Periodic gas release from the LUSI mud volcano (East Java, Indonesia)

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The LUSI mud volcano has been erupting since May 2006 in a densely populated district of the Sidoarjo regency (East Java, Indonesia), forcing the evacuation of 40,000 people and destroying 10,000 homes. Peak mud extrusion rates of 180,000 m^3/d were measured in the first few months of the eruption, which had decreased to <20,000 m^3/d in 2012. Mud volcanoes often release fluids in a pulsating fashion, with periodic timescales ranging from minutes to days, and LUSI is no exception. These oscillations, common in natural systems of multi-phase fluid flow, are thought to result from complex feedback mechanisms between conduit and source geometry, fluid compressibility, viscosity and density, changes in reservoir pressure, fluid phases or vent conditions. Crisis management workers reported observations of pulsating eruptive cycles lasting a few hours during the first two years of the eruption, and possibly beyond. Since that time, activity has shifted to individual transient eruptions recurring at intervals of a few minutes. In May and October, 2011, we documented the periodic explosive release of fluids at LUSI using a combination of high-resolution time-lapse photography, open path FTIR, and thermal infrared imagery. The mud, consisting of approximately 70% water, is erupted at temperatures close to boiling. Gases are periodically released by the bursting of bubbles approximately 3 m in diameter, triggering mud fountains ~20 m in height. No appreciable gas seepage was detected in the quiescent intervals between bubble bursts. Infrared absorption spectrometry reveals that the gas released during explosions consists of 98.5% water vapor, 1% carbon dioxide, and 0.3% methane. On rare occasions, minor amounts of ammonia were also detected. Using simplified plume geometries based on observations, we estimate that LUSI releases approximately 2,300 t/yr of methane, equivalent to 0.5% of the yearly methane production from the 4.7 million heads of cattle in East Java. We observed explosion periods from 1 to 3 minutes with a mean period of 55 s and 114 s in May and October, respectively. Two conceptual models for the periodic behavior are assessed: 1) decompressional boiling of water as fluids ascend a pathway to the surface suggests that bubbles form 10s of meters below the surface and continue to expand as they rise; periodicity results from the time to reheat and/or replace the fluid in the vicinity of bubble formation; and 2) slug flow in which carbon dioxide bubbles are seeded at much greater depths and coalesce to form evenly spaced gas slugs which rise to the surface. Our estimates of gas and mass flux, along with well-constrained fluid and mud densities, are consistent with the development of slug flow, but high measured H_2O/CO_2 ratios in the gas plume suggests that bubbles form by decompressional boiling of water, rather than by carbon dioxide bubbles exsolved at great depths.