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THE NEWBERRY CRATER LAKES, OREGON

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INTRODUCTION

Newberry volcano, just south of Bend (OR), has two crater lakes, Paulina Lake (PL) and East Lake (EL) (Reynolds, 2000, 2002). Both are fed by geothermal fluids (Sammel et al, 1988) and meteoric water inputs (Sammel and Craig, 1983; Phillips and van den Burgh, 1968). PL has hot aqueous inputs and EL has a gas input. The two different inputs are reflected in the water and sediment composition of the lakes (Morgan et al., 1997). EL has rising bubbles of CO_2, H_2S, and Hg, which turn into HCO_3^-, sulphate and methylmercury. EL water has modest cation contents and a pH of 6-7. PL water is more concentrated (about 3-4 x EL), with high carbonate contents, pH>8, and slightly elevated arsenic (15 ppb). The PL sediment is rich in arsenic and iron, while both lakes have sediments with ~ 50% biogenic silica and 10% organic carbon. In EL, the remainder of sediment is volcanic ash and very Fe-poor, whereas PL sediment is iron-rich, may contain hydrothermal silica and carries the mineral vivianite. EL has a diffuse and a bubble flux of CO_2 to the atmosphere, whereas PL with its higher pH value lacks the surface CO_2 escape. The $\delta^{13}C$ (DIC) shows a strong gradient with depth in EL (~5‰), whereas such a depth gradient in PL is very small (~0.5‰). The DIC in EL also has much higher $\delta^{13}C$ values (up to +5.5‰) versus PL at ~0‰. The stable isotopes of water reach rather extreme values for EL through sustained evaporation, but more modest values for PL, which is flushed by the outgoing Paulina Creek (PCR). The organic matter in both lakes is a mixture of phytoplankton, cyanobacteria (e.g., Nostoc sp) and vascular aquatic plant debris, as indicated by carbon and nitrogen isotopes studies of sedimentary organic matter.

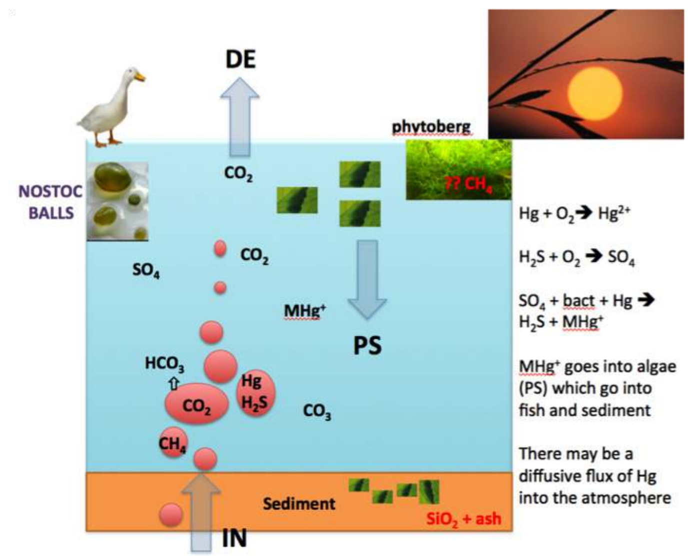

Figure 1. East Lake water column processes: CO2 escape to the atmosphere (DE), burial of photosynthetic carbon (PS) and Hg methylation. Phytobergs are floating vascular plant islands.

Processes occurring in EL are the oxidation of H_2S ➔ sulphate and the methylation of Hg, with abundant photosynthetic production of organic carbon in the photic zone (Figure 1). The formation of methane in the Newberry lakes is puzzling: the bottom waters have low concentrations of geothermal methane whereas the surface waters have 10-50 times as much methane of fermentation origin.

Mercury enters EL as Hg(0) gas with the CO_2 bubbles. EL fish are rich in Hg (2-4 ppm Hg) (Stone et al., 1996) and must have taken that in as methylHg (M-Hg). Presumably, the water column is rich in M-Hg, which forms as a by-product of bacterial sulphate reduction. This leads to a peculiar sequence of events: H_2S comes in, is oxidized by dissolved O_2 (?) into SO_4, which can then be reduced by reaction with methane to HS^- or through bacteria into H_2S, making M-Hg along the way. The EL sediment is rich in Hg, but so poor in Fe (~1%) that no pyrite forms. In PL there is an abundance of Fe but no S, so also no pyrite forms in PL sediment.

The pathways of elements brought in by the bottom hot springs of PL are sketched in Figure 2. Dissolved Fe^{2+} is oxidized to hydrous iron oxides (HFO) by dissolved O_2 which adsorb P and As (as their oxyanions). In the sediment, these HFO are reduced by C_{org} to Fe^{2+} and vivianite forms, possibly incorporating As in its structure.

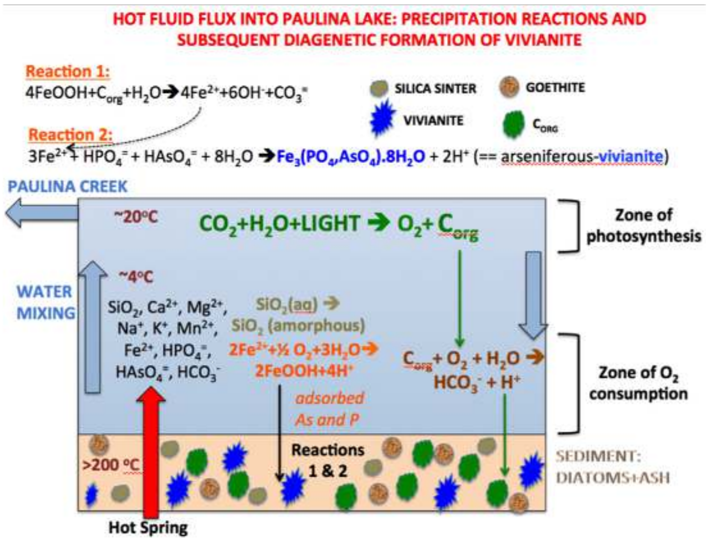

Figure 2. Element pathways in Paulina Lake with the Fe, As and P cycles highlighted.

Lena Capece (Wesleyan University). Carbon dynamics of East Lake.

Water profiles were sampled and analysed for major and trace elements as well as stable isotopes. The data show strong depth gradients for $\delta^{13}C$ (DIC), which are only very small in PL (Figure 3). The enrichment of ^{13}C in the surface waters is most likely related to the diffusive escape of CO_2 from the water-air interface, and to a lesser degree through photosynthesis and burial of isotopically 'light' organic carbon in the sediment. Lena measured the CO_2 fluxes from the lake surface during the fieldwork with our own construction floating accumulation chamber with a pump, timer, PC and LICOR CO_2 analyzer. She applied sequential Gaussian simulations techniques to obtain a best estimate of the daily CO_2 flux from the lake (~40-50 tonnes CO_2/day). She sampled gases from the accumulation chamber and the open air directly above the lake as well as background air for $\delta^{13}C$ (CO_2) measurements. Mixing plots of $1/CO_2$ versus $\delta^{13}C$ suggest that the escaping CO_2 is isotopically very light (-15 to -30‰), much lighter than calculated values based on temperature-dependent fractionation factors (~ -5‰). Presumably, a kinetic fractionation effect is active, which needs more study. More analytical data are needed to ascertain this light CO_2 value, but the existing data prove that the escaping lake CO_2 is

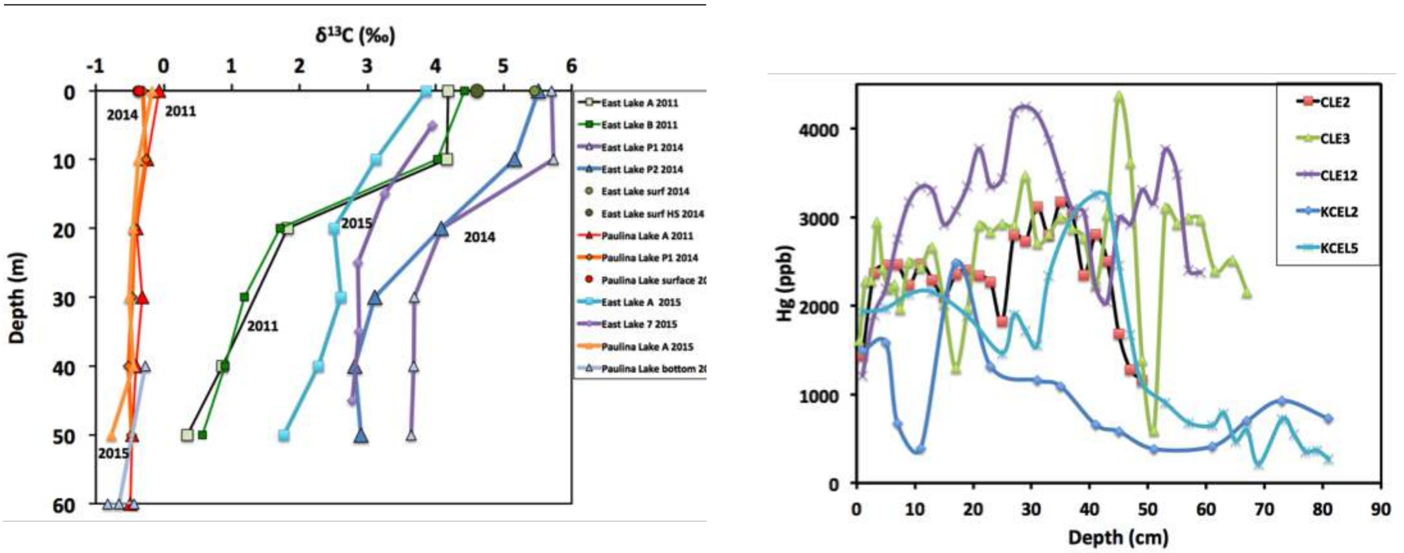

Figure 3. Left. $\delta^{13}C$ in dissolved inorganic carbon in PL and EL. Note the strong gradient in El and the minor gradient in PL. Right. Mercury in EL sediment (blue labels are 2015 samples); background Hg pollution values are ~ 400-500 ppb Hg so there is a strong natural Hg contamination signal.

substantially lighter than atmospheric CO_2 (-8.5‰). Speciation calculations were carried out with the PHREEQ speciation program to calculate internal P_{CO2}, because the ΔP_{CO2} (lake➔atmosphere) drives the diffusive CO_2 escape. Piston velocities for the escaping gas were calculated and variations with windspeed and water temperature were evaluated to arrive at annual flux estimates. Sediment bulk dry densities were determined and sedimentation rates were established through ^{210}Pb analyses, providing mass accumulation rates for the various sediment components. The organic carbon accumulation rates for several cores were calculated and the lake-wide organic carbon burial rate was determined. Combination of the gas escape and burial leads to a carbon cycling model, resulting in an estimated carbon residence time in the lake of 0.9 years. Quantitative models are being developed with a geothermal CO_2 input and CO_2 evasive loss and C_{org} burial, each with their own $\delta^{13}C$ values, in order to simulate the formation of the depth gradients in $\delta^{13}C$ (DIC). Apart from these near steady state considerations, a small (few %) secular increase in DIC may have taken place in EL over the last five years. Sediment studies show the strong Hg enrichment in EL cores (Figure 3).

Julia Horne (Colgate University) The chemical dynamics of Paulina Lake.

Field studies established that subaqueous hot spring zones occur in the NW section of PL. Temperature sondes were dragged along the bottom and temperature profiles were measured in many sites of the lake. An area with anomalous temperature profiles was singled out as the closest encounter with the hot water emission zones. Analyses for major and trace elements were done through ICP-MS studies and pathways and fluxes of the various major and minor elements were investigated. The PCR outflow exports large amounts of all elements and these are replenished by the hot springs (assuming steady state, as indicated by long-term constancy of lake water composition). An initial water budget for PL is established through stable isotope models (Figure 4). An input of silica into PL is needed to balance the combined export rate of PCR and diatom productivity with silica burial into sediment. The Si flux is determined by the hot spring water flux and

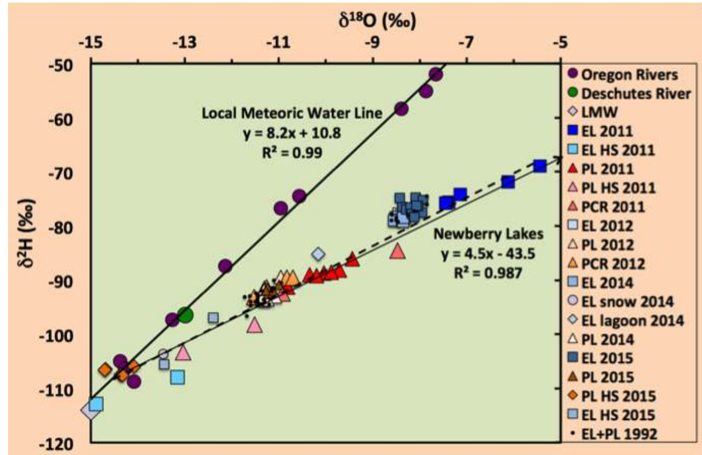

Figure 4. Stable isotope data for East Lake (EL) and Paulina Lake (PL). The lake data plot on an evaporation line, starting at the local meteoric water endpoint.

its Si concentration. The latter is a function of water temperature, providing some constraints on water flux/temperature input parameters. Additional Si sinks are direct silica precipitation upon mixing with cold lake water. Some small hot springs on the NE beaches of PL provide constraints on the composition of the hydrothermal inputs into the lake.

Heather Upin (Smith College). Catastrophic drainage events of Paulina Lake.

PL has several paleo shorelines a few m above current levels and some evidence for low stands from silicified zones with beach fossils below the current water line. PCR has major cascades (Figure 5) with a magnitude that can not have been caused by the current PCR flow regime. The canyon bed also has been virtually stripped of the Mazama ashes from

Figure 5. Paulina Falls has a drop of >20 m and the geometry of its cirque and steep falls strongly points at an origin by a catastrophic flood, not through the small water flux of PCR today.

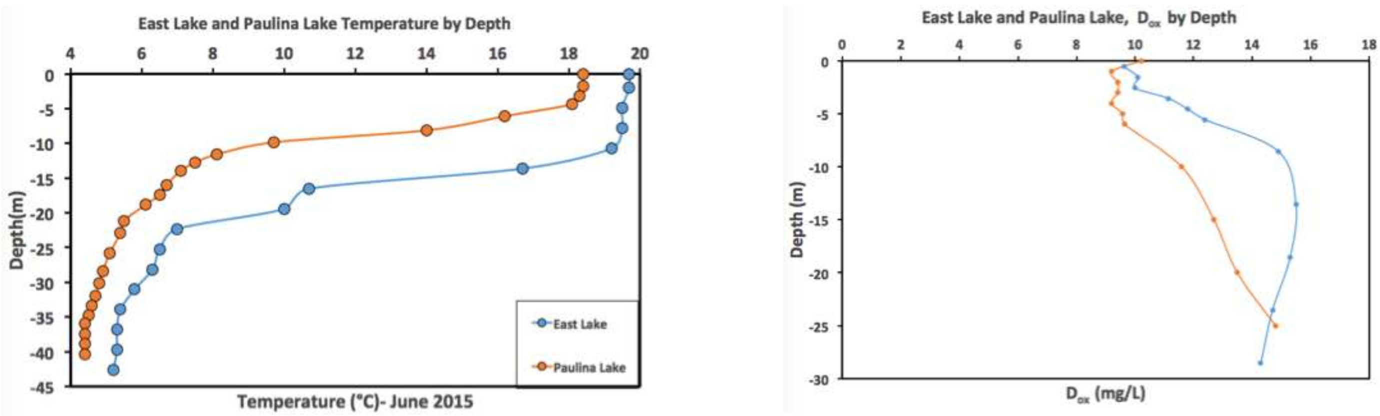

Figure 6. Temperature and DOX concentrations in the Newberry lakes. LEFT. The lakes show a pronounced thermocline at ~ 10-15m depth and bottom water temperatures of 4.4 °C in PL and 5 °C in EL. RIGHT. The lakes were well oxygenated in summer 2015. High DOX values in deep waters are a result of the low bottom water temperatures and carry a 'memory' of equilibration with atmospheric air at winter/early spring temperatures.

the 7600 BP eruption from Crater Lake, indicating that major floods occurred over the last few thousand years. A flood apron has formed at the exit of the PCR canyon, with boulders covered with thin carbonate precipitates. The PCR river bed is also cemented by carbonate minerals near the apron, which was determined to be Huntite ($Mg_3Ca(CO_3)_4$). PL has ~ 42 ppm Mg and 28 ppm Ca and up to 400 ppm HCO_3^- at a pH of 8.0 to 8.4. Heather studied short cores in the PCR and in the flood plain of the Little Deschutes River to search for depositional layers related to this "big Paulina flood". Although we could not obtain cores that went deep enough to locate the flood layer in the distal environment, her work on the apron shows that it has elevated arsenic concentrations, derived from the export of PL sediment. The As fingerprint will be useful to identify the Paulina Flood layer in future studies and then date it. Heather also evaporated modern PL water and studied by XRD-SEM the precipitates and compared it with the incrustations on the apron boulders and river bed cement. The DEM and detailed mapping of knick points in the PCR river provide further evidence for possibly several catastrophic floods from PL. The cause for such events may be seismic movements, dam collapse, or volcanic events in the lake, including Nyos-like events.

Sam Caldwell (Amherst College) Methane generation in the Newberry crater lakes

Sam collected DOX and temperature profiles in both lakes (Figure 6). Sediment cores were spun down in a centrifuge and pore waters were analysed for major elements and methane. Several profiles were sampled for methane and its isotopic composition, and data arrival is pending at the time of writing. Sam also analysed nutrient profiles in the water column. The abundances and isotopic fingerprints of methane in the twin Newberry lakes are puzzling (Figure 7 with 2014 data). Why would the fully oxygenated surface waters have elevated methane concentrations relative to the deeper, lower oxygen bottom waters?

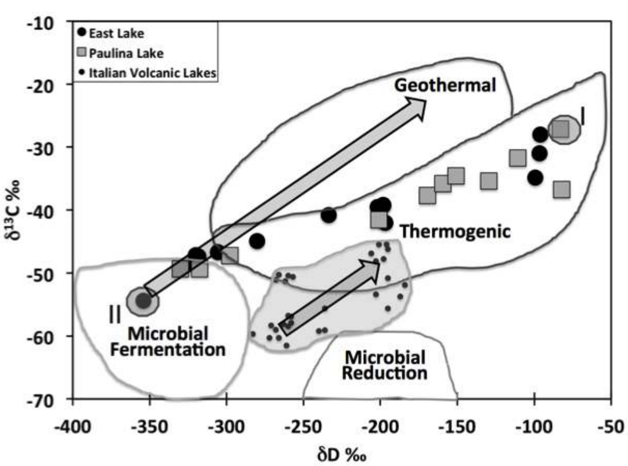

Figure 7. Methane isotope fingerprints in the Newberry crater lakes. Both PL and EL seem to have fermentation-type methane (Type II) in their surface waters, which may evolve along the grey arrows as a result of methanotrophy. The deep waters contain the thermogenic methane (Type I), possibly of geothermal origin (fields overlap). The field of methane in Italian CO2 rich crater lakes is shown for comparison, with an arrow for methanotrophy.

References

Lefkowitz, 2012, A Tale of Two Lakes: Hydrothermal Geochemistry of the Newberry Volcano, Oregon, Senior thesis, Wesleyan University, p.171

Lefkowitz, J, Varekamp, JC, Reynolds, RW, Thomas, E, 2016, A Tale of Two Lakes: the Newberry Volcano Twin Crater Lakes, Oregon, USA In: Active Crater Lakes, special volume Geological Society of London, *Active Crater Lakes*, eds Corentin et al. In revision after review (40 pages)

Morgan, D. S., Tanner, D. Q., and Crumrine, M. D., 1997, Hydrologic and Water Quality Conditions at Newberry Volcano, Deschutes County, 1991-95, *in* Survey, U. S. G., ed.: Portland, Oregon, United States Geological Survey.

Phillips, K. N., & van den Burgh, A. S., 1968, Hydrology of Crater, East and Davis Lakes, Oregon, Geological Survey water Supply Paper 1859 E., US Gov. Printing Office, Washington DC, p 60.

Reynolds, R.W., 2002, The Lakes in Newberry Caldera, (abstract) GSA Cordilleran Section - 98th annual Meeting, Corvallis, OR, p. A-83.

Reynolds, R.W., 2000, Paulina Lake Basin Studies, in *What's Up at Newberry Volcano, Oregon*, R.A.Jensen and L.A.Chitwood editors, Guidebook for the Friends of the Pleistocene Eight Annual Pacific Northwest Cell Field Trip September 15-17,2000, Bend, OR, p.101-108.

Stone, D., Smith, A., Foster, E., and Everett, R., 1996, Fish Mercury Advisory Revised for East Lake, Newberry Crater, Deschutes County, Volume 2012: Portland, Oregon, Oreg. Health Authority.

Sammel, E. A., and Craig, R. W., 1983, Hydrology of the Newberry Volcano Caldera, Oregon, *in* Interior, U. S. D. o. t., and Survey, U. S. G., eds.: Menlo Park, California, U.S. Geol. Survey.

Sammel, E. A., Ingebritsen, S. E., and Mariner, R. H., 1988, The Hydrothermal System at Newberry Volcano, Oregon: J. Geophys. Res., v. 93, no. B9, p. 10149-10162.