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Worldwide Distribution of Major Carbon Dioxide Deposits: Geologic Setting and Gas Isotopic Evidence of Mantle Sources in Areas of Crustal Extension and Transtension

Deposits of CO_2-rich gas (>50%) are present worldwide but in limited areas. One hundred twenty-one (121) have been identified and classified worldwide, but many others remain to be identified and studied. If encountered while drilling for oil and gas, CO_2 can be either an expensive nuisance or an economic resource. Traditionally, explorationists have only wanted to know how to avoid CO_2 deposits or at least learn how to calculate the risk of finding them. In certain areas there is now a desire to find CO_2. Evidence of the source of the CO_2 deposits is in their geologic setting and in the gas itself.

Tranditionally, explorationists have only wanted to know how to avoid CO_2…now there is a desire to find it

Geologic Setting

The 121 known deposits of CO_2 are typically located in areas of tectonic extension. They are distributed among: cratonic arches, 14; cratonic basins with basic igneous intrusions, 47; continental rifts, 13; areas of transtensional basins related to tectonic escape, 12; back-arc basins, 13; cross-trends in foreland basins just in front of thrust sheets, 12; plate-bounding strike-slip faults, often near basaltic volcanism, 8; and in thrust belts, 2. Although the geologic settings of these deposits suggest mantle CO_2 rising with mantle-derived basalts into the crust, other evidence is needed to support a reliable model for a source of CO_2 deposits.

Gas Composition and Stable Isotopes

Evidence of source is available from the gas itself in the stable isotopic ratios of carbon in CO_2 and in the content and isotopes of noble gases, especially of helium $^3He/^4He$. The isotopic ratio of carbon 13 to carbon 12 reported as difference in parts per thousand from the PeeDee belemnite standard ($\delta\ ^{13}C$ ‰ PDB) can aid in distinguishing different sources of CO_2. The ratio can vary from below -10 ‰ for CO_2 derived from organic matter to 0 ‰ for CO_2 from calcined limestone. Mantle CO_2 is around -5 but overlaps with CO_2 from metamorphism of limestone. The ratio $^3He/^4He$ as compared to a standard that is the ratio in air (Ra) is another useful measure. Helium 3 is a marker that can document access to the mantle as proved by values on the mid-oceanic spreading centers. The use of both these isotopes will be shown in the talk.

Example of a Typical CO_2 Deposit

A detailed study was made of a typical CO_2 deposit, Bravo Dome Field, New Mexico, U.S.A., which contains 283 billion cu. meters (10 trillion cu. ft.) of 99% CO_2. It is a combination structural-stratigraphic trap, with Permian Tubb Formation sandstone pinching out on a basement nose and sealed above by anhydrite. Gases were specially sampled and analyzed, revealing a dynamic gas deposit in which the noble gas content varies systematically across the field from near mantle values in the west, far above the gas-water contact, to higher concentrations in the east at the gas-water contact. We interpret that CO_2 entered the lowermost sandstone on basement at the west side of the field from a basalt dike below, sweeping the connate water of the sandstone down-dip as the trap filled. The field is a window to the mantle because mantle gases are preserved to the west, while in the east, atmospheric and crustal noble gases enter the CO_2 from the water below. The CO_2 of the deposit is dissolving down-dip into the water. That the CO_2 of Bravo Dome Field is clearly of magmatic origin is shown by $\delta\ ^{13}C$ values of -3.7 to -5.1 ‰ PDB in the CO_2 gas, by the relationships of noble gas concentrations, by the isotopic ratio $^3He/^4He$ being as high as 4.26 Ra, and by the high $CO_2/^3He$ ratio. This will be illustrated by maps, charts and graphs.

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Exploration Use and Conclusions

Examination of other CO_2 deposits worldwide will be shown to illustrate that a general model of generation of CO_2 deposits is possible; the use of the model in exploration to either avoid or find CO_2 will be explained.

We conclude that, in general, CO_2 trapped in sedimentary rocks came from the mantle. Fractures in the crust in areas of extension allow basic magma to rise. CO_2 is expelled from the magma and enters porous reservoirs in sedimentary sections and, where adequate traps and seals are present, forms CO_2 deposits. CO_2 is unrelated to hydrocarbons, migrating separately and at different times. ■

Biographical Sketch

Martin M. Cassidy graduated from Harvard where he majored in geology and graduated with an AB cum Laude in 1955. He accepted a summer job in geophysics with Standard of Texas in Houston before serving three years in the US Air Force in Korea and Denver as a 2nd Lieutenant. After being discharged, he earned a Masters degree in petroleum geology from the University of Oklahoma and started work on a PhD at Harvard, but decided to reenter the oil business before finishing.

In 1962 Dr. Cassidy joined Pan American Oil Company, later Amoco and then BP. He worked South Texas for seven years before moving to the international company. He became chief geologist of Pan American Libya Exploration Company, where he and the family lived until 1973. After a series of assignments in Chicago and Houston, he moved to London where he rose to Exploration Manager of Amoco UK. After the industry crash of 1986, he transferred back to the U.S. as a technical advisor and later as project leader for international new ventures. During his time at Amoco, he was involved with wells in the East Natuna Sea, Indonesia that found CO_2. The reasons for the carbon dioxide occurrences were not clear and the question of source remained unsolved.

Dr. Cassidy retired from Amoco in 1994 and entered a PhD program at the University of Houston taking as a topic the study of the source of CO_2 in the subsurface. From a subject of little interest to industry or academia, carbon dioxide has now become a topic of significant interest. Dr. Cassidy currently is pursuing the study of CO_2 in the subsurface and of petroleum geochemistry around the world as a research scientist for the University of Houston and as a consultant.