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24 February 2006

Patrick Leahy, Ph.D., Acting Director
U.S. Geological Survey
12201 Sunrise Valley Drive
Reston, VA 20192

Dear Director Leahy:

Please issue "Origins and characteristics of the basin-centered continuous-reservoir unconventional oil-resource base of the Bakken Source System, Williston Basin" as an open file report or equivalent (duly identifying it as a 1999 product). The author, Leigh C. Price, died in August 2000 after receiving review comments and working on them. USGS Professional Paper 1653 referenced the report as "in press" (Pitman et al. 2001). But the USGS lost track of Price's extensive report. It is available to very few geoscientists and members of the exploration and development community. USGS should make it equally available to one and all.

The value of releasing it now is highlighted by the hot "Bakken middle member" play of the last couple of years and by release this week by the Department of Energy of a Williston Basin report on Strategies for CO_2-EOR which states that prior studies suggest that 100 to150 billion barrels (perhaps more) of Bakken resource in place may exist in ND alone, with more in MT. The Price report estimates 200-500 billion barrels for ND and MT (and provides detailed explanations, calculations, and analyses -- many not to be found in the prior studies).

I have been working by phone and e-mail for weeks with energy team members to get this missing report released, together with other important research data. See Attachment. Today, the team informs me that USGS must have a hard-copy, formalized request in order to process the matter "with the appropriate USGS officials for consideration and response on behalf of the Bureau." This is a hard-copy request that USGS release this information to the public.

So long as USGS continues to withhold the Price report, however, may I have your assurance that USGS gives its blessing to release by another, competent organization?

Faithfully,

/s/ *David J. Bardin*
David J. Bardin

Attachment: USGS WITHHOLDS VALUABLE BAKKEN DATA & TOOLS

c: Brenda Pierce [by e-mail]

USGS WITHHOLDS VALUABLE BAKKEN DATA & TOOLS
FROM AMERICA'S EXPLORATION & DEVELOPMENT COMMUNITY

David J. Bardin

13 February 2006

At a time when American independent oil producers in MT and ND are actively exploiting Bakken resources to raise domestic oil production, the US Geological Survey (USGS) in the Interior Department continues to withhold valuable information and tools. USGS is holding back a comprehensive report and extraordinary data set (including an HI contour map) put together by one of its most brilliant and prolific scientists, Leigh C. Price.

The report* is about:

- potentially-vast crude oil resources that may remain only 10,000 feet deep in MT and ND portions of the Williston Basin in the "Bakken source system";
- how to estimate quantities of oil generated from basin-centered source rocks in the Williston Basin; and
- research recommendations and findings significant for understanding generation of petroleum in other, far deeper, less accessible, and more complex basins.

The report addresses issues of scientific and national strategic importance. USGS should have published the report in 2000 or 2001. Instead,

- USGS sat on this report after the author's untimely death in August 2000. (It posthumously released other reports: DDS-67 Chapt. H, which has information about the Bakken resources, and Bulletins 2174-A and 2174-B).
- USGS gave possession of its scientist's data sets to a single, private geologic consultant.
- Now USGS may also seek to suppress widespread dissemination (by the State of North Dakota or others) to the public -- including scientists, consultants generally, and entrepreneurs who are actively developing the very resources Price sought to understand better in the "middle Bakken member."

USGS seems inclined today, belatedly, to carve out and release only small portions. (How many of Price's 82 conclusions [pp. 247-62] the USGS may decide to release remains murky.

The data sets include Hydrogen Index (HI) contour mapping of the unconventional Bakken crude oil resource in ND and MT based on hundreds of sampled cores. Dissemination could help operators select optimal leases and drilling locations.

The report and data sets grow out of years of taxpayer-funded scientific efforts.

* "Origins and characteristics of the basin-centered continuous-reservoir unconventional oil resource base of the Bakken Source System, Williston Basin" by Leigh C. Price, Denver Federal Center, Box 25046, Denver, CO 80225. [**Unless otherwise stated, page references below marked "p." refer to that report.**]

Who was Leigh C. Price?

Price was a highly respected organic geochemist, working in the USGS energy sciences team in Denver. He had won the prestigious American Association of Petroleum Geologists (AAPG's) "best paper" award in 1973 and 1975 and gone on to do excellent work focused on several petroleum resources and processes before he died in 2000. A creative virtuoso, he significantly advanced geoscience (sometimes controversially). He was adulated and resented. He sometimes changed his views. He studied the Williston Basin (among others) for many years, revising and clarifying his ideas.

What is the comprehensive report that USGS is withholding?

The report pulls together Price's experience, research, ideas, analyses, and speculations for himself, for other geoscientists, and for a "wider audience" than the "typical scientific audience" [p. 25]. His mass balance estimates of generated oil are set forth in detail that was not previously available. [pp. 208-238; and conclusions, p.247 *ff.*] They include parameters that other scientists have overlooked or chosen not to discuss. His conclusions include:

- "Our preliminary estimate of the amount of oil generated by the Bakken shales in the Bakken-HC kitchen of northwestern North Dakota and northeastern Montana, after accounting for all known relevant parameters, is 413 billion barrels, with an ultimate oiling of 503 billion barrels, and a floor of 271 billion barrels." [p. 261.]
- "By the above mass-balance approach, we calculate that the Bakken shales have generated 413 billion barrels of oil. By changing some of the basic assumptions, we believe the lowest possible number to be 271 billion barrels of oil. Moreover, as will be discussed in future publications, we believe that at least 50% of this in-place oil (206.5 billion barrels) may be recoverable at less than $12 per barrel oil prices. … The proven recoverable reserves of the U.S. presently are 25 billion barrels." [p. 235.]
- "[T]he oil industry previously *assumed* that Bakken-generated oil was held in vertical fractures in the Bakken shales, as opposed to the real situation: horizontal fractures in the rocks adjacent to the shales." [p. 255.]
- "Wells with low cumulative productions have had inappropriate techniques applied, causing extensive formation damage." [p. 259.]
- "Different parameters have coalesced in the Williston Basin to possibly make the large in-place unconventional oil-resource base there, and its ease of recovery, unique, or at least, very unusual, on a worldwide basis. These factors are: an extremely rich source rock; extremely-high basin heat flows; no structuring basin-wide; brittle, thick, impermeable carbonate-rich rocks which sandwich the source rocks and serve as both reservoir and seal; and an unparalleled rock, oil, and well-history sample base." [p. 262.]
- "Detailed analysis of Bakken well-history files, besides documenting that production techniques appear to be completely responsible for production heterogeneities, have revealed at least 15 separate parameters controlling Bakken production. The results of this analysis thus strongly suggest that the in-place Bakken Source System oil resource base is eminently producible at current oil prices using existing technology. These results will be published in future papers." [p. 262.]

Some Price conclusions are controversial. (For example, in 1995 USGS estimated that undiscovered, technically-recoverable Bakken oil resources amounted to 150 *million* barrels; contrast Price's 200+ *billion* barrels.) They deserve to be debated. This report offers a basis upon which to debate. Even if Price was off by a factor of 2 (or of 10 or of 20), interested publics should be able to study his work in context.

What are the additional data sets that USGS withholds?

As quoted above, Price was working on additional papers to relate his understanding of the resource and particular technological parameters – in order to define what works best to produce this crude oil in quantities – and was mapping HI contours repeatedly as his growing data collection permitted enhancement of contour accuracy as scientific and exploratory tools. In USGS DDS-67, 2001 (Chapter H, p. 11) Price wrote:

> "I have collected a very large sample base of Upper Devonian-Lower Mississippian Bakken Formation shales, including all available samples on the far eastern flank of the Williston Basin … ROCK-EVAL analyses were performed on some 1,300 of these samples by Dow

> Geochemical Services, Inc. … significantly enlarg[ing] a pre-existing ROCK-EVAL data base of more than 400 Bakken shales previously run at the USGS laboratories."

[Pp. 11-12 of Chapt. H are attached. Report p. 234 discusses plans for more detailed mapping.]

One also wonders what other data, notes, drafts, and analyses Price left behind (for example, regarding "at least 15 separate parameters controlling Bakken production" and speaking to selection of appropriate existing technologies to raise recovery factors to 50 percent; the report identifies and discusses only some of these 15 factors).

After Price's death, USGS simply transferred possession of these data sets to a private, geological consultant in Denver and/or stashed them in storage – instead of making them generally available to geoscientists and the technology-transfer community (e.g., through the NDGS or PTTC).

<u>How and why is USGS withholding this comprehensive report?</u>

Price wrote his report in 1999 and in September gave hard copies to a USGS geochemist (asking him to concentrate on the mass balance portions) and a couple of USGS energy team geologists. Early in 2000, Price gave a personal communication copy to NDGS geologist Julie LeFever. He told her that he had received comments from his reviewers. In 2001, USGS released Professional Paper 1653 (Pitman et al.) identifying the report as an "in press" "USGS" reference. Then hard copies disappeared or were forgotten in USGS's Denver office until requested by HQ (Reston) in late January 2006. USGS Denver has recently hunted for an electronic copy on the computer of a former secretary, who typed most of Price's work from long hand.

Until recently, USGS was unaware of the very hot middle Bakken play by independent producers in Montana and North Dakota and, therefore, could not recognize the utility of Price's comprehensive report to here-and-now issues for these independent operators (and for those two States). USGS may not welcome such a "wider audience" of users that Price anticipated.

- USGS appears to think that only research and analytical findings aimed solely at research scientists should be released and then only if they are "new" as of 2006 *and* have not been challenged by post-2000 research publications.
- So USGS seems inclined to carve small sections out of Price's comprehensive report and release them as "new" (for example, critiques of low estimates by American Hunter's Carlisle et al. 1992 and USGS's Schmoker 1996).
- And USGS seems reluctant to let Price's *magnum opus* and all of its 82 conclusions speak for themselves (even if properly identified as a 1999 product, not a 2006 product, as they should be). Instead, USGS seems to feel obliged to withhold virtually all of Price's report about the main, unfaulted Bakken of ND and MT on the contention that Canadian geochemical research (published after Price's death), using "biomarker compounds" in a localized, highly-structured (faulted) area, suggests that, there, some Bakken-sourced oil did not remain in the "system" below but migrated upwards to Madison formation reservoirs where it mixed with other-sourced oil. (If generalized beyond the local area studied, that would tend to limit one of Price's conclusions).

Moreover, USGS may decline to release Price's detailed, unpublished calculations of oil generated from the Bakken source rock on the grounds, it would appear, that another USGS geochemist believes that they exaggerate.

<u>What were Price's calculated estimates of oil generated from Bakken shale source rocks?</u>
"We refine the ROCK-EVAL mass-balance approach by taking into account various controlling parameters not considered by previous investigators." [p. 209.] Price took an initial estimate for TOC in

immature source rock – 18 percent – "conservatively" adjusted to 21½ percent based on factors that previous estimates had ignored and then estimated oil generated taking into account:

1) cogeneration of natural gas with oil in source rocks,
2) overestimation of oil generation potential in source rocks by the ROCK-EVAL instrument,
3) underestimation of oil generation potential in source rocks due to uptake of water by kerogen via hydrolytic disproportionation of kerogen during HC generation reactions.

Price discounted the thesis (Lewan 1995) that hydrous pyrolysis may exaggerate amount of petroleum expelled (by perhaps as much as a factor of 2) by tending to shut down cross-linking. "*The Bakken shales are an excellent candidate to test the cross linking hypothesis, because the shales exist in a closed-fluid system, where the access of water is minimized.* Geographically-close Bakken shales, which cut across large ranges of hydrogen indices ≥625 to 50, demonstrate a continuous TOC decrease versus increasing maturity. This observation suggests that the process of crosslinking is minimized, if it occurs at all, in the Bakken Source System." [pp. 222-23, emphasis added.]

Price went on to suggest: "The above discussion should highlight that carrying out mass-balance calculations on expelled oil from source rocks is fraught with unknowns, and that such calculations are in reality only estimates. More insight to the topic could be achieved by cross comparing all the generated products from closed-system experiments, such as hydrous pyrolysis (expelled oil, fractionated oil remaining in the source rock, and molecularly-dispersed bitumen) with oils, stains in reservoir rocks, and source-rock bitumens in samples from the natural system for one source system. This would allow a more realistic appraisal of closed-system experiments to be made as a mimic of the natural system. *The Bakken Source System rocks and fluids would be a prime applicant with which to carry out this pivotal research.*" [p. 223, emphasis added.]

Unlike other geoscientists, Price also concluded regarding suppression of organic metamorphism in hydrogen-rich OM: "First, all maturity indices (and not just R_o), and indeed all aspects of organic metamorphism including HC generation, are suppressed at a given rank with increasing hydrogen richness. Second, the magnitude of the suppression can be *quite* large, and thus is not a trivial effect." [p. 152, and *ff.*]

<u>What would release of the report, HI contour map, and other data sets accomplish?</u>

Scientifically, release of the report could lead to further research, as suggested by Price above, even today. Its timely release in 2000/2001 might have induced consideration and discussion in studies of other basins, such as the Illinois Basin (Lewan et al. 2002) of issues Price raised in the report (notably, in his detailed mass-balance calculations that remain unpublished to this day).

These are only examples. Debates among scientists following publication of ideas advance science. Withholding or suppression of scientific ideas obviously does not.

For the wider audience of oil producing businesses and consultants, release of Price's report, HI contours, and data sets (even belatedly, in 2006) seems likely to stimulate ideas and innovations because it would provide insights and information comprehensively and raise very useful challenges.

Attachment: Pp. 11-12 of Chap. H, DDS-67 - co-edited by T. Dyman (USGS) and V. Kuuskraa (ARI).

Bakken Formation Shales

I have collected a very large sample base of Upper Devonian–Lower Mississippian Bakken Formation shales, including all available samples on the far eastern flank of the Williston Basin, where the Bakken shales are immature (see fig. 5 of Price and others, 1984). ROCK-EVAL analyses were performed on some 1,300 of these samples by Dow Geochemical Services Inc. (DGSI), Houston, Tex. The analyses significantly enlarged a preexisting ROCK-EVAL data base of more than 400 Bakken shales, previously run at the U.S. Geological Survey laboratories. The Bakken shales are an ideal candidate to check if water also hydrogenates hydrogen-rich OM, therefore increasing its hydrogen content, and thus ROCK-EVAL hydrogen-indices. This is because a large amount of work has already been carried out, and published, on the Bakken Source System (Price and Le Fever, 1992). Moreover, no other source rock worldwide, with high TOC contents and hydrogen-rich OM, has a rock-sample base equivalent to that of the Bakken shales, regarding both geographic coverage (complete coverage of North Dakota and Montana) and range of shale maturity (extremely immature (3,300 ft (1,006 m) of burial) to post-mature). The resulting data for both immature Bakken shales, and Bakken shales which have just commenced HC generation, are shown in figure 7.

Numerous investigators (including Webster, 1982, 1984; Price and others, 1984; Martiniuk, 1988; Le Fever and others, 1991; and Muscio, 1995) have documented that throughout almost all of the depositional area of the Bakken shales, both lithology and OM type of the shales are invariant. In other words, no detectable organic lateral-facies variations occur in the Bakken shales. However, concurrently, Price and others (1984) noted that as the depositional edge of the Bakken Form tion is approached, facies variations do occur in the OM, presumably from variations in depositional conditions. Thus, bot the initial TOC and hydrogen-index values decrease as the dep sitional edge of the Bakken shales is approached. Moreover, t extractable OM also changes, taking on slightly more Type-III OM characteristics. The extensive Bakken shale ROCK-EVA data base I have compiled corroborates the previous conclusio of Price and others (1984) regarding OM variations as the Bakken Formation depositional edge is approached. To avoid these OM variations in the present considerations, only ROCK EVAL data from Bakken shales whose thickness equals or exceeds 17 ft (5.2 m) were plotted in figure 7.

Three features are immediately apparent in figure 7: (1) t steep increase in hydrogen-index values versus depth from 4,000 to 8,300 ft (1,219 to 2,579 m), (2) the steep decline in hydrogen-index values deeper than about 8,300 ft (2,579 m),

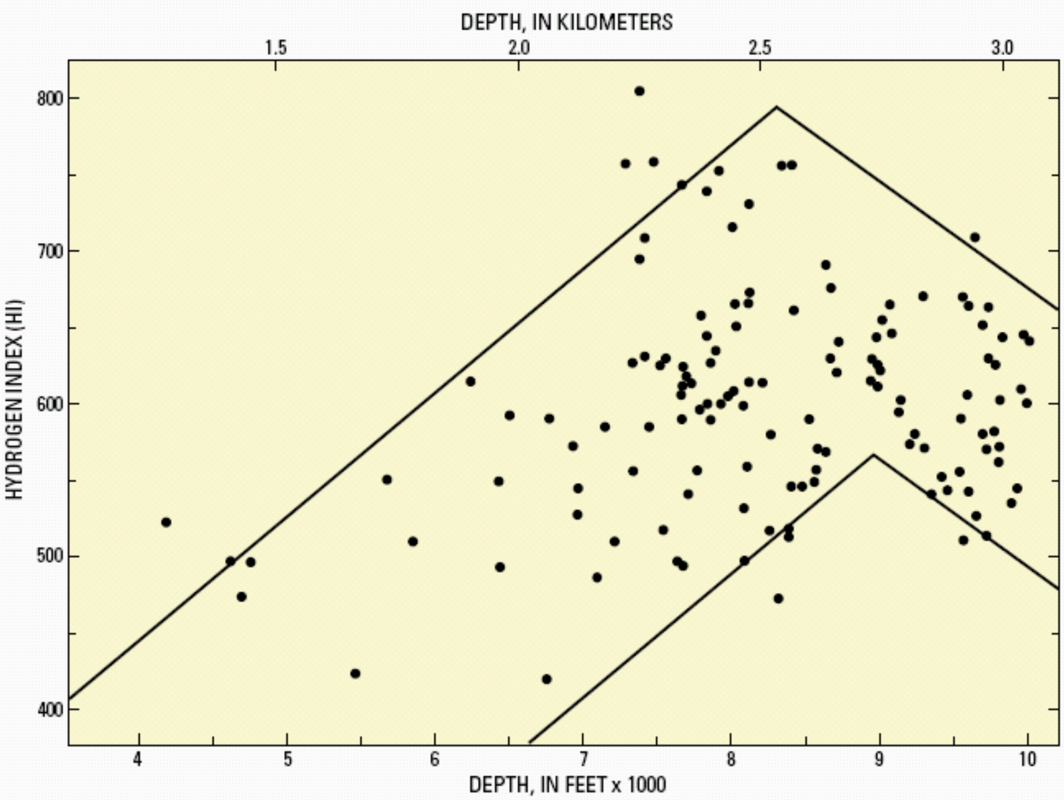

Figure 7. Plot of the ROCK-EVAL hydrogen index versus burial depth in feet and kilometers, for immature upper and lower Bakken Formation shales, Williston Basin, and for Bakken shales which have just commenced HC generation where total shale thickness is 17 ft (5.3 m) or greater.

and (3) the wide range in hydrogen-index values at any given depth. Concerning this last observation, although lateral-facies variations do not occur within Bakken shales removed from the depositional edge, significant random variations in TOC and hydrogen-index values do occur both vertically in the shales at any given site, and from site to site. For example, in figure 7, from 7,500 to 8,300 ft (2,286 to 2,579 m), hydrogen indices vary from 475 (Type-II/III OM) to 803 (Type-I OM), although most values fall between 500 and 775. TOC values (not shown in figure 7) also exhibit large variations, ranging from 15 to 40 percent. Close-spaced (3 to 6 in., 7.6 to 15.2 cm), continuous-core samples of Bakken shale from single wells also demonstrate significant vertical variation in both TOC and hydrogen-index values. Price and others (1984) reported the same observation. Thus, the large range of hydrogen-index values in figure 7 at any given depth is due to random organic-richness variations within the Bakken shales themselves.

Because of the significant range of variation of organic richness vertically through the Bakken shales, analyses of core samples of this rock are not reliable for determining mean organic-richness values. Instead, cuttings chips of Bakken shale which have been cleaned, sieved to less than 100 mesh, and picked under a microscope to a 100 percent Bakken shale sample, are *much* more desirable. Such samples represent a homogenized cross section of the entire Bakken shale interval, thus best reproducing mean organic-richness values. Such cuttings chips samples made up the sample base for figure 7. Neither the trends in the figure 7 data nor the wide ranges in hydrogen-index values at any given depth can be attributed to lack of reproducibility or precision in either sampling or analysis. Seventeen random samples were inadvertently taken, cleaned, picked, and analyzed twice. The resulting ROCK-EVAL values from the paired analyses varied no more than 10 percent, and most were within 5 percent. Thus, the trends in the figure 7 data, including the large range of hydrogen-index values at any given depth, are indigenous to the shales themselves.

The strong increase in Bakken shale hydrogen-index values versus depth from 4,000 to 8,300 ft (1,219 to 2,579 m) in figure 7 is equivalent to the same trends shown in figures 4 and 5, versus R_o, and in figure 6, versus burial temperature. The only obvious cause of the hydrogen-index increase in figure 7 is from water hydrogenating Bakken shale kerogen, thus increasing both its hydrogen richness and its hydrogen indices. Lateral-facies variations are not responsible for the hydrogen-index increases of figure 7.

The significant decrease in hydrogen-index values deeper than about 8,300 ft (2,579 m) shown in figure 7 is due to the first detectable onset of intense HC generation, which commences at around that depth. Also note that at the onset of HC generation, the Bakken shales have *mean* hydrogen indices of 625, making this an extremely rich source rock. As shown in figure 7, a mean hydrogen-index value of 475 at shallow depths increases to a maximum mean value of 625 at 8,300 ft (2,579 m). This is an increase of 31.5 percent, somewhat less than the mean hydrogen-index increases in the coals of figures 4 and 5 (47 and 53 percent, respectively) and in the Los Angeles Basin shales of figure 6 (50 percent). However, all these hydrogen-index increases from the natural system (31.5 to 53 percent) are in the same range as was observed for the excess products generated in the 30-day, variable-temperature, aqueous-pyrolysis experiments with the Phosphoria shale and the lignite (figs. 3*A*, 3*B*; 42.0 and 40.0 percent, respectively).

Data for the Los Angeles Basin mid-Miocene shales (fig. 6) provide evidence that kerogen hydrogenation was taking place not only before, but also during, HC generation. Other evidence of kerogen hydrogenation by water *during* HC generation exists in figures 4, 5, and 7. In the coals of figure 4, HC generation commences at R_o=0.6 percent increase, yet minimum hydrogen-index values continue to increase, presumably from kerogen hydrogenation, until R_o=1.0 percent, where they begin to decrease. In figure 5, minimum hydrogen-index values for the other coal suite also continue to increase past R_o=0.6 percent, again presumably from kerogen hydrogenation, up to R_o=1.0 percent, where they again begin to decrease. In the Bakken shales of figure 7, maximum hydrogen-index values demonstrate that HC generation commences at 8,300 ft (2,579 m), yet minimal hydrogen indices continue increasing in value to at least 8,900 ft (2,765.7 m).

Conclusions and Implications from the Natural Data

An abundance of data from the natural system regarding kerogen hydrogenation by water confirms that our aqueous-pyrolysis experiments are replicating Nature. Moreover, the natural data also demonstrate that, as in the laboratory experiments, this kerogen hydrogenation occurs both before *and during* HC generation, and also occurs with all OM types. Because: (1) the lower temperature (150°–333°C) aqueous-pyrolysis experiments are replicating Nature in this regard, and (2) as discussed previously, these experiments have also replicated other formerly unrecognized characteristics of HC generation in Nature, it seems reasonable to assume that, with qualifications, possibly the higher temperature (>350°C) experiments may also be replicating natural HC generation processes.

In my opinion, the hydrogenation of kerogen by water can only be explained by redox reactions between water and OM, or in other words, the hydrolytic disproportionation of kerogen. The occurrence of this kerogen-hydrogenation reaction has profound implications for HC exploration and for both source-yield and resource-base assessments: To estimate the amount of oil a source rock can generate, typically ROCK-EVAL derived organic-richness values are used from immature samples of that rock. However, the preceding discussions demonstrate that those richness values could increase by a *minimum* of 30 percent before HC generation even commences, and most probably continue to increase by similar amounts during HC generation. Of even more interest to us in this discussion, is that the very low hydrogen indices of "spent" kerogen may not preclude the possibility that deeply buried kerogen could still generate significant amounts of HC gas.