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Can We Gain Evidence About Volcanic Pyroclastic Flows from Those Who Survive Them?

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CAN WE GAIN EVIDENCE ABOUT VOLCANIC PYROCLASTIC FLOWS FROM THOSE WHO SURVIVE THEM?

Pyroclastic flows have been recognized as one of the most devastating hazards of volcanic eruptions ever since one killed nearly 28,000 people in the town of St Pierre in 1902 AD. After more than 100 years, however, there are aspects about them that scientists still do not understand, including where they will go, how far they will travel, how their velocity varies laterally and vertically, and how volcanic ash is transported within them to be deposited on the ground. Scientists rely on indirect evidence from their ash deposits or from computer models to hypothesize about such unknowns. The fundamental problem is that no one has made in situ measurements within the flows. Despite their lethal nature, however, some people have lived through them. While being enveloped by searing hot ash must be unimaginably traumatic, it is possible that survivors remember details that could help inform scientists, especially if a collective memory can be developed from multiple accounts. This study uses recollections from eyewitnesses and survivors of the 18 May 1980 pyroclastic flow from Mount St Helens to develop a collective memory that shows the leading edge of the flow is relatively ash poor, cold and even carrying ice. It is shown that this collective memory is likely sound by comparing it to the physical record of the flow from its impact on inanimate objects. What is gained is that a cold flow front would not have otherwise been imagined. It is hoped that if future encounters occur, scientists seek out eyewitnesses and survivors to gain new and potentially unexpected evidence about pyroclastic flows.

Introduction

More than 220,000 people have been killed by volcanic eruptions since 1783 AD (Simkin et al., 2001). About 27% of those died in pyroclastic flows and surges, the most catastrophic of which killed an estimated 28,000 people when it destroyed the harbor town of St Pierre, Martinique, in 1902. It is hoped that such disasters will become less likely as we gain understanding of volcanic eruptions, coupled with improved geophysical monitoring techniques. But, the global population is more than five times that of 1800 (Cohen, 1995), which can only raise the probability of more tragic events occurring. In fact, almost 500 million people, nearly 9% of the world's population, were living in 1990 within 100 kilometers of historically active volcanoes (Small and Naumann, 2001). Not surprisingly, the average number of fatalities per year from explosive eruptions has increased from 315 in the seventeenth to the nineteenth centuries to 845 in the twentieth century (Tilling, 1990).

Pyroclastic flows and surges are lethal mixes of searing hot ash and gases that move at hurricane-force speeds. One key to reducing the hazards associated with them is to understand better what controls where they go, how far they travel and how fast they move. Knowing those controls would in turn allow better modelling for predicting future events (Blong, 1984; Nakada, 2000). Until recently, pyroclastic flows and surges were thought to be different types of eruptive events, because they produce different types of volcanic deposits (Sparks, 1976; Carey, 1991). Pyroclastic surge deposits show signs of being produced by turbulent sedimentation, whereas those of pyroclastic flows appear to be products of laminar flow behavior. More recent studies, however, demonstrate that the spectrum of deposits can be produced by the same turbulent current, and hence pyroclastic flows and surges are now recognized as being the same phenomenon (Druitt, 1998; Burgisser and Bergantz, 2002). We will thus refer to them collectively as pyroclastic flows.

Pyroclastic flows travel along the ground because they are denser than the atmosphere. Despite their dense nature they can surmount obstacles, including mountain ridges hundreds to thousands of meters high, because of their high velocities (Gardner et al., 2007). As a pyroclastic flow travels, volcanic ash within it naturally settles to the bottom because of the greater density of the ash particles. As this dense sediment is lost, the rapidly moving flow becomes progressively less dense. At the same time, the high velocity of the flow causes it to be turbulent, producing turbulent eddies on its surface. These eddies engulf air and mix it into the hot flow, which heats and expands the air, further lowering the density of the flow (Bursik and Woods, 1996). As a consequence of sedimentation and air entrainment, a pyroclastic flow becomes lighter than the surrounding air, at which point it ceases moving laterally, and instead rises upward to form a buoyant plume (Woods and Wohletz, 1991).

How far a pyroclastic flow travels, and thus how much area it devastates, depends on its turbulent flow characteristics. Our understanding of those characteristics relies on studies of the deposits produced by the flows and computational models of the flows. The sophistication of such models has increased greatly in recent years with the advance in computing power, and they can now predict the runout distance, transport capacity and flow behavior when interacting with local topography and structures (Neri et al., 2003; Dufek and Bergantz, 2007; Esposti Ongaro et al., 2011). Linking model output to the deposits and natural pyroclastic flows remains difficult, however, because of the dearth of information about the physical behavior of the flows. Basic information, such as how velocity varies both horizontally and vertically within a flow, and how pyroclastic material (pumice and ash) settles through a fast moving, turbulent flow to form a pyroclastic deposit, is missing because *in situ* field measurements are impossible. No one has managed to measure the physical characteristics inside a moving pyroclastic flow.

There are people, however, who have survived being inside pyroclastic flows. The number who survive varies greatly (Baxter, 2000). In the St Pierre catastrophe only about 123 people lived through it, compared to the nearly 28,000 who did not. At Mount St Helens, almost half of the people known to have been engulfed by a pyroclastic flow survived (52 out of the 110). Most of the survivors were near the edge of the extent that the flow traveled, while the 58 that perished were closer to the volcano. Regardless of how many survive, what they might remember about the flow could provide details of what occurred within pyroclastic flows. Even basic information about the sequence of events could be clues to the behavior of flows that might not be imagined otherwise.

Following the 1980 eruption of Mount St Helens, Dr Richard Waitt of the United States Geological Survey (USGS) spent years interviewing survivors of the pyroclastic flow, as well as eyewitnesses who saw it from a safe distance. A compilation of those interviews was recently published (Waitt, 2014). This study uses those accounts to reconstruct aspects of the internal dynamics of the pyroclastic flow. The goal is twofold. First, it is to use the accounts to gain insight about the pyroclastic flow. Second, it is to show that such accounts can indeed provide insights. While the hope is never to have to conduct such interviews again, knowing that survivors can provide information may guide future scientists to seek them out to hear their stories and learn what no one wants to experience.

Methods

This study relies on the accumulated interviews with eyewitnesses and survivors carried out by Richard Waitt (Waitt, 2014). It focuses on those interviewed who were near Mount St Helens on the morning of 18 May 1980. Some were interviewed soon after the eruption and a preliminary summary was published in 1981 (Rosenbaum and Waitt, 1981). For brevity, we refer to the interviews using the notation of Rosenbaum and Waitt, which references them by the direction and approximate distance away from the volcano that the person was when it erupted. For example, a logging crew, only one of whom ultimately survived, was located about 20 kilometers to the northwest; that account is cited as 20NW. If two accounts came from separate parties who were near each other, then an additional letter is added (e.g. 20Na and 20Nb).

Rather than focus on individual accounts, which may be inaccurate or incomplete, this study focuses on a few characteristics of the pyroclastic flow that many survivors seem to remember collectively. It is assumed that if many people describe the same (or similar) event or sequence of events, then the collective memory is robust. Minor differences between interviewees would then reflect either inexact remembrances or actual differences in the flow; it is unlikely we will ever know which. Three events are highlighted: (1) the onset of the leading edge of the flow; (2) the timing of when the hot part of the flow arrived; and (3) the buoyant rise of the flow after it enveloped the survivors. The collective memories of those events are then compared to physical characteristics of the pyroclastic flow preserved by its impact on inanimate objects.

The focus is on the pyroclastic flow (sometimes called the lateral blast) generated on the morning of 18 May 1980 at Mount St Helens (Lipman and Mullineaux, 1981). For several months prior to that day the north flank of the volcano had been bulging as magma slowly intruded into the cone. An earthquake at 8:32 a.m. (local time) on 18 May caused the north face of the volcano to avalanche, exposing the hot gaseous magma, which detonated in one or two lateral explosions (Hoblitt, 2000). The pyroclastic flow raced outward at speeds of up to 360 kilometers per hour, stripping away nearly all vegetation within a 5 kilometer radius (Kieffer, 1981). Further away it flattened nearly 600 square kilometers of dense forest. In the outermost hundreds to few thousands of meters the flow no longer had the strength to topple trees, only burn them (Lipman and Mullineaux, 1981).

Outside the Pyroclastic Flow

It is important to place some constraints on the dynamics of the flow from those who were close enough to witness it but far enough away not to be enveloped. Rosenbaum and Waitt (1981) and Waitt (2014) interviewed at least 20 people who were within 30–50 kilometers of Mount St Helens but were safely outside the blast zone. A few escaped what would be devastated by the pyroclastic flow by driving away along what was known as Highway 504, which led to the resorts on the shores of Spirit Lake at the base of the volcano. All remembered how fast the pyroclastic flow came at them, and having to drive at speeds often in excess of 100 miles per hour (30–50 meters per second) to outrun it. These speeds are slower than those estimated from satellite imagery (Moore and Rice, 1984), but the survivors had a head start, and would have been travelling almost due west, which is oblique to the generally north-westerly direction of the flow in that area.

A second common observation about the pyroclastic flow by those who could see it is that the flow followed local topography, travelling down into valleys and then back up and over ridges. A few noted that when the flow hit ridges it would explode upwards, described as crashing like waves over breakwaters or like bombs exploding (e.g. 17NEa, 17NEb, 25N). The flow is also described by many as being significantly higher than the local ridges, which implies that only the basal part of the flow was closely following topography.

Several recall being able to see the bottom of the flow as it traveled along the ground, and that the trees were overrun by the flow (e.g. 29N, 15E). Many also recall their ears popping and feeling gusts of wind, but none of these sensations or gusts were strong enough to topple trees. The trees were thus flattened by the flow, rather than by something preceding it. One conclusion that can be drawn is that the pyroclastic flow was not preceded by a shock wave. Some modelling of the pyroclastic flow concluded that it was supersonic near when it started, and slowed to subsonic by decompressing through a shock wave (Kieffer, 1981; Kieffer and Sturtevant, 1988). There seems to be little support from the eyewitnesses that a strong shock wave preceded the flow.

Finally, all who saw the pyroclastic flow remarked on how it rose into the atmosphere as high as 30,000–40,000 feet (ca. 9000–12,000 meters). Those close to the outer edge were soon covered in heavy ash fall from it (e.g. 12Wb, 8W, 22N). In fact, the plume that formed when the pyroclastic flow became buoyant rose to over 28 kilometers (Harris et al., 1981; Holasek and Self, 1995). The underestimate probably comes from inexperience with judging such heights, and guessing that the plume reached as high as jet airliners fly. While it is understood why pyroclastic flows become buoyant, what is remarkable is the onset of strong winds that blew towards the volcano as the plume rose. Most describe winds reaching 40–60 miles per hour (about 65–100 kilometers per hour). There is even an account by an eyewitness near the outer edge of the plume (12Wb) that papers were sucked out of a car when the door was opened, and people had to shout to be heard over the winds. One witness as far away as Riffe Lake (30N) suggested that sudden winds of 40 knots (75 kilometers per hour) blew towards the mountain. In contrast, two people on Yale Lake, 20 kilometers to the south-southeast, mention no winds while describing the plume rising above the volcano. Some likened the winds to the backdraft generated by forest fires. While the process is different – fire sucks in air by consuming it – the result is the same. These observations could be used as input into models of plume generation from buoyantly rising pyroclastic flows, by placing reasonable constraints on both the volume and rate of air ingestion.

Inside the Pyroclastic Flow

A logger to the northwest of the volcano (20NW) became aware that Mount St Helens was erupting when he heard one of his co-workers shouting. He then noticed that the top of a tall tree started to jiggle and fall, followed by another nearer to him, and then others. At the same time rocks zinged through the woods, bouncing off trees. Tree tops then started to be snapped off. A few moments later he could hear a ‘horrible, snapping, crashing, crunching, grinding’ (Waitt, 2014, p. 164) sound coming through the woods, growing louder ‘like a gigantic locomotive’ at which point he and his fellow loggers started to run. Immediately he was knocked down and could see nothing from the blackness. It also got ‘hot right away, then scorching hot and impossible to breathe' (p. 164). When he could see again, he found that almost all trees around him had been knocked over.

To the north, two camping parties along the Green River, separated by about 70 yards (65 meters), were enveloped by the pyroclastic flow (i.e. black cloud). Just before it arrived, one group (21Na) says that winds struck that were strong enough to blow the flames of their campfire flat along the ground. The others (21Nb) saw white clouds that quickly turned black and expanded fast, and then they were also hit by a blast of wind that bent over trees. Both parties ran for cover in the trees, before being enveloped in pitch black and heard and felt trees being knocked down. One (21Nb) estimated that once the strong winds hit it was only a few seconds before it went black. After the pyroclastic flow hit, and it became black, one camper (21Na) says that he tried to start to climb through the fallen trees around them, but had to quit because it got extremely hot and his hair sizzled. Having been a baker, he estimates that it reached 500–600°F (260–315°C). Another, astonishingly, says that after it got pitch black and the ground stopped vibrating from trees falling, 'mud and ice rained down […] and I grew cold' (Waitt, 2014, p. 178). But then, after only what felt like seconds, everything burned and the wet, icy mud that coated him 'baked to clay' (p.179).

About 3 kilometers east-southeast of those along the Green River, a father and his sons (18N) were camping along Miners Creek. While packing up their gear that morning, a black cloud was seen to billow from the south, about 1000 feet (300 meters) above them. Light grey, light weight rocks (which were found to be volcanic; Rosenbaum and Waitt, 1981) fell through the trees. As they continued to pack, that cloud pulled back quickly to the south. An increasingly loud roar then came towards them and a huge 'dust cloud' exploded off the bluff, felling the tops of trees. Luckily for them, they were in a ravine and felt no winds, and most trees around them stayed standing, but tree tops were sheared off as the cloud raced overhead. It went black from ash fall, but they remembered that the material that fell was 'damp and cool like mud' (Waitt, 2014, p. 183). Soon after, the air got hot and then grew uncomfortably hot, like standing near a forest fire.

While the accounts differ, they all seem to imply that there was an extended time over which the pyroclastic flow approached, and that there may even have been separate parts to it. The logger, for example, noticed tops of trees being knocked off and rocks flying through the air before even hearing what seems to be the main body of the flow approaching. The campers along Green River all felt strong winds before the main body of the pyroclastic flow arrived. Those initial winds apparently were not strong enough to topple trees, but only bend them. In addition, one (21Nb) described the arrival as 'it got darker, then pitch black' (Waitt, 2014, p. 178), suggesting that the onset of the main pyroclastic flow was not instantaneous. Most intriguingly, those along Miners Creek clearly saw two separate clouds, the first of which was high overhead when it arrived, whereas the second was still travelling near the ground, at least until it flew over the top of a bluff.

Witnesses outside the devastated area also seem to describe separate clouds. Several remember seeing a leading cloud growing high overhead, while a basal cloud moved along the ground and climbed ridges (e.g. 17NEa, 27NE). From the north, the cloud was seen to come northwest in two waves, with a western part moving east up Green River while a slower one flowed north down Schultz Creek, a few kilometers west of Miners Creek. There are other accounts that could imply two clouds, such as two riders in a car that sped along Highway 504 trying to escape from the flow (starting from 13NW). Throughout their description of the flow they continually mention seeing a white cloud like fog that precedes a black cloud, such as '[…] white cloud still led the black chalky cloud' (Waitt, 2014, p. 162). Their account is the only one that mentions the continual appearance of two separate clouds, and so it must be viewed with caution.

Everyone engulfed by the pyroclastic flow was burned to some extent (Bernstein et al., 1986). The intense heat and pain caused by it are thus understandably one of the main foci of most accounts. Yet, just as there is a gap between when the front of the flow approaches and when its main body arrives, many survivors seem to describe a lag of when the intense heat arrives. The main impression is that the leading edge of the pyroclastic flow was cooler than what followed behind it, and may have in fact even been (icy) cold. The heat experienced by the survivors would have been the hot gases released by the magma. But, as a turbulent pyroclastic flow moves away from the volcano it ingests air (Bursik and Woods, 1996). In order for the flow to remain hot, therefore, heat must be continually supplied from the hot pumice and ash (magma) that is also being carried in the flow. If there is a leading edge of the flow that is poor in pumice and ash – that is, mainly just fast moving gas – then that part of the flow would be able to cool as it travels outwards.

After the intense heat subsided none of the survivors remember more strong winds. Instead, many recall relative calm once the pyroclastic flow subsided. They mention how they were in pitch blackness that slowly became lighter and were able to start to see around them (20NW, 19N, 21Na, 21Nb, 18N). Soon after, all mention how ash fall became steadily heavier until they were again enveloped in pitch black. It would thus seem that none felt the updraft of wind as the pyroclastic flow rose up as a large plume, in contrast to the near universal experience of strong winds blowing towards the volcano by those outside the devastated area. It would of course be understandable that some details might be forgotten by survivors after experiencing the sheer pain of being scalded by hot gases and swamped by heavy ash while all of the trees around them fell over. Even so, the renewed ash settling to the ground that all remarked on can only be ash settling from the large plume, and they remembered how they could see more clearly before the ash arrived. The survivors thus seem to have been conscious of events even shortly after being scalded and burned by the laterally moving pyroclastic flow. We can thus conclude that the lift-off of the pyroclastic flow did not induce strong winds inside the devastated area.

Survivor Accounts as Scientific Data

To assess whether survivor accounts like those from the 18 May 1980 pyroclastic flow can be used as scientific data to study such events, we compare the collective memories to other observations. The eyewitnesses seem to imply that the pyroclastic flow consisted of a flow front that became increasingly intense as it approached (i.e. blowing trees and a campfire) until it became strong enough to topple large trees. That front was then followed by its hot interior, which must have carried most of the hot ash. This picture of variable proportions of wind strength and hot ash in the flow is consistent with other physical observations found after the eruption. Many vehicles caught up in the pyroclastic flow within about 15 kilometers of the volcano were pushed, damaged and even flipped over (Waitt, 1981). The layers of ash left by the pyroclastic flow on top of those vehicles matched that on the ground next to them. Another observation is that the direction in which toppled trees were pointing was in some cases oblique to the direction inferred from sand waves preserved in the deposits (Fisher, 1990). Also, careful inspection of some of the trees knocked down revealed that the parts of trees that were covered by the first ash layers were not burned, whereas those parts left exposed were burnt. Based on the eyewitness testimony, we can hypothesize that the vehicles and trees were knocked over before the main body of hot ash arrived, just like the eyewitnesses were knocked over and felt trees fall over before the intense heat arrived with the main body of the pyroclastic flow.

But what did we learn from the eyewitnesses that we could not from the other physical data? What did those accounts add to our understanding of pyroclastic flows? First, while the observations from the vehicles and trees suggest that there was a lag between when the pyroclastic flow damaged and burned things and when deposition began, we get no sense of the variation in heat that occurred. Certainly there is nothing in the deposits to tell us that the flow front could have become so cold that it was carrying icy mud. In terms of pyroclastic flow dynamics, a flow front that has become cold would be unable to become buoyant and lift off, because it could not become buoyant relative to the surrounding atmosphere. This tells us that the front of the pyroclastic flow in fact did not rise upwards. Only its hotter interior could have done so. Second, the accounts tell us that the cold, ashpoor front was likely to be only a small fraction of the entire flow, because the arrival of the front and the intense heat seem to be separated by relatively short times. Of course, the actual separation remains speculative because probably the poorest measure from the accounts is the time frame over which various events happened. The third piece of knowledge we gain from the eyewitness accounts is that the buoyant rise of the pyroclastic flow had no physical impact on its interior, at least not at its base where the eyewitnesses were. This informs us of the way in which air is ingested into the rising plume, and that the basal part of the flow and its deposits are left undisturbed by the rise of the buoyant part of the flow.

Conclusions

One hopes that no one else will have to endure the suffering that the survivors of the Mount St Helens pyroclastic flow did. Regretfully, however, the ever-increasing number of people living near volcanoes almost ensures that they will, as seen in the recent tragedies at Mt Unzen, Souffriere Hills, and Merapi (Nakada, 2000; Baxter et al., 2005; Jenkins et al., 2013). This study sought to show that those who do survive such events may remember things that could help scientists to understand better and interpret the behavior of such flows. While individual memories may be incomplete and are certainly impacted by the trauma of the near-death experience, it seems that a collective memory can be constructed by combining stories. Indeed, the eyewitnesses and survivors of the Mount St Helens pyroclastic flow describe details that would not have been known otherwise. No volcanologist, for example, would have imagined that a pyroclastic flow that destroyed over 600 square kilometers of forest, and left many tens of people scalded and burnt, had a cold, wet leading edge. Scientists should thus be prepared to take advantage of tragic encounters, by both listening to the survivors and eyewitnesses as closely as possible and trying to incorporate oral and visual memories as input into modelling of eruptive events.

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2016 Volume 9

Insights

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