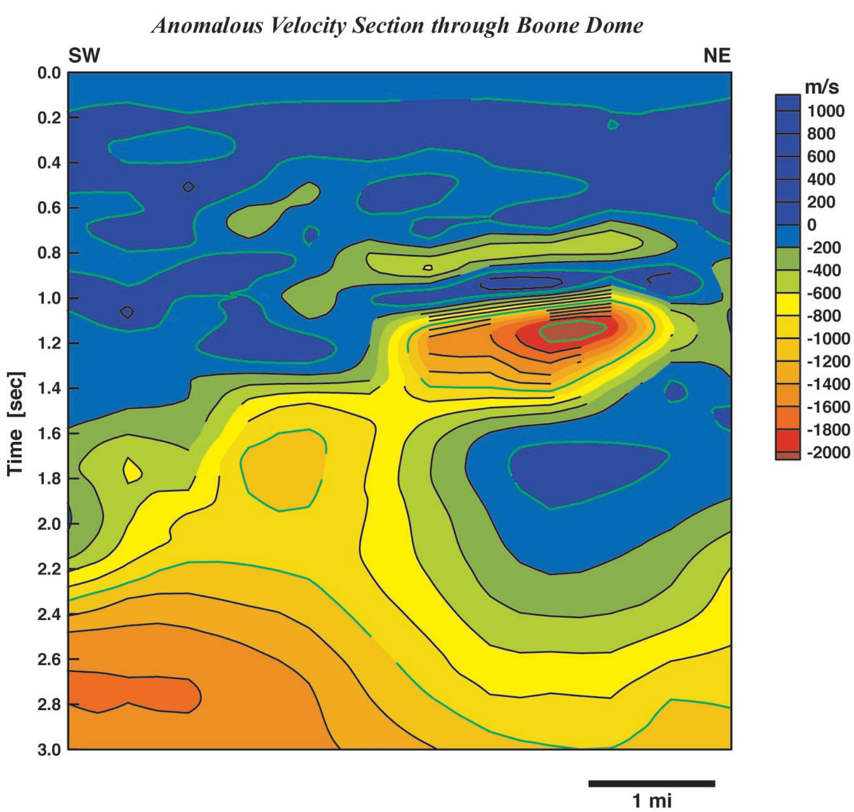


Figure 16B. Cross section through the Wind River Basin anomalous velocity volume (Figure 14A) at the location of the Boone Dome field. Note the significant anomalously slow velocity domain characterizing the productive interval on the hanging wall of the Owl Creek Thrust fault.

domain coincides with the gas productive rock/ fluid interval; there is not a single exception.

For example, see Figures 16A and 16B, which are the cross sections through the anomalous velocity volume coincident with the East Madden and Boone Dome fields. These fields were chosen for illustration because they represent two very diverse structural settings and because the velocity anomaly associated with the Lower Tertiary-Upper Cretaceous section at East Madden is one of the largest in the Wind River Basin (Figure 16A) and the velocity anomaly at Boone Dome is intense, but relatively small (Figure 16B). The Boone Dome field is associated with a structural trap on the hanging wall of the Owl Creek thrust fault at the northern edge of the Wind River Basin (Figure 16B). From Figure 16B, it is apparent that the gas accumulation at Boone Dome is above a water-rich section (blue areas in Figure 16B). In strong contrast, the gas accumulation in the Lower Tertiary/Upper Cretaceous section at the East Madden Field, associated with structural closure on the northern flank of the Wind River Basin, is in a more "basin-center" like setting with a water-rich section above and no apparent water leg below, at least down to 3.0 sec TWTT (Figure 16A). It is important to note that without exception in each of the six fields tested, the gas production is closely and spatially associated with an intense velocity anomaly (i.e., anomalously slow velocity domain). In each of the six tests, the strategy employed, the technology outlined, and the diagnostic techniques described in this report neatly and accurately delineate the anomalously slow velocity domain associated with the gas production.

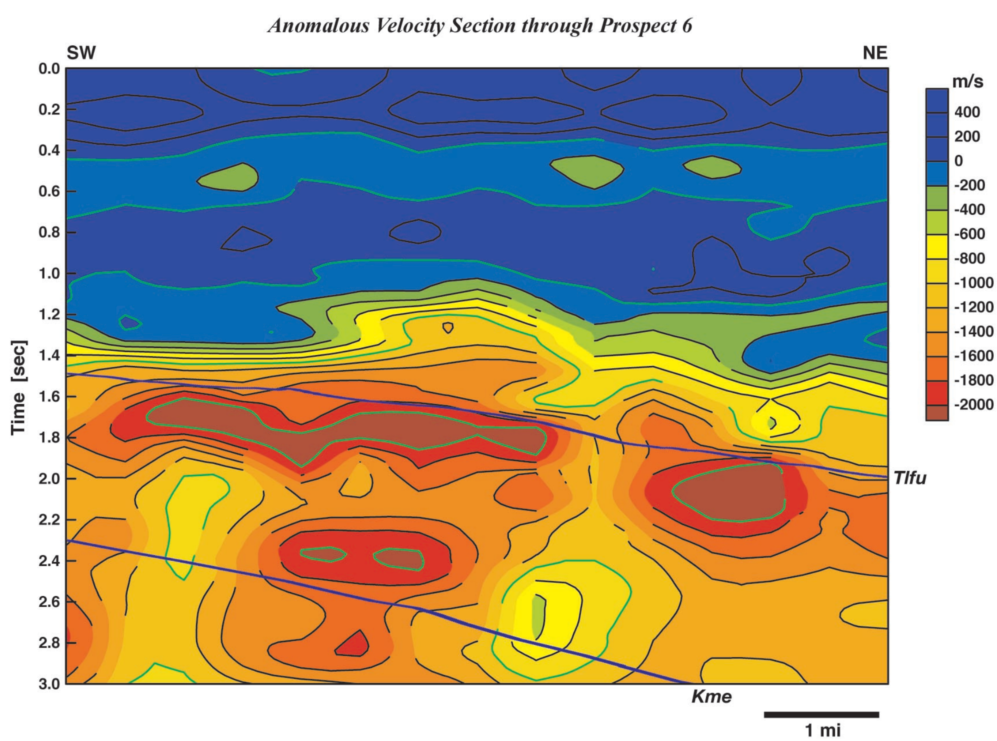


Figure 17A. Cross section through the Wind River Basin anomalous velocity volume (Figure 14A) illustrating a highly prospective undrilled area. Note the intense anomalously slow velocity domain associated with the Lower Tertiary/Upper Cretaceous interval (Tlfu-Kme). For purposes of evaluation, compare Figures 16A and 17A).

Application of Technology

To further illustrate the utility of the technology being demonstrated, six highly prospective and undrilled targets were chosen from a series of cross sections through the anomalous velocity volume. These six selected exploration targets were from a variety of structural and geographic settings; both the hanging and footwall of the Owl Creek Thrust; the northern and southern limbs of the basin as well as basin-center; and both the eastern and western portions of the basin. The prime criteria for selection of the targets were as follows: (1) they had to be characterized by an anomalous velocity domain comparable to one of the known gas fields (i.e., both in size and intensity); (2) they had to be in a spatial setting (i.e., structural, stratigraphic, and temporal) analogous to one of the known gas fields; and (3) they had to be at least six miles from the nearest known gas field.

For an illustration of the selection process, see Figures 17A and 17B, which show two of the anomalously slow velocity domains that were chosen as highly prospective areas; these targets fit the selection criteria outlined above. For field analogies, compare Figures 16A and 17A and 16B and 17B. In this rather mature exploration area, none of the six selected targets have been drilled, so obviously without application of the technology espoused in this topical report or utilization of some other similar, innovative and unconventional approach, they will remain undetected.

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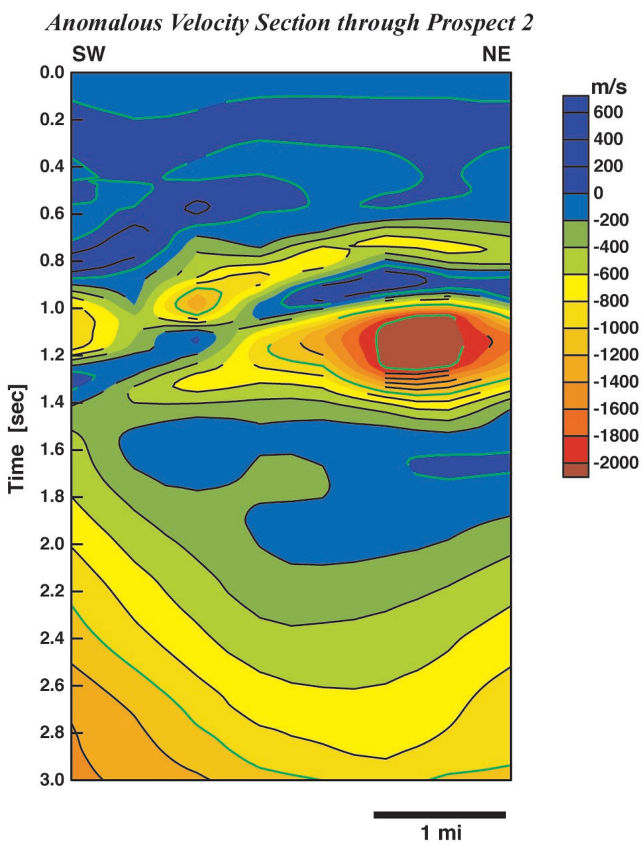

Figure 17B. Cross section through the Wind River Basin anomalous velocity volume (Figure 14A) illustrating a highly prospective undrilled area. Note the intense anomalously slow velocity domain associated with the hanging wall of the Owl Creek thrust fault. For purposes of illustration, compare Figures 16B and 17B.

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