Pleistocene reversal of the Fraser River, British Columbia


Geology 2012;40;111-114
doi: 10.1130/G32488.1

Email alerting services  click www.gsapubs.org/cgi/alerts to receive free e-mail alerts when new articles cite this article

Subscribe  click www.gsapubs.org/subscriptions/ to subscribe to Geology

Permission request  click http://www.geosociety.org/pubs/copyrt.htm#gsa to contact GSA

Copyright not claimed on content prepared wholly by U.S. government employees within scope of their employment. Individual scientists are hereby granted permission, without fees or further requests to GSA, to use a single figure, a single table, and/or a brief paragraph of text in subsequent works and to make unlimited copies of items in GSA’s journals for noncommercial use in classrooms to further education and science. This file may not be posted to any Web site, but authors may post the abstracts only of their articles on their own or their organization’s Web site providing the posting includes a reference to the article’s full citation. GSA provides this and other forums for the presentation of diverse opinions and positions by scientists worldwide, regardless of their race, citizenship, gender, religion, or political viewpoint. Opinions presented in this publication do not reflect official positions of the Society.

Notes

© 2012 Geological Society of America
Pleistocene reversal of the Fraser River, British Columbia

Graham D.M. Andrews¹,², James K. Russell³, Sarah R. Brown¹, and Randolph J. Enkin³
¹Earth Research Institute, University of California–Santa Barbara, Santa Barbara, California 93106, USA
²Department of Earth and Ocean Sciences, University of British Columbia, Vancouver, British Columbia V6T 1Z4, Canada
³Geological Survey of Canada, PO Box 6000, Sidney, British Columbia V8L 4B2, Canada

ABSTRACT

The Fraser River in British Columbia, Canada, is the longest non-dammed river on the west coast of North America and supplies 20 × 10⁶ t/yr of sediment to the Pacific Ocean. Abundant geomorphological evidence indicates that the Fraser River reversed its course to southward flow in the recent geological past. Investigation of two volcanic dams at Dog Creek demonstrates northward flow of the Fraser until at least 1.06 Ma, before reversal and erosion of the 270-km-long Fraser Canyon. We propose that the submarine Nitinat Fan off the coast of British Columbia records the reversal and sudden input of coarse continental-derived sediment ca. 0.76 Ma. This study confirms reversal of the Fraser River and places a firm constraint on the maximum age of that reversal. Reversal likely followed stream capture in response to enhanced glaciofluvial erosion and uplift of the Coast Mountains.

INTRODUCTION

Modification of major rivers and their drainage basins is a poorly understood process associated with active tectonics, glaciation, and climatically influenced erosion (Bishop, 1995). Such events strongly influence paleogeography, sediment budgets, and provenance. In this paper we identify and date a volcanic succession in central British Columbia, Canada, that records two episodes of damming of the ancestral Fraser River; reconstruction of the paleodrainage leads us to the inevitable conclusion that the Fraser River reversed course from a northward to southward flow.

Several studies have used high-precision ages of volcanic dams to date Pleistocene fluvial systems in North America (e.g., Huscroft et al., 2004; Karlstrom et al., 2007). Here we first outline geomorphic evidence for reversal of the Fraser River and then describe the lithostratigraphy and Ar/Ar geochronology of two prerelational volcanic dams. Although the exact causes of drainage reversal remain unresolved, dating of the succession tightly constrains the maximum age of drainage reversal. Furthermore, we are able to demonstrate geomorphic and sedimentological consequences of reversal in the Fraser Basin and adjacent Pacific Ocean.

Fraser River

The 1375-km-long Fraser River of British Columbia discharges 3475 m³/s of water and 20 × 10⁶ t/yr of sediment (Swain and Holms, 1985) from the 233,000 km² Fraser Basin into the Strait of Georgia and the Pacific Ocean (Fig. 1), and sustains the largest alluvial delta on the west coast of North America. Currently, the upper Fraser River and its many tributaries drain the Coast Mountains and Rocky Mountains before merging in the interior plateaus region (Fig. 1), which composes ~70% of the area of the Fraser Basin (Fig. 1 inset) at a mean elevation of ~1100 m above sea level (asl). It then drains southward through the Fraser Canyon before entering the sea at Vancouver.

Since the Miocene, evolution of the Fraser River has been accompanied by regional and global change, including uplift of the Coast Mountains (Farley et al., 2001), multiple glaciations (Jennings et al., 2007), and enhanced...
eroded basaltic lava dams and associated volcaniclastic deltas separated by the glaciofluvial Dog Creek Formation (Fig. 2B; Mathews and Rouse, 1986). The dams are asymmetric; subaqueous lithofacies only occur south of the dam axis. The lavas are part of the much larger Chilcotin Group, a basaltic volcanic province that underlies much of the Fraser River basin (Mathews, 1989).

The lower portion of this volcanic succession was emplaced onto the ancestral Fraser River valley floor at the mouth of the ancestral Dog Creek tributary (Fig. 2A). Dog Creek was then an ice-free, although recently glaciated (buried striated surfaces), U-shaped valley. The Dog Creek paleovalley is now filled by an 80-m-thick subaerial lava pile dominated by thin (<50 mm) pahoehoe and intercalated autobreccia. Imbricated stretched vesicles indicate flow along the Dog Creek paleovalley to the west, into the Fraser River valley.

The subaerial lavas progressively fed and buried a 65-m-thick southward-prograding delta of hyaloclastite pillow breccia (Fig. 3A). The hyaloclastite pillow breccia delta exhibits the typical architecture of a volcanic Gilbert-type delta (Skilling, 2002), with prominent normal-graded, palagonite-cemented foreset beds of clast-supported and angular hyaloclastite (pillow fragments, glassy pillow rinds, and pillows; Fig. 3B). The maximum height of the lava-impounded lake (65 m) is marked by the passage zone between hyaloclastite pillow breccia and subaerial lavas (Figs. 2B and 3A; Jones, 1968).

The lavas, and hence the dam and delta, were emplaced very rapidly based on: (1) the absence of intervening erosions surfaces, paleosols, and sediment horizons; and (2) paleomagnetic evidence of emplacement during a single period of geomagnetic secular variation, probably ≤1 k.y. (Fig. DR1 in the GSA Data Repository\(^1\)).

Following a period of glaciofluvial erosion and deposition (Dog Creek Formation; Mathews and Rouse, 1986), a second, upper volcanic suc-

---

\(^1\)GSA Data Repository item 2012035, paleomagnetic and geochronological data sets, is available online at www.geosociety.org/pubs/ft2012.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.
cessation was emplaced onto the remnants of the first. Streaked vesicles in the upper lavas sug-

gest a vent on the western margin of the ances-
tral Fraser River valley opposite Dog Creek (Fig.
2A). The vent location is marked by local-
ized scoria in float at the head of a narrow gully,
below which the lavas are well exposed. Flow of lava diverged about a second dam axis and
formed thin subaerial lavas to the north and a
thin (10 m) subaerial lava-fed hyaloclastite pil-
low breccia delta to the south (Fig. 2).

AR/Ar GEOCHRONOLOGY

New 40Ar/39Ar whole-rock and existing K/Ar
whole-rock ages for basalts in the Fraser Can-
yon are shown in Figure 2A (for descriptions of
analytical methodology and samples, see the
Data Repository). A sample of lava from the
base of the first dam in Dog Creek yields an
age of 2.79 ± 0.3 Ma (Fig. DR2). Lava within the
second dam was sampled on both sides of the
Fraser Canyon and yielded ages of 1.107
± 0.050 Ma (Fig. DR3) and 1.058 ± 0.013 Ma
(Fig. DR4), with a weighted mean of 1.06
± 0.15 Ma (Fig. DR5). All errors are 2σ (95% confidence).

DISCUSSION

Paleogeography of the Fraser River

Our reconstruction of the ancestral Fraser River valley from mapping of terraces and over-
lying lavas reveals a ≤10-km-wide, low-relief

surface dipping gently northward at an elevation of ~730 masl at Dog Creek; this is similar to the
present-day valley north of the Fraser Canyon
(Andrews et al., 2011). Moreover, the presence of
two hyaloclastite pillow breccia delta sets indicates that two deep (60 m and 10 m) lava-impounded
lakes existed to the south of Dog Creek. This is
consistent with northward flow of the ancestral
Fraser River at 2.79 Ma and 1.06 Ma; the vol-
canic deltas are exclusively on the southern side
(paleo-upstream) of the lava dams.

Timing of Reversal

The early Pleistocene stratigraphy of the Fra-
sier River valley and Fraser Canyon is not under-
stood, in part due to a lack of dateable geologi-
cal or morphological units. Our data indicate
that reversal of the Fraser River occurred after
1.06 Ma, and this is supported by the limited
additional relative and absolute age constraints
discussed here. The Fraser Canyon dissected
the prevolcanic terrace and both volcanic dams,
such that the river is now 400 m lower at the
confluence with Dog Creek. Canyon erosion was most likely in response to knickpoint retreat
and change in river gradient when the Fraser
River reversed course (e.g., Bishop, 1995). The
bedrock floor of the Fraser Canyon is locally
overlain by ca. 24 ka glacial sediments (Hunt-
ley and Broster, 1994) and rare gravel and sand
deposits that may be as old as ca. 59–74 ka
(Lian and Hicock, 2001); therefore the Fraser
Canyon was probably extant by ca. 74 ka.

Implications

Our hypothesis can be tested and improved in
several ways. Cosmogenic exposure dating and
4He/3He thermochronometry (e.g., Schil-
dgen et al., 2010) within the Fraser Canyon
would provide an independent date of the can-
yon incision event. We also expect that drainage
reversal, independent of canyon incision, should
be recorded in the downstream and/or marine
sedimentary records. Sudden or rapid initiation
of a major river draining a sediment-rich contin-
ental interior would be expected to manifest as
a large, contemporaneous, terrigenous sedimentary
fan at the mouth of a submarine canyon.
This idea has hitherto not been explored with
gard to the Fraser River.

The Fraser River supplies the large submarine
Nitinat Fan, an ~15,000 km² sedimentary fan
filling the Cascadia Basin of the Pacific Ocean
off the coast of Vancouver Island (Fig. 4; Car-
son, 1973). It is a ≤2.7-km-thick turbidite fan
deposited on the younger than 8 Ma Juan de
Fuca abyssal plain (Flueh et al., 1998; Under-
wood et al., 2005), where the Strait of Juan de
Fuca empties westward across the Cascadia
margin through several submarine canyons.
Sediment provenance studies of the turbidi-
tite layers indicate that the Fraser River is the

source of the ca. 0.76 Ma or younger Nitinat
Fan (Underwood et al., 2005; Kiyokawa and
Yokoyama, 2009). A pronounced detrital mona-
zite age peak identifies a distinctive ca. 1.8 Ga
source within the Fraser Basin (Kiyokawa and
Yokoyama, 2009); Paleoproterozoic basement
rocks only occur in the Omineca and Foreland
belts in the northern and eastern headwaters of
the Fraser Basin (Fig. 4; Gabrielse et al., 1991).

Distal hemipelagic sedimentation began
ca. 1.6 Ma before a sudden transition to meter-

thick sand turbidites between 0.76 and 0.46 Ma
(Su et al., 2000; Chamov and Kurnosov, 2001;
Underwood et al., 2005). The ca. 0.76 Ma age
corresponds with the continental-scale marine
isotope stage 16 glacial event (Jennings et al.,
2007). The implications are that the Fraser River
had to (1) drain the central and eastern Canadian
Cordillera (Fig. 1), and (2) flow to the Pacific
Ocean by 0.76–0.46 Ma. This demands reversal
between 1.06 and ca. 0.76 Ma.

River incision rates can be estimated by meas-
suring the difference in elevation between two
dated terraces (e.g., Karlstrom et al., 2007).
The provisional, minimum incision rate at
Dog Creek between 2.79 Ma and 74 ka was
~150 m/m.y.; if reversal and canyon incision
occurred at 0.76 Ma, the minimum incision rate
was ~200 m/m.y. To the best of our knowledge
these are the first long-term incision rate esti-
mates for the Fraser River and are comparable
to long-term incision rates in the eastern Grand
Canyon (Karlstrom et al., 2007) and rivers in the
Cascade forearc (Stock et al., 2005).

Without reversal of the Fraser River, the
1000 km² Fraser Delta and Vancouver would not
exist; instead the area would have been drained
by a multitude of small montane rivers, simi-
lar to the drainage elsewhere along the Coast
Mountains. The Fraser River would instead
flow elsewhere, perhaps across the low drain-
age divides (~50 m) into the adjacent Peace-
ACKNOWLEDGMENTS
We thank the Hancock family and the Dog Creek and Canoe Creek First Nations for their hospitality. Janet Garbites and Brian Jicha provided the Ar/Ar analyses. Comments from Bert Struk, Bob Anderson, and reviews by John Smellie, Ryan Crow, and two anonymous reviewers greatly improved the manuscript. Funding provided by the Geological Survey of Canada’s Targeted Geoscience Initiative 3 Program. Geological Survey of Canada Contribution 20090430.

REFERENCES CITED
Manuscript received 24 May 2011
Revised manuscript received 2 September 2011
Manuscript accepted 9 September 2011
Printed in USA