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ON TONE AND LENGTH IN TAHLTAN (NORTHERN ATHABASKAN)*

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1. *Introduction*

This article has two related goals. The first goal is to document the linguistic structures of tone and length in Tahltan, a northern Athabaskan language of British Columbia.[1] These structures are examined instrumentally in a set of minimal pairs, and the phonetic attributes associated with low-marked tone (as opposed to unmarked tone) and different types of length are characterized. This work therefore contributes to cross-linguistic phonetic studies by providing detailed descriptions of tone and length in a particular language.

The second goal is to test certain hypotheses about the development of tone and length and the interaction between these structures. In particular, Athabaskan tonogenesis theory (Krauss 1979, this volume; Leer 1979, 1999) accounts for the development of tone in a number of Athabaskan languages as a reflex of Proto-Athabaskan (PA) 'vowel constriction', a kind of phonation

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[1] Tahltan is a critically endangered language spoken in the communities of Telegraph Creek, Iskut, and Dease Lake (northwestern British Columbia). While these communities have vibrant language programs and a practical orthography, Tahltan is in desperate need of linguistic documentation (see Alderete & Bob 1999, for summaries of existing materials).

type due to syllable-final glottalic consonants. Studies of Tahltan prosody, however, have largely focused on stress (Cook 1972; Alderete & Bob this volume), almost to the exclusion of tone, with some work even denying a role for constriction in tonal development (Hardwick 1984). Against this background, one might reasonably ask if the occurrence of low tone in Tahltan can be accounted for as a consequence of vowel constriction. A stem list is therefore constructed in which each stem is categorized by the syllable type of its internally reconstructed PA form, and the historical classification that emerges is then used to identify the historical sources for tone. The finding reported below is that all cases of low-marked tone did in fact derive from hypothesized vowel constriction in a pre-Tahltan ancestor language, providing further empirical support for Athabaskan tonogenesis theory.

A second hypothesis is considered concerning the interaction between tone and length. Impressionistic and instrumental examination of the tone minimal pairs reveals a pattern in which long vowels with low tone are slightly longer than long vowels without it. It is conjectured that length is a by-product of the development of tone, introduced specifically in long vowels with low-marked tone. Tone-induced length is then compared with other types of length and its phonological and historical implications are considered.

2. *Tone*

Tone has not been systematically studied in Tahltan, but where it has been examined at all, it has been concluded that Tahltan has low-marked tone (Leer 1985, Nater 1989, cf. Hardwick 1984). What this analysis means phonemically is that syllables may contrast in having low tone (marked tone) or not (unmarked). Low-marked syllables have a low tonal target that results in a low F_0 peak, a phonetic structure that contrasts with the comparatively higher F_0 found in unmarked syllables. In addition, marked and unmarked stressed syllables can be distinguished by F_0 shape. Under stress, F_0 may rise and fall as a function of stress in unmarked syllables. This differs from low-marked stressed syllables, which typically have a low level F_0 profile (illustrated below). The rest of this section presents some results of an exploratory study designed to give a phonetic characterization of the marked versus unmarked tone contrast. This characterization will then be used to explore a wider range of data in 2.3.

2.1 *Some Pilot Results*

Four adult native speakers of Tahltan were asked to produce the test words in (1), the only known stem minimal pairs for tone.[2] These words were elicited in preverbal position in a sentence frame [Subject _____ Verb] in order to obtain consistent prosody. At least four tokens of each test word were elicited, but in a few instances, one or two tokens had to be thrown out, because they did not meet the conditions for the experiment. In this article, marked tone is transcribed with a grave accent over the vowel contained in a low-marked syllable. Unmarked syllables have no accent.

(1) Tone Minimal Pairs

Unmarked tone		Marked tone	
xɪθ	"pus"	xɪ̀θ	"knoll"
ʔa·h	"snowshoe"	ʔà·h	"fog"
xe·ɬ	"pack"	xè·ɬ	"trap"

The words within these pairs differ in the quantity of the stem vowel: the first contains a member of the class of short vowels /i ɪ e a ɔ ʊ/, while the last two contain long vowels /i· e· a· o· u·/ (section 3.1 discusses the historical sources for these quantity contrasts).[3] As discussed below, the phonetic correlates of these contrasts seem to be sensitive to this difference.

The phonetic attributes commonly associated with tone were then measured using the speech analysis package Praat. In particular, the F_0 peak of the stem syllable was measured, as were the pitch shape characteristics, i.e., the difference in F_0 from the vowel onset to peak and from vowel peak to offset. Duration was also measured in order to confirm an audible difference between the members of some pairs, namely that marked tone syllables sounded longer

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[2] The speakers for this study (in all experiments reported here) were from the communities of Telegraph Creek and Iskut. It is not clear that these communities represent distinct dialect areas. My investigations of the advancement of affricates in these communities, probably the most useful feature for studying dialect variation, has found the same patterns of variation in both communities. In terms of comparing the findings reported here with those of Hardwick 1984 and Nater 1989, which also focused on these areas (Telegraph Creek and Iskut, respectively), any differences are most likely due to differences in method and analysis, because I worked with the same speakers as those that participated in these previous studies.

[3] For consistency with the historical literature and the Tahltan Practical Alphabet, the mid front vowel and the low vowel are written as /e/ and /a/, but their IPA transcriptions are /ɛ/ and /ɑ/, respectively.

than unmarked syllables.[4] Standard methods for segmenting the vowel structures were used (as in Peterson & Lehiste 1960): vowel duration was measured from the release of the pre-vocalic consonant to the vowel offset. Intensity was also measured, to see if the above phonetic properties co-varied with stress properties. Intensity was not found to correlate with F_0 or duration in significant ways, however, so it is not reported.

In the numerical data presented below, the mean F_0 peak and durations of each member of a pair are compared side-by-side, with the difference of mean between the two population samples given in the rightmost column. The standard deviations for each sample are given in parentheses, as are the combined standard deviations in the Diff-mean columns. The difference of mean is boxed if it is statistically significant for the appropriate t-test[5] and shaded if it is not.

In the first pair, [xɪθ] "pus" versus [xɪ̀θ] "knoll", a significant difference was found in F_0 for speaker 2 where the low-marked tone stem was 26.5 Hz lower than the unmarked stem. No other differences were found in this pair, which, as discussed below, may be due to the fact that the stem contains a short vowel.

(2) Minimal Pair I: [xɪθ] "pus" versus [xɪ̀θ] "knoll"

Speaker	Attribute	[xɪθ]	[xɪ̀θ]	Diff-mean
1	F_0	205.3 (15.6)	190.8 (15.9)	14.5 (19.3)
	Dur	115 (8.2)	126.5 (4.9)	11.5 (8.4)
2	F_0	219.8 (7.8)	193.3 (10.1)	26.5 (11.1)
	Dur	106.5 (1.7)	112.3 (10)	5.8 (8.9)
3	F_0	195 (16.8)	195.8 (8.8)	0.8 (17.1)
	Dur	130.3 (5.2)	134.5 (7.2)	4.2 (8.1)

The next two pairs, which contain long vowels, show much more robust differences. In pair II ([ʔa·h] versus [ʔà·h]), all speakers showed significant differences in duration, with the differences in mean ranging between 40.2 and 62.4 milliseconds (ms). Speaker 3 also showed a significant difference in F_0. The pairs I and II therefore show that the contrast between the stems can either be in F_0 or in duration, or both.

[4] This observation was pointed out to me by two native speakers, suggesting that it is a part of their conscious knowledge of the contrast.

[5] In particular, these are one-tailed t-tests for the difference of two population samples, where $\alpha = .05$. This test was used because it was known ahead of time that syllables with marked tone would be longer and have lower F_0.

(3) Minimal Pair II: [ʔa·h] "snowshoes" versus [ʔà·h] "fog"

Speaker	Attribute	[ʔa·h]	[ʔà·h]	Diff-mean
1	F_0	177 (16.5)	184.3 (20.1)	7.3 (22.6)
	Dur	251.7 (4.2)	305.5 (10.3)	53.8 (9.7)
2	F_0	182 (4.2)	186.8 (5.8)	4.8 (5.9)
	Dur	219.5 (3.5)	259.7 (16.9)	40.2 (14.1)
3	F_0	166.8 (7)	148.3 (10)	18.5 (11.1)
	Dur	231.8 (3.6)	294.2 (9.3)	62.4 (9.1)

The final pair, [xe·ɬ] versus [xè·ɬ], showed significant differences in both F_0 and duration for two speakers. In this pair, the durational differences between the stems were greater than with pair II, with a difference of mean in both cases a little more than 80 ms. The F_0 differences range from 11 Hz for speaker 2 and 39.3 Hz for speaker 3; the latter value is roughly twice as great as pair II [ʔa·h]/[ʔà·h] above. An unexpected difference in duration was also found for speaker 1, where the unmarked member of the pair is slightly longer than the marked member.

(4) Minimal Pair III: [xe·ɬ] "pack" versus [xè·ɬ] "trap"

Speaker	Attribute	[xe·ɬ]	[xè·ɬ]	Diff-mean
1	F_0	180 (7.1)	184.5 (.7)	4.5 (5.9)
	Dur	237 (1.4)	226 (2.8)	-11 (2.7)
2	F_0	204 (6.2)	193 (0)	11 (5.2)
	Dur	186.8 (9.7)	268.5 (12)	81.8 (12.6)
3	F_0	209 (1.4)	169.7 (3.5)	39.3 (3.2)
	Dur	217.3 (2.5)	298 (4.2)	80.7 (4.1)

Another salient difference in this pair is the overall pitch shape of the syllables. As illustrated below in Figure 1, the rise and fall of F_0, which is generally an effect of stress, is far greater in unmarked syllables than in syllables with low-marked tone. Thus, the mean rise in F_0 for [xe·ɬ] is 15.5 Hz, as opposed to .6 Hz in [xè·ɬ]. Likewise, the mean drop from the F_0 peak to the end of the vowel is 14 Hz in the unmarked stem, but only 3 Hz in the marked stem. In addition to differences in F_0 peaks, the overall shape of the F_0 excursion therefore seems to function as a correlate to tone as well.

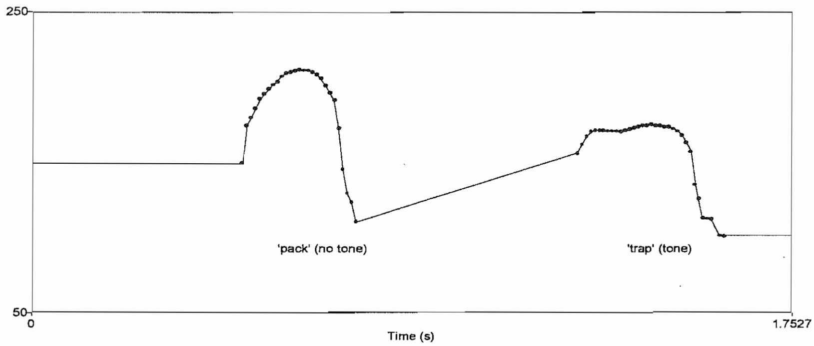

Figure 1: *Pitch shape differences in [xeɬ] "pack" versus [xèɬ] "trap" for speaker 3*

It should be noted that these differences in pitch shape were only clearly observed in this pair. In the pair [ʔa·h]/[ʔà·h], there were no clear differences in the rise and fall of F_0, and with [xɪθ]/[xɪ̀θ], there was a fall in pitch from the release of the pre-vocalic consonant in both stems, which leveled off before a slight fall at vowel offset.

2.2 *Summary and Implications*

The findings of the pilot study are summarized below.

(5) Acoustic Correlates to Stem Contrasts

- F_0 peaks of syllables with low-marked tone are lower than F_0 peaks of unmarked syllables; significant differences of 39 Hz (speaker 3 for pair III), 27 Hz (speaker 2 for pair I), 19 Hz (speaker 3 for pair II), and 11 Hz (speaker 2 for pair III) were found
- Stressed syllables with unmarked tone have rises and falls in F_0 ranging between 14-16 Hz, while stressed syllables with marked tone have rises and falls in F_0 between 1-3 Hz
- The duration of long vowels with marked tone is roughly $1^{1/4}$ the duration of long vowels with unmarked tone

The F_0 differences above compare rather well with the phonetic behavior of low-marked tone in other Athabaskan languages. In Tanacross, for example, Holton (this volume) reports that the difference between high and low tone (where low derives historically from vowel constriction) varies between 20 and

40 Hz. In Fort Ware Sekani, Sharon Hargus (p.c.) has found an average difference of approximately 24 Hz between high and low tones in stem syllables, with the individual differences ranging between 10 and 46 Hz. The Tahltan data therefore seems to fall somewhere between the two, with significant contrasts ranging from 39 to 11 Hz.

These findings are also relevant to the classification of Tahltan as a tone language. The observed intra-speaker variation for F_0 involves both variation in the degree of contrast, and perhaps also, whether or not a speaker has a contrast in a particular form. While it is important to understand that the tests for statistical significance do not identify lack of contrast, it seems plausible to infer from the total absence of significant F_0 differences in speaker 1's data that a contrast between these stems is not reliably cued by pitch. Furthermore, the variation between 2 and 3 seems to suggest that a tone contrast may not be consistently realized in particular lexical items. These possible patterns of neutralization imply that pitch differences may be difficult to detect and may not be realized systematically within a linguistic community, which may have led some researchers to conclude that Tahltan does not have tone. Mindful of this variation, the next section sets out to study tone more systematically, with the goal of determining whether Tahltan has low-marked tone in the contexts predicted by Athabaskan Tonogenesis Theory.

Another important result worth studying further is the increased duration in the marked syllables in pairs II and III. The internally reconstructed forms for these pairs do not differ in quantity (see section 3.2), so the increased duration in [ʔà·h] and [xè·ɬ] is unexpected diachronically. Furthermore, as illustrated by pairs I and II, there is not a systematic relationship between length and tone in the present day language. Speakers 2 and 3, for example, have a significant contrast in duration for the pair [ʔa·h]/[ʔà·h], but no contrast in F_0. Duration cannot therefore be seen as a synchronic consequence of tone in this case. I conjecture, therefore, that increased duration is a consequence of the historical process sketched below.

(6) Tone-Induced Length (TIL)

CV̓·C’ > CV̀·C > CV̀·C
↘
<u>CV̀·ˑC</u> > CV·ˑC

After constricted full (=long) vowels received low-marked tone, suppose that TIL introduced additional length in these vowels, signified here by [ˑ] after the traditional length marker (the output of TIL is underlined). TIL does not apply to forms like [xì̀θ] "knoll", however, because it has a short vowel (though this restriction should be tested on a wider range of data). The variation we find in Tahltan—some extra long vowels do not have low tone—can thus be attributed to the loss of tone in the second development in the lower branch. Such an analysis successfully accounts for the two classes of long vowels in Tahltan, i.e., long vowels that developed from full vowels and long vowels with added length due to TIL.

As far as the implications for other Athabaskan languages, it is interesting to note that Nater (1989: 35) mentions in passing a correspondence between length in Tahltan and low tone in Central Carrier and Chipewyan (sometimes referred to as Dene Soun'line) and long vowels with low tones in Western Apache (Chiricahua Apache, in particular), e.g., [t'e·s] (T), [t'ès] (cC), [t'è·š] (A) "charcoal". While I am not in a position to extend the application of TIL beyond Tahltan, we may note that the correspondences between Tahltan and these tone languages can be captured by saying the latter did not undergo TIL. Thus, the difference between what Nater transcribed as [t'e·s] in Tahltan and Central Carrier [t'ès], is represented here as the difference between the output of TIL and the third development in the first row. As for Chipewyan, if Nater's correspondences are valid, this case shows that TIL just targets vowels with low tone, and not other tones that developed from constriction, since vowel constriction is generally considered to have given rise to high tone in this language (Krauss 1979, this volume; Gessner 1999).[6]

In section 3, I test the implications of TIL for Tahltan more rigorously by studying tone-induced length alongside other types of length to see if more than one long vowel is indeed motivated in Tahltan.

2.3 *Historical Sources for Tone*

As is well-known, many Athabaskan languages are tone languages, and there is a well-defined theory of how tone came about in these languages (Krauss 1979, this volume; Leer 1979, 1999). According to Athabaskan tonogenesis theory (ATT), pre-PA syllables ending in /ʔ/, glottalized stops (/C'/), and glottalized sonorants (/R'/) led to the development of so-called vowel constriction in the preceding vowel (see Leer 1999, for an especially explicit statement of the distinct processes involved). While the exact characteristics of this constriction are not known (but see Kingston this volume, for some conjecture), ATT proposes that constriction led to the

[6] As for the case of Western Apache, the correspondence between length and tone is probably spurious, because length developed in both constricted and non-constricted vowels in Western Apache (de Reuse this volume).

development of two different tones, i.e., low tone in languages like Dogrib and Sekani and high tone in, for example, Chipewyan and Slave.

Though the occurrence of low tone seems to classify Tahltan as a low-marked tone language, many words in Tahltan do not have tone in the contexts predicted by ATT. Indeed, the low frequency of tone in Tahltan seems to have led Hardwick (1984: 23) to conclude that "Tahltan is not a tone language and there is no evidence of a constricted/non-constricted distinction in the vowel development." The results of 2.1, however, suggest that this conclusion is premature, since the observed intra-speaker variation may give the illusion of the lack of tone in the speech of some speakers and in the pronunciation of particular words. A systematic study of tone seems warranted, therefore, and what follows investigates a stem list designed to determine the distribution and source of low tone in Tahltan. In particular, a list of noun stems are examined and classified by the syllable type of their internally reconstructed PA form. These syllable types, which distinguish the presence or absence of vowel constriction, provide a basis for identifying the historical source for low tone.

The method used to diagnose tone in present day Tahltan was to match the phonetic properties of a test word with those properties identified in the previous subsection. Thus, words are transcribed with low tone if they have relatively lower F_0 (20 Hz minimum) and a flat pitch shape, when compared with a similar non-tonal word. Several tokens of each word were elicited from at least two speakers, examined both in isolation and in a sentence frame to ensure consistent prosody.

Starting first with the reflexes of PA open syllable stems, ATT makes a basic distinction between stems with full vowels and stems that are composed of a syllable that ends in a glottal stop. Only the latter case had constriction and therefore led to the development of tone. The data below show that this distinction is still intact in Tahltan, though some forms deriving from the PA syllable type *CV̓ʔ do not have tone (here and throughout ̓ represents vowel constriction).[7]

[7] The PA forms given below constitute a working model for the internal reconstruction of Tahltan. This model is based on the important insights of Krauss (1979, this volume), Leer (1979) and Krauss & Leer (1981), where most of these PA forms can be found. The reconstructions for "dirty", "war", and "half" are based on materials provided by Jeff Leer (p.c.).

(7) Reflexes of PA stems with open syllables

a. *CV·

*ya·	ya·	"sky"
*tse·	tθe·	"stone"
*tu·	tu·	"water"

b. *CV̓ʔ

*ya̓ʔ	yàʔ	"louse"
*tša̓ʔ	tsàʔ, tsaʔ	"beaver"
*-ta̓ʔ	-tàʔ, -taʔ	"father"
*-ɣa̓ʔ	-ɣàʔ, -ɣaʔ	"hair"
*-la̓ʔ	-làʔ	"hand"
*-qe̓ʔ	-keʔ	"foot"
*-da̓ʔ "mouth"	-daʔ	"beak"

We note in passing that the only cases in (7b) that have low-marked tone for all of the speakers also have sonorant onsets.[8] One may conjecture that the presence of an obstruent onset had the effect of raising the pitch of the vowel, effectively leading to the loss of tone in just these cases.

Next consider stems that developed from PA syllables closed by sonorants. ATT predicts that only syllables closed by glottalized sonorants led to the emergence of tone, which is also consistent with the patterns below. With a certain amount of intra-speaker variation, we find tone in stems that are descendents of stems with both reduced (8) and full (9) constricted vowels (which have reflexes as short and long vowels in present-day Tahltan).

(8) Reflexes of PA stems with sonorant-closed syllables and reduced vowels

a.*CvR

*ts'ən	-tθ'e(h)ne, -ts'ene	"bone"
*tən	ten̥	"ice"

b.*Cv̓R'

*qʊ̓n'	kʊ̀n', kon'	"fire"
*sə̓m'	θɔ̀n', θɔn'	"star"

[8] This generalization is probably one that refers to phonetic sonorants, because the /l/ of "hand" is not a sonorant phonologically (this is the case with /l/ in many Athabaskan languages; see Bob 1999, for evidence from Tahltan). It is clear from spectrographic analysis, however, that the acoustic structure of voiced /l/ should be classed with phonetic sonorants in terms of its impact on the fundamental frequency of the following vowel.

(9) Reflexes of PA stems with sonorant-closed syllables and full vowels

a.*CV·R			b.*CV̓·R’		
*k^{y}a·n	tš̆a·	“rain”	*tš^{w}a̓·n’	tsà·ʔ	“excrement”
*dz^{w}e·n	dðeneθ	“day”	*-ɢa̓·-nəʔ	-gà·ne	“arm”
			*-t’a̓·n’	-t’a·n(e)	“leaf”
			*ŋ^{y}e̓·n’	ni·ʔ	“moss”
			*-ne̓·n’	niʔ	“face”

As for obstruent-closed syllables, tone is attested in these syllables as well, which are differentiated below by the reduced versus full vowel distinction. The evidence for tone in the syllables that had reduced vowels is rather weak: only one form showed the expected tone, namely the word for “knoll”. Perhaps this fact stems from the weak status of these vowels, which are much shorter than full vowels, and therefore are less likely to provide salient cues for pitch differences.[9]

(10) Reflexes of PA stems with obstuent-closed syllables and reduced vowels

a.*CvC			b.*Cv̓C’		
*χəz	xɪθ	“pus”	*x^{y}ə̓ts’	xɪ̀θ, xɪθ	“knoll”
*wəs	beθ	“riverbank”	*-zə̓t’	-ðet	“liver”
*wɑx^{y}	bah	“dirty”	*-ɢʊ̓t’	-gɔt, -gʊt	“knee”
*tɬ’ʊχ	tɬ’oɪh	“grass”	*χəŋ^{y}ə̓s	keneθ, kineθ	“raft”

In contrast to these cases, obstruent-closed stems deriving from PA syllables with full vowels show strong evidence for the development of tone. Stem syllables that had glottalized coda consonants in Pre-PA forms got vowel constriction in PA forms, which produced an opposition in PA between stem syllables with glottalized coda consonants *CV̓·C’ and syllables with non-glottalized coda consonants *CV·C. PA syllables also had a contrast in constricted and non-constricted vowels before stem-final glottalized consonants, i.e., *CV̓·C’ versus *CV·C’; in the latter case, the stem vowel did not become constricted because the stem-final glottalized consonant was not in

[9] The claim is not that low tone is inherently incompatible with reduced vowels; the fact that both constricted and non-constricted reduced vowels received low tone in Apache shows that this is not the case (see de Reuse this volume). Rather, I assume reduced vowels are more likely to lead to loss of tone because of their weak status.

coda position in pre-PA. For the most part, this contrast in two directions is still observed in present-day Tahltan, as exemplified below.

(11) Reflexes of PA stems with obstruent-closed syllables and full vowels

a. *CV·C

*χe·ɬ	xe·ɬ	"pack"
*we·š	be·s	"knife"
*ts'i·x^{y}	tθ'i·h, ts'i·h	"mosquito"
*-na·ɢ/ɣ-əʔ	-daʔ	"eye"
*tɬ'u·ɬ	tɬ'u·ɬ	"rope"

b. *CV̓·C'

*he̓·ɬ	xè·ɬ, xe·ɬ	"trap"
*wa̓·ɢ	bà·h	"war"
*-de̓·dž-əʔ	-dè·dze	"younger sister"
*t'e̓·š	t'è·s, -t'e·s	"charcoal"
*te̓·ɬ	tè·ɬ	"mat"

c. *CV·C'

*ʔa·q'	ʔà·h, ʔa·h	"fog"
*ts'a·tɬ'	tθ'a·tɬ	"diaper moss"
*ɬu·t'	ɬu·t	"scab"
*ɬu·q'ə/e·	ɬu·we	"fish"

The variant [ʔà·h] of "fog" presents an interesting exception to the otherwise general patterns of tonogenesis, because the hypothesized PA form **ʔa·q'* did not have a constricted vowel and yet it has low tone. It seems, however, that some ancestor language of Tahltan had constriction, as exceptional tone marking is found in this stem in a number of northwest Canadian languages, including Slave, Sekani, Kaska, and Southern and Northern Tutchone, suggesting that this case represents a kind of northwestern Canadian innovation rather than a problem for the application of ATT to Tahltan in particular.

These results show beyond a reasonable doubt that tone in present day Tahltan developed from vowel constriction, the basic premise of ATT. All of the examples with tone had vowel constriction in a pre-Tahltan ancestor language. Furthermore, stems that do not have tone but are predicted to have it by ATT appear to have lost it for plausible reasons, i.e., because of the presence of pitch-elevating onset consonants in CVʔ stems (7b) and the lack of phonetic salience in reduced vowels (10b). Given the predominance of stress in the present-day prosodic system, it may not be wise to classify Tahltan with other Athabaskan tone languages. However, the residue of low marked tone observed in Tahltan provides clear evidence for the constricted/non-constricted distinction fundamental to ATT.

3. *Length*

The goal of this section is to document the phonetic structures of vowel length in Tahltan, and furthermore, to test the hypothesis sketched above that length is a by-product of the development of tone in long vowels. The section starts by identifying plausible historical sources for length in present-day Tahltan as a way of accounting for the minimal pairs I have found in my stem list. These stems are examined more carefully in a phonetic study of vowel length, and tone-induced length is contrasted with other types of length, both phonetically and phonologically.

3.1 *Background*

In order to study vowel length in present-day Tahltan, we need to briefly review the historical sources of length. The Proto-Athabaskan vowel system, shown below, makes an important distinction between so-called full vowels and reduced vowels.

(12) Proto-Athabaskan Vowels (based on Krauss 1964 and Leer 1979)

Full:	i		e[ɛ]		a		u
Reduced:		ə		ɑ		ʊ	

In some languages, like Navajo, a short versus long contrast developed as a result of this distinction (Leer 1979). Length contrasts in Tahltan also appear to be a reflex of the PA reduced versus full contrast. For example, a merger of /*e/ and /*ə/ gave rise to a contrast in the front mid vowels, e.g., **we·š* > [be·s] "knife", as opposed to **wəs* > [beθ] "riverbank". Because of certain controversies in the internal reconstruction of Tahltan vowels, it is difficult to determine the extent to which vowel mergers like this led to length contrasts. However, my assessment of Story (1975) and Hardwick (1984) suggests that this contrast probably emerged in both /e/ and the low vowel /a/, and possibly in the high vowels /i/ and /u/ as well.

Another source of length appears to be lengthening compensatory for the loss of coda nasals. For example, the opposition between [-ɣaʔ] (<*-*γa̓ʔ*) "hair" and -[ɣa·ʔ] (<*-*γa̓·n'*) "half" shows that the timing unit associated with

/*n/ was not lost.[10] Note that the length opposition in words like this cannot be a co-development with the tone that derived from vowel constriction, as many pairs that have this contrast end in consonants that produced constriction in PA, which entails that both members of the pair should have gotten tone.

A third source of length is suggested by the pilot study in 2.1. In particular, full vowels that developed tone appear to be slightly longer than the corresponding vowels that did not develop tone, e.g., *χe·ɬ > *xe·ɬ "pack" versus *he̓·ɬ > *xè·ɬ "trap". I do not mark the length contrast because it is not clear that it is phonemic, but I will use tone-marking as a means of identifying additional length in long vowels.

These three sources of length are exemplified below, together with some additional pairs that seem to fall outside of these length categories.

(13) Historical Sources of Length in Tahltan

a. *Reflex of full versus reduced vowels*

*wəs > beθ	"riverbank"	*vs*	*we̦·š > be·s	"knife"
*wɑx^{y} > bah	"dirty"	*vs*	*wa̓·ɢ > bà·h	"war"

b. *Compensatory lengthening*

*tša̓ʔ > tsàʔ	"beaver"	*vs*	*tš^{w}̓a·n' > tsà·ʔ	"excrement"
*-ɣa̓ʔ > -ɣaʔ	"hair"	*vs*	*-ɣa̓·n' > -ɣa·ʔ	"half"

c. *Tone-induced length* (low-marked tone syllables slightly longer)

*ʔa·x^{y} > ʔa·h	"snowshoes"	*vs*	*ʔa̦·q' > ʔà·h	"fog"
*χe·ɬ > xe·ɬ	"pack"	*vs*	*he̓·ɬ > xè·ɬ "trap"	

d. *Miscellaneous*

*-da̓ʔ "mouth" > -daʔ "beak"		*vs*	*-na·ɢ-əʔ > -da·ʔ	"eye"
*χəŋ^{y}̓əs > keneθ	"raft"	*vs*	kané·st > kene·θ Tlingit borrowing	"cross"
*-ne̓·n' > niʔ	"face"	*vs*	*-ŋ^{y}̓e·n' > ni·ʔ	"moss"

Concerning the -[daʔ]/-[da·ʔ] opposition in (13d), this case appears to be the result of the fusion of the possessive suffix -[əʔ] with the stem, a possible source of (phonetic) length noted in Leer (1979: 12). One might conjecture that this type of length is grouped with the compensatory lengthening examples, since the additional length can be attributed to the preservation of the timing

[10] The loss of syllable-final /n/ is typically understood as a part of a general set of processes in which consonant features are "supra-segmentalized" and realized on the preceding vowel (Leer 1979). While such an analysis leads one to expect a nasal vowel here, I have not found reliable evidence for nasality in stems of this type.

unit of the suffix. As for [keneθ] versus [kene·θ], it seems likely that stem-final /é·/ of the Tlingit loan (the acute accent is a high tone) was adapted to Tahltan as the long vowel /e·/, yielding an opposition much like that arising from the full/reduced contrast. Alternatively, this case could be construed as a kind of lengthening compensatory for the loss of the complex coda. The last example in (13d) presents an interesting puzzle. It submits neither to an interpretation in terms of compensatory lengthening, because both proto-forms have a syllable-final nasal, nor to one in terms of tone-induced length, as both should have gotten tone. Perhaps this example involves an incomplete process of neutralization, where the length compensatory for the loss of /n/ was gradually eroded away in the form for "face". If such an analysis is correct, one might expect there to be some variation as to the length contrast in these forms: some speakers may still preserve the length in the short form [niʔ], while others may have lost it, perhaps as a shortening effect due to the weak status of /i/ in a syllable checked by a glottal stop.

This summary of the historical phonology of length has identified four plausible sources for length in the present-day system: length as a reflex of the reduced versus full contrast in PA, compensatory lengthening, tone-induced length, and length due to the fusion of the PA possessive suffix. The next section examines the phonetic basis for these different sources of length and clarifies some important differences among them.

3.2 *A Phonetic Study of Length*

As with the previous study, minimal pairs were elicited as a means of quantifying the phonetic structure of the contrast. Five native speakers were asked to produce carrier sentences in which the stems in (13) appeared in preverbal position. The carrier sentence for each test word is given in the appendix.[11] The native speakers were asked to produce two to four repetitions of each sentence at both normal and fast speech rates, resulting in roughly 6 tokens (= 2 rates × 3 trials) for each item. The vowel structures were then measured using the same methods described in 2.1, i.e., the duration of the vowel was measured as the interval between pre-vocalic consonant release and vowel offset.

[11] The carrier sentences were not the same for each test word, because the participants of the study desired to produce sentences that fit thematically with the test words. While the variables introduced by the different sentence frames may have introduced influences on the durational properties of the test forms, this tack represents a necessary trade-off between control in experimental design and the greater likelihood for natural realizations of the minimal pairs.

One of the basic limitations of this study is that the paucity of minimal pairs precluded the creation of a balanced list of test words. As a result, the differences in consonants and vowels, as well as syllable count (monosyllabic versus disyllabic), introduce some noise into the comparison of these pairs. In the interpretation of the results given below, efforts are made to identify the influences from these factors, which are interesting to document in their own right. These influences are subsequently factored out through the use of relative versus absolute values in order to focus on the core questions before us, namely the significance of the different length contrasts and the status of tone-induced length.

A useful way of summarizing the durational difference between two vowels is as a ratio. In the table below, all of the collected data is summarized as a list of durational ratios where the duration of the short member of a pair is the denominator and the long member is the numerator. So, for example, a value of 1.35 for speaker 5 for [ʔa·h]/[ʔà·h] means that the long member (with marked tone) is roughly one and a third the duration of the short member.

(14) Durational Ratios, Sorted by Individual and Historical Source[12]

Code	Pair	1	2	3	4	5
t-a-1	ʔa·h/ʔà·h	1.42	1.28	1.28	1.10	1.35
t-e-1	xe·ɬ/xè·ɬ	0.95	0.98	0.94	1.21	1.45
rf-a-1	bah/ba·h	1.64	—	—	—	1.90
rf-e-1	beθ/be·s	1.60	1.88	1.87	2.07	1.86
cl-a-1	tsaʔ/tsa·ʔ	1.99	2.44	2.78	2.26	1.76
cl-a-2	-ɣaʔ/-ɣa·ʔ	1.47	2.54	2.28	2.00	1.74
p-a-2	-daʔ/-da·ʔ	2.85	2.69	2.01	2.10	1.87
ht-e-2	keneθ/kene·θ	1.79	1.77	1.63	2.39	2.11
ʔ-i-1	niʔ/ni·ʔ	2.00	1.80	1.85	1.62	1.35

The table above reveals some considerable variation across speakers. For example, some speakers do not appear to have a durational contrast in the pair [xe·ɬ]/[xè·ɬ] (ratios below 1.0 are shaded). In order to assess the influence from speakers on the length contrasts, a two-way ANOVA (2×5) was done with duration as the dependent variable and length and speaker as the independent

[12] The leftmost column also encodes the different factors inherent to each pair, giving the historical source for length ("t" for tone, "rf" reduced/full, "ht" high tone in Tlingit loan, "cl" compensatory lengthening, and "p" possessive suffix, and "?" for an unknown source), the quality of the vowel, and the syllable count.

variables. This analysis showed significant effects for both length ($p < .0001$) and speaker ($p = .0006$), but no significant interaction between the two. Fisher post-hoc tests[13] clarified, however, that most of the speaker influence comes from speakers 1 and 5, with speakers 2, 3, and 4 representing a homogeneous group. In both long and short vowels, speaker 1 tends to pronounce them shorter than the rest, while speaker 5 tends towards longer vowels. For example, speakers 2, 3, and 4 have a mean duration of 214 ms for long vowels, with a very low spread (standard deviation = 1.32), while the mean for long vowels is 177 for speaker 1 and 243 for 5. Likewise, the cumulative duration of short vowels for the middle three is 126 (standard deviation = 1.36), as opposed to 107 for speaker 1 and 146 for 5. It is interesting to note that this difference correlates with age: speaker 1 is the youngest of the participants at 44, while speaker 5 is the oldest, who, at age 82 is a full generation older the other three speakers.

Another possible factor affecting the assessment of the length pairs is vowel quality, as the stem minimal pairs used either /a/, /e/, or /i/. These vowels differ in vowel height, which is well-known to co-vary with duration differences (Lehiste 1970). A two-way ANOVA (2×3) was done to examine the influence from vowel quality, using duration as the dependent variable, and length and vowel quality as the independent variables. While no influence was found for vowel quality ($p = .3194$), the lack of significant differences among vowel types may have been due to the variation in the flanking consonants and the historical source for length. When pooled together, however, the mean durations for long vowels seem to support a cross-linguistic tendency for low vowels to be longer than high vowels, as shown below in (15). This trend is somewhat weaker in short vowels, as short /a/ is shorter globally than short /e/.

(15) Vowel Durations, Sorted by Vowel Quality and Length

	a	e	i
long	220.9 (36)	206.6 (42)	189.8 (12.2)
short	122.3 (42.5)	133.4 (40.4)	112.8 (25)

It seems likely, therefore, that the intrinsic duration of vowels affects the length contrasts, and it should be factored out in some way.

In order to reduce the noise from intra-speaker variation and vowel quality, a set of ANOVAs were done that used durational ratios as the dependent variable. The idea here is that by using a relative value, instead of

[13] The significance level for this and subsequent Fisher post hoc tests is 5%.

the absolute value of the actual duration, the effects from speakers and vowel quality can be reduced. A two-way ANOVA (3×5) was therefore performed using durational ratios as the dependent variable and vowel quality and speaker as independent variables. This analysis showed no significant effects from vowel quality or speakers and no interactions between the two. In other words, with durational ratios, length differences tend to be realized the same way, independently of vowel quality and speaker.

We are now in a position to assess one of the more interesting results of the study, namely the effect due to historical source. A two-way ANOVA (2×6) with durational ratio as the dependent variable and speech rate and historical source as independent variables showed that durational ratios were significantly affected by historical source ($p < .0001$), but ratios were not affected by speech rate. The differences among the various types of length contrasts are charted below.

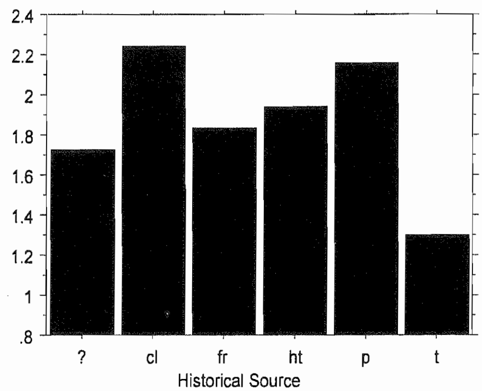

Figure 2: *Durational ratios of length contrasts distinguished by historical source*

Fisher post-hoc tests showed that the significant differences were primarily due to two classes of historical sources, namely compensatory lengthening (= cl) and possessive (= p), on the one hand, and tone-induced length (t) on the other hand, which is also evident above in Figure 3. The ratios of the former class differed from all other types, except [keneθ]/[kene·θ] (= ht) (see (13) for glosses of minimal pairs), which, as noted in 3.1, has an ambiguous historical classification. The ratios of tone-induced length differed significantly from all other classes, which leaves a residual class consisting of length as a reflex of the full/reduced contrast (= fr) and [niʔ]/[ni·ʔ] (= ?). If length due to the fusion of the PA possessive suffix is grouped with compensatory lengthening, which seems supported both analytically and by the above results, and [keneθ]/[kene·θ] is grouped with the higher class (motivated below), this analysis suggests three basic classes, given below with the durational ratio of each member and the standard deviation of each sample in parentheses.

(16) Durational Ratios Sorted by Classes

a. Compensatory lengthening: cl = 2.25 (.39), p = 2.16 (.43), ht = 1.94 (.31)
b. Full versus reduced: fr = 1.83 (.16), ʔ = 1.73 (.25)
c. Tone-induced length: t = 1.30 (.12)

It is useful at this point to return to some of the minimal pairs that resisted a straightforward historical classification and consider the factors that may have contributed to observed differences between them and the other members of their assumed class. One important point is that many of the ambiguous items differed in syllable count from the other members of their class. As is clear from a number of length studies (e.g., Hubbard 1995), length contrasts tend to be reduced as the size of the word increases. Syllable count therefore has implications for the assessment of the disyllabic pairs -[daʔ]/-[da·ʔ] and -[ɣaʔ]/-[ɣa·ʔ] (which received the prefix [mẹ]- in the test words). Perhaps the slight difference in the mean durational ratios in (16a) between cl and p is accounted for by the fact that the cl stems [tsaʔ]/[tsa·ʔ] are monosyllablic, while the p stems -[daʔ]/-[da·ʔ] are disyllabic. This tack also seems to account for some of the speaker differences between [tsaʔ]/[tsa·ʔ], on the one hand, and disyllabic -[ɣaʔ]/-[ɣa·ʔ] in (14); the differences observed in speaker 1 and 3 are indeed outside the standard deviation for this class (16a). With the case of [keneθ]/[kene·θ], the difference of syllable count suggests a grouping with the highest class, namely compensatory lengthening. If this pair was grouped with those in (16b), the slightly higher durational ratio is unexpected. The differences in syllable count, therefore, may account for some of the differences within classes.

Finally, it is interesting to return to the pair [niʔ]/[ni·ʔ], which was not satisfactorily classified for historical source. It seems implausible to subsume this pair with the class of compensatory lengthening pairs, as conjectured in 3.1, given the significant differences between its durational ratio and those of the cl and p categories. One interesting pattern in (14) is that the ratio of the oldest speaker 5 is rather low: 1.35, while speaker 1, the youngest, is the highest at 2.00. Furthermore, the middle block composed of speakers 2, 3, and 4 is in between these ratios. One possibility, therefore, is that the contrast in this pair was originally due to tone-induced length and was later re-analyzed by other speakers as a different length type. Indeed, speaker 5's ratios for this case compare quite well with those of the tone-induced length class. For this analysis to work, however, the short member of the pair, [niʔ] "face", must have lost tone before TIL was introduced and the coda nasal was lost in the proto-form *-[ne·n']; otherwise, both forms would be expected to undergo lengthening.

3.3 *Tone-Induced Length Reconsidered*

The results above distinguish tone-induced length from other sources of length. Long vowels with marked tone are roughly one and a third the duration of long vowels without tone. This ratio distinguishes tone-induced length from other length classes such as compensatory lengthening and the reflexes of full versus reduced vowels, which had ratios of 2.25 and 1.83 respectively. To a certain extent, this difference is not unexpected. After all, tone-induced length is an opposition between long vowels, i.e., the descendents of historically full vowels, while the other length contrasts involve oppositions between long and short vowels. This finding, however, raises an interesting question, namely how the different length contrasts are encoded in the grammar. Concretely, how is short/long distinguished from long/long+marked tone?

(17) Two Types of Length Contrasts

Short	Long		Long+marked tone
beθ	xe·ɬ	be·s	xè·ɬ

In standard models of the phonetics-phonology interface (as in Pierrehumbert 1990), it seems we have at least two options. First, the grammar may distinguish these length types by assigning them distinct phonological categories; for example, they may be distinguished in mora count. Alternatively, tone-induced length may be viewed as a phonetic pattern superimposed on moraic structure, i.e., TIL could be a phonetic process that increases the duration of a long vowel by a third if it bears a low tone.

Two facts about TIL speak against the latter view. First, as noted above, TIL is not sensitive to rate changes, which distinguishes it from many phonetic processes of coarticulation. Thus, if one's model of the phonetics-phonology interface makes a distinction between categorical phonological patterns, on the one hand, and gradient phonetic patterns (see Cohn 1995 and references therein), TIL does not appear to be a phonetic process. A second and perhaps more significant point is the facts of TIL do not support a systematic relationship between marked tone and increased length. As shown in some detail in 2.1, the contrast between unmarked and marked syllables is realized as either an F_0 difference, or a durational difference, or both. In speaker 2's results of the pair [xɪθ]/[xɪ̀θ], for example, a significant difference in F_0 was found but not in duration. Conversely, for the pair [ʔa·h]/[ʔà·h], all three speakers showed significant differences in duration, but only one speaker distinguished the stems with F_0. Clearly, duration does not co-vary systematically with F_0, so it is impossible to see tone-induced length as a synchronic consequence of tone.

So how are unmarked long vowels distinguished from marked long vowels? To start, the contrast is between two long vowels, i.e., full vowels in the historical sense, which are typically analyzed as bimoraic to distinguish them from short vowels (see Tuttle 1998). To distinguish them phonologically, one would either need to increase the mora count of long vowels with marked tone, like the stem vowel in [xè·ɬ], bumping it up to three. Alternatively, unmarked long vowels could be analyzed as monomoraic, and short vowels could be moraless. In this context, it is worth mentioning that Hargus 2001 provides both phonetic and phonological evidence for the former type of analysis in Witsuwit'en, though the source for the 'extralong' vowels is not tonal in nature. In this work, the three classes of vowels distinguished on a phonetic basis are also crucial to the 'heaviness scale' relevant for phonological stress. A three-way contrast is therefore not unprecedented in Athabaskan languages. This study therefore has provided phonetic evidence for a phonological contrast in length, which shifts the focus of future work to the phonology for additional evidence for the three-way contrast.

A final point worth mentioning is that the results of the length study dovetail in a nice way with the study of the historical sources for Tahltan tone. TIL shows that there is increased length in syllables predicted to have tone, though in some cases the predicted low tone has been eroded away. The existence of the length structure, however, is predicated on the prior existence of tone, and so TIL gives additional support for the claim that tone in Tahltan developed according to Athabaskan Tonogenesis Theory, because this length structure correlates with predicted tone.

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APPENDIX

A. Pairs with length as a reflex of PA full/reduced vowels

beθ "riverbank"	be·s "knife"
dža·n beθ yeneʔin	dža·n be·s ʔenelin
"John is looking at the riverbank"	"John wants a knife"
bah "dirty"	ba·h "war"
kudži melaʔ bah ʔadadžah	kudži ba·h ʔahudžah
"His hands became dirty"	"Now the war is here"

B. Pairs with tone-induced length

ʔa·h "snowshoes"	ʔà·h "fog"
ʔe ʔeskiye ʔa·h ʔenelin	dža·n ʔà·h neʔin
"The boy wants the snowshoes"	"John sees the fog"
xe·ɬ "pack"	xè·ɬ "fog"
dža·n xe·ɬ ʔenelin	dža·n xè·ɬ yeneʔin
"John wants a pack"	"John is looking at the trap"

C. Pairs with length as a reflex of PA possession

meɣaʔ "his hair"	meɣa·ʔ "his half"
ʔetɬi·ʔ meɣaʔ ʔutɬ'a·n	dahuni meɣa·ʔ ʔeneθʔitɬ'in
"The dog has a lot of hair"	"We want our half"
medaʔ "his beak"	meda·ʔ "his eye"
ʔe tsesk'iye medaʔ ɬe·gas	dža·n meda·ʔ ta·dah
"The crow broke his beak"	"John's eye hurts"

D. Other length minimal pairs

tsaʔ "beaver"	tsa·ʔ "excrement"
dža·n tsaʔ yeneʔin	dža·n tsa·ʔ keʔede·
"John is looking at the beaver"	"John is cleaning up the excrement"
keneθ "raft"	kene·θ "cross"
dža·n keneθ ʔetšotš	dža·n kene·θ ʔenelin
"John is paddling the raft"	"John wants a cross"
niʔ "face"	ni·ʔ "moss"
dža·n niʔ yeneʔin	dža·n ni·ʔ kadešyah
"John is looking at the face"	"John is getting the moss"