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The stop contrasts of the Athabaskan languages

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Abstract

The Athabaskan languages have a particularly rich series of stop contrasts, plain stops and affricates, each exhibiting a three-way laryngeal contrast, unaspirated, aspirated and ejective. Several aspects of this inventory are interesting to phonetic and phonological studies, among them the length and 'heaviness' of the releases on the aspirated plain stops, the temporal properties of the ejectives, and the richness of the stop contrast set, approximately 21 distinct segments. This paper is an investigation of the phonetic realization of the stops in five Athabaskan languages: Dene Sųłiné (CL), Dene Sųłiné (FC), Dogrib, North Slavey, and Tsilhqut'in, compared with data from Navajo from McDonough [(2003). *The Navajo sound system*. Kluwer: Dordrecht]. Based on the phonetic patterns in the data, we argue that, among the consonants, the primary organizing feature of the contrasts is a temporal distinction, which we model as simplex–complex contrast, based on Laver [(1994). *Principles of phonetics*. Cambridge: Cambridge University Press], in which the temporal properties of medial phase of the segment's articulation play a significant role in the contrast. This classification represents a major divide in the inventory between the unaspirated plain stops (orthographically (*b*), *d, g,* (*q*)) and the rest of the stops in the inventory. These data suggest first that aspirated plain stops (orthographically *t, k*) are mislabeled. Instead, in keeping with much of the early literature on the Athabaskan languages, the *t* and k phonemes are the affricates /tx, kx/. Second, related to this, long release periods are a characteristic feature of all but the unaspirated stops in the inventory. As such they represent a feature of a larger grouping in the Athabaskan inventory, realized in a temporal domain and persistent in the family, in a pattern likely inherited from the parent language. We model this temporal distinction as a simplex–complex distinction, which separates out the 'unaspirated' plain stops, as simplex segments with short offsets, from the rest of the stops, including the plain 'aspirated' stops and ejectives, which have complex medial phases with long release periods. Furthermore, the proposal suggests that the languages have exploited the sets of simplex stops and fricatives to build their rich inventories of complex segments, as several linguists have observed. The analysis serves as a basis for understanding sound change and alternation patterns in the family.

1. Introduction

The Athabaskan languages are a group of closely related languages indigenous to North America that share similar structural features, including a similar complex morphological structure and similar phonemic inventories. The northern Athabaskan languages are spoken across northern North America, from interior

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Alaska to the Hudson Bay and from the Arctic circle south to the Canadian–US border. Languages from this family are found in two other areas, the American southwest (Apachean or Southern Athabaskan) and the Pacific coast (Coastal Athabaskan). The most well known and best documented of these languages is Navajo (Apachean), though many of the languages of the Athabaskan family have been studied and documented for over 100 years. A very rich body of linguistic research exists on this family from early work (Goddard, 1907, 1912, 1929; Morice, 1932) to more contemporary grammars (Cook, 1984; Golla, 1970; Rice, 1989; and the work that has come out of the Alaskan Native Language Center, to name but a few). Of particular mention is the work on Navajo of Young and Morgan (1987); Young, Morgan, and Midgette (1992) and Young (2000) who have produced a series of grammars and dictionaries whose breadth and scope make Navajo one of the best-documented indigenous languages in North America.

From almost the beginning, the documentation of Athabaskan included phonetic descriptions. Instrumental phonetic work began with Pliny Earle Goddard (Goddard, 1912, 1929) who collected data using the kymograph (a device measuring airflow and pressure) from Kato and Hupa (Coastal Athabaskan) as well as the Cold Lake, Bear Lake, and Beaver languages (Northern Athabaskan) at the turn of the last century. The present has seen a strong revival of the interest in instrumental phonetic documentation of Athabaskan and other Native American indigenous languages (For Athabaskan, Bird, 2002; Gordon & Ladefoged, 2001; Gordon, Potter, Dawson, De Reuse, & Ladefoged, 2001; Hargus, 2007; Rice & Hargus, 2005 and the papers within; McDonough, 1999, 2003; Tuttle, 2003; Tuttle & Sandoval, 2002; Wright, Hargus, & Davis, 2002).

In this paper, we discuss the phonetic realization of the stop consonants in five Athabaskan languages: Dene Sųłiné (CL), Dene Sųłiné (FC), Dogrib, North Slavey, and Tsilhqut'in. While traditional views found in the inventories of the grammars and dictionaries of the Athabaskan languages assume that the stop inventory (except the labials) exhibits a three-way manner contrast (unaspirated, aspirated, and ejective), the proposed analysis argues that the primary organizing feature of the consonantal contrasts in Athabaskan is a temporal distinction between simplex and complex segments. According to the analysis proposed here, the unaspirated plosives (/p t k q/) are simplex segments, whereas the aspirated and ejective stops (/t^h t'/ and /k^h k'/) pattern together and form the class of complex segments with affricates. The proposed classification of the Athabaskan stop system into simplex and complex segments is based on a phonetic pattern observed in the data collected from eight speakers of five diverse Athabaskan language communities. These data suggest that aspirated stops are phonemic affricates in Athabaskan, and that these affricates share with ejectives and plain aspirated stops the feature of having long release periods.

The described phonetic pattern persists across the languages of the Northern Athabaskan family, which has a time depth of 2500 years (Rice & Hargus, 2005), and—as the data presented here demonstrates—exists among widely dispersed communities of speakers. The presence of this pattern, amidst variation, indicates that it is a likely feature inherited from the parent language.

The organization of the paper is as follows: the next section provides a brief outline of the Athabaskan languages and their phoneme inventories. Section 3 discusses the data collection and analysis. The results are presented in Section 4, which is followed by a discussion of the data.

1.1. The simplex–complex distinction

Simplex and complex segments are, following Laver (1994), distinguished by the temporal properties of these segments. In Laver's view, segments are comprised of three phases: an onset, the medial phase, and an offset. The articulators are in a stable or steady state relationship to each other during the medial phase of the segment's articulation. The medial phase is the most prominent part of the articulation; the onset and the offset are the periods of transition into and out of the medial phase. For Laver, simplex stops, including affricates, the medial phase of the segment is the closure period. For fricatives, the medial phase is the portion of the articulation during which the active articulator remains stable (Laver, 1994, pp. 205–227).

In complex segments the articulators have an asynchronous timing relationship to each other during the medial phase of the segment's articulation. Laver, whose discussion of complex segments centers around pre- and post-nasalized stops, argues that complexity entails a dynamic timing relationship between concurrent nasal and oral gestures during the oral closure. That is, there is a timing asynchrony between two articulators during the medial phase of the production of the stop, the nasal gestures begins or ends during the closure period.

In Laver's model, the temporal properties of the segment are key elements. He argues that the timing asynchrony between the oral and nasal gesture in complex segments is reflected in the temporal profile of these complex segments. While the gestures of the medial phase in simplex segments are longer than those that might occur in the onset and offset, in complex segments, the gestures of the medial phase are shorter compared to independent simplex segments, with which they may contrast. This is important to the present discussion as the temporal aspects of a segment's articulation play a role in its categorization.

We take Laver's notion of simplex and complex segments and extend it slightly. We retain the notion that a segment has three phases, an onset, a medial phase and an offset that defines its temporal profile. But we redefine complex to allow medial phases to contain sequential as well as asynchronous relationships. We allow the medial phase to contain both a closure period and another articulation pattern, which are reached and held sequentially before the offset at the right margin of the segment. Thus, a complex segment is defined as a segment framed by an onset and offset, with a medial phase of at least two gestures that are in a concurrent or sequential timing relationship to each other. For us then stops may be either simplex or complex, and the distinction will be reflected in the temporal profile of their articulation. For instance, we predict a contrast between simplex and complex affricates. Complex affricates will have closure and fricated release occurring in the medial phase of the segment's articulation, framed by an onset and offset. In complex affricates the offset will occur after the fricated release and may itself contain contrastive laryngeal transitions. In simplex affricates, the offset contains the fricated release. Crucially, the difference between the two segment types will be reflected in the temporal domain.

As Laver notes, this theory predicts that simplex versus complex articulation strategies may be reflected in speaker variation within or across languages, or may function as contrastively in a language. We take a slightly stronger stance. As we define the simplex–complex distinction it is a basic strategy in the production of segments differing in the properties of the medial phase of the segment, reflected in the temporal properties of that segment's articulation. If this is the case, we ought to be able to find simplex and complex realizations of segmental contrasts, and this difference ought to play a role in the phonology and be an observable aspect of the phonetics.

We present evidence that such a contrast can be found in the Athabaskan languages. In this paper we argue for a simplex and complex distinction, which constitutes a primary division in the consonantal inventories of the Athabaskan languages. We contend that this analysis has explanatory power and brings together several factors in the phonetics and phonology of the Athabaskan languages, including diverse phenomena such as the temporal patterns in the stops series, the frication present in aspirated stops, the containment of laryngeal variation to unaspirated stops, and the conflation of some ejectives with unaspirated stops.

2. Language background

In this section we will cover the background for this discussion: the Athabaskan communities, the terminology used in this discussion, and the phonemic inventories.

2.1. The Athabaskan communities

The Athabaskan[1] languages are spoken throughout a large portion of western North America. The languages are grouped into the three areas by location: Pacific Coast (California and Oregon), Southern or Apachean (in the American Southwest), and Northern Athabaskan. Most of these languages are spoken in the sparsely populated north, which covers an area from inland Alaska across the interior of northwestern Canada and western providences to Hudson Bay. Many of the Northern Dene communities are small, and during many parts of the year they are accessible only by air. So while there has been contact between members of these communities, the communities themselves are spread out over a large region. Apart from Navajo (Southern Athabaskan), the data in this paper is collected from speakers from five different Northern

[1]Athabaskan peoples call themselves the Dene or Diné, 'The People'. The term 'Dene' is used when referring to the communities.

Table 1
The Athabaskan languages and communities in this study

Language	Community	Wordlist	Speakers
Dene Sųłiné CL	Cold Lake, Alberta	Dene Sųłiné	1
Dene Sųłiné FC	Fort Chipewyan, Alberta	Dene Sųłiné	2
Dogrib	Rae, NWT	Dogrib	1
North Slavey	Delina, NWT	North Slavey	3
Tsilhqut'in	Central British Columbia	Tsilhqut'in	2

Dene communities: Dogrib in Rae, Northwest Territories, on Great Slavey Lake; North Slavey in Deline, Northwest Territories, on Great Bear Lake on the Arctic circle; Dene Sųłiné FC in Fort Chipewyan, Alberta, on Lake Athabasca, Dene Sųłiné CL in Cold Lake, Alberta; and Tsilhqut'in in central interior British Columbia (see Table 1).

The Dene Sųłiné consultants were from two different communities, Cold Lake (Dene Sųłiné CL) and Fort Chipewyan (Dene Sųłiné FC), Alberta. Though the languages of these two communities are mutually intelligible, there are dialect differences noticeable to speakers, and these communities will be treated as distinct in this paper. The other languages are not mutually intelligible.

2.2. The inventories of the Athabaskan languages

The general structure of the Athabaskan consonant inventory is shared by all the Athabaskan languages. It is characterized by a high percentage of obstruent contrasts, due to two features: a reported three-way laryngeal contrast, aspirated, unaspirated and ejective, among a rich set of stops: plain stops, affricates and lateral affricatives. In general, present day Athabaskan languages also tend to have at least four fricatives: three alveolar fricatives, two central ([s, ʃ] or [θ, s/ʃ])[2] and one lateral ([ɬ]), and at least one back fricative, either velar or uvular, or both. Some Athabaskan languages also have labialized versions of the velar and/or uvular fricatives. Voicing among fricatives is principally contextual. The Athabaskan languages tend to have affricates at the same place of articulation as the fricatives, in effect exploiting the stop and fricative contrasts to produce the affricates (Holton, 2001; McDonough, 2003), a point we will take up in Section 5.6.

The inventories differ from each other in regular ways, principally in the places of articulation of the stop and fricative contrasts. For instance, Navajo and Apache have three alveolar fricatives, *s, sh, ł,* with matching affricates (Hoijer & Sapir, 1945; Kari, 1976; McDonough 2003; Young & Morgan 1987). In some languages, such as North Slavey and Dene Sųłiné (Chipewyan), the place of articulation has shifted forward; these languages have an interdental series of fricatives and affricates (*th, ddh, tth, tth'*/ θ, ð, dð, $\text{t}\theta^{h}$, tθ′/), losing a contrast between *s* and *sh* (Goddard, 1912; Li, 1933, 1946; Rice, 1989). Some of the Athabaskan languages, such as Witsuwit'in (Babine) (Hargus, 1991; Story, 1984) and Tsilhqut'in (Cook, 1989), have velar and uvular contrast sets, which include labialized velar and uvular stop and fricative series. Others, like Navajo (Young & Morgan, 1987; Kari, 1976), Jicarilla Apache (Phone, Olsen, & Martinez, 2007), San Carlos Apache (de Reuse & Goode, 2006) have only a few non-coronal contrasts, resulting in a heavily coronal inventory. The Athabaskan languages tend to avoid labials, except as secondary articulations, also reflected in the fact that the bilabial stop does not show the full contrast set, and shows up in only a small number of morphemes. The Athabaskan languages tend not to have a robust distinction between fricatives and approximants, with approximants often appearing chiefly as reflexes of fricatives (Holton, 2001; McDonough, 2003; Young & Morgan, 1987). These characteristics are exemplified in Fig. 2, which shows the phonemic inventories in the Athabaskan orthography for two of the languages in this study, Navajo (from Young & Morgan, 1987) and Slavey (Rice, 1989) (see Fig. 1).

[2]Words and sounds written in the Athabaskan orthographies are in italics; the phonetic transcription is written in brackets (yishcha [jɪʃtʃʰɑh] 'I cry', Navajo). Phonemic symbols that are not also orthographic symbols will be written in slanted brackets: the phoneme *d* /t/.

Navajo (Young and Morgan 1987)

	lab	alveolar		Post-alveolar	Velar	·
		central	lateral			
stops	(p)	d t t′			g k k′ g^w k^w	ʻ
affricates		dz ts ts′	dl tɬ^h tɬ′	j ch ch′		
fricatives		s z	ɬ l	sh zh	x	h
nasals	m	n				
approx				y	w	

Slavey (Rice 1989, Mithun 1999)

	lab	Inter dental	alveolar		Post-alveolar	Velar	glottal
			central	lateral			
stops	(p)		d t t′			g k k′ g^w k^w k$^{w\prime}$	ʔ
affricates		ddh tth tth′	dz ts ts′	dl tɬ^h tɬ′	dʒ tʃ^h tʃ′		
fricatives		dh th	s z	ɬ l	sh zh	x gh	h
nasals	m		n				
approx					y	w	

Fig. 1. The consonantal inventories of Navajo and Slavey (in their orthographies).

Although they are similar in structure, these inventories differ from each other in characteristic ways: in the place of articulation of the fricatives and the stops, and in the voicing values of the unaspirated stops (not reflected in the orthography). We are arguing that the phonemic system has a different organization from the one represented in these charts; we take this up in the discussion section (Section 5 and Fig. 6).

There are gaps in the inventory, which we consider a type of variation around a norm and not a central tendency in the system. Navajo does not have an ejective version of the labialized velar stop /k$^{w\prime}$/. Some Athabaskan languages do not report the full series of lateral affricates. Tsilhqut'in has a pharyngealized series of coronal affricates (Cook, 1983; Hansson, 2000). We present these inventories to demonstrate their general properties. For a fuller description of the variation in the sound contrasts in Athabaskan, we refer the reader to grammars and descriptions of individual languages, and the literature on comparative and reconstructive studies (Krauss, 1964, 1973; Krauss & Leer, 1981, 1976; Leer, 1979, 1996; Rice & Hargus, 2005). The phoneme inventories suggested for the languages included in this study are listed in Appendix A.

Finally, it is a general tendency in the orthographies of the Athabaskan languages to represent the *unaspirated* version of a stop in a series with the voiced symbols *d, dz j dl*, whether or not these sounds are voiced in a given Athabaskan language. The unaspirated stops in Navajo are voiceless (McDonough, 2003; McDonough & Ladefoged, 1993) but voiced in Dene Sų̨łiné, though both orthographies use the voiced symbol to represent this sound. We will take up a discussion of voicing briefly in Section 5.5.

2.3. Terminology

For ease of discussion, we differ slightly from IPA terms; we use the term 'stops' to refer to the sounds that involve a (central) closure period; in IPA terminology, the plosives and affricates. In contrast to the IPA, we use this term to include ejectives. We will use the term 'plain stops' for the stops with 'plain' oral releases, i.e. the sounds of the plosive series, but also the ejective in the series. These stops stand in contrast to affricates, i.e. stops that have fricative and lateral fricative releases. Thus there are three series of stops: plain stops, affricates and lateral affricates. One aspect of the discussion centers on the phonemic status of the aspirated plain stops. We will argue, contra their place in the traditional inventory as aspirated stops, that they are phonemic affricates; we take this up in Section 5.2 and 5.4.

3. Methodology

3.1. Data collection

Data were collected from nine native speakers of four distinct Northern Athabaskan languages. All the participants were studying at the *Canadian Indigenous Language and Literature Institute* (CILLDI), summer 2004, at the University of Alberta, Edmonton Canada. The consultants were recruited by word of mouth. The consultants were adults in their 30s through 70s. They were paid for their participation.

The sessions with the consultants were split into two parts, word list preparation and recording. Prior to the sessions, a Northern Athabaskan model word list was prepared in a spreadsheet by one of the co-authors, who has been a director of a language revitalization project in her community. The wordlist exemplified the phonemic contrasts of the Dene Sųłiné, Cold Lake language. The spreadsheet had three columns: the orthographic symbols for a phoneme, a word exemplifying that sound in either stem or word initial position, and its English translation. The goal of finding words that exemplified the sounds of their language was explained. Consultants were directed to the structure of the example word list and asked to develop one in their own language. All but one of the consultants (the monolingual Tsilhqut'in speaker) were familiar enough with an orthography of their language that they could write words down. General familiarity with orthographic transcription also varied by consultant, a reflection of the inherently oral Athabaskan cultures.

The consultants constructed the word lists to their own preferences. The Dogrib consultant used the phoneme wordlist in the Dogrib dictionary (Dogrib Divisional Board of Education, 1996). The Tsilhqut'in consultant developed an extensive word list, containing both words and expressions. For the recording session, the consultants' word lists were used, thus the number or kind of items in a given phonemic category was not controlled for. In all, five word lists were prepared: in Dene Sųłiné CL, Dene Sųłiné FC, North Slavey, Dogrib, and Tsilhqut'in. See Appendix B for further discussion.

Following the construction of the wordlist, the consultants recorded their prepared wordlists in a sound booth at the Centre for Comparative Psycholinguistics in the Department of Linguistics at the University of Alberta. The recitations were recorded directly to disk. The forms were spoken in isolation. Participants were asked to recite each word three times for the recording session. The recitations of the word lists in the recordings were done in careful lab-type speech, by the speakers' inclinations rather our request. The most extreme example is the careful speech of the Dogrib speaker, as reflected in the length of her segments in the data reported on in this paper. However, except for the monolingual Tsilhqut'in speaker, the speakers were reading from a word list they themselves worked on.

All but one of the speakers are female; the male speaker is the primary Dene Sųłiné FC speaker. The data is marked for community rather than by speaker, mainly because of a disparity in the number of tokens for a given speaker. Data for some tokens were not used because of disfluencies in producing a word, audible discomfort with a word, or recording errors (paper shuffling during the speech, hitting the microphone, etc.). We did not use any tokens where a speaker hesitated or stumbled over a pronunciation or indicated that they did not understand a written word. The digital recordings were copied to CD's. Copies were given to participants.

3.2. Measurements

The transcription, segmentation, examination, and analysis of the data was done at the Phonetics Lab, Department of Linguistics, University of Rochester. The acoustic analysis was done using *Praat* (Boersma & Weenink, 2007).

The focus of this study is the temporal profile of Athabaskan stops and the spectral qualities of the release periods of the plain aspirated stops. For the temporal profile, both the closure and release periods of the stops were segmented. The closure was measured from the offset of voicing or frication in the pre-stop segment to the onset of the release burst. The release period was measured from the onset of the release burst to the onset

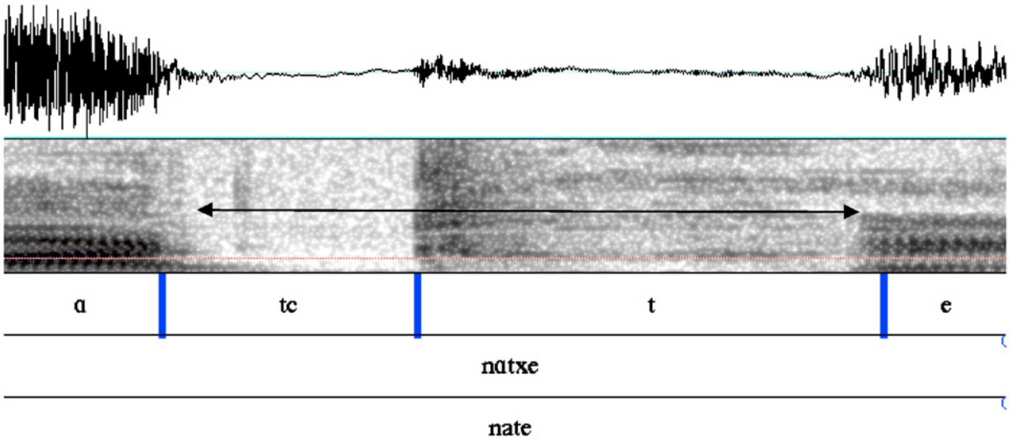

Fig. 2. An example of the Praat annotation used in this study. The segment under study, the 'aspirated' plain coronal stop *t* [tx] (301 ms) is indicated by the arrow. The scale of the spectrogram is 0–10 kHz.

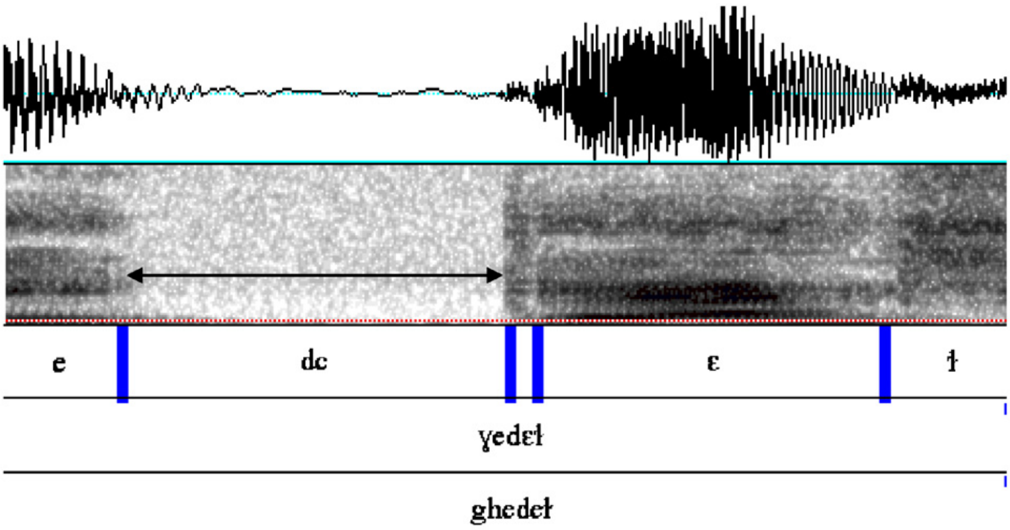

Fig. 3. An example of an 'unaspirated' plain coronal stop, *d* (203 ms), in Dene Sųłiné CL (scale: 0–10 kHz). The closure period is marked by an arrow, the stop burst is 12 ms.

of voicing and formants in the post-stop vowel.[3] For the spectral analysis of the release portion of the aspirated plain stops, a Moments analysis was performed on the LPC spectrum, using the parameters of Center of Gravity and Standard Deviation as a measure of differences.

Figs. 2 and 3 show examples of waveforms, spectrograms and the annotation system used in the study to segment the data. In Fig. 2 is a token of the Dene Sųłiné CL word *náte* [natxe] 'he is dreaming', showing the temporal profile of the phoneme *t*, an the aspirated plain coronal stop and an example of a complex segment under the analysis presented in this paper. The phoneme is in stem initial position, the principle position of consonantal contrast, indicated by the arrow (the full segment *t* in Fig. 2 is 301 ms; the release period is 191 ms and is audibly fricated).

Fig. 3 shows an example of the word *ghedel* [ɤedɛɬ] 'they are walking' in Dene Sųłiné CL. The segment *d*, a unaspirated plain coronal stop (209 ms) is an example of a simplex segment. The stop burst was 12 ms.

[3]In Cho and Ladefoged (1999), McDonough and Ladefoged (1993), McDonough (2003), the release period of the stop series in Athabaskan was called the VOT.

4. Results

Sections 4.1 and 4.2 present results for the temporal profile of the stop phonemes and the spectral analysis of the release portion of the aspirated plain stops in the five languages from which the data for this study were collected. These data are furthermore compared to data from Navajo, taken from McDonough (2003).

4.1. The temporal profiles of stops

The median values and standard deviations for the closure and release periods in the plain stop and the affricate series were taken from the data from six languages: Dogrib, Dene Sųłiné CL, Dene Sųłiné FC, North Slavey, Tsilhqut'in, and for comparison, Navajo. The languages vary in whether or not the unaspirated stops are voiced; the orthography is not an indicator of voicing. We did not record a measure for voicing, thus no negative VOT appears in the data. We are choosing to report median values here, rather than average, because of the nature of the data in the study. We did not control for position in word or morpheme category (stem versus prefix) as the McDonough (2003) study did. Using wordlists constructed by the consultants resulted in uneven distributions of the segments in the languages across the study; the $n = 237$ for the release periods of unaspirated stops in North Slavey, to $n = 0$ for the closures of the unaspirated affricates in Dene Sųłiné FC (no closures were measured because all unaspirated stops were in word initial position). Also the North Slavey data was taken from three speakers, whereas the other four languages had either one or two speakers, whose tokens were used according to the measures discussed. Thus these values are indicative of general trends in the temporal profiles of the languages of the study, as a baseline description of the phenomena under discussion. The full sets of descriptive statistics, the Median, Standard Deviation, Interquartile range (IQR), Range and count, for the closure and duration periods of the contrasts in the stop series for each of the five languages in the study are listed in Appendix C. In t-tests, all pairwise comparisons between the stop phoneme groups in the data reached significance with p-values below 0.001.

A noticeable trend in the duration data split the stop phonemes into two groups across the languages, dividing the unaspirated plain stops from the rest of the stops in the inventories. The unaspirated plain stops, *b, d, g*, had short release periods that are about the size of the stop burst, befitting an unaspirated stop contrast. However, the rest of the phonemes in the stop series, plain and affricate, across the languages, had quite long release periods that are on average over around 100 ms.

Fig. 4 shows a bar graph of the distribution of the averages of the release durations of unaspirated, aspirated and ejective plain and affricated stops in ms. The six broad stop phoneme groups in the six Athabaskan languages (the five languages in this study plus Navajo) are: unaspirated plain stops (Un), aspirated plain stops (As), ejective plain stops (Ej), unaspirated affricates (unAF), aspirated affricates (aAF), and ejective affricates (eAF). (The lateral and regular affricates were conflated.)

The graph breaks the phonemes into three clusters, a main division between the unaspirated plain stops (Un) and the rest of the phonemes, and a secondary grouping found among the segments with longer releases, between two clusters whose members tend to be of a type. Note that the unaspirated plain stops comprise a clear cluster near the bottom of the chart. The mid cluster is defined as 'tends to be ejectives'; it contains the plain ejectives from all six languages and two of the six ejective affricates. Within this cluster other segments types are found: four unaspirated affricates, as well as two of the six aspirated plain stops. The second cluster contains the rest of the segments. It groups together the aspirated affricates from all six languages, as well as four of the ejective affricates and two of the six unaspirated affricates. It also contains four aspirated plain stops. The clusters demonstrate that the aspirated affricates (aAF) tend to be the longer than the plain ejectives (Ej) and the unaspirated affricates (uAF), though there is variation in the groups. The aspirated plain stops, *t* and *k*, however, show a large range of values and are spread out over the data. The unaspirated stops, and perhaps the plain ejectives, are the only groups that comprise clear categories.

For the unaspirated plain stops (Un), as with all the stops, the duration of the period between the release of the stop and the onset of voicing and vowel formants was measured. For these stops only, we call this period the VOT. This is done to distinguish it from the releases of the other stops; an issue, we will take up in Section 5.5. Table 2 summarizes the median VOT measures for the three unaspirated plain stops computed across the languages in the study.

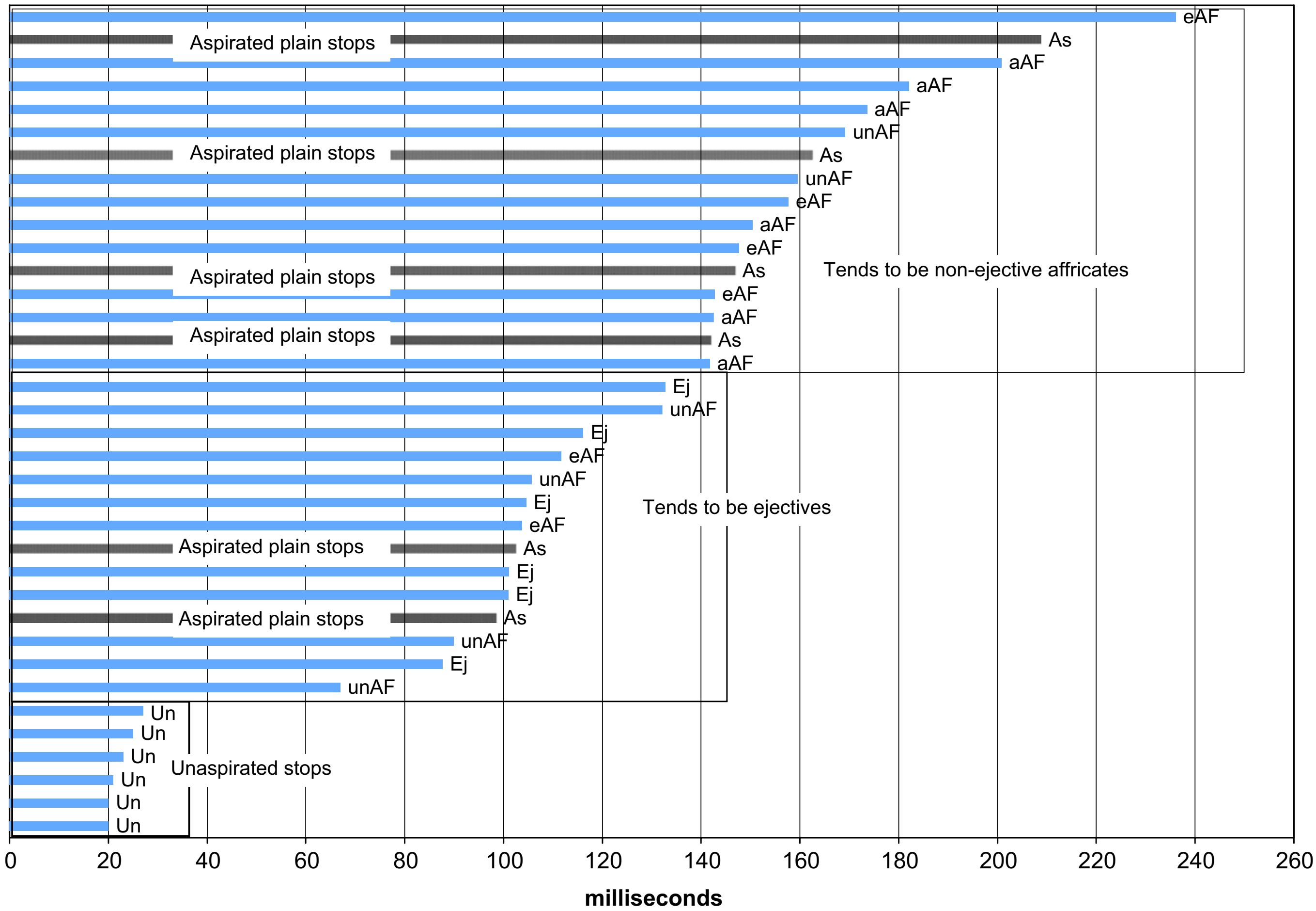

Fig. 4. Average distributions of the release periods of the stop manner contrasts in the study by language and phoneme type.

Table 2
The median release (VOT) values (in ms) for the three unaspirated stops (across the languages in the study)

Release period	*b*	*d*	*g*
Median	19.4	22.35	37.26
StDev	7.19	11.8	13.4
N	153	286	90

For the unaspirated stops, the release bursts of the three phonemes (*b, d, g*) follow the common cross-linguistic pattern (Keating, 1984) of having smaller-to-larger VOTs as place of articulation moves back in the vocal tract. The differences between the VOT values in pairwise *t*-tests were all significant, all below $p = .001$.

By compassion, for the rest of the stop phonemes, the release periods are considerably longer. They are generally above 100 ms in all but four cases: in Tsilhqut'in, the plain aspirated stops (*t k*) (92 ms), and ejectives (*t'*, *k'*) (80 ms), and the unaspirated affricates (81 ms), and in Navajo the unaspirated affricates (67 ms). In Tsilhqut'in however the segments on average were shorter. The ratio of closure to release in Tsilhqut'in does follow the general pattern of segments having release periods that make up a considerable portion of the duration of the consonant. The closure/release ratios of Tsilhqut'in unaspirated plain stops were 4.7, in contrast to aspirated plain stops, 0.71; plain ejective stops, 0.92; unaspirated affricates, 0.97. Keep in mind, however, that the data sets were uneven and the segments drawn from different positions in the word, though we did not use word final segments. However the trend still holds, the release portions of these stops are long compared to their overall duration.

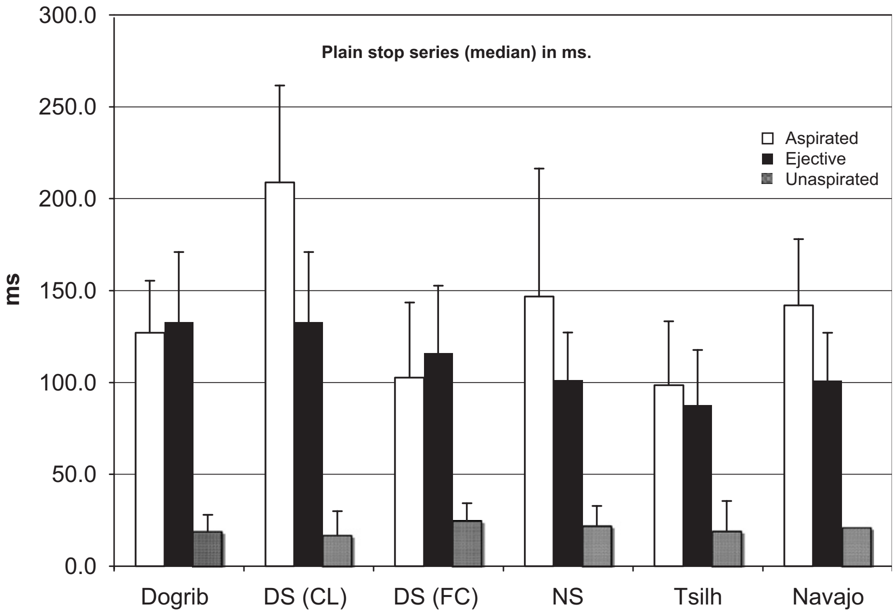

Fig. 5. A bar graph indicating the median durations in milliseconds of the release portions of the plain stop series in the languages in the study.

In Fig. 5 are the release periods of the unaspirated, aspirated and ejective plain stop contrasts for the data in the study demonstrating this release period pattern. The bar graph shows the mean durations in milliseconds of the release portions of these segments in the 6 languages. The whiskers indicate their standard deviations. Both the ejectives and aspirated stops are considerably longer than the unaspirated stops; in all but Tsilhqut'in, they are over 100 ms. Note also that the aspirated stops are longer than the ejectives in all but Dene Sųłiné FC, and all but the Tsilhqut'in ejectives are at 100 ms.

Fig. 6 is a bar graph of the mean durations of the aspirated plain stops and aspirated affricates versus the unaspirated stops in the languages in the study again demonstrating the tendency of the aspirated stops to pattern with affricates and against the unaspirated stops.

In two of the languages, Dene Sųłiné CL and North Slavey, the release periods of the aspirated plain stops (*t*, *k*) are actually longer on average than the aspirated affricates. In Dene Sųłiné CL, the mean release of the aspirated plain stop is over 200 ms. In Dogrib, Dene Sųłiné FC, Tsilhqut'in and Navajo, the mean durations of the aspirated stops are shorter than the aspirated affricates. In all cases, the lower edge of the average values for both affricates and aspirated plain stops is around 100 ms. Measures of significance indicate that all the groups were statistically distinct from each other, but no analysis of variance was possible because for we had no way of assessing a baseline comparison that we might hold for any of the speakers in the sessions.

4.2. The *t* and *k* phonemes

To provide a broad description of the acoustic properties of the release periods of the *t* and *k* phonemes, a moments analysis was performed, using the parameters of center of gravity and standard deviation as a measure of difference. The Moments analysis was performed on three 20 ms windows: the first window was taken from the beginning of the release (at 10 ms after release onset), the second window was taken towards the end of the release (40 ms before the release offset), and the third window was taken from the beginning of the vowel following the stop (20 ms after vowel onset). This was done to give a sense of any spectral changes that occur within the duration of the release. Despite the reported variation in the velar fricatives, which is greater than that of other fricatives, all the languages in this study exhibit clearly audible velar or velarized releases in the *t* and *k* phonemes. Examples of words with *t* and *k* phonemes are in the sound files that accompany this paper.

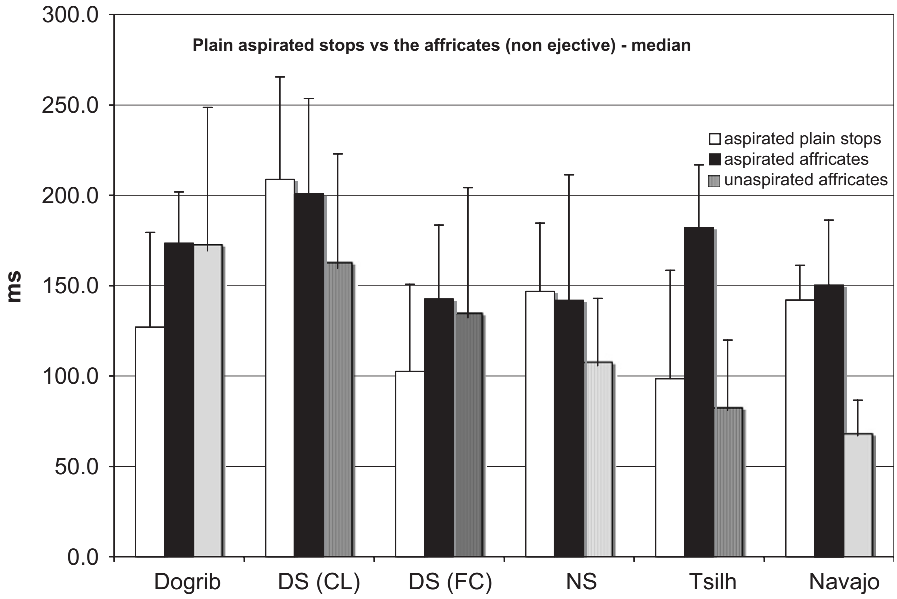

Fig. 6. A comparison of the median release periods of the aspirated plain stops and the aspirated and unaspirated affricates in six Athabaskan languages.

A posthoc analysis was performed on the data. For all the languages but Dene Sųłiné CL and Dene Sųłiné FC, the Center of Gravity as well as the Standard Deviations measure were significantly different between the languages ($p<0.001$). For Dene Sųłiné CL and Dene Sųłiné FC, there were no significant differences for either Center of Gravity or Standard Deviation. In Fig. 7 are the box and whisker plots for the Center of Gravity for the five languages in the study, indicating the mean, interquartile range, the range of the data, and the outliers (circles) at three measured points. The width of the box indicates the number of samples in the set. (North Slavey (3 speakers) has the largest data sets.)

Of the five languages, Dogrib had the most heavily fricated releases, as represented in the box plots. For Dogrib, the Center of Gravity at the first measured period (begin, 10 ms into the release) was 3821 Hz, with an upper reach of around 5800 Hz. For all the other languages the upper reach of the interquartile range was lower, at around 2 kHz, though they differed among themselves in the mean values and in their range. The Dogrib releases were also quite high (above 2 kHz) at the second measure (end, ending 40 ms before the end of the release). Also note the lowering of the mean and the shrinking of the IQR and range for all languages towards the end of the release period, and the contrast to the narrow IQR range in the following vowel. In Dene Sųłiné CL, the mean is actually lower at the end of the release than in the following vowel. But for all the languages, the release periods have a higher Center of Gravity and a more energy in the higher spectrum at the beginning of the release than at the end. And all have more diffuse energy in the spectrum of the release than in the vowels.

The patterns in the *k*-phoneme release were significantly different from the *t* phoneme, especially for the Dogrib data. Note that difference in the mean and IQR range for the beginning period in the release of the *t* versus *k* phoneme in Dogrib, the *k* release is as low as the *t* releases of Dene Sųłiné CL and Dene Sųłiné FC in the first measure of their releases. For Dene Sųłiné FC, the mean at the beginning of the *k* phoneme was higher by about 800 Hz than the for the *t* phoneme (1252 versus 2081 Hz). For Tsilhqut'in, the values for *t* and *k* were similar, a difference of a little over 100 Hz. For the other three languages in the study, the values were lower for the *k* release. The lower values indicate a more approximant-type release than higher values, i.e. they may be understood to signify the existence of formant structure in the release period. For all of the languages in the study there was a positive correlation between the Center of Gravity and the Standard Deviation, indicating that the higher the Center of Gravity the more diffuse the energy in the spectrum, which is what we might expect in fricative spectrum.

As a point of comparison, the Center of Gravity for the Navajo velar fricatives before high vowels in McDonough (2003) was determined to be around 2779–3429 Hz, and around 385 Hz for the very

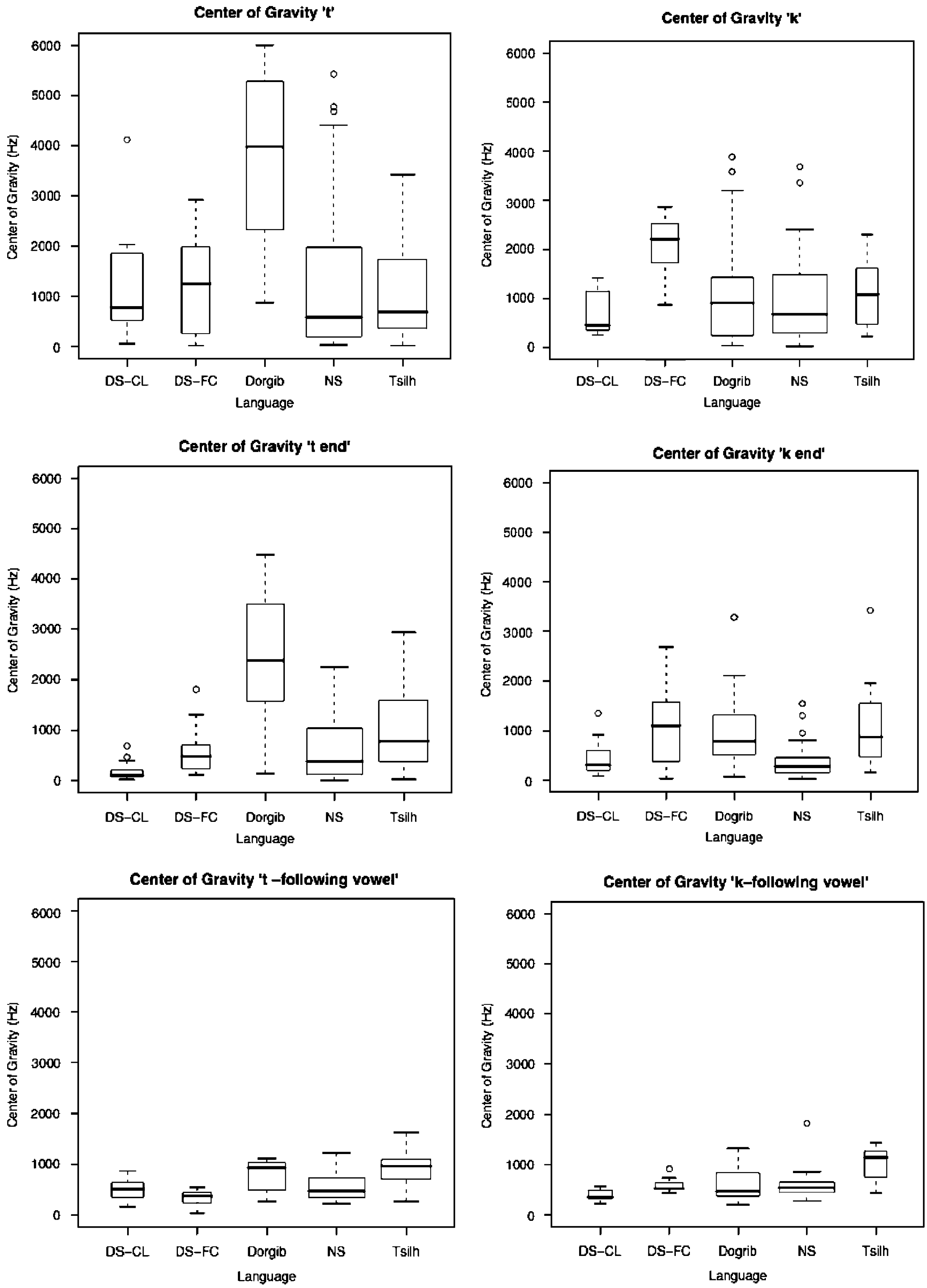

Fig. 7. Box and whisker plots for Center of Gravity for the release periods of the t and k-phonemes for 20 ms windows, from top to bottom: 10 ms into the release, 40 ms from the end of the release, and 20 ms into the following vowel.

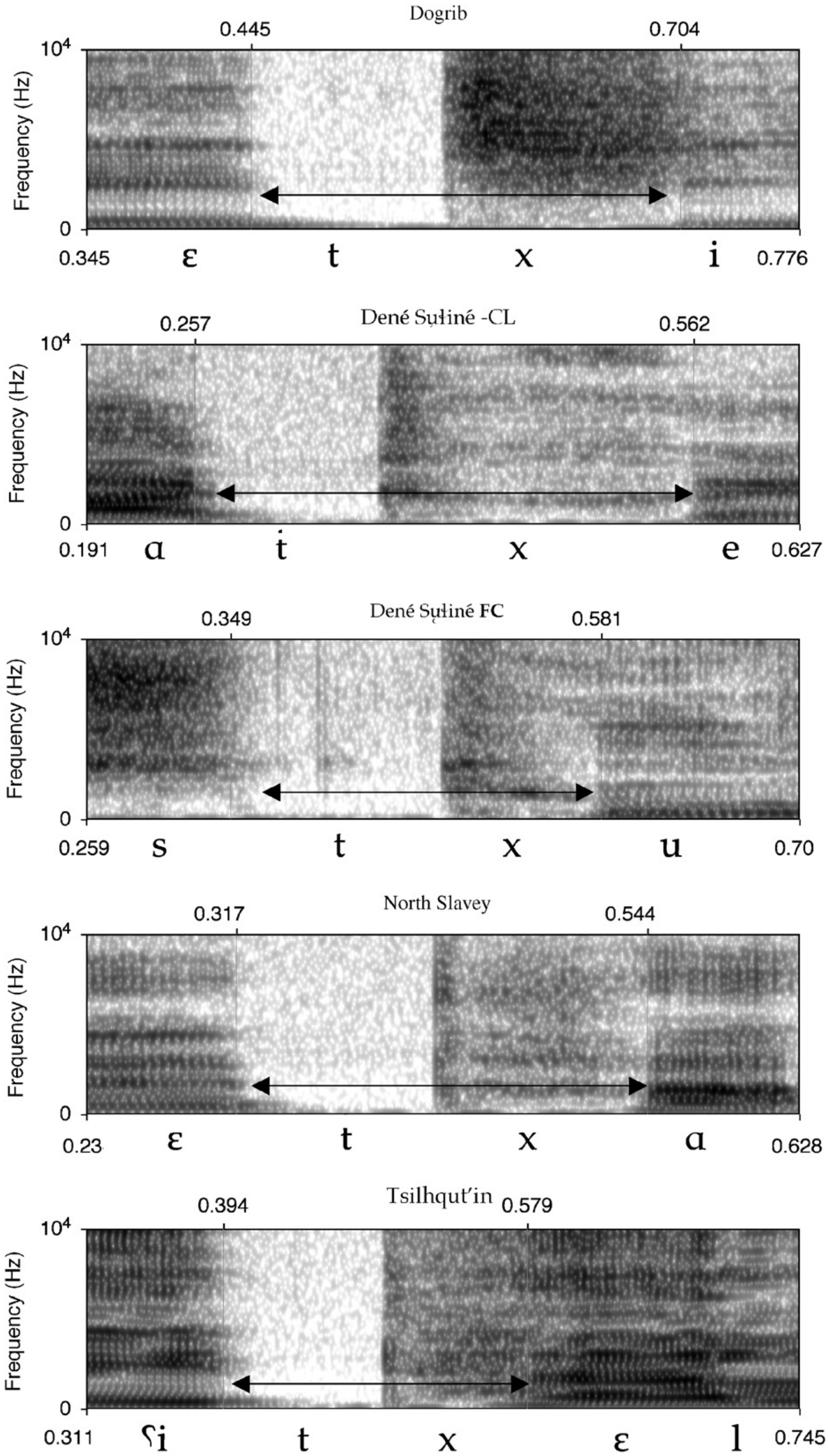

Fig. 8. Spectrograms of tokens of the plain stop *t* [tx] in five languages.

approximant-like realization of the velar fricatives before the round and low vowels. In Navajo, a very strong audible coarticulatory effect was present in all the instances of velar fricatives, supported by a follow up ultrasound study (McDonough, Iskarous & Whalen, ms). The more approximant-like velar fricatives in Navajo had formant structure, though energy was present throughout the spectrum. The study found no difference between the releases of the phonemes t/tx/ and k /kx/ and the velar fricatives. That study was done with data from 14 speakers, using the same word list throughout. We cannot approach a similar consistency with the data in this study. However, an overarching pattern can be observed in the present data that is analogous to the Navajo data.

The spectrograms in Fig. 8 are tokens of the *t* phoneme from the five languages in the study demonstrating the pattern and variation in the releases: Dogrib *dètì* [dɛ̀txì] 'it is expensive'; Dene Sų̨łiné, CL *náte* [nátxɛ] 'he is dreaming'; Dene Sų̨łiné, FC *destur* [dɛstxuɹ] 'I mix it'; North Slavey *setá* [sɛtxá] 'father'; Tsilhqut'in *qitél* [qˤitxɛ́l] 'socks'. For all these tokens, there was a clear audible velar release to the *t* phoneme.

The most strongly fricated releases are found in Dogrib *t* phoneme, as indicted in the comparatively high Center of Gravity (3821 Hz) and Standard Deviation (2518 Hz). These values are comparable to the Navajo fricatives before high vowels. This frication is visible in the *t* phoneme in the spectrogram in Fig. 8 of the Dogrib token *dètì* [dɛ̀txì] 'it's expensive', which shows a closure followed by a velar fricative that makes up around half the duration of the segment, a clear example of a heterorganic affricate. This sound has been classified as an aspirated plain stop in the orthography and phonemic system. In the spectrogram for Tsilhqut'in *qitél* [qˤitxɛ́l] 'socks', the frication of the initial uvular fricative (which causes pharyngealization on the following vowel) and the frication present in the release of the *t* phoneme are comparable. In Dene Sų̨łiné CL, Dene Sų̨łiné FC and North Slavey, formant structure is present during the release period, though there is still energy throughout the spectrum and up into the higher frequencies. In the Navajo data, the most constricted velar fricatives, transcribed as palatal fricatives, were found before the high front vowel, the round and back vowels were less fricated. This does not seem to be the case in the Dene Sų̨łiné languages which show the presence of formant structure in the release periods to the *t* phoneme before the high back and mid front vowels.

5. Discussion

5.1. The temporal profile of the stops

Although the literature on the Athabaskan languages consistently reports a three-way laryngeal contrast among the stops, the pattern we are finding in the Athabaskan languages does not fit neatly into the VOT pattern usually associated with laryngeal contrasts. First, a VOT or release burst division in the data in this study separates unaspirated plain stops from the rest of the stops in the series. It only incidentally acts as a contrast between unaspirated and aspirated stops. In the light of recent reports on VOT contrasts, which have considered data from the Athabaskan languages (Cho & Ladefoged, 1999), the data in this study contradict the norm. In their study of the VOT parameter, Cho and Ladefoged consider data from several languages not included in the original VOT studies of Lisker and Abramson (1964), several Na-Dene languages among them. They classify the Navajo and Tlingit aspirated stops as outliers because of the length of their release periods. Two other Athabaskan languages in the study, Hupa and Western Apache, showed VOT values more in keeping with common VOT distinctions. In this study, we have demonstrated that long releases are characteristic of the family in general. Long releases occur in all but the unaspirated stops. We have also shown that VOT or, as we prefer, the release period alone is not a good measure of distinction among the stop contrasts, other than to separate out the unaspirated stops. It is a poor predictor of aspirated plain stops, which show a wide range of release values.

We suggest a different classification. We propose that the Athabaskan stops are divided into two groups: simplex or complex. This distinction represents a basic division in the inventory, one that has an effect in the phonology and in the phonetics. We will take up the role of this distinction in the discussion of the Athabaskan ejectives in Section 5.3. As discussed above in Section 1, this distinction is realized in the temporal profile of the stops, which is reflective of a timing organization among the articulators during the production of the segment. The unaspirated plain stops are simplex segments. Their release bursts, or any other VOT distinctions they may have, are part of the offset and transition into the following vowel. In this view, these are not unaspirated per se but simplex stops. The rest of the stops in the series are complex segments, including the *t* and *k* phonemes, the plain ejectives *t′* and *k′*, and the affricates. We will take up discussions of thee segments separately in the next sections, and then return to a brief discussion of the status of the unaspirated stop as a simplex stop.

5.2. The Athabaskan plain 'aspirated stops' as affricates

In the descriptions of many Athabaskan languages, the aspirated plain stops, *t* and *k* phonemes, are often depicted as having strong or heavy aspiration or spirantization, with stricture which has been described as velar or velarized (Morice (1932) on Carrier (Dakelh)); Hoijer (1938, 1946) on Chiracahua Apache; Sapir and Hoijer (1967), Young and Morgan (1980, 1987), McDonough and Ladefoged (1993), McDonough (2003) on Navajo; Rice (1989) on five Slave dialects; Holton (2001) on Tanacross (Alaskan); Goddard (1912), Li (1933, 1946), Haas (1968) on Chipewyan (Dene Sųłiné); Haas (1968), Tuttle and Sandoval (2002) on Jicarilla Apache). Hoijer on Chiracahua Apache writes, "…t and k are unvoiced fortes and are always followed by a heavy spirantal aspiration similar to the [velar] consonant x." (1946, p. 58). Li (1946) on Chipewyan states, "Aspirated stops are strongly aspirated with a guttural spirantal glide" (1946, p. 398). Holton's (2001) study of the Alaskan Athabaskan language of Tanacross states, "…the pulmonic velar stops are essentially affricates, i.e., [k^x] and [$g^ɣ$]" (2001, p. 29). Young and Morgan, who classify the *t* phoneme as an affricate /tx/ and not a aspirate, write the *t* is "a strongly aspirated phoneme produced by placing the tip of the tongue in a t position, followed by raising the back of the tongue to a point of near contact with the velum…" (1987, p. xv). Haas (1968) writes that the t and k phonemes are "phonetically t^x and k^x" (1968, p. 165). Both Goddard (1912) and Haas (1968) have pointed out that the sound change of t > k in Apache is a natural one—the change is actually from [tx] to [kx].

The evidence from the study of the five languages in this paper concurs with these observations. The Center of Gravity and Standard Deviation values indicate a dispersion of energy in the high regions of the spectrum compatible with constriction in the back of the vocal tract. The variation in the values in the data and examination of the spectrograms, especially in comparison to the Navajo data, indicate some coarticulation with the following vowel is occurring during the release. Only in the Dogrib did the speaker maintain robust frication throughout the duration of the release.

A small study was done of the aspiration in English *p* and *t* phonemes from a database at the University of Rochester as a point of comparison to the release periods of the Athabaskan stops. The data came from one male speaker. The words were segmented and a similar Moments analysis was done over the VOT of the initial stop in 11 words. The words were monosyllables, the average duration of the VOT was about 50 ms. The average Center of Gravity was 85.4 Hz, with an average Standard Deviation of 294.4. These figures are even lower than those of the vowels, indicating an absence of energy in the spectrum, especially striking in comparison to the releases of the *t* and *k* phonemes in the Athabaskan languages. It is clear that the release portions of the Athabaskan sounds are not aspirated in the English sense. They have affricate-like properties, arguably involving supralaryngeal constriction. Based on this observation, we side with Hoijer (1938), Holton (2001), Young and Morgan (1987), Golla (p.c.) and others, who consider the *t* and *k* phonemes to be affricates. In system adopted here, they are also complex segments. We differ from Tuttle and Sandoval (2002), McDonough (2003), Rice (1989), and Hargus (2007) who assign them the status of aspirated stops in the inventory. The *t* and *k* phonemes are phonemic as well as phonetic heterorganic affricates /tx/ and /kx/.

However, it may not be the case that *t* and *k* phonemes are affricates in every Athabaskan language. Gordon et al. (2001) on Western Apache and Gordon (1996) on Hupa do not report these values. de Ruese and Goode (2006, p. 8) writes that the *t* phoneme in San Carlos Apache is like "English *t* in *too, tap*". However, insofar as the data in this study is representative of an inherent Athabaskan pattern, the production of the Athabaskan *t* and *k* phonemes as English-type aspirated stops is not a trivial difference. An aspirated plain stop is not a phoneme in the Athabaskan inventory, we will take this up in Sections 5.6. The production of an Athabaskan phoneme *t* as an aspirated stop, then, may well represent a shift away from an Athabaskan type system towards an English type system. Such a change may be due to a reduced speech community and/or contact with English speaking populations and educational practices.

5.3. Ejectives

The ejectives in the Athabaskan languages have caused considerable interest among the linguists who have been exposed to them (Bird, 2002; Gordon, 2001; Gordon & Ladefoged, 2001; Gordon et al., 2001; Hogan, 1976; Lindau, 1984; McDonough, 2003; McDonough & Ladefoged, 1993; Tuttle & Sandoval, 2002; Wright et al., 2002). Lindau (1984) first noted a difference between the Navajo ejectives and those found in the Bantu languages. She observed that there was a considerably longer period between the oral and glottal release in the Navajo ejectives compared to their counterparts in Bantu.

The difference between the two ejective types seems to be mainly realized in the temporal profile of the release portion of these segments. Lindau's observation about the ejective types is in our view a contrast between a simplex and a complex realization of the segment. The 'regular' or Bantu type ejectives are simplex segments in which the release occurs as part of the offset portion of the segment since the glottal release follows closely after the oral release. The Athabaskan type ejectives, on the other hand, are complex segments in which the medial phase contains a the closure period and a fricative release.

Earlier instrumental work on Athabaskan ejectives by Hogan (1976) on Chipewyan (Dene Sųłiné CL). Noted that the Dene Sųłiné CL ejectives had a 'period of silence' during the release period. This is visible in the spectrogram in Fig. 9 (a pattern was also discernable in the kymographs that were made by Goddard (1912) in the same Cold Lake community in the early 20th century). Table 3 is a comparison between the average release periods of ejectives in Dene Sųłiné CL of the Hogan (1976) study, and the data from the present study. Both studies collected data from a single speaker.

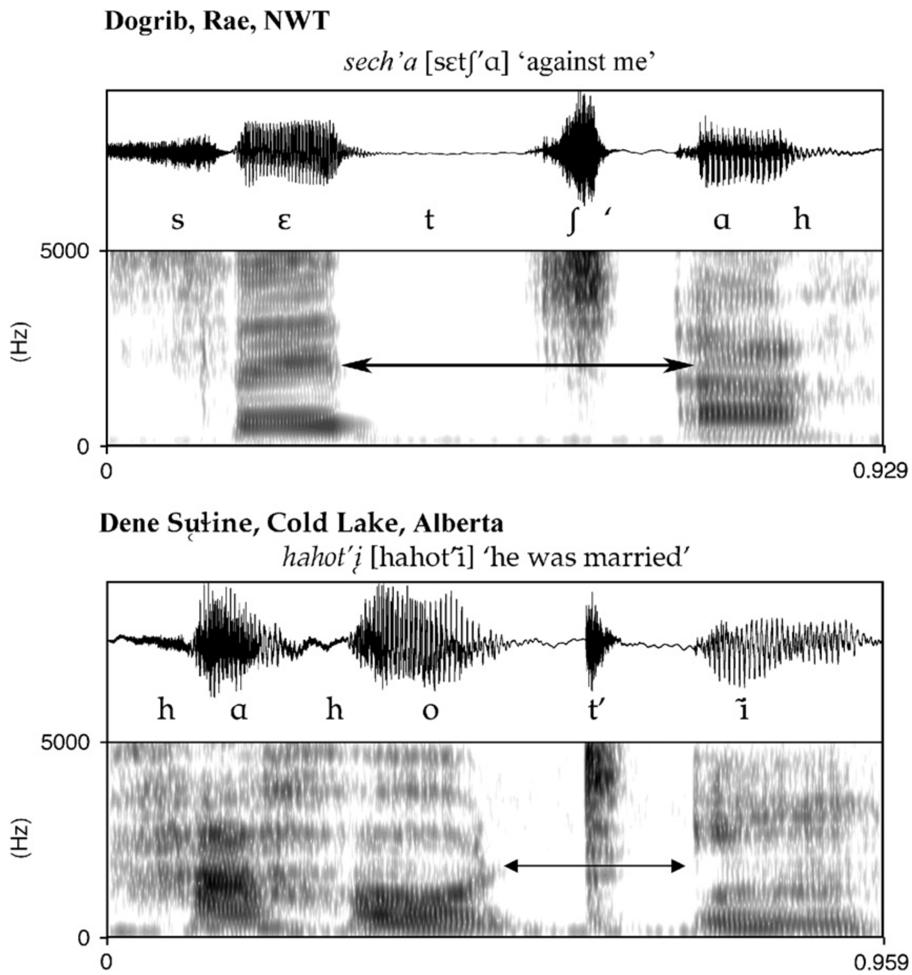

Fig. 9. Plain and affricate ejectives in Dogrib and Dene Sųłiné demonstrating the 'period of silence' in their production. The arrow indicates the duration of the ejective.

Table 3
The average release durations for the ejectives in Dene Sųłiné, Cold Lake from the Hogan (1975) and the present study

Ejectives	Duration (ms)	Range (ms)
Hogan (1976)		
Plain	114.2	86.3–147.3
Affricates	166.6	151.5–203.5
Present study		
Plain	132.7	55–162
Affricated	236	135–314

The difference between the two sets of figures may be a reflection of speaking rate differences. But the data show the same pattern of long releases on the ejectives in the same community studies 30 years apart. In the simplex–complex view, the temporal profile of these ejectives is not an incidental aspect of their production. In the view that ejectives are complex segments, the closure and release periods, part of the medial phase of the segment's articulation, have a distinctive temporal profile leading to a relatively long 'period of silence' between oral and glottal release. This production strategy has an audible effect and these ejectives are often called 'strong'.

The spectrograms in Fig. 9 demonstrate both plain and affricated ejectives. Since the 'strong' ejectives have been identified with the Athabaskan languages, we will call these strong ejectives the 'classic' Athabaskan ejective, although similar patterns in the production of ejectives have also been reported for Kabardian (Gordon & Applebaum, 2006) and Tlingit (Maddieson, Smith, & Bessell, 2001).

5.4. Strong and weak ejectives

Several of the reports on the production of ejectives in Athabaskan languages have noted significant variation in their production. A production and perception study of ejectives in Witsuwit'in (Babine) (Northern Athabaskan, British Columbia) by Wright et al. (2002) investigated this variation.

The Wright et al. study was based on the observation that, for some Witsuwit'in speakers, the ejective plain stops (the phoneme *t′*) were not easily distinguishable from the unaspirated plain stops (the phoneme *d*). The study measured several variables in the production of the ejective plain stops, including VOT, and F0 perturbation, jitter and rise time in the vowel following the ejective; factors that have been associated with a 'slack' versus 'stiff' distinction in ejective types (Kingston, 1990).

Wright et al. found two kinds of ejectives in the data, strong ejectives with longish releases that contained a 'period of silence', and weak ones that were indistinguishable from the unaspirated stop *d* in the series. Their perception study demonstrated that the weak ejectives were sometimes hard to tell from the unaspirated plain stops for native speakers. Although they attempted to model the ejective variation along the lines of the 'slack' versus 'stiff' classification, they found no consistent correlates of Kingston's measures in their data.

Bird (2002) also proposed the existence of two types of ejectives, which she also called strong and weak. Her study on ejectives in the northern Athabaskan language Dakelh (Carrier) (also from central interior British Columbia) found that the strong ejectives were characterized by long release periods; weak ones had no period of silence between the oral burst and the glottal release. Additionally, she notes, as in Witstwit'in, the weak ones are 'perceptually difficult to distinguish from unaspirated stops'. Her data is split along slightly different lines than the Witsuwit'in data. In her data the plain *t′* and *k′* ejectives are weak ejectives, whereas the affricate ejectives are strong. She found a significant difference between the two groups in the duration of their releases; the plain ejectives *t′* and *k′* patterned with the unaspirated stops. In Witsuwit'in, by contrast, the variation occurred within the phoneme type. However, in both languages, the feature of contrast is identifiably in the temporal profile of the ejective in question.

In the phonetic model proposed in this paper, the strong–weak distinction is a distinction between a simplex and complex realization of the ejective phoneme. In strong or complex ejectives, both the closure and oral release are part of the medial phase of the articulation of the segment, the glottal release marks the offset. These are the classic Athabaskan ejectives. In the weak or simplex ejectives, the medial phase contains only the

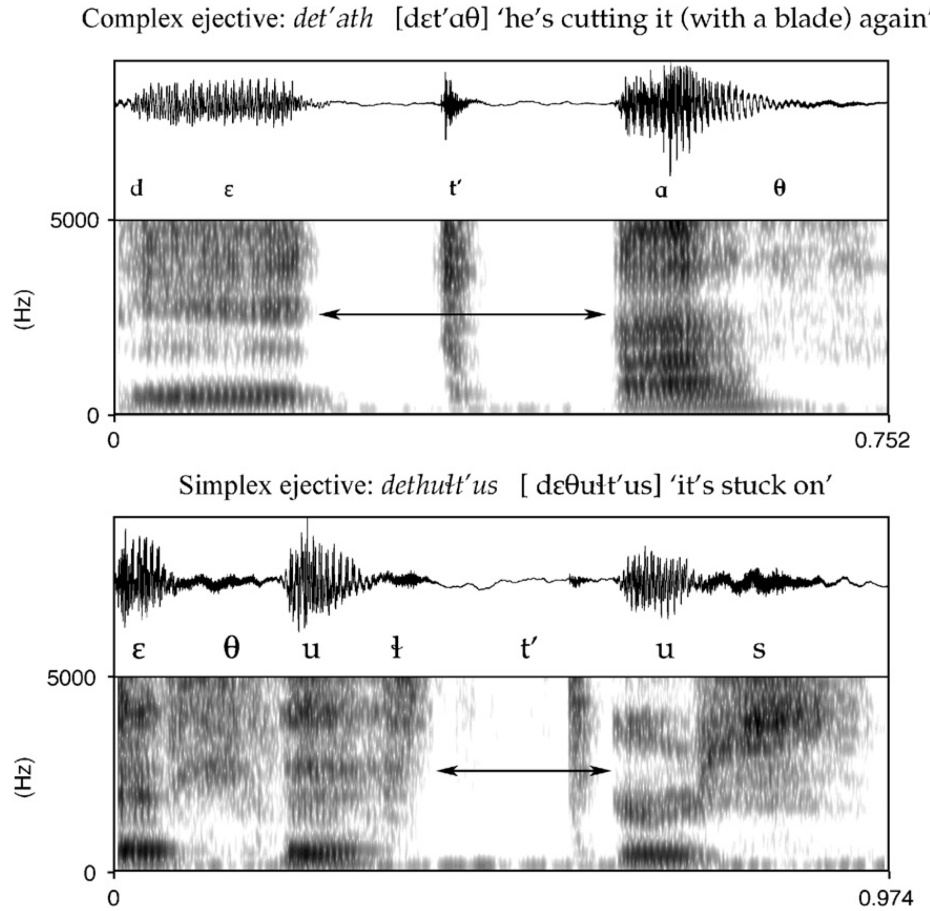

Fig. 10. Two types of plain ejective stops: complex (strong) *det′ath* [dɛt′ɑθ] 'he's cutting it (with a blade) again', and simplex (weak) *dethuɬt′us* [dɛθuɬt′us] 'it's stuck on', one speaker Dene Sųłiné FC.

closure period; the period between the oral and the glottal releases are part of the offset portion of the segment. In Athabaskan, the only other simplex stop is the *d* phoneme, an unaspirated plain stop. In fact—just as reported by Wright et al. for Witsuwit'in—the simplex or weak ejectives are often confused with the *d* phonemes. We suggest that in Witsuwit'en the ejectives may conflate the distinction between unaspirated and ejective segments by switching categories from complex to simplex segments. That is to say, the distinction between simplex and complex governs the allomorphy among the ejectives.

Although the current study was not set up to examine the variation among the ejectives, variation among and within speakers was in evidence in the data, such as they found in Witsuwit'in. We found a considerable range of values for ejective releases in the plain ejective stops *t′* and *k′*, ranging from 27 to 178 ms in Dogrib; 25 to 300 ms in Dene Sųłiné CL; 51 to 252 ms in Dene Sųłiné FC; 52 to 174 ms in North Slavey and 45 to 166 ms in Tsilhqut'in. The plain ejectives in this study tended to be complex or strong ejectives; as noted in Fig. 4, the average duration of the releases were in the higher range. Clear tokens of simplex and complex ejectives are demonstrated in the spectrograms in Fig. 10. These are examples of a strong and a weak ejective *t′* from the male speaker of Dene Sųłiné FC. The strong ejective in *det′ath* [dɛt′ɑθ] 'he is cutting it' has a duration of 308 ms and the release period is 172 ms. The weak ejective in the word *detheɬt′us* [dɛθɬɛt′us] 'it is stuck on' has a duration of 228 ms and the release portion is 51 ms.

In summary, the ejectives across Athabaskan appear to fall into two categories, strong ejectives, which are complex segments with closure and releases that occur during the main phase of their production[4] and simplex

[4]Catford (1977) discusses the two sets of contrastive lateral affricate pairs (plain and ejective) in the Caucasian languages of Avar and Akhwakh, transcribed as *tɬ, tɬ′* and *tɬɬ, tɬɬ′*. Catford characterizes them as strong and weak versions of each other, attributing the difference between the pairs as determined solely by the temporal properties of their release periods (1977:214).

Table 4
The revised Athabaskan inventory

	Bi-labial	Alveolar	Alveo-palatal	Velar	Labiovelar	Glottal
Simplex stops	p	t		k		ʕ
Affricates		tx		kx	kw	
		ts ts^h	tʃ $tʃ^h$			
		tɬ $tɬ^h$				
Ejectives		t′		k′		
		ts′	tʃ′			
Fricatives		s z	ʃ ʒ	ɣ x		(h)

ones in which the medial phase ends at the oral closure. Complex ejectives are of the classic Athabaskan type, containing a characteristic period of silence after the oral and before the glottal release. In the simplex 'regular' or weak ejectives, the medial phase contains the closure period only. The period between oral and glottal release forms the offset portion of the segment. These segments have been shown—through studies and through reports on the sounds of these languages—to be hard to distinguish from the unaspirated consonants in several Athabaskan languages. We suggest this is an alternation pattern governed by the simplex–complex distinction. In the view adopted in this paper, the existence of these two types of ejectives is an expression of a basic simplex–complex division in the sound inventory.

5.5. The simplex stops

We are reclassifying unaspirated plains stop, the phonemes *b, d, g*, as simplex segments, and not as unaspirated stops. There are two reasons to reconsider their classification. First, the reports on several Athabaskan languages observe that the unaspirated stops are voiced. The distinction between voicing and unaspiration is a laryngeal distinction: the onset of vocal fold vibration occurs either close to the release (unaspirated) or it occurs during the closure (voiced); they cannot be both. The observation, then, is that in some Athabaskan languages the simplex stops are unaspirated, and in some they are voiced, i.e. the laryngeal distinction between voicing and unaspiration does not affect the contrast of these segments with the complex segments. As simplex segments, the contrast with complex segments is in the temporal domain, and not in the laryngeal one. Characterizing the distinction between the *d* and the *t* phonemes as laryngeal (unaspirated–aspirated) is inaccurate.

Second, we are suggesting that these languages exploit the stop and fricative contrasts to produce affricates (see Table 4). In Athabaskan languages with voiced simplex stops, we would expect all the affricates to have voiced closures, since the simplex versions of those stops are voiced. Although we did not measure voicing during stop closures as part of this study, we believe that there is a significant difference between voiced and unaspirated languages in the laryngeal properties of the stop closures. Fig. 11 shows the waveforms of contrasting unaspirated and aspirated affricates from Navajo and Dene Sųłiné CL. These languages differ in the laryngeal values of the simplex stops. Navajo stops are not voiced, the Dene Sųłiné CL stops are. The top waveform in each pair is unaspirated. Some evidence of voicing during the closure is present in the Dene Sųłiné CL examples, in both the aspirated and unaspirated versions, but much less voicing is present in the Navajo pair. Note that in both languages the distinction between the two affricates is in the length of their releases (see also Fig. 4 in Section 3).

5.6. Summary: Athabaskan phonemes

The analysis discussed in this paper breaks up the conventional symmetry of the phonemic inventory of the Athabaskan languages represented in the inventories in the Appendix. Instead of a simple three-way laryngeal contrast among stops and affricates, aspirated, unaspirated and ejective, the temporal profile of the segments in the data in this study suggests a different, less obviously neat, phonemic system. The inventory is divided into two basic groups: simplex and complex segments. The unaspirated stops are simplex stops, and crucially

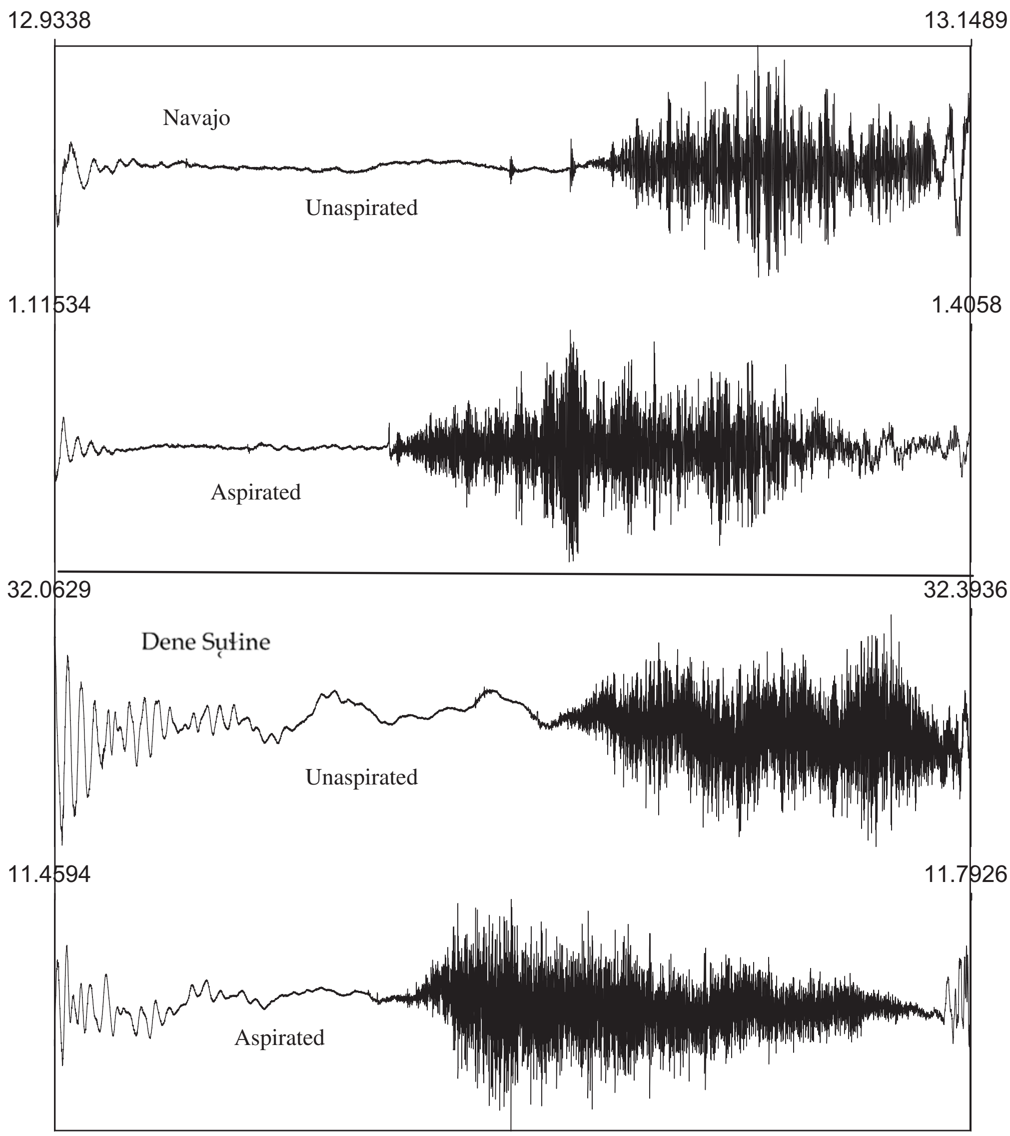

Fig. 11. Waveforms of the unaspirated and aspirated pairs of affricates in Dene Sųłiné CL (voiced) and Navajo (voiceless).

not unaspirated per se. The rest of the stop series, including the aspirated and ejective plain stops, are complex segments. Table 4 is a sample Athabaskan inventory as we see it.

We suggest that this is likely a more accurate representation of the phonemic contrasts in the Athabaskan languages. In this inventory, there are no aspirated plain stops. The phonemic system exploits the fricative and stop contrasts to build the complex segments, which are primarily found in stems. Ejectives are also complex, though this is apparently a more fragile contrast pattern and may vary within and across the Athabaskan languages, especially among the plain ejectives.

The homorganic coronal affricates [ts, ts^h, tʃ, $tʃ^h$, tl, $tɬ^h$] are the only stops to have the laryngeal contrasts aspirated and unaspirated. Under the classification of the affricates as complex segments, this contrast appears in the offset of the medial phase, at the release of the fricated part of the articulation as a transition into the vowel. It is an audible quality of these sounds.

There is variation among the Athabaskan languages in how this basic inventory is constructed, but the changes are not systemic. In Dakelh (Bird, 2002), for instance, the plain ejectives appear to be simplex segments. The simplex stops may vary from language to language in their VOT specification or their phonation type. In the Athabaskan languages with voiced simplex segments, the affricates have voicing during their closures, in both the aspirated and unaspirated versions. As noted, there is evidence in our data that this is the case, though a more detailed study of this phenomenon is needed. A more careful study of the articulation of Athabaskan back fricatives is also warranted, especially with respect to the pattern of heterorganic affricates with velar releases.

There are several other factors that come into play in this analysis. This view predicts that Athabaskan languages will exploit the series of simplex sounds to produce the complex ones. In Tsilhqut'in, in addition to the usual sets of Athabaskan stops and affricates, there is a set of uvular fricatives and stops, but no uvular affricates. There is, however, an additional set of alveolar affricates that are pharyngealized; these, with the pharyngeal stops and fricatives, cause a 'flattening' effect on the following vowel (Cook, 1993; Hansson, 2000), filling the missing gap. Tsilhqut'in also contains, by reports, an unaspirated and aspirated *p* phoneme (no instances of an aspirated *p* occurred in our data.) Given the tendencies in these languages, we might expect this aspirated *p* to show properties of the other aspirated plain segments, i.e. we might expect it to appear as a complex segment, perhaps another heterorganic affricate.

Another aspect of this distinction is found in the contrast between stem versus prefix phonotactics. McDonough (1990, 2003) has observed that in Navajo, the phonemic contrasts in prefixes are severely neutralized. The stem morpheme, the final syllable in the morphologically complex verb, is the only position where the full set of phonemes occurs.[5] We observed that the phonotactic distinction between stems and prefixes falls along the simplex–complex line; complex segments only occur in stem initial position in Navajo, the prefixes consonants are simplex. We suggest that other Athabaskan languages also may exhibit this pattern. In general, however, phonotactic patterns in the Athabaskan languages have not been well studied, due in large part to the level of documentation needed to make phonotactic generalizations.

Given the persistence of these patterns in the present day Athabaskan languages, we suggest that the patterns discussed in this paper are inherited from the parent language and have been maintained over time, because, as we have argued, the distinction between simplex and complex is a primary distinction in the sound system and is the foundation for the organization of the phonemic contrasts.

6. Conclusion

In conclusion, we define the simplex–complex distinction as a temporal organization pattern involving the timing of articulators with respect to each other framed within the articulation of a consonantal segment. We suggest that the simplex–complex distinction may be an active principle in the development of contrast sets. We have demonstrated the viability of such a contrast in understanding the phonemic systems of the Athabaskan languages and the persistence of certain kinds of phonetic realization patterns across the family. The contrast is not confined to Athabaskan. The existence of a simplex–complex distinction in affricates and ejective fricatives is indicated in reports on other languages, such as Tlingit (Na-Dene) (Maddieson et al., 2001) and Kabardian (Catford, 1977; Causcasian, Gordon, & Applebaum, 2006).

Further studies are needed, with materials set up to examine specific issues, and including more speakers if possible. A study of stop voicing in the Athabaskan languages is in order. A cross-Athabaskan study of the fricatives, especially the velar and uvular fricatives and affricates, is called for.

A final and vital point concerns the value of the instrumental phonetic documentation of endangered and underdocumented languages. Without it, we are dependent on orthography, especially as these communities lose fluent speakers or lack adequate documentation. The sound systems of these languages have internal integrity, and beg to be investigated as integrated systems. Moving away from orthographic based analyses is absolutely essential to investigating the internal coherence of sounds systems in these languages. Baseline phonetic documentation of these languages, which are almost entirely oral cultures, is a necessary and crucial aspect of language documentation, and likely to be beneficial to both linguistics and the members of the communities.

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[5]Stems also occur as incorporated elements in Athabaskan, in productive (Axelrod, 1990) or residual incorporation (Position Ib in Young and Morgan's Navajo template, Young & Morgan, 1987). Also in Navajo, the 3rd person marker has a complex reflex *ji-*.

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Appendix A. Supplementary Materials

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.wocn.2007.11.001.

References

Axelrod, M. (1990). Incorporation in Koyukon Athapaskan. *International Journal of American Linguistics*, *56*(2), 179–195.

Bird, S. (2002). Dakelh ejectives: Evidence for new ways of classifying sounds. Paper presented at the 76th meeting of the Linguistic Society of America, San Francisco, CA.

Boersma P., & Weenink, D. (2007). Praat: Doing phonetics by computer (Version 4.3.14) [Computer program]. Retrieved June 2007, from 〈http://www.praat.org/〉.

Catford, J. C. (1977). *Fundamental problems in phonetics*. Bloomington: Indiana University Press.

Cho, T., & Ladefoged, P. (1999). Variation and universals in VOT: Evidence from 18 Languages. *Journal of Phonetics*, *27*(2 April), 207–229.

Cook, E.-D. (1983). Chilcotin flattening. *The Canadian Journal of Linguistics/La Revue Canadienne de Linguistique*, *28*(2), 123–132.

Cook, E.-D. (1984). *A Sarcee grammar*. Vancouver: University of British Columbia Press.

Cook, E.-D. (1989). Chilcotin tone and verb paradigms. In K. Rice (Ed.), *Athabaksan linguistics: Current perspectives on a language family* (pp. 145–198). Mouton.

Cook, E.-D. (1993). Chilcotin flattening and autosegmental phonology. *Lingua*, *91*(2–3 Nov), 149–174.

de Ruese, W., & Goode, P. (2006). *A practical grammar of the San Carlos Apache language.* LINCOM Studies in Native American Linguistics.

Dogrib Divisional Board of Education. (1996). Tłı̨́chǫ́ Yatí Enįhtł'é: A Dogrib Dictionary. Rae-Edzo: Dogrib Divisional Board of Education. Available in a revised and expanded form at 〈http://tlicho.ling.uvic.ca/〉.

Goddard, P. (1907). *The phonology of the Hupa language*. Berkeley: University of California Press.

Goddard, P. E. (1912). *Texts and analysis of Cold Lake dialect, Chipewyan*. New York: The Trustees.

Goddard, P. E. (1929). *The Bear Lake dialect of athapasca*. Berkeley: University of California Press.

Golla, V. (1970). *Hupa grammar*. Berkeley: University of California Press.

Gordon, M. (1996). The phonetic structures of Hupa (pp. 164–187). University of California Working Papers in Phonetics, 1996, 93, December.

Gordon, M. (2001). Linguistic aspects of voice quality with special reference to Athabaskan. *Athabaskan languages conference.*

Gordon, M., & Applebaum, A. (2006). Phonetic structures of Turkish Kabardian. *Journal of the International Phonetic Association*, *36*(2), 159–186.

Gordon, M., & Ladefoged, P. (2001). Phonation types: A cross-linguistic overview. *Journal of Phonetics*, *29*(4), 383–406.

Gordon, M., Potter, B., Dawson, J., De Reuse, W., & Ladefoged, P. (2001). Phonetic structures of Western Apache. *International Journal of American Linguistics*, *67*(4), 415–448.

Haas, M. (1968). Notes on a Chipewyan dialect. *International Journal of American Linguistics*, *34*(3), 165–175.

Hansson, G. O. (2000). Chilcotin vowel flattening and sibilant harmony: Diachronic cues to a synchronic puzzle. *Athabaskan language conference*. Moricetown, British Columbia.

Hargus, S. (1991). The disjunct boundary in Babine-Witsu Wit'en. *International Journal of American Linguistics*, *57*(4), 487–513.

Hargus, S. (2007). *Witsuwit'en Grammar: Phonetics, phonology, morphology*. University of British Columbia Press.

Hogan, J. T. (1976). An analysis of the temporal features of ejective consonants. *Phonetica*, *33*, 275–284.

Hoijer, H. (1938). *Chiricahua and Mescalero Apache Texts*. Chicago: University of Chicago Press.

Hoijer, H. (1946). Chirachua Apache. In H. Bloomfield & Haas (Eds.), *Linguistics structures of native America*. New York: Viking Fund Publications in Anthopology.

Hoijer, H., & Sapir, E. (1945). *Navaho phonology*. Albuquerque: The University of New Mexico Press.

Holton, G. M. (2001). The phonology and morphology of the Tanacross Athabaskan Language. *Dissertations International A: The Humanities and Social Sciences*, *62*(2), 552-A.

Kari, J. (1976). Navajo verb prefix phonology, Garland.

Keating, P. (1984). Phonetic and phonological representations of stops consonant voicing. *Language*, *60*, 286–319.

Kingston, J. (1990). Articulatory binding. In K. A. Beckman (Ed.), *Papers in laboratory phonology I: Between the grammar and physics of speech* (pp. 406–434). Cambridge: Cambridge University Press.

Krauss, M. (1964). Proto-Athabaskan-Eyak and the problem of Na-Dene I: Phonology. *International Journal of American Linguistics*, *30*, 118–131.

Krauss, M. E. (1973). Na-Dene. In T.A. Sebeok (Ed.), *Linguistics in North America* (pp. 903–78) Mouton: Current Trends in Linguistics (Vol. 10). The Hague.

Krauss, M., & Leer, J. (1981). *Athabaskan, Eyak and Tlingit Sonorants*. Alaskan Native Language Center Papers #3.

Krauss, M., & Leer, J. (1976). *Proto-Athabaskan-Eyak *y and the Na-Dene Sonorants*. Fairbanks: Alaska Native Language Center.

Laver, J. (1994). *Principles of phonetics*. Cambridge University Press.

Leer, J. (1979). *Proto-Athabaskan verb stem variation, Part One: Phonology*, Alaskan Native Language Center Research Papers.

Leer, J. (1996). The historical evolution of the stem syllable in Gwich'in (Kutchin Loucheux) athabaskan. In E. Jelinek, S. Midgette, K. Rice, & L. Saxon (Eds.), *Athabaskan language studies* (pp. 193–234). Albuquerque, New Mexico: U New Mexico Press.

Li, F.-K. (1933). Chipewyan consonants. *Ts'ai Yuan Pe'i Anniversary Volume* (pp. 429–467). Shanghai, Academic Sinica, Supplementary Volume: Institute of History and Philology:

Li, F.-K. (1946). Chipewyan. *Linguistic structures of Native America* (Vol. 6). C. Osgood : Viking Fund Publications in Anthropology.

Lindau, M. (1984). Phonetic differences in glottalic consonants. *Journal of Phonetics*, *12*, 147–155.

Lisker, L., & Abramson, A. S. (1964). A cross-language study of voicing in initial stops: Acoustical measurements. *Word*, *20*, 384–422.

Maddieson, I., Smith, C., & Bessell, N. (2001). Aspects of the phonetics of Tlingit. *Anthropological Linguistics*, *43*(2), 135–176.

McDonough, J. (1990). *Topics in the morphology and phonology of Navajo verbs*. GLSA University of Massachusetts at Amherst.

McDonough, J. (1999). Tone in Navajo. *Anthropological Linguistics*, *41*(4), 503–539.

McDonough, J. (2003). *The Navajo sound system*. Dordrecht: Kluwer.

McDonough, J., Iskarous, K., & Whalen, D. (ms). An ultrasound study of the back fricatives in Navajo. ms.

McDonough, J. M., & Ladefoged, P. (1993). Navajo stops. Fieldwork studies of targeted languages, UCLA Working Papers in Phonetics: pp. 151–165.

Morice, A. G. (1932). *The carrier language*. Winnepeg.

Phone, W., Olsen, M., & Martinez, M. (2007). *The dictionary of Jicarilla Apache*. M. Axelrod, S. Gomez de Garcia, & J. Lachler (Eds.), University of New Mexico Press.

Rice, K. (1989). *A Grammar of slave*. Berlin: Mouton de Grutyer.

Rice, K., & Hargus, S. (2005). Introduction to Athabaskan prosody. In Hargus, & Rice (Eds.), *Athabaskan Prosody* (pp. 1–47). John Benjamins.

Sapir, E., & Hoijer, H. (1967). The phonology and morphology of the Navajo language.

Story, G. (1984). Babine and carrier phonology: A Historically Oriented Approach.

Tuttle, S. G. (2003). Archival phonetics: Tone and stress in Tanana Athabaskan. *Anthropological Linguistics, 3*(fall), 316–336.

Tuttle, S., & Sandoval, M. (2002). Jicarilla apache. *International Journal of American Linguistics*, 105–112.

Wright, R., Hargus, S., & Davis, K. (2002). On the categorization of ejectives: Data from Witsuwit'en. *Journal of the International Phonetic Association*, *32*(1), 43–78.

Young, R. W. (2000). *The Navajo verb system: An overview*. Albuquerque, NM: University of New Mexico Press.

Young, R., & Morgan, W. (1980). *The Navajo language*. Albuquerque: University of New Mexico Press.

Young, R., & Morgan, W. (1987). *The Navajo language*. Albuquerque: University of New Mexico Press.

Young, R., Morgan, W., & Midgette (1992). *An analytic lexicon of Navajo*. Albuquerque: University of New Mexico Press.

Further reading

Mithun, M. (1999). *The languages of native North America*. Cambridge, UK; New York: Cambridge University Press.