Geohazard detection and other applications of chimney cubes

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The "chimney cube" is a new processing and interpretation tool that highlights vertical anomalies on seismic data associated with gas clouds and gas chimneys. They are used to address drilling hazards caused by shallow gas pockets and platform stability problems due to subsea mud volcanoes. Chimney cube data also assist exploration of hydrocarbon targets by high grading prospects and improving understanding of the petroleum system.

Practically, chimney cubes can reveal where hydrocarbons originated, how they migrated into a prospect, and how they spilled or leaked from this prospect and created shallow gas, mud volcanoes, or pockmarks at the sea bottom. Current applications include detecting shallow gas and geohazards, distinguishing between charged and noncharged prospects, determining vertical migration of gas, and unraveling a basin's migration history. New applications include identifying potential for overpressure, predicting hydrocarbon phase and charge efficiency (especially in multiphase petroleum systems), distinguishing active versus nonactive fault migration pathways, predicting seal capacity, and supporting and refining basin models. This paper presents initial models for applications of these very new concepts. The payback from the concepts is expected to increase significantly by gathering experience and updating the initial models.

TheChimneyCube is a new concept that uses a 3D volume of stacked seismic data with prior information (e.g., the interpreter's insight and/or other geologic data) to highlight vertical chaotic seismic character often associated with gas chimneys. Figure 1 shows a slice of a chimney cube overlaid on a conventional seismic cross-section. The methodology was discussed in detail in Meldahl's "Interpreter's Corner" article in the May 2001 *TLE*. The appendix overviews the methodology and processing sequence. The main body of this article will highlight specific applications of chimney cubes for different geohazard problems.

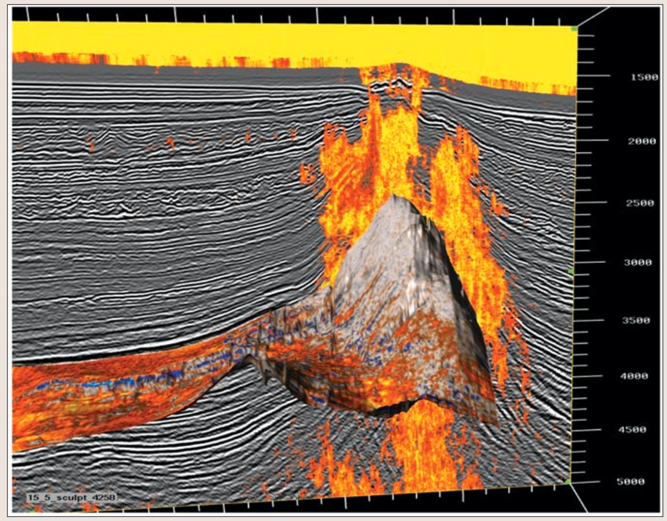

Figure 1. A slice of a chimney cube overlaid on a conventional seismic cross-section. (Figure courtesy of ChevronTexaco.)

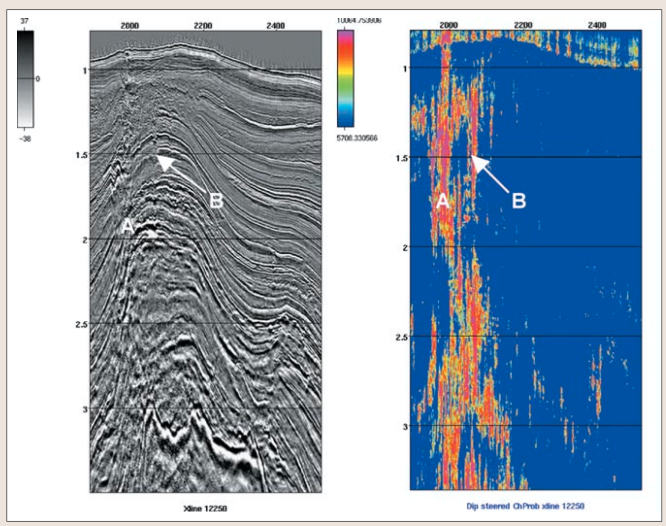

Figure 2. Examples of near-surface gas pockets in the Gulf of Mexico highlighted by gas chimney processing (right). The original seismic section is on the left.

Detecting shallow gas pockets. The impetus for developing the chimney cube technology originated from different sources of knowledge and experience—for example, the blow out of a well and destruction of a platform in the North Sea due to a shallow gas pocket—and resulting research into the detection of such hazards. The development of new seismic characterization technology using neural networks and the unused potential in seismic acquisition and processing techniques also motivated the tool building.

Gas hazards are often manifested by pock marks or seafloor mud volcanoes. Figure 2 shows an example of the output of chimney processing that highlights near-surface gas pockets in the deepwater Gulf of Mexico. Obvious chimneys, which extend to the seafloor (events A in Figure 2), can be observed from conventional seismic. The chimney cube data, however, can highlight more subtle chimneys and those which do not extend to the seafloor (events B). Chimney cube data can also aid in distinguishing deeply seated anomalies from shallow anomalies. The deep anomalies in this example are likely related to hydrocarbon migration; the shallow anomalies are possibly associated with dewatering of the shallow sediments. Moreover, any evidence of problems with seafloor stability, observed from seafloor bathymetry or dip-azimuth maps, could easily be linked to the presence of gas columns using chimney cubes. Chimney cube data can also be integrated with velocity volumes or overpressure prediction data to optimize prediction of geohazards.

Predicting shallow geopressure. Prediction of shallow abnormally pressured areas is very important, especially in unstable deepwater settings. Because fracture pressures in these shallow sections are very low, any excess geopressure can make drilling difficult. Gas chimneys are a critical means by which excess geopressure is released from a reservoir. Figure 3 shows a shallow channel levee interval in the Gulf of Mexico deepwater. High amplitudes, indicated in white, represent channel facies. These channels are segmented by faults (shown in black). Gas chimneys (shown in yellow) show vertical

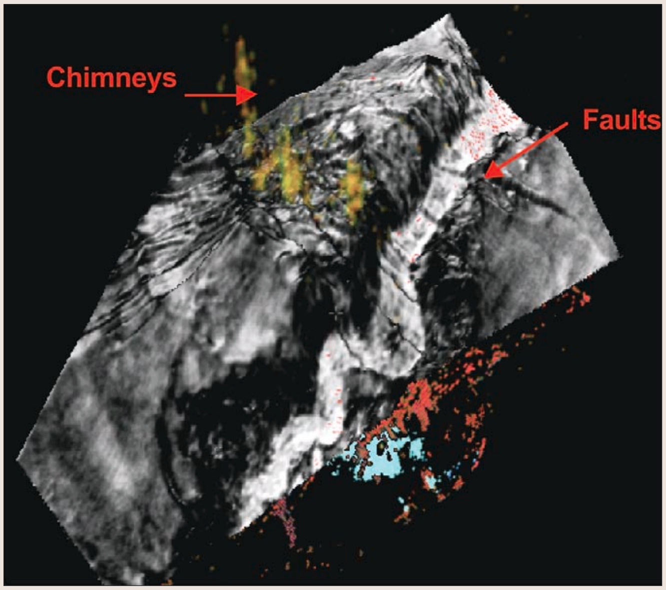

Figure 3. *High-amplitude channel facies (white) are segmented by faults (black). Chimney data (yellow) show degassing or dewatering of the levee facies. No chimneys are present where faults cross the channel. This indicates that if gas is present, the faults may be sealed and the gas overpressured. (Figure courtesy of Statoil.)*

degassing or dewatering of the levee facies. However, no chimneys are present where faults cross the channel. This indicates that, if gas is present, the faults may be sealed and the gas may be overpressured. Combining chimney data with shallow geopressure anomalies, often related to abnormal compaction gradients (negative velocity gradients), can improve the reliability of our predictions.

Chimney cube data can often show charging of shallow

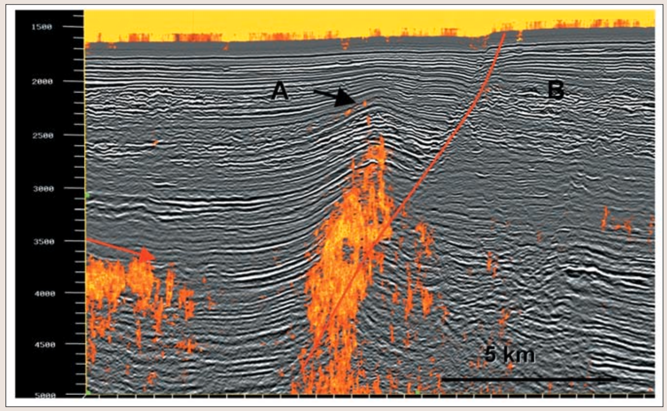

Figure 4. *Event marked A shows probable vertical migration of hydrocarbons into shallow reservoir areas. Note the lack of vertical migration (B) into traps on the upthrown side of the major basin-bounding fault. (Figure courtesy of ChevronTexaco.)*

reservoirs that may cause shallow geohazards. In Figure 4, anomalies were recognized in the shallow reservoir interval. The chimney cube data showed a prominent chimney associated with this reservoir unit. Often it is difficult to distinguish lithologic and hydrocarbon-related effects in AVO anomalies. Shallow reservoirs with AVO anomalies clearly linked to vertical chimneys are more often gas-filled. Because there is no evidence in the chimney data for vertical leakage from this trap, this shallow sand is more likely to be geopressured.

Distinguishing shallow fault geohazards. Faults which are migration pathways for deep, highly pressured hydrocarbon fluids are likely to be drilling hazards. A seafloor dip-azimuth map from deepwater, Nigeria (Figure 5) shows the charac-

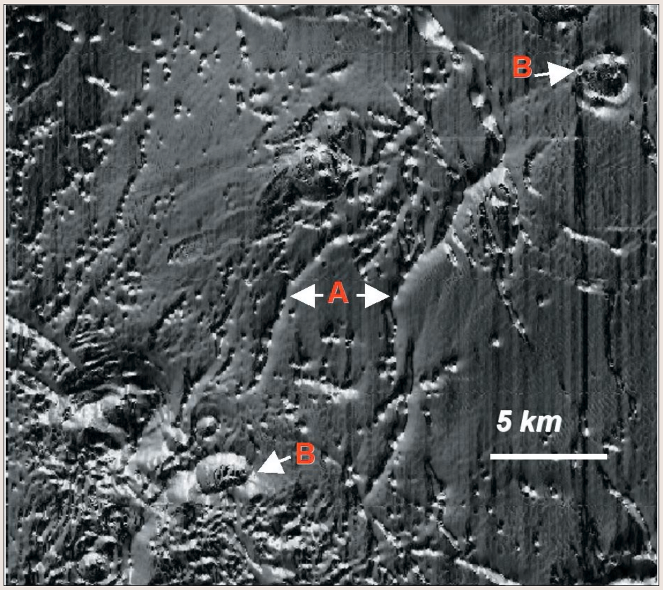

Figure 5. Seafloor dip-azimuth map showing characteristics of active hydrocarbon seepage indicated by piston core data. A indicates faults with active seepage that are characteristically pockmarked. B indicates large mud volcanoes that are sites of active oil and gas venting. (Figure courtesy of Statoil.)

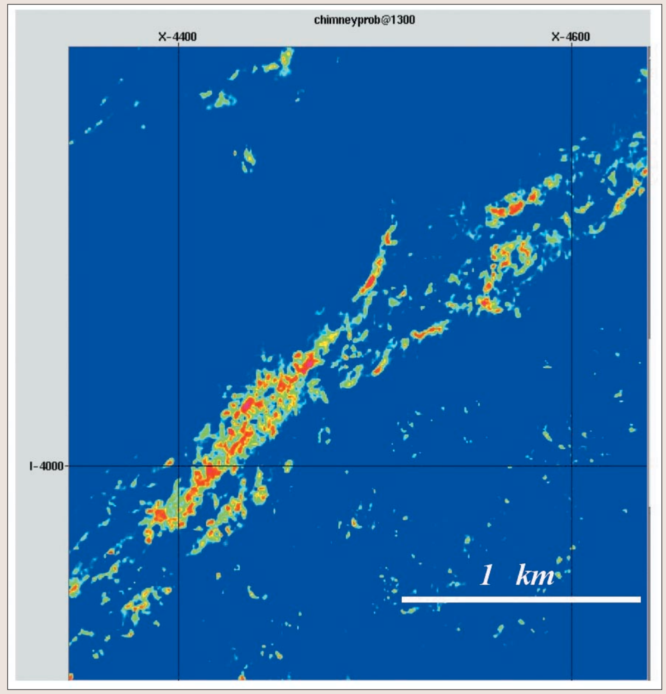

Figure 6. Linear fault-related gas chimneys in the shallow subsurface show similar pockmarked character, indicating hydrocarbon migration.

teristic pockmarks associated with active hydrocarbon seepage along faults (A) and active venting of hydrocarbons in large mud volcanoes (B). Piston core data in the area substantiate hydrocarbon seepage related both to the faulting and to the mud volcanoes (Graue, 1998). Seabed cores contain both live oil and gas. When observing a time section through a chimney volume in the same area, a similar pockmarked pattern can often be seen along some fault trends (Figure 6). Often the faults showing this pockmarked character have a preferential trend, related to current-day stress fields. Many basins, such as the Gulf of Mexico, are essentially undercharged, and migration of hydrocarbons via faults is dominant. Understanding which faults are the major hydrocarbon conduits is critical to assessing risk for both charge and seal.

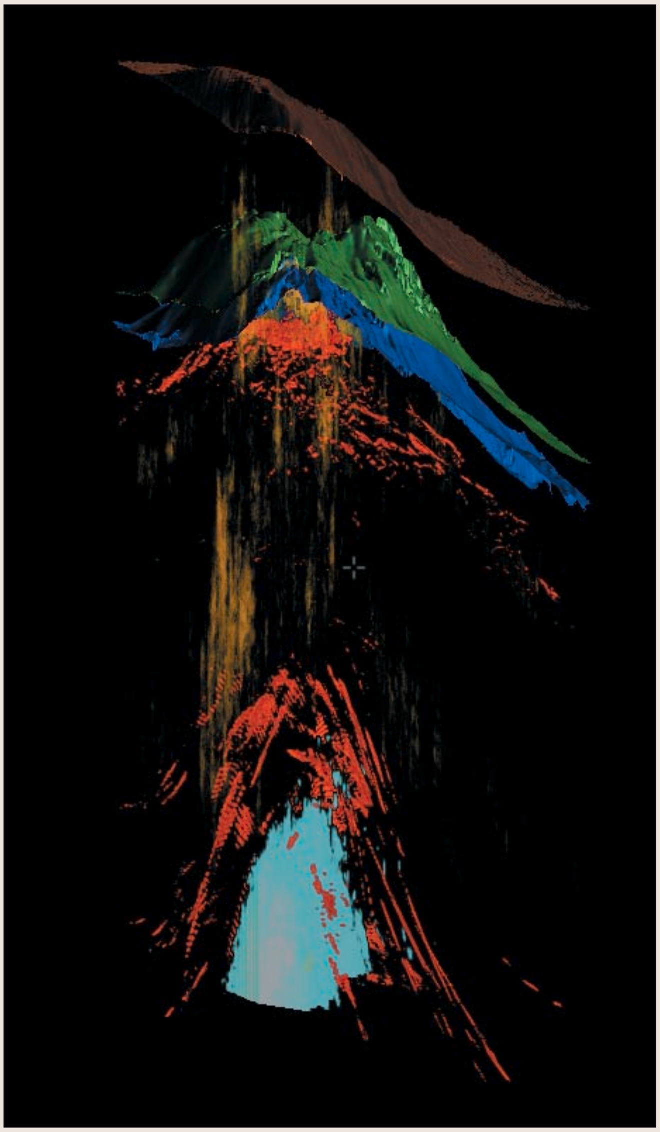

Figure 7. A 3D image showing chimneys related to high strain rates over salt diapirs. (Figure courtesy of Statoil.)

Discussion and conclusions. It is very important for chimney cube data to be integrated with other geologic information such as pore pressure estimation or velocity cubes in assessing the risk of geohazards. Dip and azimuth maps generated from 3D seismic data have proved useful in identification of surface anomalies related to shallow gas or fluid seepage. New tools, such as Sea Bed Logging (SBL), may also be used with chimney data to delineate shallow gas occurrences (Eidesmo, 2002). It has been observed frequently that gas chimneys are in areas of high strain. Thus, many gas chimneys and mud volcanoes are over shale diapirs and salt bodies. Figure 1 is one such case with gas chimneys related to highly strained shale diapers. Figure 7 displays chimneys related to high strain rates over salt diapirs. These structural features are often attractive prospects but can be significant drilling hazards.

In conclusion, processing 3D seismic data using a multiattribute approach with a neural network can delineate vertical discontinuities in the data often related to hydrocarbon migration. This chimney cube can then aid detection of shallow gas hazards by highlighting subtle gas chimneys and chimneys which do not go all the way to the seafloor. Chimney cubes also can be used in conjunction with geopressure analysis from velocity data to predict shallow geopressured sands. Gas chimneys often act as a pressure valve on shallow reservoirs to relieve excess pressure. Finally chimney cubes can distinguish faults which are conduits for hydrocarbons. These "leaky" faults may act as conduits for that transport deep geopressured fluids into the shallow section where they would be drilling hazards.

Suggested reading. "Using gas chimneys as an exploration tool" by Aminzadeh et al. (*World Oil*, Part 1, May 2001; Part 2, June 2001). "Interpretation of chimney cube" by Connolly and Aminzadeh (*Proceedings of 2002 AAPG Hedberg Conference* in Vancouver). "Sea Bed Logging (SBL), a new method for remote and direct identification of hydrocarbon filled layers in deepwater areas" by Eidesmo et al. (*First Break*, 2002). "Mud volcanoes in deepwater Nigeria" by Graue (*Marine and Petroleum Geology*, 2000). "Seismic chimney interpretation examples from the North Sea and the Gulf of Mexico" by Heggland et al. (*American Oil and Gas Reporter*, 2000). "Detection of seismic objects, the fastest way to do prospect and geohazard evaluations" by Heggland et al. (EAGE 2002 *Extended Abstracts*). "Shale intrusions and associated surface expressions—examples from Nigerian and Norwegian deepwater areas by Heggland and Nygaard (1998 OTC *Proceedings*). "Identifying faults and gas chimneys using multiattributes and neural networks" by Meldahl et al. (*TLE*, 2001). "Method of seismic signal processing" by Meldahl et al. (Patent application GB 9819910.02). "Evaluating trap integrity in the Vulcan subbasin, Timor Sea, Australia, using integrated remotesensing geochemical technologies" by O'Brien et al. (in *The Sedimentary Basins of Western Australia 2: Proceedings West Australia Basin Symposium*, 1998). "Seal strength vs. trap closure—A fundamental control on the distribution of oil and gas" by Sales (in *Seals, Traps and the Petroleum System, AAPG Memoir 67*, 1997). TLE

Appendix

Here we briefly describe the workflow for chimney processing. See Meldahl et al. (2001) for more details. In this process, a seismic volume (and corresponding attributes) is provided as input to a neural network and a chimney cube is generated as its output (Figure A1). The procedure involves:

1) Picking known or suspected chimneys and nonchimneys from the seismic volume for training and test data sets.
2) Calculating a set of single-trace and multitrace seismic attributes that distinguish between chimneys and nonchimneys.
3) Designing and training a neural network with attributes extracted at interpreted chimneys (red circles) and nonchimney (yellow circles) areas.
4) Creating the "chimney cube" volume, which represents vertical chimneys as a probability from 1 to 0.
5) Visualizing and interpreting the chimney volume.

It has to be emphasized that a key feature of this approach is an implicit design of an objective function that discriminates between chimneys and nonchimneys through proper selection and weighting of the attributes.

This is done by training a neural network on multiple attributes extracted at locations identified by the interpreter as chimneys and nonchimneys. In the learning phase, the network aims to optimize the classification by adjusting the weighting function. Figure A2 compares the classification power of a single attribute and the multiattribute neural network approach. The figure on the left shows the distribution of a similarity (a kind of coherency) attribute for chimney (red) and nonchimney (green) examples from the training set. The distributions grossly overlap and, consequently, classifying the

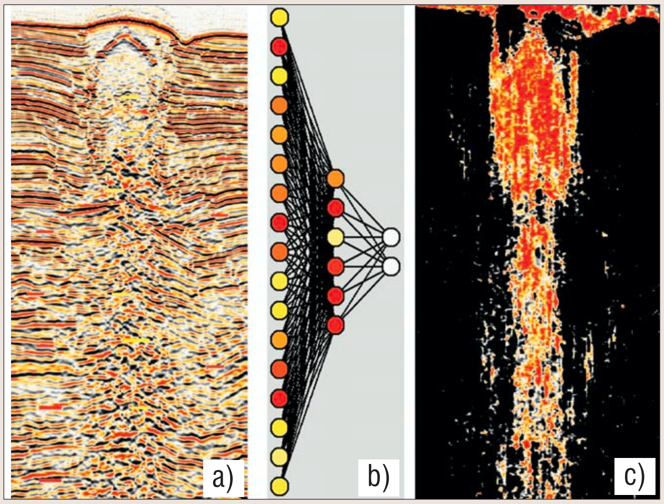

Figure A1. *Picked chimneys (yellow circles) and nonchimneys (red circles) are used (a) to train a neural network composed of weighted attributes (b) to predict chimneys throughout the seismic cube (c).*

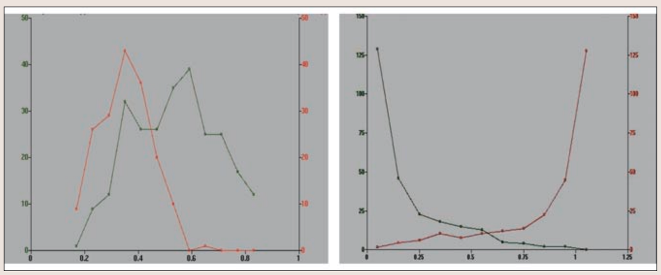

Figure A2. *The left figure shows overlapping distributions of single-attribute similarity values for manually picked locations of chimneys (red) and nonchimneys (green). The right figure shows distributions from two neural network output nodes that have learned how to predict chimneys (red) and nonchimneys (green). Considerably better classification has been achieved.*

data based on this single attribute will yield poor results. The right figure shows distribution of the neural network output nodes for the same training set. The network has two output nodes, respectively representing chimneys and nonchimneys. Ideally the nodes return the values 1 and 0 if the example is a chimney, and 0 and 1 if the example is a nonchimney. In reality, the output data are floating point numbers that range between approximately 0 and 1. The two distribution curves on the right reveal a much better separation between chimneys (red) and nonchimneys (green). Figure A3 compares the chimney cube processing with the similarity attribute processing alone. Note the much clearer definition of the vertical chimneys.

David Connolly has joined dGB-USA as chief geologist. David has more than 20 years of industry experience in various aspects of petroleum geology and geophysics. Formerly with Texaco, he has worked on many exploration assignments. Most recently he has been developing applications for chimney and fault cubes in deepwater Nigeria and the Gulf of Mexico to better understand petroleum migration and phase. His areas of expertise include reservoir characterization, sequence stratigraphy, integrated seal analysis, petroleum migration, and 3D visualization. He has developed methodologies for determining net sand from multiattribute volumes and inversion. Prior to joining Texaco, he worked as a core analyst for Schlumberger-Anadrill.

Paul de Groot is cofounder and director of dGB (de Groot-Bril Earth Sciences BV), which specializes in quantitative seismic interpretation, stratigraphic analysis, seismic inversion, neural networks-based reservoir characterization, and gas chimney/fracture detection. He began his career in 1981 with Shell. He then became director of Quest Geophysical Services and subsequently served as senior geophysicist for TNO Institute of Applied Geoscience before cofounding dGB in 1995. He holds a MSc and a PhD in geophysics from the University of Delft.

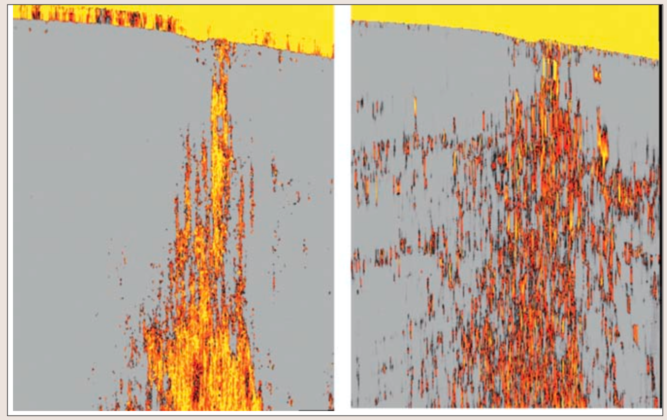

Figure A3. *Comparison of chimney processing (left) with similarity attribute processing alone (right). Note the much clearer definition of vertical chimney objects.*

For biographies of other authors see TLE, *April 2002 and February 2001.*

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